Fluid Compatibility in SprayCool Products

By A. Finch *December 2009*

ABSTRACT

Cooling fluids have been utilized in the military and electronics industry for decades. With increasing demand for computational performance, thermal management of electronics has become a challenge. Liquid cooling has growing appeal, especially for those who do not have the luxury of operating electronics in office environments. While liquid cooling offers substantial benefits, compatibility between fluid and all other materials is a consideration to maintain optimal system performance. For embedded electronics, most materials are fluid compatible with a long history of use in SprayCool enclosures. This document discusses compatibility of common materials found in electronics enclosures relative to 3MTMPerformance Fluid PF-5060 and PF-5070 only. Performance Fluids are also marketed under FluorinertTM; the equivalent grades are FC-72 and FC-84, respectively.

BACKGROUND

SprayCool products utilize evaporative or direct spray, in which liquid droplets are sprayed directly onto the hot electronic components and then evaporate to remove excess heat. Depending on the system configuration, either vapor, liquid or a liquid-vapor mixture is transported to a heat exchanger where the waste heat is rejected. Thus, the fluid is continuously recycled for reuse within a closed loop system as shown in Figure 1.

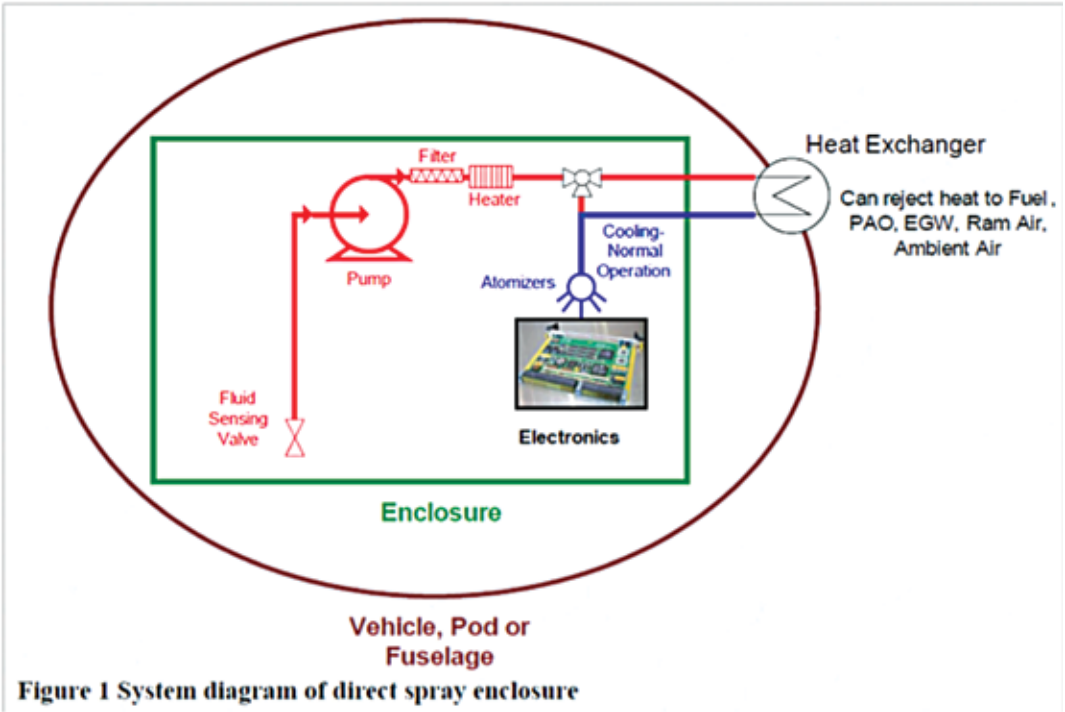

Figure 1 System diagram of direct spray enclosure

SprayCool uses Performance Fluid (PF) 5070 by 3M as the primary working fluid. PF-5070 is an electrically insulating, inert perfluorocarbon fluid which is used in many heat transfer applications. Because all electronics in SprayCool enclosures get wet, the compatibility of those materials with perfluorocarbon fluids is important. Fortunately, customers have been able to cool commercially available electronics for years within direct spray enclosures; thereby taking advantage of increased performance density along with Size, Weight, and Power (SWaP) reductions and improved reliability. A partial list of embedded electronics employed by customers is included in Table 1.

