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# Cleaning and Materials Compatibility Test Results For Elimination of Flammable Solvents in Wipe Applications

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Prepared by Sandia National Laboratories
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## Abstract

In recent years, efforts have been made within the nuclear weapons complex (National Nuclear Security Administration) of the Department of Energy (DOE) to replace Resource Conservation and Recovery Act (RCRA) regulated solvents (i.e., flammable, toxic, corrosive, and reactive) and ozone-depleting chemicals (ODC) with more benign alternatives. Within the National Nuclear Security Administration (NNSA) and the Department of Defense (DoD) sectors, these solvents are used for cleaning hardware during routine maintenance operations. A primary goal of this study is to replace flammable solvents used in wiping applications. Two cleaners, including a hydrofluoroether (HFE) and an azeotrope of the HFE and isopropyl alcohol (IPA), have been studied as potential replacements for flammable solvents. Cleaning efficacy, short-term and long-term materials compatibility, corrosion, drying times, flammability, environment, safety and health (ES&H) and accelerated aging issues were among the experiments used to screen candidate solvents by the interagency team performing this work. This report presents cleaning efficacy results as determined by the contact angle Goniometer as well as materials compatibility results of various metal alloys and polymers. The results indicate that IPA (baseline cleaner) and the HFE/IPA azeotrope are roughly equivalent in their ability to remove fluorinated grease, silicone grease, and a simulated finger print contaminant from various metal alloys. All of the ASTM sandwich and immersion corrosion tests with IPA, HFE or the HFE/IPA azeotrope on metal alloys showed no signs of corrosion. Furthermore, no deleterious effects were noted for polymeric materials immersed in IPA, HFE, or the HFE/IPA azeotrope.

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# I. INTRODUCTION

Sandia National Laboratories, BWXT Pantex Plant, Kansas City Plant, Los Alamos and other NNSA sites have teamed to identify suitable replacements for RCRA solvents and ozone depleting chemicals, used in nuclear maintenance operations. The primary goal of this project is to systematically reduce the usage of flammable solvents (principally isopropyl alcohol) used in proximity to and near nuclear operations. It includes a risk-cost benefit assessment of solvent and combustible material elimination, minimization or substitution. The cost benefits to all programs at BWXT Pantex Plant by removing a flammable solvent, such as IPA, would include (1) the savings of significant process time if the requirements for task exhaust, bonding and drying times were lifted due to the use of nonflammable solvents; (2) the ability to use facilities that are not currently available for weapons work due to the absence of exhaust systems; (3) the reduction of waste disposal costs for both the NNSA/BWXT Pantex Plant and the DoD because the waste generated has the potential of not being categorized as hazardous or mixed; and most importantly (4) the enhancement of safety through the elimination of flammable solvents.

# II. EXPERIMENTAL

***Solvents Evaluated***

Isopropyl alcohol (IPA) was the baseline solvent evaluated in this study. A hydrofluoroether (HFE-7100) and HFE-7100/IPA azeotrope (a liquid mixture that is characterized by a constant boiling point which is lower or higher than any of the components) were evaluated as potential replacements for IPA. HFE-7100 is an inseparable mixture of methoxynanofluorobutane and methoxynanofluoroisobutane. A comparison of some of the physical properties of IPA, HFE-7100, and HFE-7100/IPA azeotrope are shown in Table 1.

***Cleaning Efficacy - Contact Angle/Goniometer Substrates***

The substrates used for the cleaning study were 1.5” diameter metal disks that were ¼” thick and machined to a 16 rms finish. The metal alloys tested included; bare, alodined, and anodized 2024 and 6061aluminum, alodined and anodized 7075 aluminum, bare 303 and 304L stainless steel, passivated 304L stainless steel, and titanium.

***Cleaning Efficacy - Contaminants***

The contaminants selected were a representative cross-section of those found on weapon surfaces. The three contaminants included Krytox 240-AD fluorinated grease, Dow Corning 4 (DC-4) silicone insulating compound, and dust sebum emulsion (a simulated fingerprint oil).

***Sample Preparation and Cleaning Procedure***

Following machining, the metal discs were vapor degreased in trichloroethylene (TCE) followed by an IPA rinse and then flushed with dry nitrogen to create a uniform initial substrate surface.

