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Fluorochemicals in Heat Transfer Applications

Frequently Asked Questions

Questions not answered herein may be directed to the 3M Technical Service Hotline at 800-833-5045.

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1. How Do I select a fluid for a particular application?

The selection process depends upon whether the application is single phase or two phase. Single phase applications are applications in which the fluids remains a liquid. In two phase applications the fluid changes phase (usually it boils).

Single Phase

In these applications, the fluid is most often pumped in a loop between a heat source and a heat sink. To choose a fluid, one must consider the temperature range of the application. Consider the following application:

Example
Cooling of Semiconductor Tester
Operating range –40 to +40°C
Which Fluorinert™ to use?

Because the equipment will be operating in this range, we can reasonably expect that fluid within the tester will not exceed 40°C while fluid in the chiller may reach –50°C. Our goal then is to find a fluid which will function well within this range.

Obviously we want a fluid which will not boil at 40°C. We could choose FC-72 which boils at 56°C. Investigation of its low temperature properties indicate a viscosity at –50°C of 1.5 centistokes (cSt), a little higher than water at room temperature. Obviously the fluid will be very pumpable at this temperature and should enter the turbulent regime easily providing good heat transfer with relatively low pumping power demands.

Use of FC-72 could lead to excessive fluid loss however. Because this system operates over a wide temperature range, the fluid will expand and contract considerably (usually 1 volume % for every 10°C). Many chiller expansion reservoirs are ventilated to take in and purge air as a means of accommodating this expansion. Because the air which leaves this reservoir is typically saturated with fluid vapor, the only way we can reduce the amount of fluid carried with the air during each thermal cycle is to reduce the vapor pressure of the fluid. This is accomplished by looking to a fluid with a higher boiling point.

We might consider FC-84. This fluid has a boiling point of 80 deg. Its vapor pressure at 40°C is only about 40% that of FC-72. Although the actual vapor loss must be calculated by using a vapor pressure relation and integrating with temperature, use of FC-84 would greatly decrease losses. The viscosity of FC-84 at –40°C is 3.0 cSt, still very pumpable and probably

quite acceptable. Use of a still higher boiling fluid like FC-77, cuts the vapor pressure at –40°C to 20% that of FC-72. The viscosity of FC-77 at –40°C is 6.6 cSt which is still probably very workable for this application.

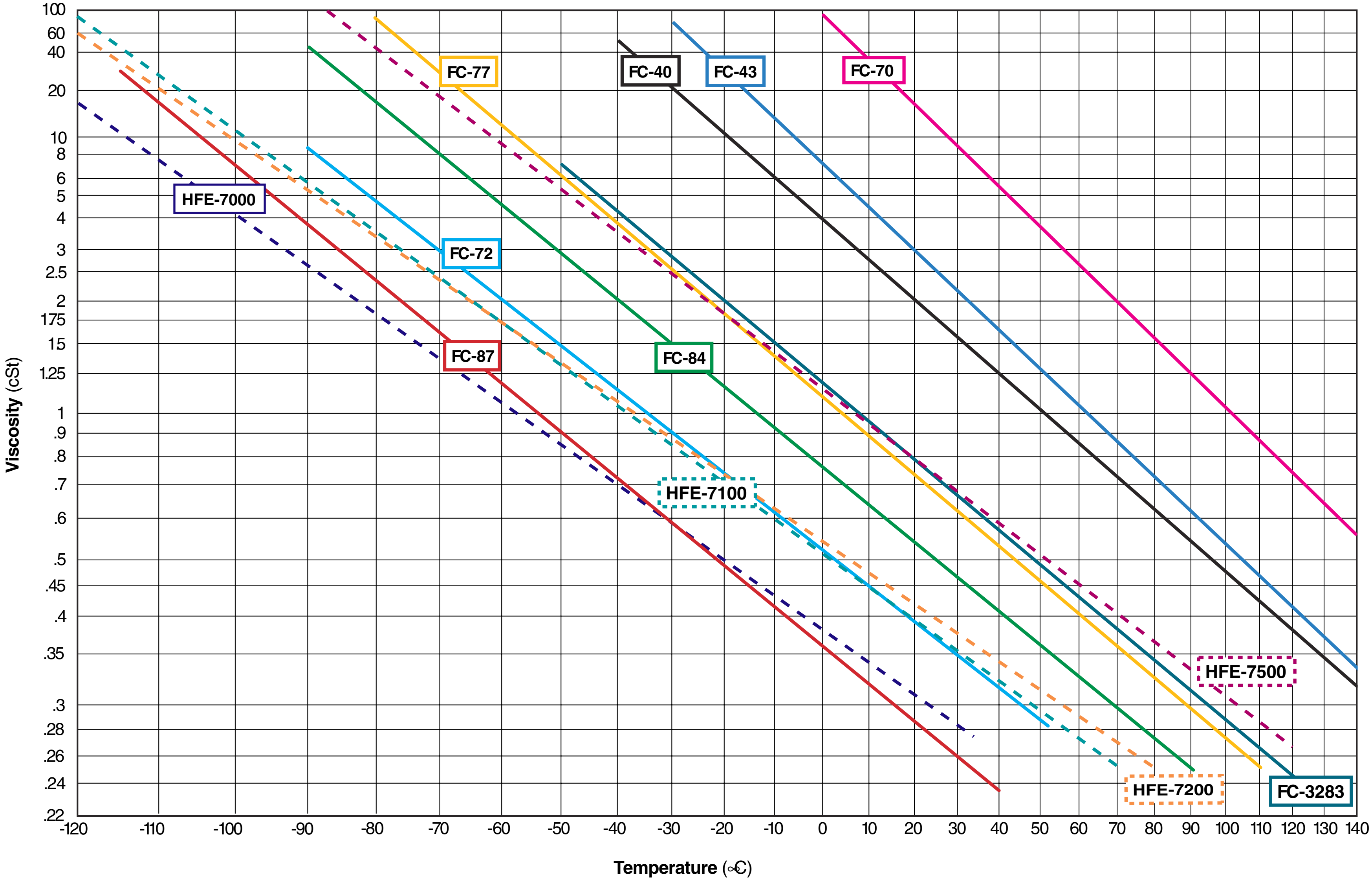
Unless the operating temperature range is quite narrow, the choice of a Fluorinert™ or Novec™ HFE fluid for single phase application is generally a compromise between volatility at the high end and heat transfer or pumping power performance at the low end.

Two-Phase

The selection of a fluid for two phase applications is generally based upon the boiling point. For heating applications such as vapor phase soldering, the boiling point of the fluid is chosen such that it will melt the eutectic being used as a solder.