Commercial Embedded Electronics	OEM
SAS PMC	ASTEK
CDDI; PCI MEZZANINE CARD ADAPTER	C2I2
MAR3200 ROUTER	Cisco
PERITEK ECLIPSE; PMC VIDEO CARD PMC	CWEC
DVME 181 PROCESSOR	CWEC
PCI BRIDGE; PMC SPMC-605	CWEC
UTILITY CAN BUS	CWEC
VISTA RS-422; PMC 10068204-151	CWEC
GPPI 178, GPP	CWEC
SVME 210 PMC CARRIER	CWEC
GPPI 179, GPP	CWEC
DVME 182, GPP	CWEC
ECLIPSE GRAPHICS	CWEC
CHAMP AV IV	CWEC
DVME 183, GPP	CWEC
R4000 VME VHF/UHF Receiver	ECLIPSE
DARKSTAR ROUTER	GD Canada
FIBER TO COPPER MEDIA CONVERTER	GD Canada
CP 613 PMC CARRIER	GE Fanuc
TEWS PMC/PCMIA ADAPTER	GE Fanuc
LEUTRON: PICPORT PMC	GE Fanuc
OCTAL; SERIAL PCMIP	GE Fanuc
CR-9; PENTIUM M; 1.1GHz, 1.6 GHz	GE Fanuc
CR-11; CORE2 DUO	GE Fanuc
SCSI ULTRA 160 ADAPTER	GE Fanuc
CK3; MPC7410	GE Fanuc
CK5; MPC7447 G4	GE Fanuc
CAN BUS PMC	GE Fanuc
SERIAL PMC; RS232, RS485	GE Fanuc
1394 FIREWIRE PMC	GE Fanuc
CP6-GESW24M3 Switch	GE Fanuc
CP640 Carrier Card	GE Fanuc
PMC-OCTPRO-232	GE Fanuc
PMC-USCSI3BP SCSI PMC	GE Fanuc
CP921 24 PORT GIG SWITCH	GE Fanuc
VR-9	GE Fanuc
C2P4 DUAL PROCESSOR P3, 850 MHz, GPP	GMS
TEKNOR DMXS64-GX DUAL P3, GPP	Kontron
MCJ6	MERCURY
ETHERNET SWITCH; PT-CPC-4406F-11346	PTI
PT-CPC6600 SWITCH	PTI
SENTIRIS VIDEO PMC	Quantum 3D
RM 940	RAMIX
PCMICA SPTCIM	Raytheon
PCMCIA CARD, TAC LINK 3000	Raytheon
THUNDERBOLT V-600 FPGA	SKY
CP1500S-440; UltraSparc IIi	Sun
CP2140-650-1G; ULTRASPARC IIi	Sun
USPIIi-1V/1, 1V/2P GPP	THEMIS
UltraSparc Iie - USB GPP	THEMIS

Table 1 Embedded electronics examples used by customers in SprayCool enclosures

The list in Table 1 does not include commercial or proprietary electronics employed by customers that are produced by prime contractors or system integrators such as RF receiver/tuners, analog boards, KVMs, memory devices, etc. In many instances, customers are using the same part number for air-cooled and SprayCool hardware.

COMPATIBILITY

Fluid compatible materials can be defined as those that do not wash off, degrade or require significant fluid filtration during long term exposure to fluid. In general, fluid compatibility of a given material can be determined by material hardness: The harder the material, the more compatible it is with perfluorocarbon fluids. Still soft materials have a broad spectrum of compatibility with Fluorinert and Performance Fluids. Table 2 provides examples of materials that are generally compatible.

GENERALLY COMPATIBLE MATERIALS
Epoxies & Adhesives
Labels (polyamide, vinyl, etc.)
Thermal Interface Materials (various from Chomerics, FujiPoly, Bergquist, Al Tech, Apteck Labs, Emerson & Cumings, 3M)
Polymers
Fluorinated Polymers: FEP, PTFE, Tefzel, Viton, ETFE, PVDF
Nylon 6, 6/6, 12
Polyethylene (HDPE, MDPE)
Polypropylene
Polyurethane (ester)
Ethyl Vinyl Acetate (with <10% VA content)
Rigid Polymers (PET, Acetyl, Acrylic, Polycarbonate, etc.)
Heat Shrink (Kynar, Polyolefin, PVDF)
O-Rings (fluorocarbon, Viton, and fluorosilicone)
Conformal Coating (acrylic and urethane)
Electrical Components/PCBs
Solder
Metals
Coatings (Alodine, Anodize, TCP, etc.)

