SANDIA REPORT
SAND2005-7896
Unlimited Release
Printed February 2006

Compatibility of Fluorinert™, FC-72, with Selected Materials

James H. Aubert and Patricia S. Sawyer

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND 2005-7896
Unlimited Release
Printed February 2006

Compatibility of Fluorinert™, FC-72, with Selected Materials

James H. Aubert and Patricia S. Sawyer
Organic Materials Department, 01821
Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185-0888

ABSTRACT

Removable encapsulants have been developed as replacement materials for electronic encapsulation. They can be removed from an electronic assembly in a fairly benign manner. Encapsulants must satisfy a limited number of criteria to be useful. These include processing ease, certain mechanical, thermal, and electrical properties, adhesion to common clean surfaces, good aging characteristics, and compatibility. This report discusses one aspect of the compatibility of removable blown epoxy foams with electronic components. Of interest is the compatibility of the blowing agent, Fluorinert™ (FC-72) electronic fluid with electronic parts, components, and select materials. Excellent compatibility is found with most of the investigated materials. A few materials, such as Teflon® that are comprised of chemicals very similar to FC-72 show substantial absorption of FC-72. No compatibility issues have yet been identified even for the few materials that show substantial absorption.

This Page Intentionally Left Blank

Table of Contents

Figures

Tables

This Page Intentionally Left Blank

Compatibility of Fluorinert™, FC-72, with Selected Materials

Introduction

Polymeric encapsulating foams are frequently used to protect high-value electronic and electro-mechanical components from shock, vibration, and environmental factors as well as to provide thermal and electrical insulation. All polymeric foam encapsulants for electronics are electrical insulators. The most common encapsulants are rigid, thermosetting polyurethane or epoxy foams. The typical foaming process is to enclose the electronics in a mold and then pour the pre-mixed reactive components into the mold. The reactants simultaneously foam and cure around the electronics, and the mold is then removed.

For some electronic components, it is important to be able to remove the encapsulants at a later time for repairs, upgrades, or to salvage expensive components (figure 1). This requires encapsulants that can be removed without damage to electrical components. However, it is also necessary for removable encapsulants to have mechanical and processing properties that are typical of an epoxy or polyurethane encapsulant. We have developed new encapsulants for this purpose that have mechanical properties similar to conventional encapsulants, but can be removed with a chemical process that is relatively benign [1,2]. Conventional epoxy or polyurethane encapsulants are difficult to remove due to crosslinking, solvent resistance, and mechanical toughness. In some instances,

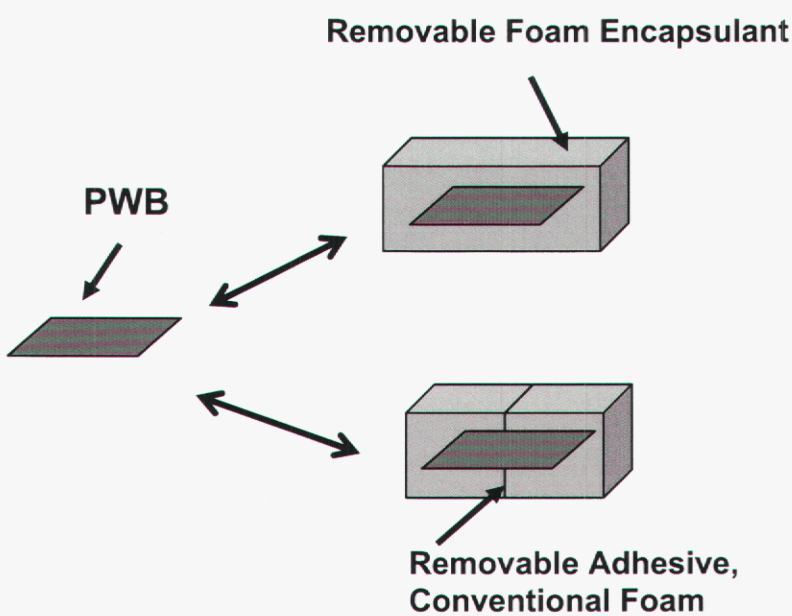

Figure 1. Possible ways to remove an encapsulated PWB.

these materials have been removed by resorting to harsh means such as chiseling or by using aggressive solvents such as n-methyl pyrrolidinone. These harsher methods of encapsulant removal can often damage electronic components.

An example of a foamed electronic component and the same electronic component after foam removal is shown in figure 2. This foam was formulated with an epoxy resin that incorporated thermally reversible Diels-Alder adducts. Adducts can be opened by increasing the temperature and the encapsulant can be removed with a combination of elevated temperature and a solvent [3].

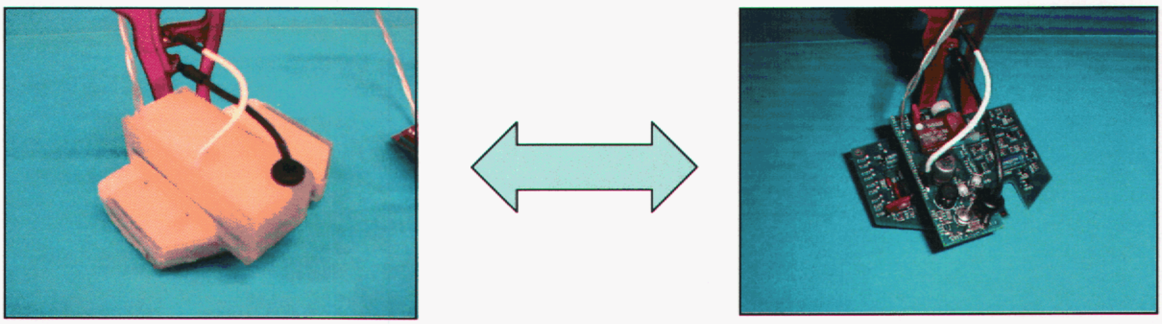

Figure 2. An electronic component encapsulated with removable epoxy foam and the same component with the foam removed.