For cooling applications such as microelectronics cooling, the boiling point of the fluid is chosen such that it maintains the heat generating component at the desired temperature. Thought must also be given to the temperature of the final heat sink. In some electronics modules for example, FC-72 is used not because its boiling point of 56°C is an ideal temperature for operating electronics but because this boiling point allows the condenser to deposit its heat to ambient air without a compressor. Keep in mind that Fluorinert or HFE fluids generally require heat fluxes of more than 2 W/cm^2 to sustain boiling. Wall superheats are generally between 15 and 25°C during boiling and the critical heat flux is usually about 15-20 W/cm^2 for pool boiling More Info

Viscosity vs. Temperature



2. Why would I choose a Novec™ Fluid over a Fluorinert™ fluid?

In some cases, a Novec™ HFE fluid will be chosen because of its wider liquid range or superior heat transfer properties. More often than not, though, the decision is based upon the superior environmental properties of an HFE. Although all 3M fluids, Fluorinert™ and HFE alike, are non-ozone depleting, the Fluorinert Fluids have long atmospheric lifetimes and high global warming potentials (GWPs). Novec™ HFEs have very low global warming potentials and are therefore favored by some users as the "greener" option More Info.

The user should consider the following facts:

- **Use of perfluorinated fluids like the Fluorinerts is not currently regulated by any US regulatory agency except in CFC replacement applications. In such applications, the US EPA's Significant New Alternatives Program (SNAP) permits use of perfluorinated fluids "when no other alternative is available." The bulk of Fluorinert applications today never employed a CFC.**
- **There are a few applications for which HFEs are not suited. Generally these are very high voltage direct contact applications. These applications may always require the superior electrical properties of Fluorinerts.**
- **Perfluorinated fluids have a long and well-documented history in direct contact cooling of sensitive electronics. Though many scientists are researching the use of Novec™ HFEs in these applications, a long history is not yet available.**
- **The vast majority of indirect contact, dielectric heat transfer applications which employ Fluorinert fluids could just as easily use Novec™ HFEs. This includes: ion implanters, etchers, testers, fuel cells, reactor cooling, freeze dryers, and others.**

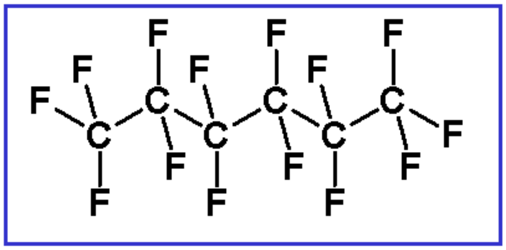
3. How Do Novec™ HFE fluids differ from Fluorinert™ Fluids?

For practical purposes relevant to heat transfer, Novec™ HFE fluids differ from Fluorinert fluids in the following ways: chemical structure, global warming potential (GWP), hydrocarbon solubility and Electrical properties.

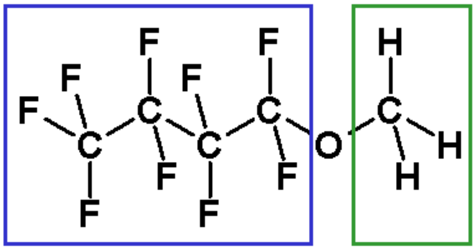
Chemical Structure

This difference is best illustrated by considering FC-72 and HFE-7100 (see figure below). FC-72 is perfluorinated meaning that all available bonding sites on its carbon backbone are occupied by fluorine atoms. The strength of the carbon fluorine bond is one reason that the Fluoirnert™ line of fluids (all of which are perfluorinated) are so chemically inert. HFE-7100, on the other hand, contains not only fluorine, but also hydrogen and oxygen. Also, HFE-7100 and all of the Novec™ HFEs are what 3M calls "segregated" HFEs. The molecules are segregated in the sense that a perfluorinated portion of the molecule is "segregated" from a fully hydrogenated portion by an oxygen or "ether" linkage. It is the presence of hydrogen on the molecule, distributed in this way, which leads to the unique properties of Novec™ HFEs

FC-72



HFE-7100



Global Warming Potential

The presence of the hydrogenated portion of a segregated HFE makes these molecules susceptible, once in the troposphere, to hydroxyl radicals that break the HFE down. This breakdown is relatively rapid so that HFEs have very short atmospheric lifetimes and consequently low global warming potentials. HFEs GWPs are superior to those of HFC-134a, a refrigerant used today in many air conditioning systems.

	Atm. Lifetime [years]	GWP [100 year ITH]
CFC-12	102	8500
FC-72	**3200**	**7400**
FC-77	**2300**	**6700**
HFC-134a	14.6	1300
HFE L-13791	***4.9***	***370***
HFE-7100	***4.1***	***320***
HFE L-15381	***<2***	***<250***
HFE-7200	***0.8***	***55***

The L-number designation is used by 3M to indicate

Because they contain no chlorine, all Fluorinert™ and Novec™ HFE fluids are inherently non-ozone-depleting.

Hydrocarbon Solubility

The presence of hydrogen on an HFE molecule makes that molecule a better solvent for hydrogenated materials. Since most of the organic additives and plasticizers used in the manufacture of elastomers are hydrocarbon-based, Novec™ HFEs will extract these materials from elastomers more easily **more info.**

Electrical Properties

The Fluorinert™ fluids are excellent dielectrics. This is the primary reason they are used in many applications. Novec™ HFEs are also very good dielectrics but their resistivity may fall short in a very small number of applications. The table below shows electrical properties for some typical Fluids.

	Dielectric Strength [kV 0.1" gap]	Volume Resistivity [ohm-cm]
FC-72	**40**	**1.0E+15**
FC-77	**40**	**1.0E+15**
HFE-7100	**40**	**1.0E+09**
HFE-7200	**40**	**1.0E+08**
HFE-7500	**40**	**1.0E+09**

The L-number designation is used by 3M to indicate a material which is developmental

At a given relative humidity, the dielectric strengths of HFEs are comparable to those the Fluorinert™ fluids. The electrical resistivity of a Novec™ HFE, though several orders of magnitude lower than that of a Fluorinert™, is still higher than the best attainable DI water (about 18 Mohm-cm).

4. Is there a materials compatibility chart for use with Fluorinert™ and Novec™ Fluids?

Before 3M commercialized HFE-7100, the first or its Novec ™ or HFE product line, there were only the Fluorinert™ Fluids. These perfluorinated fluids are very poor solvents. For this reason, they are "compatible" with a variety of polymeric materials. It was easy at that time to make very sweeping statements about polymer compatibility. In other words, we could assemble a table which listed common materials of construction (EPDM, butyl, nitrile, nylon, etc) and tell you which perform well with the Fluorinerts™ and which did not. As a rule, most performed pretty well.