Table 2 Generally accepted list of compatible materials

Of most interest to customers is the availability of compatible electronic components and thermal interface materials. Almost all electronic components are compatible with Fluorinert. Thermal interface materials come in so many variations it is difficult to identify a singular class of materials that are compatible. After compatibility testing various TIMs from the leading OEMs, it is evident that all companies have materials that are viable in a SprayCool enclosure. The specific application, thickness, conductivity requirements and operating temperatures of the board impact material selection. Some materials may not have a suitable replacement. However, it is noteworthy that even several phase change materials offering low thermal resistances for components such as processors, video graphics chips, etc. have proven compatible with perfluorocarbon fluids.

LESS DESIRABLE MATERIALS

Materials such as paste, grease and gels are typically not compatible. Other examples are included in Table 3. Again, incompatible materials in the system do not cause immediate catastrophic failure of electronics or cooling system. Over time materials will wash away or degrade until replacements are necessary. Adequate filtration is essential to minimizing system level impacts of contaminants. More detail on specific materials is provided in Appendix A, Material Compatibility Details.

GENERALLY LESS COMPATIBLE
RTV
Paper labels
Paste, grease and silicone based TIMs
Polyvinyl Chloride (PVC)
Polyethylene (LDPE, LLDPE)
Silicone
Silicone based coatings
Solder flux
Paint

Table 3 Materials that are generally less preferred for use in SprayCool enclosures

SprayCool's approach to managing materials of lesser compatibility is best described in Figure 2 where the relationship of percent mass extracted and the total amount of material in the system are used to determine filtration capacity requirements. The principal constituent of residue in the system is often plasticizers out of softer materials. As shown in Figure 1, there are filters in every SprayCool enclosure for both organic and inorganic contamination. The filter capacity and maintenance frequency varies between systems and use cases, but all systems have filtration independent of the material compatibility of a specific configuration. The sum of all incompatibilities will determine the filter life. Filters are readily replaced in SprayCool enclosures during routine maintenance of the electronics.

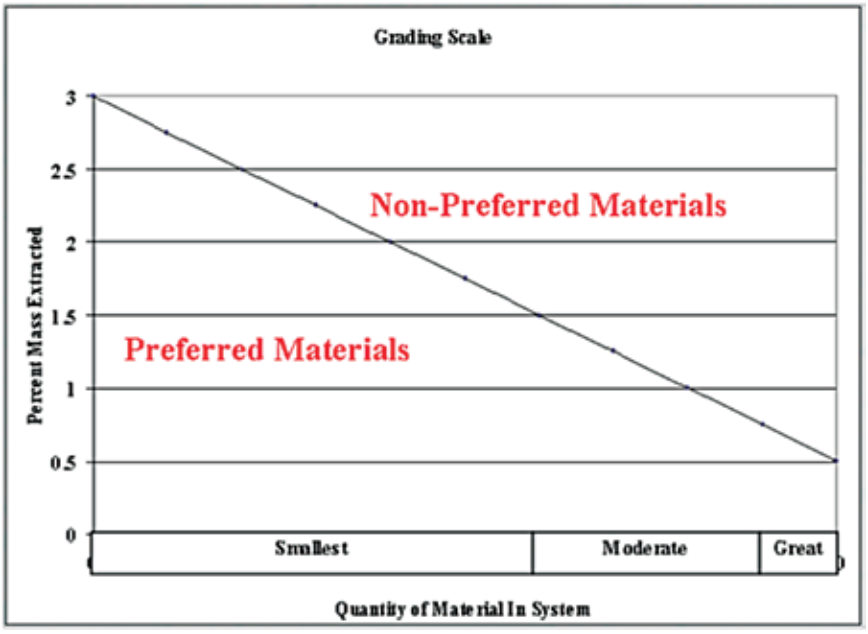

Figure 2 Compatibility grading scale for materials in SprayCool enclosures

Over the last two decades, SprayCool has amassed a database of nearly two thousand materials of interest to electronic system integrators. Additional compatibility information is available on the 3M website in a document for Heat Transfer Applications.