Fluorinert™ electronic fluid, FC-72, obtained from the 3M company [4], is the physical blowing agent used in removable epoxy foams, REF308 and REF320 [1,2]. The boiling point of FC-72 is 56 °C. The approximate empirical chemical formula is C_6F_{14} and the molecular weight is approximately 338 g/mole. Additional data on FC-72 is available from 3M [4] and also in Appendix I. When removable foams are prepared, REF308 contains approximately 15 wt% FC-72 and REF320 contains approximately 7.6 wt% FC-72. Very little of the blowing agent leaves the foam during the cure schedule, (2 hours at 65 °C followed by 24 hours at 75 ° [1,2]). FC-72 will slowly diffuse out of the foam during the lifetime of assembly and will enter the system atmosphere. In a sealed system, the equilibrium vapor pressure of FC-72 is 232 torr [4]. In a system that is backfilled with 1 atm (760 torr) of an inert gas, the FC-72 will become 23% of the equilibrium atmosphere [232/(232+760)] if a sufficient supply of FC-72 is contained within the system. Although FC-72 is chemically inert, it could interact physically with other materials in the assembly.

We have investigated the compatibility of Fluorinert™ electronic fluid, FC-72, with a number of common polymers and other materials that are present in some systems.

Experimental Procedure

In this work we investigated physical interactions of FC-72 with a variety of materials. The physical interactions were inferred by measuring weight or dimensional changes of material coupons, pieces of components, or pieces of materials after exposure to FC-72. Coupons and materials were purchased from commercial sources or obtained at SNL as indicated in the Tables of results shown below. The initial weight, dimensions, and appearance of the materials were recorded. The coupons were then exposed to an environment of FC-72 for four weeks. Periodically, the weight, dimensions, and appearance of the coupons were again recorded. For the size of materials tested, one to two weeks appeared to be a sufficient length of time to equilibrate with FC-72. The weights are accurate to approximately 0.002 grams. The dimensional measurements are reported to only 0.01 inch because of a number of sources of dimensional measurement error including some of the materials being soft and flexible and some coupons not being precisely rectangular. In addition, the silicon pressure pad was particularly difficult to obtain accurate results on because, in addition to the two sources of error mentioned above, it was also porous.

In the initial set of experiments, two conditions of FC-72 exposure were investigated. One condition was complete submersion of the coupons in liquid FC-72. The other was FC-72 vapor that was obtained by placing 1 gram of FC-72 along with the coupon in a sealed glass bottle that had a volume of 130 cm^3. This created an atmosphere of FC-72 within the bottle that would correspond to approximately what would be expected in a sealed system atmosphere at equilibrium, 232 torr [4]. The presence of the atmosphere could be confirmed by noting a pool of liquid FC-72 in the bottom of each bottle through the duration of the test. Thermodynamics teach us that both of these conditions are identical since the vapor and the liquid are in equilibrium (equal chemical potentials).

The coupons chosen for study included some materials that are present in some systems. These include RTV (silicone rubber), Teflon® (wire insulation), silicone pressure pad, and copper. In addition, we also investigated other common polymers. Their interactions with FC-72 may provide us with insight into the interactions of additional polymers not currently identified as being present in any system. These polymers include polymethylmethacrylate (acrylic), polystyrene, Sylgard® 184 elastomer, high-density polyethylene (HDPE), polycarbonate, polyurethane elastomer, Viton® O-Rings, and Nylon 6/6.

In the second set of experiments, we investigated the physical interactions of FC-72 with coupons of printed wiring board materials, (FR4, TMM10i, polyimide/glass, Duroid® 3010), coupons of Polytrifluoro-chloroethylene (Kel-F®), and a coupon of pressed Estane® 5703P pellets. The Estane® sample was prepared by pressing pellets into a film. Only weight changes were recorded since the film dimensions were very irregular. These samples were purchased as indicated in the Table of results shown below or obtained from sources within SNL. Coupons of Duroid® 3010 were not available. Instead we used a small piece of board with somewhat irregular dimensions that was cut from a populated board. We also used a small board that was populated with a number of components. The initial weights, dimensions, and appearances of the coupons/test boards were recorded. They were then submerged in liquid, room temperature, FC-72 for four weeks. The weights, dimensions, and appearances were recorded after each week of exposure. We did not see statistically significant changes in the uptake of FC-72 after the first week. Therefore, we concluded that equilibrium absorption was obtained. The weights are accurate to approximately 0.002 grams. The dimensional measurements are reported to 0.01 inch due to a number of sources of measurement error as previously described above.

Experimental Results

The experimental results are shown in Table I and in Table II. A small number of the polymer coupons had significant FC-72 uptake as noted by both the measured weight gains and dimensional changes. These polymers are highlighted in bold in Table I and include Sylgard® 184, RTV, and Teflon®. The copper coupons were photographed after two week and four week exposures. These photographs are shown in figures 3 and 4.