While the first HFEs were being commercialized, 3M engineers performed exhaustive compatibility testing using standard materials and arrived at what we thought was a well-researched table like the one described above. As complaints from the field started coming in, it quickly became apparent that not all materials of a given class are similar. For example, we might test ten EPDM compounds and find that eight of them perform very well. The other two may perform miserably. There is simply too much variability in the formulations of various materials. This situation is compounded by the fact that construction materials may be completely untraceable. For example. If 3M engineers test an elastomeric O-ring from the pump used by a chiller manufacturer and find it to perform very well, they would like to recommend it to other OEMs. Most often though, the O-ring is known only by the chiller manufacturer's part number. That part number may have another part number belonging to the pump manufacturer who may buy it as yet another part number from the O-ring vendor. The vendor may in turn buy the raw polymeric materials from a formulator who uses a formulation number. It is easy to see why it becomes a very complicated matter to gather meaningful compatibility data that can be used to make design recommendations.

We have a dilemma. On the one hand, there is a need for a simple, easy to understand compatibility chart which design engineers can use when selecting materials of construction. On the other hand, such a chart cannot be foolproof because there will always be exceptions to the rules. Use of such a chart can and has lead to expensive field problems.

What then is the solution? One possible solution is to educate customers on the issues involved with material compatibility and the use of Novec™ Fluids and then to provide testing procedures and even testing services. Simultaneously, 3M could gather test data for as many commercial polymer formulations as is practical. Data of this type would be traceable to the formulator's ID numbers and permits the end user to contact the polymer

formulator directly, order the part they need and feel certain that it will perform well with a given Novec™ Fluid. This is what 3M is doing.

4a. What are the compatibility issues with Fluourinert™ and Novec™ Fluids?

The issues are these: plasticizers, plasticizers and additives. During the production of elastomers, or of polymers in general for that matter, it is common to add to the polymer matrix a plasticizer or additive. Most often the material is an oil or wax which is added to the polymer to increase its workability during manufacture or to enhance some mechanical property in the end use. A classic example of the latter is the addition of the hydrocarbon plasticizer dioctyl pthalate (DOP) to polyvinyl chloride (PVC) to make a flexible shower curtain. The amount added can range from very little to very much depending upon the polymer matrix, the plasticizer and the mechanical properties being sought.

So why is this such an issue? The primary issue is one of solubility, namely, the solubility of the plasticizer in the fluid. If the plasticizer is soluble in the fluid, it is more likely to be extracted from the polymer matrix by the fluid. The solubility, then, can tell us something about how the polymer and the fluid will be effected.

4b. Why is it more of an issue with Novec™ fluids than with Fluorinerts?

Fluorinert™ fluids are fully fluorinated or perfluorinated molecules. An example is the molecule C_6F_{14} or FC-72 on which all available carbon bonds are occupied by fluorine atoms. A fundamental observation of physical chemistry is that "like dissolves like" and so perfluorochemicals like the Fluorinerts do a rather poor job of dissolving anything but other fluorochemicals. Since 99+% of plasticizers used in the polymer industry are hydrocarbon-based compounds, few of them are very soluble in the Fluorinerts. The Novec™ HFEs on the other hand, are a different story.

Hydrofluoroethers molecules like HFE-7100 or $C_4F_9OCH_3$ contain not only Fluorine but also hydrogen (the ether oxygen plays a relatively minor role for the purposes of the present discussion). Because "like dissolves like," hydrofluoroethers are more capable of dissolving common hydrocarbon plasticizers than are the Fluorinerts™.

4c. What types of materials ARE NOT an issue?

As a rule of thumb, those materials which we commonly think of as hard plastics are not an issue. These materials are rarely plasticized to a

significant degree or in a way which causes problems in HFE systems. Materials in this category include (there are many others):

Polyethylene
ABS
polyvinlychloride (PVC)
Acrylic (Plexiglas™)
PTFE (Teflon™)
Ryton™
polyetheretherketone (PEEK)
Thermoplastics
Polypropylene
Nylon
Polycarbonate (Lexan™)
Rulon™
polysulfone
phenolic

4d. What types of materials MAY BE an issue?

As a rule of thumb, any material which you would describe as "rubbery" is suspect because it may be plasticized. All common elastomeric materials fit into this category:

Nitrile
Butyl
Fluorosilicone
Chloroprene
Polyacrylate
Styrene Butadiene
Silicone
Fluorocarbon
Natural Rubber
Polysulfide
Polyurethane
Ethylene Propylene (EP or EPDM)

Of these, EP, butyl and natural rubber tend to perform quite well as a class. However, there may be members of this class which do not perform well just as there may polyuerethanes and others that do. Those that perform well generally contain little plasticizer. It is worth noting that Silicones and Nitriles are notoriously bad. Fluorocarbons generally are not heavily plasticized but they will swell in the presence of HFEs because once again "like dissolves like" and they are fluorinated like the fluid.

4e. What is meant by compatibility?

There is a natural tendency when talking about elastomer compatibility (we'll use the term "elastomer" from now on because we're referring to rubbery materials) to focus on the effects the fluid will have on the elastomer. It is true that extraction of plasticizers from an elastomer can cause it to harden or shrink and it may even crack. In many industrial applications, this may be the most important consideration. However, most people overlook the effect that plasticizer extraction can have on the fluid.

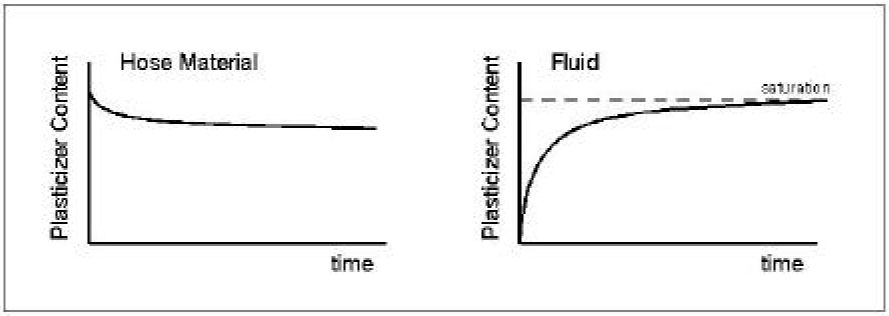
The effects of dissolved plasticizer on the fluid's performance can be dramatic and this can be a critical issue in the types of sensitive, high value applications which use a Fluorinert™ or Novec™ fluid. Typical problems caused by plasticizer in the fluid include:

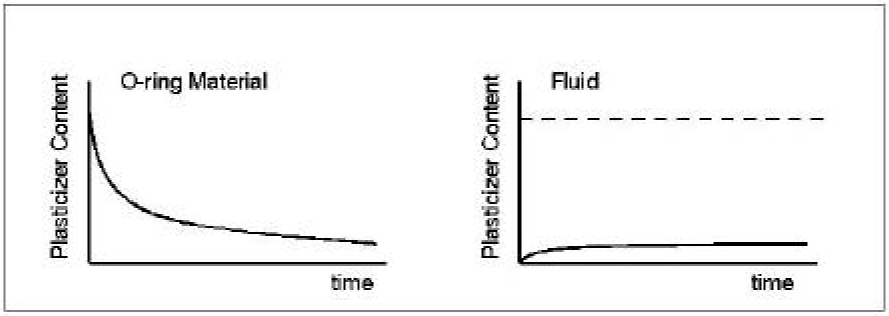
- **Clogging of filters or small fluid passages**
- **High static voltages or static discharge**
- **Fluid decomposition (resulting from high voltage discharge)**
- **Coating of desiccants or fluid conditioning reagents.**

4f. How do you approach and elastomer application?

The primary considerations when selecting an elastomer for a given application and the potential effects on elastomer and fluid are: fluid to elastomer ratio and dimensional tolerance.

Fluid to Elastomer Ratio: Because extraction is an equilibrium process, knowing this ratio can help you assess the potential for extraction and its effects on fluid and elastomer. An example of one extreme is a system with hundreds of feet of plasticized silicone rubber tubing. In such an application, the fluid may become saturated with plasticizer before the hose degrades in any appreciable way. Expect the fluid properties to degrade but the hose may be just fine. The opposite extreme is an application which contains one very small O-ring with many gallons of fluid. In such an application, the fluid acts as an infinite sink for plasticizer. If plasticizer extraction is an issue for the elastomer, it will be worst in this case. Because the fluid volume is large and it will receive relatively little plasticizer, the fluid may not be adversely affected.





Dimensional Tolerance: If the O-ring described above was a radially-loaded seal in a quick connect, we might expect the quick connect to leak as the plasticizer is extracted and the O-ring shrinks. If, however, the O-ring was used as a face seal for pipe flanges, a little shrinkage might not be an issue. In this latter case neither the fluid nor the O-ring is adversely effected by the extraction.

These considerations are summarized for some typical applications in the table below.

Elastomer Application	Key Features	Issues
Shaft Seal on a Pump or Valve	-Large fluid to elastomer ratio. -Dimensional tolerances may be critical.	- Extraction will be maximized, expect shrinkage if elastomer is plasticized. - Likely source of leak. - Choose very compatible elastomer. - Expect little fluid contamination. This may not be an issue.
Quick Connect Seal	-Large fluid to elastomer ratio. -Dimensional tolerances may be critical.	- Extraction will be maximized, expect shrinkage/degradation if elastomer is plasticized. - Likely source of leak. - Choose very compatible elastomer. - Expect little fluid contamination. This may not be an issue.
Face seal or gasket	-Large fluid to elastomer ratio. -Dimensional tolerances generally not critical.	- Extraction will be maximized, expect shrinkage if elastomer is plasticized. - Shrinkage may or may not be a concern. - Expect little fluid contamination unless many such seals are present. This may not be an issue.

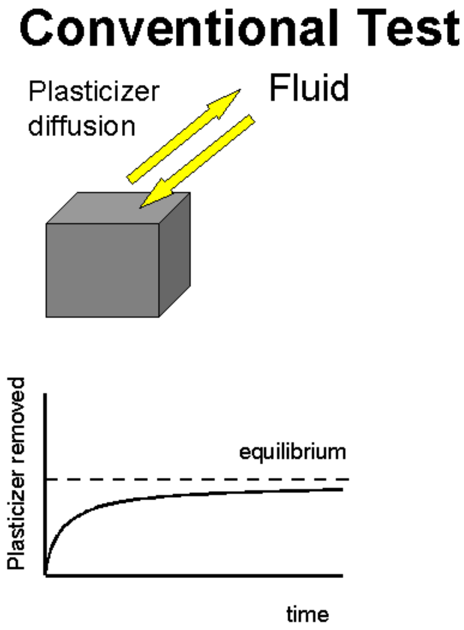
Tubing	- Small fluid to elastomer ratio	- Fluid may take up a lot of plasticizer. May even saturate or supersaturate. - Tubing may become brittle. - Electrical properties of fluid could alter allowing discharge or static generation. - Plasticizer can precipitate as solid or separate liquid phase during temperature changes. - Dessicant material can become coated and inactivated. - Filters can become clogged.

4g. What is the best way to test for compatibility of elastomers?

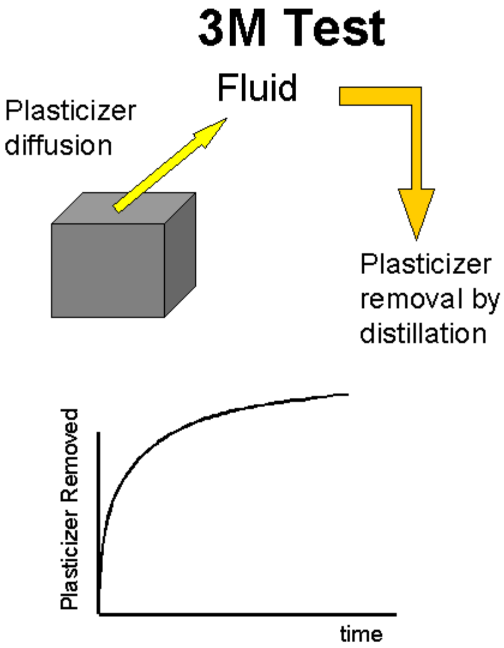
The most common method in industry is to measure volume change, weight change and hardness change following exposure of an elastomeric sample to a small amount of fluid at a known temperature for a given amount of time. These changes are usually reported as a percent of the initial value (i.e. 15% weight change). This testing is often accelerated by performing the testing at elevated temperatures, sometimes necessitating pressure vessels.

The method described above is a good one and the data obtained in such tests is meaningful. Unfortunately, it can be misleading in some instances. One such instance occurred with a quick disconnect (QD) used in semiconductor test equipment. The QD had worked fine for years with Fluorinert FC-77. When the manufacturer converted to HFE-7100, the quick connect began to leak. The manufacturer of the quick connect did thorough testing of the O-ring seals using conventional methods and they appeared to perform quite well. Weight gain, volume swell and hardness changes appeared acceptable.