SUMMARY

While fluid compatibility is something to consider, it is typically not as complicated as many first think. SprayCool customers have flown commercial and proprietary electronics in systems on aircraft such as RQ-4 Global Hawk, U-2 Dragon Lady, MQ-1 Predator, UH-60 Blackhawk, MQ-1C Warrior, and Little Bird. Ground based vehicles include the Marine Corps' Expeditionary Fighting Vehicle that has been operating vehicles with SprayCool enclosures since 2001. SprayCool has a large database for quick reference to simplify the material selection process. For materials that SprayCool has not tested, the procedure to test material samples for compatibility is quick and easy. Further compatibility information is available from the fluid manufacturer, 3M, for heat transfer applications such as electronics cooling.

APPENDIX A MATERIAL COMPATIBILITY DETAILS

INTRODUCTION

The most common materials tested are epoxies, thermal interface materials, soft and rigid polymers, and electrical components. In general, materials that are pasty, stinky, gooey, greasy and squishy tend to show the greatest percent mass extraction. Two-part epoxies do not generally pose a compatibility risk unless they do not cure. Thermal interface materials include pastes, phase change materials and papers which can vary in material composition. Soft and rigid polymers are broken into their respective families for classification. Polymers are present in numerous applications including tubing, structural components, o-rings, and metal replacement components. Electrical components consist of printed circuit boards and their components, solder, and conformal coatings. Additional materials such as metals and conversion coatings are also included. Whenever testing is required, the sample is tested in its operational form to represent application conditions.

SILICONE

There are a few silicone-based materials that do well in SprayCool enclosures, but most exhibit significant extraction. Silicone is the highest risk contaminant because it is only partially removable by the filtration system. The unique challenge with silicone is the filter media will become coated with the silicone oil, significantly decreasing the effectiveness and life of the filter. A component that becomes coated with silicone could have its heat dissipation performance decreased. The overall amount of silicone must be managed to extend filter life and reduce risk of thermal performance degradation.

EPOXIES & ADHESIVES

Most epoxies are cured to a very hard state and consist of similar materials that are compatible. These materials are usually used in such low quantities that compatibility is not a significant concern. High temperature, oven cured epoxies and adhesives have the most success of being compatible, while low and room temperature epoxies and adhesives may require filtration.

When testing for compatibility, epoxy samples are cured and immersed in fluid on a light-weight aluminum coupon for maximum exposure. Some adhesives, such as anaerobic materials, require specific curing conditions in which the manufacturer recommended material selection is followed.

LABELS

More robust materials such as polyamide or vinyl withstand fluid exposure much better and are becoming more common on today's electronics. Paper labels will degrade with exposure to fluid over time. If electronics have conformal coating, any label material can be used.

THERMAL INTERFACE MATERIALS

Many thermal interface materials are compatible with the fluid and do not require filtration. Although several companies produce silicone based materials, most companies offer silicone-free products comparable to their silicone counterparts. Thermal interface papers are worthy of review as binders that hold the fibrous materials together could break down in the fluid environment. Several phase change materials are compatible. Generally pastes have mixed success in the fluid environment.

POLYMERS
With few exceptions, hard polymers are compatible. Flexible polymers vary widely in chemical composition. All manufacturers' formulas for polymers are different. Due to this, it is difficult to qualify one family of polymers as compatible. Both material extraction and material volume should be managed on a case by case basis.

FLUORINATED POLYMERS: FEP, PTFE, TEFZEL, VITON, ETFE, PVDF
Nearly all fluorinated polymers are compatible, with conditions. FluorinertTMis a fully fluorinated fluid, therefore any fluorinated material will absorb high volumes of fluid, typically absorbing between 4 and 8% of the polymers weight in fluid. This can lead to slight swelling that may cause problems depending on the application.