The contaminants were then applied as follows. For the dust sebum emulsion, approximately 4 microliters (µL) [i.e., 4 milligrams (mg), assuming a density of 1 gram/milliliter (g/ml)] of the simulated fingerprint oil were deposited and spread over the center of each disc using a micro dispenser. The dust sebum emulsion consists primarily of organic acids, paraffin, and oils**.** Since a fingerprint weighs ca. 0.1 milligrams, each deposit corresponds to 40 superimposed fingerprints. The Krytox fluorinated grease and the DC-4 silicone grease were each deposited by weighing 0.05grams (g) [or 50 milligrams] of the contaminant on a disc and then lightly spreading the contaminant across the entire surface of the disc. After being applied to the disc, the samples were allowed to dry for 30 minutes before being wiped clean and the contact angle measured.

The contaminants were removed by wiping with HFE-7100, IPA or 4.5 wt.% IPA in HFE-7100 using a Kimwipe or KayDry impregnated with roughly 5 ml of solvent. One wipe consists of applying a light pressure with the middle and forefingers on the wiper and dragging it across the surface of the metal disc. A second wipe consists of using a fresh Kimwipe or Kay Dry impregnated also with fresh 5 ml of solvent, etc. In some cases, up to six wipes were necessary to remove the contaminant from the surface, regardless of the type of solvent used. Removal of the three contaminants from the metal substrates was evaluated with water drop contact angle method. Replicates of three samples per condition were performed.

***Cleaning Efficacy - Contact Angle Measurements***

The contact angle is a qualitative measurement that is used as an initial screening tool. A Contact Angle/Goniometer instrument manufactured by Advanced Surface Technology Inc., (Video Contact Angle System, Model 2500) was used to determine relative surface cleanliness.[1] The test measures the contact (tangent) angle that is formed between a drop of water and its supporting surface. The method is a relative measure of surface wettability. In general, the cleaner the surface is of organics, the lower the contact angle measurement. The contact angle results are reported in Table 3 as the differential between the initial pre-contaminated surface and the post clean surface. The smaller the difference the cleaner the surface is of organics.

***Sandwich Corrosion per ASTM F1110-90 – Metal Alloys***

In addition to the cleaning efficacy of the solvents, it is important to know that the solvent does not react with or corrode the substrate. Therefore, corrosion tests were conducted that included the Sandwich Corrosion Test per ASTM F1110-90, and the Immersion Corrosion Test per ASTM F483-98.[2,3]

The Sandwich Corrosion Test is a comparative accelerated aging test used to determine the corrosiveness of cleaners (i.e., solvents), generally on aluminum alloys. In this case, the study was expanded to include other metal alloys listed below. The metal samples (2” X 4” X 0.04”) were machined to a 16 rms finish and were then pre-cleaned with mineral spirits and methyl ethyl ketone. The beryllium samples were pre-cleaned with methanol.

The sandwiches are created by placing a filter paper (1” X 3”) saturated with a candidate solvent between two plates (2” x 4”) of the same alloy. The sandwiches (replicates of

three per condition) are cycled between warm air at ambient relative humidity (100°F, 30-60% RH) and warm, humid air (100°F, 95-100% RH) for five days and then left in the warm humid air environment over the weekend, for a total of 168 hours of exposure. After the entire cycle is completed, the samples are inspected with the naked eye and then with 10X magnification to determine whether corrosion has occurred. A relative corrosion severity rating system is used to numerically rank the results (Table 2). Only the surfaces that were in contact with the saturated filter paper are compared. Any corrosion at the edge of the sandwich is disregarded per ASTM F1110-90. Any corrosion in excess of that shown by the control group ($H_20$) is cause for rejection per the ASTM standard definition.

Metals tested in IPA, HFE and $H_2O$ include:

1) 304 L Stainless Steel
2) Passivated 304L Stainless Steel
3) 303 Stainless Steel
4) Titanium 6A14V
5) Beryllium
6) 7075 Aluminum
7) 2024 Aluminum
8) Alodined 2024 Aluminum
9) Anodized 2024 Aluminum
10) 6061 Aluminum

***Immersion Corrosion Test per ASTM F483-98 – Metal Alloys***

The Immersion Corrosion Test determines the corrosiveness of the solvents on metals under conditions of total immersion by a combination of weight change measurements and a visual qualitative inspection. The metal types tested were the same as those in the sandwich corrosion tests.

The procedure was as follows: 1) replicate samples of each alloy (9 each for IPA and 8 each for HFE) were pre-cleaned with mineral spirits and methyl ethyl ketone, 2) the samples were weighed to the nearest 0.1 mg prior to immersion, 3) the samples were immersed in the solvent for a 24 hour period at 100°F, 4) at the end of the 24 hour period, the samples were removed from the solvent, reweighed and inspected (for discoloration, dulling etching, presence of growth, pitting, presence of selective or localized attack, etc.). Results were compared to the control sample.