3M tested the same O-rings and found that they performed quite poorly. Why the difference? 3M uses a different test method which we feel is more meaningful for the applications in which our fluids are used. The 3M method is a Soxhlet extraction test using the fluid as a solvent. In an extraction test the part is exposed to distilled fluid condensate which is replenished about every 10 minutes. This condensate is at roughly the boiling temperature of the fluid and because it is distilled, it contains no plasticizer. This does 2 things: It provides a worst case temperature (as most applications do not exceed the boiling point) and it maximizes diffusion of the plasticizer out of the elastomer. Because the method allows the extracted plasticizer to be collected and weighed, it provides a measure of the true weight loss. Since we also measure the elastomer mass before and after, we have a measure of both the weight lost (extracted) and the weight gained (fluid absorbed). The 3M method, we feel, gives more insight into the true compatibility of an elastomer.


Conventional Test

Example: 100g fluid with 0.1% plasticizer solubility. 20g elastomer sample can lose only 0.5% of its plasticizer.


3M Test

Sample may lose 10g of plasticizer.

May be more accurate for real applications which may have large fluid volumes or sinks for plasticizer

As an example, consider the Norprene hose shown below. Conventional soak testing at the fluid boiling point shows a weight gain of 4.0%. This number is small and based on these results, one might expect the hose to perform quite well. When tested by the 3M method, the same hose lost 21.8% of its weight in plasticizer and it simultaneously absorbed fluid equivalent to 3.8% of its weight. This is certainly not a good result.

– Comparison of Methods - Norprene 6410 hose

- Conventional Test Data (24 hr soak in HFE at B.P.)
  - – 4.0% weight gain
    - Indicates good compatibility
    - Conclusion erroneous
- 3M test data (24 hr extraction in HFE at B.P.)
  - – 21.8% extracted material, 3.8% absorbed fluid
    - Plasticizer was leached from the elastomer and it would become brittle upon drying
    - The polymer matrix absorbed some fluid

      may be permeable or may swell

      fluid may plasticize the elastomer

Why the differences? The conventional testing is done in a closed vessel with a fixed amount of fluid. Though plasticizer will leave the polymer, it can only go as far as the surrounding fluid. As its concentration builds in the fluid, eventually an equilibrium is set up at which the plasticizer in the elastomer is in equilibrium with that in the fluid. At this point extraction stops. This equilibrium does not represent what the elastomer experiences in the application. When the test is over, the elastomer is weighed. A 4% weight gain is recorded but there is no way to know how much weight gain might have been camouflaged by the lost plasticizer which is still unaccounted for. A hardness test would have little meaning because even though the elastomer has lost its plasticizer, it could be plasticized by the fluid. By baking the fluid out of the elastomer in a vacuum oven and then re-measuring volume, mass and hardness, one could gain some additional insight but there are still many unknowns.

The 3M method does not necessarily reproduce what the elastomer experiences in the application but it does represent a worst case for reasons already described. The data indicate that the elastomer lost a lot of plasticizer (21.8%). This is plasticizer which would enter the fluid in the actual application and this is important information in sensitive applications.

The data which follow were taken from a test performed for a customer. The intended to switch from compound 1 to compound 2 for their very critical application. Sample #1 was recommended by 3M for the application.

Example: Extraction Compatibility Testing of two EPDM compounds
Testing done to determine extractables and general compatibility

Fluid is HFE-7100, Boiling point 61°C
Customer: XXXXXXXXXXX
Date: XXXXXXXXXXX

Data

Sample No	Sample Description	Sample		Flask	
		Mi [g]	Mf [g]	Mi [g]	Mf [g]
1	EPDM 06270K52	4.0933	4.1171	113.6821	113.7661
2	EPDM 06280K36	4.6947	3.9235	117.4613	118.4291

Results

Sample No	Sample Description	Fluid %mass	Residue %mass	Observations
1	EPDM 06270K52	2.6	2.05	Clear white oil extracted. Sample unchanged.
2	EPDM 06280K36	4.2	20.61	Clear white oil extracted. Sample was stiff and dry.

Additional Notes:

Static discharge: **Fluorochemicals have an enormous affinity for electric charge. Because they are also dielectric, they tend to hold that charge very well. For this reason, they generally absorb a charge but carry it harmlessly through a system. Plasticizer seems to effect the chemicals' ability to hold onto charge relative to other components. A fluorochemical which in its pure form would hold charge in the presence of a particular material, may give up charge to that same material when plasticizer is dissolved into the fluid. If the material taking up charge is insulated from another which does not, then an electric potential forms between the two. This can lead to static discharge.**

Filter Clogging: **As mentioned before, some plasticizers are solids even at room temperature. Others may be liquid at room temperature but solid within the operating range of a heat transfer system. Plasticizer solubility is temperature dependent drops very quickly as the melting temperature of the solute is reached. For this reason, it is quite possible that plasticizer will precipitate from the fluid in heat a transfer system. The precipitated plasticizer can harden to form crystals large enough to clog fine filters or small fluid passages.**

High voltage discharge: **Because they are excellent dielectrics, fluorochemicals are often used as heat transfer fluids in direct contact with high voltage components. The presence of plasticizer dissolved in the fluid or in separate liquid phase may not significantly effect its dielectric**

properties. Particulate in the fluid, however, definitely will. The plasticizer crystal described above may allow electric discharge and thermal decomposition.

Adhesive Deterioration: **It is common in many direct contact electronics cooling applications to have adhesives present. Electronic components may be constructed with adhesives or waxes. Though these materials are usually compatible with the fluid, they may not be compatible with the plasticizer. The plasticizer can diffuse into the adhesive and degrade it.**

Coating of Chemisorbent Materials**: Often times a cartridge containing a chemical reagent is put into a heat transfer system to absorb unwanted contaminants. An example is the use of a silica gel or desiccant cartridge to absorb water. Plasticizers will often adsorb onto the reagents in such cartridges. They can form a coating which impedes the diffusion of species into the reagent and may essentially deactivate the cartridge.**

A note about Fluoroelastomers: **Materials like Viton, Fluorel and Kalrez are touted as the Cadillacs of elastomers and rightly so. These materials are impervious to many process fluids and have a wide temperature range. For this reason they're often specified rather blindly especially for high value applications which can afford their price tag. However, because "like likes like," fluorinated fluids tend to swell fluorinated elastomers. Some will gain as much as 18 wt % fluid. For many static gasket and O-ring applications swelling causes few problems. However, if the O-ring is tightly confined or the O-ring seat dimensions are very critical, then swelling can be a problem. In these instances O-rings can actually burst or fragment as they swell outside their confines. Fortunately, much cheaper, low plasticizer materials like EPDM and Butyl generally work much better.**

4h. Can you recommend hose and seal materials to me?