NYLON 6, 6/6, 12
There are many forms of Nylon. Overall, Nylon requires filtration in a SprayCool system. Some exceptions are Nylon 6/6 when used in test equipment where the fluid is maintained at room temperature or the fluid integrity is not critical. The lower grades of Nylon, such as 6, produce solids after exposure to the fluid. The higher grades of Nylon, such as 12, produce very high quantities of oils and show significant material degradation.

POLYETHYLENE: HDPE, MDPE, LDPE, LLDPE, COPOLYMERS
HDPE (high density polyethylene) is a very rigid polymer and is compatible. MDPE (medium density polyethylene) has mixed results in past compatibility tests. Additional grades may be evaluated as necessary in the future. LDPE (low density polyethylene) and LLDPE (linear low density polyethylene) require filtration. Few types of ethylene copolymers have been tested.

POLYPROPYLENE
Polypropylene is a rigid polymer that comes in many forms, such as tubing and containers. It rarely requires filtration.

POLYURETHANE
Polyurethane has two base forms, ether and ester. They are most commonly found as flexible jacketing or tube material. Ester based polyurethane is currently used as the current flexible tube solution, Tygothane C-210-A. Filtration can be required for polyurethane.

ETHYL VINYL ACETATE
EVA (ethyl vinyl acetate) is commonly used in tubing and hot melt adhesives. Products vary depending on vinyl acetate content. Lower VA content materials, less than 10%, increase the likelihood of the product being compatible. Products containing higher percentages will produce more residues, and would be included in the filtration budget.

PVC
Polyvinyl Chloride (PVC) requires filtration. PVC can also become brittle over time in the presence of FluorinertTM. PVC is commonly found as a wire jacket which can easily be confused with the preferred material, Tefzel. Where possible, PVC should be replaced with compatible substitutes. If no replacements are available, PVC degradation can be monitored to swap parts out over time. In some cases years of constant exposure are required to breakdown PVC.

RIGID POLYMERS: MACHINED, MOLDED
These materials include PET, Acetyl, Acrylic, Polycarbonate, and HDPE to name a few. Typically these are fluid compatible due to the lack of plasticizers found in them. Like all other polymers, slight variation does occur among manufacturers.

HEAT SHRINK: KYNAR, POLYOLEFIN
SprayCool utilizes Kynar heat shrink because it does not require filtration. The base polymer for Kynar is PVDF. Other materials evaluated are classified as polyolefin, which does not specify a base polymer. Such non-fluorinated heat shrink materials should be reviewed for compatibility or filtration requirements.

O-RINGS
O-ring materials come in many types: fluorocarbon, Viton, fluorosilicone, silicone, NBR, EPDM, urethane, butyl, and Teflon encapsulated. SprayCool predominately utilizes fluorocarbon, Viton, and fluorosilicone o-ring materials. One silicone material has been used for o-rings. Other material types have been tested, but require filtration. Not all Viton grades are the same, so using the specific material description is necessary the determine compatibility.

CONFORMAL COATING
Although not required for electronics in SprayCool products, conformal coatings are widely used. They are made of several base materials, most commonly acrylic, urethane, and silicone. Acrylic and urethane based conformal coatings are acceptable although some require filtration. SprayCool recommends Humiseal 1A33, a urethane based coating. Whenever possible, silicone coatings should be avoided in SprayCool enclosures.

ELECTRICAL COMPONENTS/PCBS
Most electrical components are made of metal, epoxy resins, and/or ceramic. All of these materials have passed compatibility with few instances of failure. Visual inspection of boards is made to identify any potential problems. All non-coated paper labels on PCBs should be removed as they will come off over time.

SOLDER
All solders are compatible; however, solder flux should be removed from printed circuit assemblies. Flux-less solder may require filtration. In the event boards have flux, the flux can be removed at the board or system level without much effort.

METALS
FluorinertTMis compatible with nearly all metals. The only exceptions are highly reactive metals such as finely divided active metals, alkali and alkaline earth metals. These types of metals are not commonly found in commercial products.

COATINGS
Conversion coatings, such as Alodine and Anodize, are required by many military applications. These coatings are acceptable. In most applications, paint and powder coatings do not come in contact with Fluorinert. For applications requiring direct exposure to the cooling fluid, an analysis should be completed on a case by case basis.

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