Metals tested in IPA, HFE and HFE Azeotrope include:

1) Bare 7075 Aluminum Alloy
2) Alodined 7075 Aluminum Alloy
3) Bare 2024 Aluminum Alloy

4) Bare 6061 Aluminum Alloy
5) Bare 303 Stainless Steel
6) Passivated 304L Stainless Steel
7) Bare 303se Stainless Steel
8) Bare 301 Stainless Steel
9) Bare 304L Stainless Steel
10) 6AL4V Titanium

***Materials Compatibility of Other Materials - Immersion of Polymeric Materials per SAND2000-1084***

Compatibility is the degree to which materials can coexist in a shared environment without adverse reaction for an acceptable period of time. Compatibility tests on polymeric materials were performed to evaluate the long-term effects of the solvent on the polymers in the event of an inadvertent spill. This compatibility test consists of a minimum 2-minute immersion of representative polymers in either HFE or IPA.[4] The polymeric samples were tested in the as-received condition. No pre-test cleaning or conditioning was done. Weight and visual analyses (discoloration, swelling, dissolution, texture change, etc.) of the materials were recorded before and after immersion.

**Samples Tested – 1st round**

Samples A = 186 Sylgard,
Samples B = 184 Sylgard,
Samples C = Wilethane 44,
Samples D = Epoweld 8173,
Samples E = Nitrile Gloves,
Samples F = PVC Gloves,
Samples G = Butyl Gloves,
Samples H = Silastic J,
Samples I = Barco Bond,
Samples J = O-Ring,
Samples K = PolyethyleneTerephthalate Shim Stock

**Samples Tested – 2nd round**

Samples A = Coax Wire Polyimide Insulation,
Samples B = EN-7Polyurethane Encapsulation,
Samples C = PET-90 Polyurethane Encapsulation,
Samples D = CF3262 Samples,
Samples D2 = CF3262 copper end,
Samples E = Compression Pad # BBN-3725-F82,
Samples F = Compression Pad # BBN-3586-E82,
Samples G = Compression Pad # BBN- 4267 B84,
Samples H = Compression Pad # BBN- 2848 J80,
Samples I = Aft det Hold down #530851,
Samples J = Aft det Hold down #326799,
Samples K = Aft det Hold down #607526,
Samples L = Fwd det Hold down #834223,
Samples M = Fwd det Hold down #396294,
Samples N = Cable Protector 422078 WSN468459 Cycle 21,
Sample O = Tube Protector 422012 WSN 834223.

**Samples Tested 3rd Round - Lockheed Materials**
Samples A = White Chalky pieces,
Samples B = Black with Metal,
Samples C = Long Black

## III. RESULTS AND DISCUSSION

***Goniometer/Contact Angles Measurements***
Table 3 shows a summary of contact angle differences for substrates that were wiped (3X and 6X) with the HFE/IPA azeotrope, HFE and IPA. The differences were calculated by subtracting the post clean contact angle values from the pre-contamination contact angle values. More detail on the performance of each cleaner, including contact angles before and after wiping with standard deviations are shown in Tables 4-10.

Initially, the HFE-7100 solvent in neat form was the primary candidate solvent that was selected for testing. Each substrate was wiped 3X with the HFE and then compared to substrates that were wiped the same number of times with IPA. In general, the HFE-7100 solvent was very poor at removing the contaminants when wiped 3X (Figure 1, Table 3 and 9). For example, on titanium, a difference in contact angle of 16.6º, 18.9º and 18.2º was obtained after wiping 3X with HFE on substrates contaminated with Krytox, Silicone, and DSE respectively. Comparatively, the contact angles when wiped 3X with IPA were 7.7 º, 6.7 º, and 5.3º. Recall, the lower the contact angle the cleaner the surface. In some cases, moderate improvements were noted when the number of wipes was increased to six with HFE. For example, the contact angles were reduced when wiping the contaminants from bare 2024 aluminum (Table 3 and 7). There were also instances where the contact angles were actually worse after wiping 6X with HFE versus 3X (ex., anodized 2024 aluminum).

The data illustrate the inconsistent cleaning performance that can occur when wiping with the neat HFE solvent. In some cases as already indicated, the contact angle values were significantly worse than wiping 3X with IPA and sometimes moderately improved when the number of wipes was increased to six with the HFE solvent. A further illustration of the inconsistency of neat HFE was the result that wiping with the HFE solvent was sometimes comparable to IPA. For example, contact angle values compared favorably with IPA when wiping bare 2024 bare and alodined 2024 aluminum coupons for all three contaminants. However, it normally took wiping 6X with the HFE solvent to clean as well as IPA. In summary, it was apparent that the neat HFE solvent (which has a low solvency property) would not satisfactorily remove the contaminants in a consistent manner.