Table I. Solvent uptake and swelling of polymer coupons in two environments of FC-72 (approximately 232 torr and liquid). Some of the polymers chosen are present in systems and others are for comparative purposes only. Copper exposure was also monitored for corrosion. The materials that are highlighted in bold had a significant uptake of FC-72.

Coupons/ Exposure	**FC-72 Vapor 2-weeks**	**FC-72 Vapor 4-weeks**	**FC-72 Liquid 2-weeks**	**FC-72 Liquid 4-weeks**
Polymethyl-methacrylate (a)	Initial dimensions/ weight: 4.355g 0.07"x1.04"x3.02" 2-week dimensions and weight: 4.356g 0.07"x1.04"x 3.02"	Initial dimensions/ weight: 4.355g 0.07"x1.04" x3.02" 4-week dimensions and weight: 4.354g 0.07"x1.04"x 3.02"	Initial dimensions/ weight: 4.215g 0.07"x0.99"x3.01" 2-week dimensions and weight: 4.215g 0.07"x1.00"x 3.02"	Initial dimensions/ weight: 4.215g 0.07"x 0.99"x3.01" 4-week dimensions and weight: 4.215g 0.07"x1.00"x3.01"
Polystyrene (b)	Initial dimensions/ weight: 2.765g 0.06"x 0.90"x3.03" 2-week dimensions/weight 2.765g 0.06"x.90"x 3.03"	Initial dimensions/ weight: 2.765g 0.06"x 0.90"x3.03" 4-week dimensions/ weight: 2.766g 0.06"x.90"x3.03"	Initial dimensions/ weight: 2.995g 0.060"x0.97"x3.01" 2-week dimensions/ weight: 2.977g 0.06"x.97"x 3.02"	Initial dimensions/ weight: 2.995g 0.06"x 0.97"x3.01" 4-week dimensions/ weight: 2.977g 0.06"x.98"x 3.02"

Sylgard® 184 Coupon (c)	**Initial dimensions/ weight: 2.885g 0.05"x1.02"x3.01" 2-week dimensions and weight: 2.990g (+3.6%) 0.05"x1.03"x3.03"**	**Initial dimensions/ weight: 2.885g 0.05"x1.02"x3.01" 4-week dimensions and weight: 2.987g (+3.5%) 0.06"x1.02"x3.03"**	**Initial dimensions/ weight: 2.742g 0.05"x1.00"x3.01" 2-week dimensions and weight: 2.817g**	**Initial dimensions/ weight: 2.742g 0.05"x1.00" x3.01" 4-week dimensions and weight: 2.804g (+2.3%) 0.06"x1.00x3.03**
RTV coupon (d)	**Initial dimensions/ weight: 2.597g 0.04"avg x 1.00"x2.97" 2-week dimensions and weight: 2.676g (+3.0%) 0.05"avg x 1.02"x 2.99"**	**Initial dimensions/ weight: 2.597g 0.04"avg x 1.00" x2.97" 4-week dimensions and weight: 2.673g (+2.9%) 0.05"x1.03"x3.00"**	**Initial dimensions/ weight: 2.473g 0.04"x 1.00"x3.00" 2-week dimensions and weight: 2.526g (+2.1%) 0.04"x1.00"x 2.99"**	**Initial dimensions/ weight: 2.473g 0.04"x 1.00"x3.00" 4-week dimensions and weight: 2.514g (+1.7%) 0.05"x1.03"x3.04"**
High density polyethylene (e)	Initial dimensions/ weight: 2.774g 0.06"x 0.99"x2.97" 2-week dimensions and weight: 2.774g 0.06"x0.99"x 2.98"	Initial dimensions/ weight: 2.774g 0.06"x 0.99"x2.97" 4-week dimensions and weight: 2.774g 0.06"x.99"x2.97"	Initial dimensions/ weight: 2.816g 0.06"x 1.00"x2.99" 2-week dimensions and weight: 2.816g 0.061"x1.00"x 2.99"	Initial dimensions/ weight: 2.816g 0.06"x 1.00"x2.99" 4-week dimensions and weight: 2.816g 0.06"x1.00"x2.99"
Polycarbonate (f)	Initial dimensions/ weight: 3.676g 0.06"x 1.01"x3.00" 2-week dimensions and weight: 3.678g 0.06"x1.00"x 3.00"	Initial dimensions/ weight: 3.676g 0.06"x 1.00"x3.00" 4-week dimensions and weight: 3.676g 0.07"x1.03"x3.00"	Initial dimensions/ weight: 3.544g 0.06"x 0.97"x3.02" 2-week dimensions and weight: 3.544g 0.07"x.97"x 3.00"	Initial dimensions/ weight: 3.544g 0.06"x 0.97"x3.02" 4-week dimensions and weight: 3.543g 0.07"x.98"x3.00"
Polyurethane elastomer (g)	Initial dimensions/ weight: 3.796g 0.06"x 1.03"x2.99" 2-week dimensions and weight: 3.796g 0.06"x 1.03"x 3.01"	Initial dimensions/ weight: 3.796g 0.06"x 1.03"x2.99" 4-week dimensions and weight: 3.795g 0.06"x1.03"x3.01"	Initial dimensions/ weight: 3.564g 0.06"x 1.01"x2.99" 2-week dimensions and weight: 3.564g 0.06"x1.01"x 2.99"	Initial dimensions/ weight: 3.564g 0.06"x 1.01"x2.99" 4-week dimensions and weight: 3.563g 0.06"x1.01"x2.99"