The materials shown below have been found to perform well

Recommended Flex Hoses for General Use

Tubing Name	Type	Extraction %	Weight gain %	Comments
Tygon™ C-544-A I.B.	Clear Braided Polyurethane	0.09	0.3	Excellent Compatibility. Good pressure resistance. Temperature Range –73 to 82C. www.tygon.com
Tygon 3370 I.B.	Clear Braided Silicone	1.47	4.8	Good Compatibility. Good Pressure resistance. Temperature Range –73 to 160C.
Flexfab™ 5521-050	Green braided silicone hose	2.08	NA	Good Compatibility. Good Pressure resistance. Temperature range –54 to 150C. http://www.flexfab.com
Nalgene™ 290 PUR	Clear Yellow. No Braid.	0.74	0.3	Excellent Compatibility. Little pressure resistance.

				Temperature range –56 to 80C.
Tygon Phar-Med (65)	Brownish opaque. No braid.	40	4.7	SHOWN FOR CONTRAST. This material not compatible.
C-Flex™ (Cole Parmer 6425-19)	White. No braid.	26	5.3	SHOWN FOR CONTRAST. This material not compatible.

Extraction tests conducted in HFE-7100 (HFE-8401HT) for 48 hours.

Material Name	Type	Extraction %	Weight gain %	Comments
Hytrel® 4056	Opaque Polyester rubber	0.05	1.1	Excellent Compatibility. Good pressure resistance if braided Temperature Range –50 to 170C (variable)

Extraction tests conducted in HFE-7100 (HFE-8401HT) for 48 hours.

Recommended Elastomers for General Use

Elastomer Name	Type	Extraction %	Weight gain %	Comments
Stillman SR721-80	EPDM	1.2	1.8	Good Compatibility.
Stilllman SR634-70	Butyl	0.12	0.56	Excellent Compatibility.
Parker EPR 540-80	EP	1.5	2.2	Good Compatibility.
Jackson Flexible Products EPR E3450-80	EPR	1.2	2.3	Good Compatibility.
Parker Seal Co. EPR E515-80	EPR	1.8	2.2	Good Compatibility.
Newman EPDM 2107	EPDM	2.2	1.5	Good Compatibility.
International Seal E480	EP?	2.0	3.0	Good Compatibility.
Bay Seal Co. B0612-70	Butyl	0.24	0.90	Excellent Compatibility.
EPDM 06280K36	EPDM	21	4.2	SHOWN FOR CONTRAST
???	TFE-wrapped Viton	1.0	20	SHOWN FOR CONTRAST

Extraction tests conducted in HFE-7100 (HFE-8401HT) for 48 hours.

Of course, 3M offers free compatibility testing if you have other materials in mind.

5. What type of pump should I use with Fluorinert™ or Novec™ fluids?

Both Fluorinert™ and Novec™ HFE fluids have very low surface tensions and viscosities. This combined with the very low contact angles these fluids have on most surfaces, means that they will leak very easily through the smallest of passages. Seals which would easily hold back water at 10+ atmospheres may leak generously with a fluorochemical fluid. Though shaft seals have been used successfully with fluorochemicals, magnetically coupled or canned pumps are generally preferable. These pumps are much less apt to leak.

There are many manufacturers of magnetically-coupled pumps. Below are just a few:

Fluid-O-Tech International, Inc.
Plantsville, CT
860/620-0193
http://www.fluidotech.it

Gorman-Rupp Industries
Bellville, OH
419/886-3001
http://www.gripumps.com

Integrated Designs LP
Carrollton, TX 75007
972/466-2626
http://www.integrated-designs.com

Laing Thermotech, Inc
San Diego, CA
619/575-7466
http://www.lainginc.com

Liquiflow
Garwood, NJ
908/518-0666
http://www.liquiflow.com

MicroPump, A Unit of Idex Corp.
Vancouver, WA
360/253-3229
http://www.micropump.com

Modular Products, Inc.
Gear Pump Div.
Penn Yan, NY
800/347-6055

Speck Pumps
Jacksonville, FL 32256
800/223-8538
http://www.usa.speck-pumps.com

Zenith Division, Parker Hannifin
Sanford, NC
919/775-4600
http://www.zenithpumps.com

6. I frequently have to add fluid to my Fluorinert™ or Novec™ system. Where is the fluid going?

Fluid loss can generally be attributed to the following mechanisms: fluid loss resulting from fluid expansion and contraction, fluid loss resulting from the temperature dependence of gas solubility, leaky seals.

Fluid loss resulting from fluid expansion

As a rule of thumb, Fluorinert™ and Novec™ HFE fluids typically increase in volume 1% for every 10°C. Since the expansion reservoir in many chiller systems is permitted to “breathe,” air will enter and leave the expansion reservoir as the fluid expands and contracts with each thermal cycle. The air which leaves the expansion reservoir as the fluid expands is generally saturated with fluid vapor. This loss mechanism can be easily quantified by assuming that the fluid and air behave as ideal gases. The fluid carried out during a thermal cycle can then be estimated as

$$dV = V_{liq}(T)\,b(T)\,dT$$

$$dn_{vapor} = \frac{P_{vap}(T)}{RT}dV$$

$$dm_{vapor} = Mdn_{vapor}$$

dV = change in system liquid volume
$P_{vap}(T)$ = fluid vapor pressure
V_{liq} = system liquid volume
$\beta(T)$ = fluid coefficient of thermal expansion
n = moles
m = mass
M = molecular weight

This assumes that the system “breathes” freely (i.e. it is at atmospheric pressure). The temperature dependence of the vapor pressure can be obtained from 3M technical service personnel.

Fluid loss resulting from the temperature dependence of gas solubility

Although the above leakage mechanism is intuitive, people often find that losses in an otherwise tight system are larger than those attributable to the it. They fail to realize that air is soluble in Fluorinerts and HFEs and that this solubility (typically around 50 volume % far from the boiling point) is temperature dependent. Because the solubility increases as the temperature decreases, the fluid will hold more air at low temperatures