Due to the poor performance of the neat HFE-7100, a mixture of IPA and HFE-7100 was tested. The addition of IPA to the formulation increases the overall solvency property particularly for ionic soils. The solvent is an azeotrope consisting of 4.5 wt% IPA in HFE-7100.
In most cases, the HFE/IPA azeotrope compared favorably and more consistently with IPA than did the HFE-7100 neat solvent (Figure 2, and Table 3). For example, the

contact angle differences after cleaning Krytox, Silicone and DSE from anodized 6061 aluminum by wiping 3X with the azeotrope were 8.0º, 8.5º and 8.5º respectively. The contact angle differences for IPA after wiping 3X were 3.7º, 5.3º, and 5.3º respectively. A slight improvement in cleaning with the azeotrope was noted when the number of wipes was increased to 6X, with contact angle differences of 6.1º, 7.3º, and 7.8º respectively. The same trend was observed for alodined 6061 aluminum, and anodized and alodined 7075 aluminum.

The azeotrope solvent was the only cleaner that successfully removed all three contaminants from anodized 2024 aluminum. However, it required wiping six times. For example, the contact angle difference after cleaning Krytox 3X and 6X with IPA was 16.2º and 24.7º respectively as compared to 27.3º and 9.0º respectively for the HFE azeotrope. Similarly, the contact angle differences after cleaning silicone and DSE were lower for the azeotrope than for IPA when wiped 6X with the azeotrope. It was hypothesized that poor cleaning of this particular alloy was a result of the high porous surface oxide produced by the anodization process. The resulting anodized surface permits trapping of the 3 contaminants in the pores. The solvent has limited access to the contaminants in the pores and therefore light cleaning by wiping can be inefficient.

An anomaly occurred during wiping of the DSE contaminant from 304L SS. In this case, the contact angle differences were less after wiping with all three solvents, indicating that the post clean surface was actually cleaner than the initial pre-cleaned baseline surface. It was hypothesized that an additive within the DSE formulation, (such as an organic acid or a detergent) was responsible for lowering the surface tension and giving an erroneous contact angle reading, i.e., the surfaces were still contaminated. The contact angle differences after cleaning the DSE contaminant form 304L stainless steel (by wiping six times with the azeotrope and IPA) were less by 12.3º and 12.0º respectively. Similarly, a post clean contact angle of 16.1º less was obtained after wiping three times with HFE-7100 (Table 3). For comparison sake, a 304L SS sample that was contaminated and not wiped had a contact angle difference of 37.2º better. Surface cleanliness needs to be verified with x-ray photoelectron spectroscopy.

In summary, the cleaning ability for the neat HFE-7100 solvent was inconsistent, sometimes requiring wiping six times. The HFE/IPA azeotrope, while also at times requiring 6X to remove the contaminants, appears to be more consistent than the neat HFE-7100 solvent and overall compares favorably with IPA.

***Materials Compatibility of Metal Alloys***

**1)** Sandwich Corrosion Test – the relative corrosion rating system per ASTM F1110-90 is listed in Table 1. Sandwich corrosion test results for all alloys are listed in Table 10. In almost every case, an average corrosion rating of 1 was obtained when IPA was the candidate solvent, regardless of which metal alloy was tested. A rating of 1 indicates very slight corrosion or discoloration on up to 5% of the affected area. When HFE-7100 was tested, the average corrosion rating was 0 for all metal alloys with the exception of beryllium which was 0 to 1. This effectively means that there was no visible corrosion observed on any part of the

$_2$0), with an average corrosion rating of 4, 3, and 3 respectively.

**2)** Immersion Corrosion Test per ASTM F483-98 – the immersion corrosion test results for ten metal alloys are shown in Table 11. No corrosion effects were observed on any of the metal alloys after exposure to IPA or HFE-7100 for 24 hours at 100ºF. Also, there was negligible weight change noted after exposure of all alloys.

***Materials Compatibility of Polymer Materials***

None of the materials that were tested by exposing to IPA or HFE exhibited any significant weight change. Furthermore, there were no detectable visual changes such as discoloration, swelling, dissolution or texture change. Examples of materials that were tested included polyurethane, polyimides, compression pads, polyesters and other polymers.