Viton® O-Ring (h)	Initial dimensions/ weight: 1.408g .10" dia 1.53" size 2-week dimensions and weight: 1.409g .10" dia 1.53" size	Initial dimensions/ weight: 1.408g .10" dia 1.53" size 4-week dimensions and weight: 1.414gm .10" dia 1.48" size	Initial dimensions/ weight: 1.405g .10" dia 1.52" size 2-week dimensions and weight: 1.410g .10" dia 1.52" size	Initial dimensions/ weight: 1.405g .10" dia 1.52" size 4-week dimensions and weight: 1.412g .09" dia 1.50" size
Teflon® (i)	**Initial dimensions/ weight: 2.495g 0.02"x 1.14"x3.04"** **2-week dimensions and weight: 2.694g (+8.0%) 0.02"x 1.17"x 3.10"**	**Initial dimensions/ weight: 2.495g 0.02"x 1.14"x3.04"** **4-week dimensions and weight: 2.588g (+3.7%) 0.02"x1.12"x3.10"**	**Initial dimensions/ weight: 2.354g 0.02"x 1.06"x3.07"** **2-week dimensions and weight: 2.548g (+8.2%) 0.0.02"x 1.06"x 3.14"**	**Initial dimensions/ weight: 2.354g 0.02"x 1.06"x3.07"** **4-week dimensions and weight: 2.538g (+ 7.8%) 0.02"x1.07"x3.16"**
Nylon 6/6 (j)	Initial dimensions/ weight: 3.529g 0.06"x 1.02"x3.01" 2-week dimensions and weight: 3.532g 0.06"x 1.01"x 3.01"	Initial dimensions/ weight: 3.529g 0.06"x 1.02"x3.01" 4-week dimensions and weight: 3.531g 0.06"x1.02"x3.01"	Initial dimensions/ weight: 3.497g 0.06"x 1.01"x3.01" 2-week dimensions and weight: 3.496g 0.06"x 1.01"x 3.01"	Initial dimensions/ weight: 3.497g 0.06"x 1.01"x3.01" 4-week dimensions and weight: 3.496g 0.06"x1.01"x3.01"
OFE Copper coupon (k)	Initial dimensions/ weight: 1.469g 0.01"x 1.01"x 1.01" 2-week dimensions and weight: 1.469g 0.01"x 1.00"x 1.01" No visible change	Initial dimensions/ weight: 1.469g 0.01"x 1.01"x 1.01" 4-week dimensions and weight: 1.468g 0.01"x 1.01"x 1.01" No visible change	Initial dimensions/ weight: 1.482g 0.01"x 1.01"x 1.02" 2-week dimensions and weight: 1.482g 0.01"x 1.01"x 1.02" No visible change	Initial dimensions/ weight: 1.482g 0.01"x 1.01"x 1.02" 4-week dimensions and weight: 1.482g 0.01"x 1.01"x 1.02" No visible change
Silicone Pressure Pad (l)	Initial dimensions/ weight: 0.864g 0.05"x .95"x3.18" 2-week dimensions/ weight: 0.864g 0.06"x .99"x 3.19"	Initial dimensions/ weight: 0.864g 0.05"x .95"x3.18" 4-week dimensions/ weight: 0.863g 0.06"x0.96 "x3.17"	Initial dimensions/ weight: 0.808g 0.05"x.95"x3.09" 2-week dimensions/ weight: 0.815g (+0.9%) 0.06"x .95"x 3.12"	Initial dimensions/ weight: 0.808g 0.05"x.95"x3.09" 4-week dimensions/ weight: 0.808g 0.06"x0.94"x3.10"

(a) Acrylic LUCITE, Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(b) High-impact polystyrene, Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(c) Sylgard® 184; Dow Corning; from World Precision Instruments, Inc. 175 Sarasota Center Blvd., Sarasota, FL 34240, 1-866-606-1974
(d) RTV 3110F; Dow Corning; South Saginaw Rd., Midland, MI 48686-0994; 989-496-6000
(e) High Density Polyethylene from Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(f) Polycarbonate from Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(g) Polyurethane from Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(h) Viton® O-ring from VWR scientific; p/n CG-305
(i) Teflon® from Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(j) Nylon 6/6 from Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(k) OFE Copper obtained from Rob Sorenson, dept. 1832, SNL.
(l) Silicone pressure pad obtained from Ed Wyckoff, dept. 2132, SNL.