$$dx_{air,liq} = \frac{dP_{air}}{K} = -\frac{dP_{vap}}{K}$$

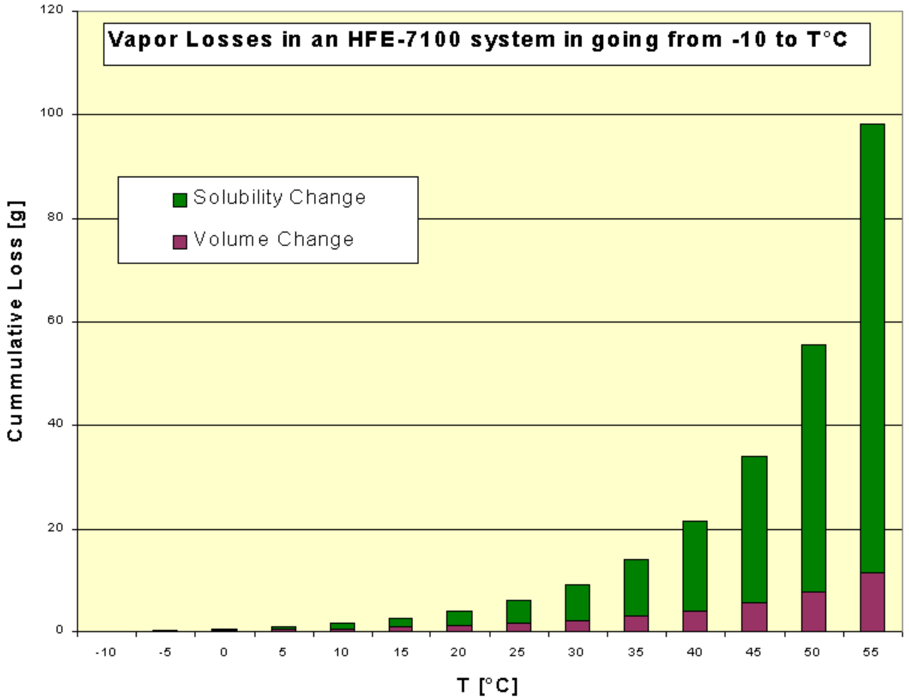
$$dn_{air} = dx_{air,liq} * n_{liq}$$

$$dm_{vapor} = Mdn_{air}\frac{P_{vap}(T)}{}$$

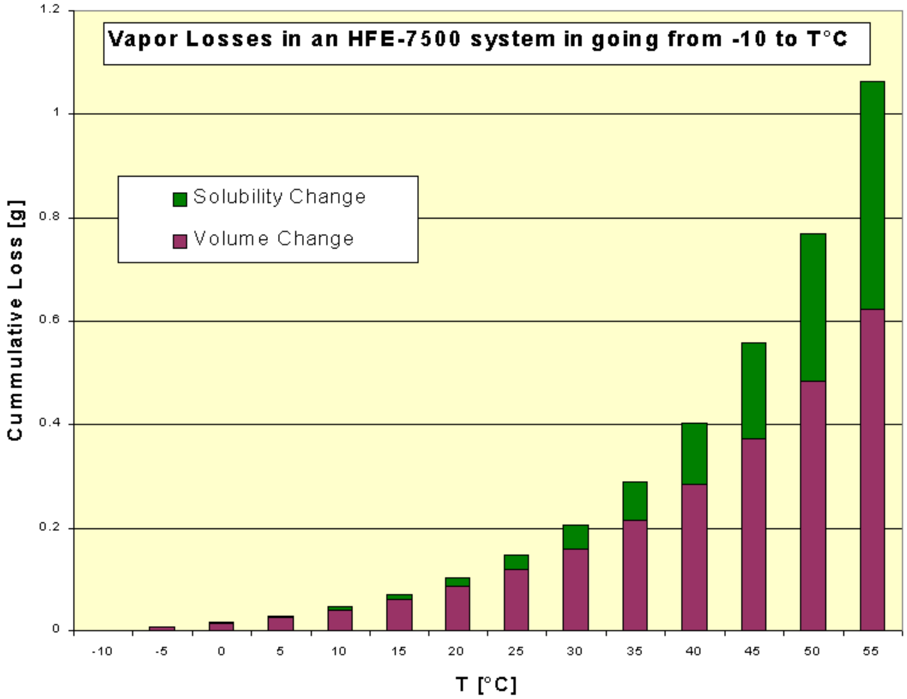
than at high temperatures. Therefore, as a heat transfer system warms, air will leave the system not only because the fluid is expanding, but also because the air solubility is decreasing in accordance with Henry's Law. Vapor carried with this air can be estimated as shown below

$dx_{air,liq}$=change in mole fraction of air in liquid
K = Henry's law constant for air in liquid
n_{liq} = moles of liquid

As an example, consider a 5 gallon HFE-7100 (boiling point = 61°C) system operating between –10 and 55°C and kept at atmospheric pressure via a "breathing" expansion reservoir:



If HFE-7500 (boiling point 128C) is used, the picture looks much different:



Obviously, staying as far from the boiling point of the fluid can reduce the losses from both of these mechanisms. In practice, the boiling point of the fluid is often dictated by heat transfer properties of the fluid more info.

A system is often outfitted with a vacuum break and a positive pressure purge. An analysis similar to that shown above can be used to calculate if and when such a system will vent and how much fluid loss will result. In practice, this analysis depends upon many variables and can be quite involved. 3M engineers can provide tools for modeling such systems.

leaky seals

The low viscosity and surface tension combined with the excellent surface wetting properties of fluorochemicals makes them very difficult to seal. Below are some seals which, in our experience, are likely to leak:

Pipe threads – This 150 year old technology works very well for a variety of fluids and this is probably why so many off-the-counter fluid components are still sold with pipe thread connections. Unfortunately, common methods of sealing pipe threads, such as PTFE tape or pipe sealants, will not work with Fluorinert™ and Novec HFE fluids. Leakage can range from very small leaks detectable only with a sensitive halogen leak detector, to gross leaks detectable by the large puddle beneath them. These leaks can

be avoided by using compression fittings (Swagelok™ is an example) wherever possible. Since pipe thread connections seem to be unavoidable in some cases, we recommend sealing them with an epoxy. Another option is a product called "Leak Lock." It is sold by Highside Chemicals (www.highsidechem.com).

Pump shaft seals – Any pump with a shaft seal is suspect more info.

Shrunken or cracked O-rings – An O-ring which is not compatible with the fluid may well shrink to the point that it is no longer able seal. This is common in dimensionally critical applications like quick disconnects and pump shaft seals. Even in applications which are not dimensionally critical, such as face seals or gaskets, sufficient material (plasticizer, etc.) may be extracted by the fluid that the O-ring will crack and allow fluid to leak more info.

Reliance on lubricated O-rings – Some fluid couplings rely heavily on lubricated seals. Without this lube, the coupling may be difficult to operate or it may fail quickly due to friction. Though the particular lube may be soluble in the fluid only at part per million levels, there is generally a very large amount of fluid in the system relative to the amount of lube. Even if the solubility limit of the lube in the fluid is inadequate to dry the O-ring, the lube may use the fluid as a vehicle to get to a sink such as a polymeric hose. If lubricants must be used, choose a silicone grease with the highest molecular weight available.