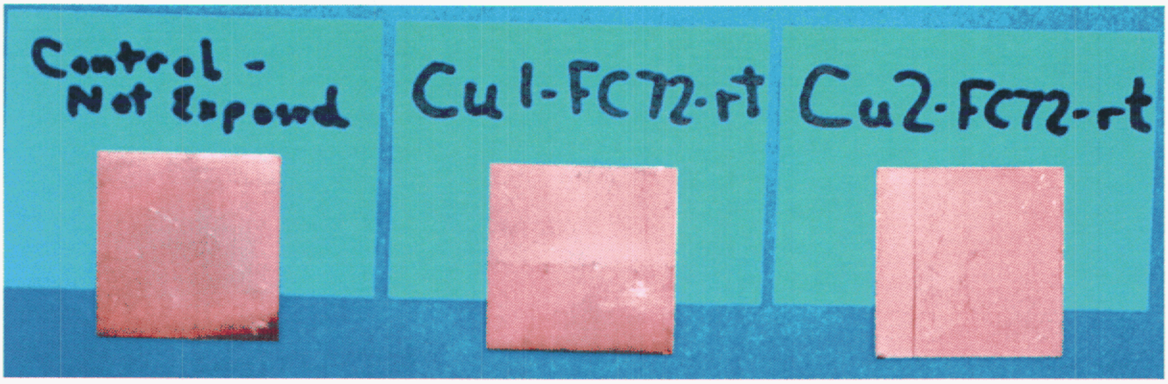

Figure 3. Two week exposure of copper samples in FC-72. Left to right: original copper, copper exposed to approximately 232 torr of FC-72 for two weeks, copper submerged under liquid FC-72 for two weeks. There was no corrosion visible and all of the coupons looked identical.

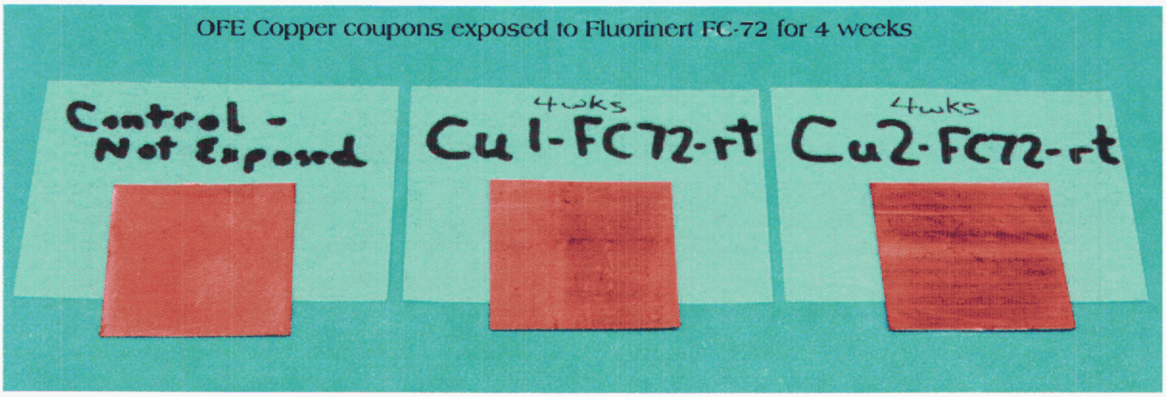

Figure 4. Four week exposure of copper samples in FC-72. Left to right: original copper, copper exposed to approximately 232 torr of FC-72 for four weeks, copper submerged under liquid FC-72 for four weeks. There was no corrosion visible and all of the coupons looked identical.

Table II. Absorption and swelling of polymer coupons after submerging in liquid room temperature FC-72.

Coupons/ Exposure	**FC-72 Liquid 1-week**	**FC-72 Liquid 2-week**	**FC-72 Liquid 3-week**	**FC-72 Liquid 4-week**
FR4 (m)	Initial dimensions/ weight: 5.401g 0.06"x1.00"x3.00" 1-week dimensions and weight: 5.401g 0.06"x1.00"x3.00"	Initial dimensions/ weight: 5.401g 0.06"x1.00"x3.00" 2-week dimensions and weight: 5.396g 0.06"x1.00"x3.00"	Initial dimensions/ weight: 5.401g 0.06"x1.00"x3.00" 3-week dimensions and weight: 5.4000.06"x1.00"x 3.00"	Initial dimensions/ weight: 5.401g 0.06"x1.00"x3.00" 4-week dimensions and weight: 5.400g 0.06"x1.00"x3.00"
KEL-F®, (PCTFE2) LOX-grade Polytrifluoro-chloroethylene (n)	Initial dimensions/ weight: 6.681g 0.07"x1.02"x2.99" 1-week dimensions and weight: 6.680g 0.07"x1.02"x2.99"	Initial dimensions/ weight: 6.681g 0.07"x1.02"x2.99" 2-week dimensions and weight: 6.680g0.07"x1.02" x2.99"	Initial dimensions/ weight: 6.681g 0.07"x1.02"x2.99" 3-week dimensions and weight: 6.680g 0.07"x1.02"x2.99"	Initial dimensions/ weight: 6.681g 0.07"x1.02"x2.99" 4-week dimensions and weight: 6.680g 0.07"x1.02"x2.99"
TMM10i (o)	Initial dimensions/ weight: 8.511g 0.06"x1.00"x3.00" 1-week dimensions and weight: 8.511g 0.06"x1.00"x3.00"	Initial dimensions/ weight: 8.511g 0.06"x1.00"x3.00" 2-week dimensions and weight: 8.513g 0.06"x1.00"x3.00"	Initial dimensions/ weight: 8.511g 0.06"x1.00"x3.00" 3-week dimensions and weight: 8.511g 0.06"x1.00"x3.00"	Initial dimensions/ weight: 8.511g 0.06"x1.00"x3.00" 4-week dimensions and weight: 8.511g 0.06"x1.00"x3.00"
Polyimide Glass (p)	Initial dimensions/ weight: 3.478g 0.06"x.50"x3.20" 1-week dimensions and weight: 3.477g 0.06"x.50"x3.20"	Initial dimensions/ weight: 3.478g 0.06"x.50"x3.20" 2-week dimensions and weight: 3.479g 0.06"x.50"x3.20"	Initial dimensions/ weight: 3.478g 0.06"x.50"x3.20" 3-week dimensions and weight: 3.478g 0.06"x.50"x3.20"	Initial dimensions/ weight: 3.478g 0.06"x.50"x3.20" 4-week dimensions and weight: 3.477g 0.060"x.50"x3.20"
Duroid® 3010 Populated board (q)	Initial dimensions/ weight: 18.215g 0.05-0.06"x1.47"x2.61"	Initial dimensions/ weight: 18.215g 0.05-0.06"x1.47"x2.61"	Initial dimensions/ weight: 18.215g 0.05-0.06"x1.47"x2.61"	Initial dimensions/ weight: 18.215g 0.05-0.06"x1.47"x2.61"

	1-week dimensions and weight: 18.394g 0.05-0.06"x1.47"x2.61"	2-week dimensions and weight: 18.388g 0.05-0.06"x1.47"x2.61"	3-week dimensions and weight: 18.392g 0.05-0.06"x1.47"x2.61"	4-week dimensions and weight: 18.375g 0.05-0.06"x1.47"x2.61"
Duroid® 3010 Cut board without components (r)	Initial dimensions/weight: 0.957g 2.33mmx3.99mmx 27.25mm No 1-week data	Initial dimensions/weight: 0.957g 2.33mmx3.99mmx 27.25mm 2-week dimensions and weight: 0.968g (1.1%) 2.33mmx4.15mmx 27.23mm	Initial dimensions/weight: 0.957g 2.33mmx3.99mmx 27.25mm 3-week dimensions and weight: 0.967g (1.0%) 2.33mmx4.29mmx 27.40mm	Initial dimensions/weight: 0.957g 2.33mmx3.99mmx 27.25mm 4-week dimensions and weight: 0.967g (1.0%) 2.33mmx4.30mmx 27.24mm
Estane® 5703P Pellets pressed into a film (s)	Initial weight: 1.524 g 1-week weight: 1.524g	Initial weight: 1.524 g 2-week weight: 1.524g	Initial weight: 1.524 g 3-week weight: 1.524g	Initial weight: 1.524 g 4-week weight: 1.524g

(m) Circuit Shop, 8512 San Joaquin S.E., Albuquerque, NM 87108.
(n) Ridout Plastics, Ruffin Rd., San Diego, CA 92123.
(o) Circuit Shop, 8512 San Joaquin S.E., Albuquerque, NM 87108.
(p) Circuit Shop, 8512 San Joaquin S.E., Albuquerque, NM 87108.
(q) Test board provided by Sarah Leming, 2332.
(r) Cut piece of test board (unpopulated) provided by Paul Vianco, 1824.
(s) Estane® 5703P, film of pressed pellets provided by R. Assink, SNL, dept. 1821.

Discussion of Results

The glassy polymers investigated do not absorb very much FC-72. On the other hand, elastomeric polymers absorb more FC-72. Both Sylgard® 184 and RTV absorbed nominally 3 wt% FC-72. There could be both Sylgard® 184 and RTV in some systems. Surprisingly, the Viton® O-Ring absorbed almost no FC-72 and the dimensions remained constant. This is a little surprising because Viton® is a fluorinated polymer. Some types of Viton® are utilized in some systems. Estane® 5703P and KEL-F®, (Polytrifluoro-chloroethylene), which are also utilized on some systems, absorbed no FC-72. Copper showed no corrosion in FC-72 (no weight or dimensional changes, no visible changes). This is as expected since FC-72 is unreactive (i.e. *inert* as in Fluor*inert*). Silicone pressure pads absorbed less than 1 wt% of FC-72 although the results on the pressure pads were questionable due to the experimental difficulties mentioned above.

Although the absorption of FC-72 on silicon pressure pads was less than 1 wt%, one might question whether the compression set of the pads will be different which would affect their functionality. Teflon® took up the most FC-72, about 8 wt%. The question is whether this would affect the insulating ability of wire insulation that might be comprised of material that is Teflon-like. This is not a likely scenario, but could be investigated for verification. Except for Teflon®, the elastomeric materials took up the most FC-72. The effect of FC-72 on o-rings could be investigated. Even though the Viton® o-ring that we investigated took up very little, other o-rings could be affected more significantly.

The printed wiring board materials, (FR4, polyimide/glass, and TMM10i) absorbed no measurable amount of FC-72. Duroid® 3010 absorbed a small amount of FC-72, 1.1%. None of the boards and coupons showed any visual change after exposure to FC-72 for four weeks.

Conclusions

No real detrimental interactions of FC-72 were found in this study. No chemical reactivity was indicated with any coupon based upon the unchanged appearance of the coupons. Copper coupons were not affected by FC-72. Most tested polymers were not affected by FC-72. A few tested polymers (Teflon®, Sylgard® 184, and RTV silicone) showed substantial uptake of FC-72 (3% - 8%). We do not expect that the functional requirements of these materials would be negatively affected by the FC-72 absorption. For example, Teflon®, used as electrical insulation, should still insulate as well with the absorbtion of FC-72 that is itself an excellent insulator. Silicone used in system dessicants, GE615, was reported to not absorb FC-72 [5]. Some polymers that have chemical structures containing fluorine and chlorine might be expected to absorb FC-72 as Teflon® did. However, neither KEL-F® nor Viton® absorbed any FC-72.