Diffusive losses – Diffusion rates of Fluorinert™ and Novec™ HFE fluids though most polymeric materials will be very low. For example, experiments indicate that diffusion of HFE-7100 through Stillman EPDM SR721-80 is less than 0.0007 g-mm/(in^2-day). This means that diffusion through a 10 foot length of 0.5 inch I.D. hose with a 1 mm wall thickness will be less than 0.13 g/day. Experiments with one particular PTFE indicated diffusion rates as high as 0.002 g-mm/(in^2-day).

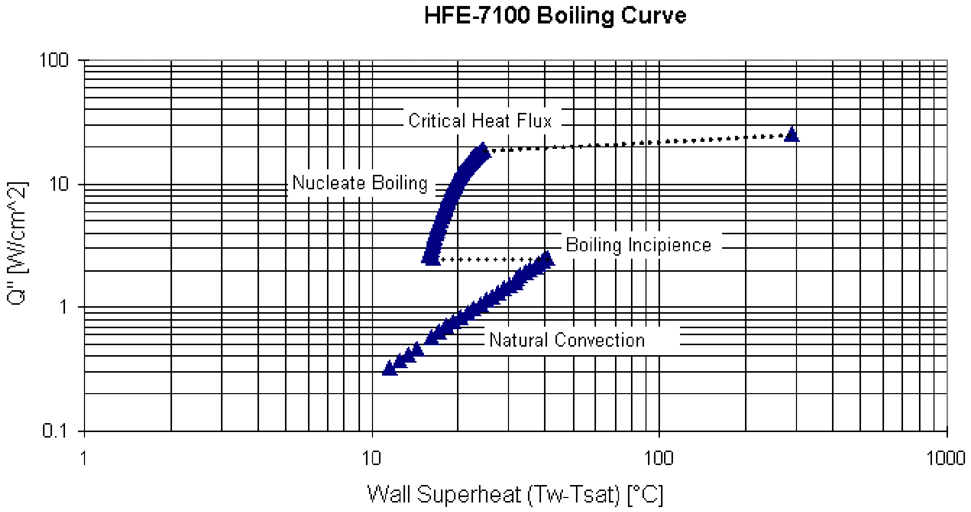
7. How can I detect fluid leaks?

Any halogen leak detector can be used to detect fluid leaks. These detectors are commonly used to detect refrigerants and are available from local refrigerant retailers in every major city.

8. How do I size a heater for use with Fluorinert™ or Novec HFE fluids?

Heaters should be sized such that their heat flux or power output does not exceed 6-10 W/cm^2. Much larger heat fluxes are possible but the safe value for a given application depends strongly upon the geometry, flow field etc. The decision to go beyond this level should be made by the customer.

How do we get 6-10 W/cm^2? 3M performs nucleate boiling experiments with our fluids: A 0.5 mm diameter platinum wire is immersed in a quiescent pool of saturated liquid. The current through the wire is gradually increased. The heat flux being dissipated is recorded as a function of the wire superheat (the difference between the wire temperature and the bulk fluid temperature). Typical results are shown below:



As the heat flux is increased, the wall temperature rises in the natural convection regime until boiling begins. Boiling for both Fluorinerts and Novec HFEs generally begins at heat fluxes of around 1-2 W/cm^2 though this "incipience" point can vary greatly depending upon surface finish, level of

degassing, etc. Once boiling starts, the wall superheat drops and remains relatively low throughout the nucleate boiling regime until the critical heat flux is reached. At this distinct and repeatable point, boiling is no longer stable, a vapor blanket forms on the wire and the wire temperature skyrockets. This is the condition to avoid. Keep in mind that very high heat fluxes may be obtainable if fluid is forced over the wire. We recommend 6-10 W/cm^2 because it appears to offer a good margin of safety for applications in which the heater is simply immersed in still fluid.

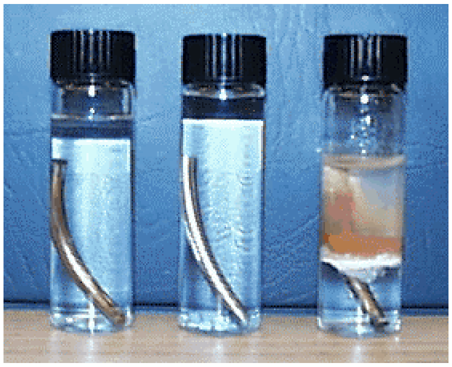
The above recommendations are based upon safety considerations. Designers should be aware that there may be other practical reasons to keep heat fluxes far below 6-10 W/cm^2. For example, an HFE-7100 recirculating chiller system which operates between –40 and 50 C may be expected to reach 15.5 psig assuming that it has a vacuum break and a 20 psig pressure seal. However, if a large amount of gas is liberated at the heater surface, system pressures may exceed the purge setting and allow vapor leakage.

9. Will Fluorinert™ or Novec™ fluids cause corrosion?

No. Corrosion in fluorochemical heat transfer systems can generally be linked to either a separate water phase or thermal decomposition of the fluid.

Water in the fluid: By this we mean water beyond the saturation level of the fluid. The saturation level of water in a Fluorinert or Novec HFE fluid is usually less than 100 ppm by weight. Water present in the fluid at or below this level has never been linked to significant corrosion. Water present above this level means a separate water phase. If such water is entrained into contact with metal parts, corrosion can be rapid.

This is shown in the picture below: Vial #1 contains HFE-7100 with water on top. The water does not contact the zinc-plated iron wire. Vial #2 contains HFE-7100 with no water and some desiccant to keep the fluid dry. Vial #3 contains HFE with water on top. Unlike vial #1, the water contacts the wire at about mid height. Vials #1 and #2 show no corrosion whatsoever indicating that even water-saturated HFE-7100 will not corrode the metal. Vial #3 shows zinc and iron oxide. These samples had been aged 5 months but the corrosion was evident in vial #3 at 1 day.



Water can enter heat transfer systems in a few different ways: Components can be hydro-tested and never dried before installation. The moisture contained in air which enters an expansion reservoir while the fluid in contracting can condense if the fluid is below the dew point. Air which enters an expansion reservoir can become saturated with water vapor if the purge is set much higher than the inlet regulator.

Water from these sources can be removed with any common molecular sieve or silica gel desiccant sold for refrigeration systems.

Thermal decomposition of the fluid: Fluoride ion can be generated any time the fluid is brought above its decomposition temperature and this can lead to corrosion. Decomposition is generally very slow below 200-300°C with most Fluorinert and HFE products. Experience indicates that corrosion resulting from decomposition is very rare and is only observed in systems which have undergone a failure. Examples include: a burned out heater, high voltage discharge in dielectric systems or a burned out electrical component in a direct contact electrical application.