The tested printed wiring boards, (FR4, polyimide/glass, and TMM10i) absorbed no FC-72. Duroid® 3010 absorbed a small amount of FC-72, 1.1%.

Some additional compatibility work could be useful. This would include looking at the effect of a small absorption of FC-72 on the dielectric properties of Duroid® 3010. Pressure pads could be looked at to see if their functionality is compromised from exposure to FC-72. The main functionality is their compression set. The ability of Teflon® to insulate could be looked at also to see if it is compromised at all by exposure to FC-72, although this seems unlikely. Compatibility work could be considered on other system materials not identified in time for this report.

Acknowledgements

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

References

[1] James H. Aubert, James R. McElhanon, Randall S. Saunders, Patricia S. Sawyer, David R. Wheeler, Edward M. Russick, Peter B. Rand, and Douglas A. Loy, Sandia Report, SAND2001-0295, "Progress in Developing Removable Foams, Adhesives, and Conformal Coatings for the Encapsulation of Weapon Components (2001).

[2] J. R. McElhanon, E. M. Russick, D. R., Wheeler, D. A. Loy, and J. H. Aubert, J. Appl. Polym. Sci., **85**, 1496-1502 (2002).

[3] James H. Aubert, Sarah K. Leming, and Patricia S. Sawyer, "Component Compatibility of a Removal Process for Removable Encapsulants," SAND report, SAND2005-7211, 2005.

[4] 3M Fluorinert™ Electronic Liquids For Electronic Reliability Testing, *2005,* http://multimedia.mmm.com/mws/mediawebserver.dyn?ggggggQO&svgAKhguKhgggj23S1GGGGF-.

[5] L. Serna, "Small Core Materials Test Status as of June '05," presentation to the Technical Interchange Meeting, Sandia National Labs, 6/8-9/2005.

Distribution

MS-0311	G. Benavides, 2616
MS-0311	G. Randall, 2616
MS-0311	J. Schare, 2616
MS-0481	S. Barnhart, 2132
MS-0481	R. Harrison, 2132
MS-0481	J. Montoya, 2132
MS-0481	D. Thomas, 2132
MS-0481	E. Wyckoff, 2132
MS-0501	M. Craig, 5332
MS-0537	G. Luguna, 5353
MS-0537	T. Rohwer, 5353
MS-0537	D. Weiss, 5353
MS-0537	R. Woodrum, 5353
MS-0638	S. Kalemba, 12341
MS-0885	R. Salzbrenner, 1820
MS-0888	J. Aubert, 1821 (x10)
MS-0888	P. Sawyer, 1821 (x10)
MS-0888	R. Clough, 1821
MS-0888	P. Rand, 1821
MS-0888	E. Russick, 1821
MS-0889	J. Braithwaite, 1825
MS-0889	S. Monroe, 1825
MS-0899	Technical Library, 4536 (2)
MS-9018	Central Technical Files, 8945-1 (2)
MS-9403	J. McElhanon, 8762

Honeywell FM&T, KCP

MS-2C43	M. Benkovich
MS-2C43	D. Bowen
MS-2C43	E. Grotheer
MS-2C43	E. Nail
MS-2D39	M. Gerding
MS-2D39	S. Mistele
MS-2D39	D. Tran
MS-MG39	D. Brandenberg
MS-MG39	D. Jarrell
MS-SC4	T. Wilson
MS-XD44	D. Brown

Appendix I.

Data from 3M on Fluorinert™ Electronic Liquids

This Page Intentionally Left Blank

3M

Fluorinert™ Electronic Liquids

For Electronic Reliability Testing

Application Information

Introduction

3M™ Fluorinert™ liquids are a family of clear, colorless, odorless, perfluorinated fluids having a viscosity equivalent to water but approximately 75% greater density. These products are thermally and chemically stable, compatible with sensitive materials, including metals, plastics and elastomers, non-flammable and practically non-toxic.

The dielectric strength of perfluorinated liquids is high—in excess of 35,000 volts across a 0.1 inch gap. Water solubility is on the order of a few parts per million. The nominal boiling point of each fluid in this series is determined during their manufacture; Fluorinert liquids are available with boiling points ranging from 30°C to 215°C, and pour points as low as -101°C.

Electronic Reliability Testing

The thermal stability, non-reactivity, high dielectric strength and non-solvent characteristics of Fluorinert liquids make them ideal for electronic quality control testing. Components may be tested both physically and electrically while immersed in a non-conductive fluorocarbon liquid. Tested devices dry quickly with no residue, and no post-test cleaning is required.

Fluorinert liquids have a wide liquid range of approximately 200°C from pour point to boiling point, with good heat transfer properties throughout the range. This means reliability tests can be conducted over an extremely wide temperature range with a single inert, non-flammable and non-explosive liquid. See "Typical Physical Properties" chart for a listing of Fluorinert electronic testing fluids.

Hermetic Seal/Gross Leak Testing

Commercial tests for device hermetic seal integrity generally follow Military Standards 883-1014, 750-1071 and 202-112. Fluorinert liquids conform to these Military Standards.

Three different types of gross leak procedures are included in these Military Standards, confirming reliability to 10^{-5} atmospheres per cc/sec or more. Before the availability of Fluorinert liquids, gross leak testing reliability was limited to 10^{-3}-10^{-4} atmospheres cc/sec.

With these tests, users can determine the hermetic integrity of electronic device housings. Two procedures are bubble tests and vapor detection, with escaping cavity gas identifying faulty units.

Product Recommendations: **Fluorinert Electronic Liquid FC-40/43**
Fluorinert Electronic Liquid FC-72
Fluorinert Electronic Liquid FC-84

Thermal Shock Testing

Components can be thermally pre-stressed by means of rapid cycling between temperature extremes, taking advantage of the unique thermal properties of 3M™ Fluorinert™ liquids. Thermal shock tests are followed by secondary testing related to device end use to eliminate components that did not withstand the procedure.

Thermal shock testing is largely concerned with Military Standard 883-1011 specifications that call for five minute exposures to alternating high and low temperatures and a total of fifteen cycles. Fluorinert liquid advantages for this application include precise temperature control, rapid heat transfer due to thermal conductivity, excellent material compatibility and no post-test clean up.

Product Recommendations:

Hot phase: Fluorinert Electronic Liquids FC-40 or FC-43
Cold phase: Fluorinert Electronic Liquids FC-6003 or FC-77

Thermal Shock Testing Liquid 3M™ FC-6003 Typical Properties
(Not for Specification Purposes)
Low Temperature Reservoir

Density @ 25°C, gm/ml	>1.76
Dielectric Strength, volts/mil	>350
Viscosity @ -75°C	<50
Residue, micrograms/ml	<10
Appearance	Clear/colorless liquid

Other Electronic Tests Using Fluorinert Liquids

- Electrical Environmental Testing
- Temperature Calibration
- Failure Analysis
- High-Voltage Testing of Components and Devices
- Dielectric Testing
- Air/Fuel Ratio Testing

Typical Properties
(Not for Specification Purposes)

All values determined at 25°C unless otherwise specified

3M™ Fluorinert™ Liquid	FC-40	FC-43	FC-72	FC-77	FC-84
Typical Boiling Point, °C	155	174	56	97	80
Pour Point, °C	-57	-50	-90	-95	-95
Density, g/cm³	1.87	1.88	1.68	1.78	1.73
Density, g/cm³, -54°C	□	□	1.90	1.97	1.93
Kinematic Viscosity, cs	2.2	2.8	0.4	0.8	0.55
Kinematic Viscosity, cs, -54°C	□	□	1.9	6.9	4.0
Vapor Pressure, torr	3	1.3	232	42	79
Specific Heat, g-cal/g - °C	0.25	0.25	0.25	0.25	0.25
Heat of Vaporization @ Boiling Point, cal/g	17	17	21	20	19
Thermal Conductivity, watts/(cm²) (°C/cm)	0.00066*	0.00066	0.00057	0.00063*	0.00060*
Coefficient of Expansion cm³/(cm³)(°C)	0.0012	0.0012	0.0016	0.0014	0.0015
Surface Tension, dynes/cm	16	16	12	15	13
Dielectric Strength, KV(0.01in.gap) KV(2.54 mm gap)	46	42	38	40	42
Dielectric Constant, (1KHz)	1.89	1.90	1.76	1.86	1.81
Volume Resistivity, ohm-cm	$4.0x10^{15}$	$3.4x10^{15}$	$1.0x10^{15}$	$1.9x10^{15}$	$1.2x10^{15}$
Solubility of Water ppm (wt.)	7	7	10	13	11*
Solubility of Air ml gas/100 ml liquid	27	26	48	41	43*
Average Molecular Weight	650	670	340	415	388

* Estimated values   □ Not measured, due to relative proximity to pour point

Toxicity Profile

Fluorinert liquids are non-irritating to the eyes and skin, and are practically non-toxic orally. They also demonstrate very low acute and sub-chronic inhalation toxicity. These products are not mutagens or cardiac sensitizers.

Safety and Handling

3M™ Fluorinert™ liquids are nonflammable, and are highly resistant to thermal breakdown and hydrolysis in storage and during use. Recommended handling procedures are given in the Material Safety Data Sheets, which are available upon request.

Environmental

3M™ Fluorinert™ liquids have zero ozone depletion potential. These materials are not defined by the U.S. EPA, nor regulated, as volatile organic compounds (VOCs) and do not contribute to ground-level smog formation.

Fluorinert liquids, which are perfluorocarbon (PFC) materials, have high global warming potentials and long atmospheric lifetimes. As such, they should be carefully managed to minimize emissions.

3M recommends that users of Fluorinert liquids further limit emissions by employing good conservation practices, and by implementing recovery, recycling and/or proper disposal procedures. 3M offers a program for used fluid return. Specific guidelines for the safe handling and use of 3M products are provided in the Material Safety Data Sheets.

Resources

3M has representatives in virtually all regions of the world where electronics are manufactured. In addition, 3M products are supported by global technical and customer service resources, with fully-staffed technical service laboratories in the U.S., Europe, Japan and Southeast Asia. Users benefit from 3M's broad technology base and continuing attention to product development, performance, safety and environmental issues. For assistance, contact:

3M Specialty Materials
3M Center
Bldg. 223-6S-04
St. Paul, MN 55144
800-833-5045

3M

Specialty Fluids
3M Specialty Materials

3M Center, Building 223-6S-04
St. Paul, MN 55144-1000

Issued: 2/99

98-0212-2158-9 (HB)