Tables 12-14 shows the results for all materials tested. Negligible weight changes were observed for all materials after exposure for 2 minutes in IPA or HFE-7100. Weight changes were recorded immediately after removal from the solvent, after 5 minutes, after 10 minutes and after 180 minutes. Only one material, PVC gloves, had a visual change as a result of exposure to IPA. In this case the PVC gloves became brittle and hard after the 2-minute immersion.

## IV. SUMMARY

Contact angle test results indicate that isopropyl alcohol and the hydrofluoroether/4.5 weight % isopropyl alcohol azeotrope were roughly equivalent in the removal of the three representative contaminants. The hydrofluoroether (neat) solvent exhibited inconsistent cleaning results. All of the ASTM sandwich and immersion corrosion tests performed with either isopropyl alcohol or hydrofluoroether showed no signs of pitting, etching or other evidence of corrosion on any of the metal alloy substrates. With the exception of the poly vinyl chloride gloves, (which became hard and brittle after exposure to IPA), no deleterious effects were noted for polymeric materials after immersion in isopropyl alcohol, hydrofluoroether or the hydrofluoroether /isopropyl alcohol azeotrope.

## V. REFERENCES


1. **E. P. Lopez, et.al, Chemical Substitution for Nuclear Weapons Maintenance Operations, SAND2000-1084, Unlimited Release, May 2000.**
2. **Standard Test Method for Sandwich Corrosion Test, ASTM F1110-90.**
3. **Standard Test Method for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals, ASTM F483-98.**
4. **Two Minute Immersion Monitoring Weight Change, Discoloration, Swelling, and Texture Change, SAND2000-1084, Unlimited Release, May 2000.**

## Tables

**Table 1 Solvent Properties**

| Solvent Properties | IPA | HFE-7100 | HFE-IPA Azeotrope |
|---|---|---|---|
| Boiling Point @ 760 mmHg | 82ºC | 61ºC | 54.8ºC |
| Vapor Pressure | 43 mm Hg @ 25ºC | 202 mm Hg at 25ºC | 207 mm Hg at 25ºC |
| Flash Point | 12º C | None | None |
| Time Weighted Average (8hr.) | 400 ppm | 750 ppm | 750/400 ppm |
| Global Warming Potential | | 320 (lb equivalent $CO_2$) | 310 (lb equivalent $CO_2$) |
| Ozone Depletion Potential | 0 | 0 | 0 |

**Table 2 – Relative Corrosion Severity Rating System**

| | |
|---|---|
| 0 | No visible corrosion |
| 1 | Very slight corrosion |
| 2 | Slight corrosion |
| 3 | Moderate corrosion |
| 4 | Excessive corrosion |
| | |
| 0 | 0% |
| 1 | Up to 5% of the surface area corroded |
| 2 | 5 to 10% of the surface area corroded |
| 3 | 10 to 25% of the surface area corroded |
| 4 | 25% or more of the surface area corroded |

**Table 3** - ***Contact Angles – Difference after wiping 6X and 3X with HFE/IPA Azeotrope, Isopropyl Alcohol, and HFE-7100***

| Metal Alloy | Azeo. 6X | Azeo. 3X | IPA 6X | IPA 3X | HFE 6X | HFE 3X |
|---|---|---|---|---|---|---|
| 2024 Al -Krytox | 8.2 | 10.6 | 6.4 | - | 8.7 | 11.8 |
| 2024 Al -Silicone | 8.2 | 9.8 | 10.6 | - | 9.3 | 13.8 |
| 2024 Al - DSE | 12.0 | 12.3 | 4.3 | - | 3.7 | 13.7 |
| 2024 Al - Alodine Krytox | - | 7.3 | 0.5 | 6.4 | 7.8 | 10.2 |
| 2024 Al - Alodine Silicone | - | 6.3 | 4.8 | 9.3 | 7.6 | 5.9 |
| 2024 Al - Alodine DSE | - | 4.7 | 5.6 | 7.4 | 6.0 | 7.6 |
| 2024 Al Anodized - Krytox | 9.0 | 27.3 | 24.7 | 16.2 | 39.8 | 27.2 |
| 2024 Al Anodized - Silicone | 7.3 | 20.7 | 29.1 | 38.6 | 44.8 | 32.3 |
| 2024 Al Anodized - DSE | 7.2 | 28.2 | 36.5 | 33.6 | 39.3 | 36.4 |
| 6061 Al-Krytox | - | 2.3 | - | 2.1 | - | 2.6 |
| 6061 Al-Silicone | - | 4.5 | - | 4.6 | - | 4.9 |
| 6061 Al-DSE | - | 4.5 | - | 6.5 | - | 5.3 |
| 6061 Al Alodined - Krytox | 6.1 | 8.0 | - | 3.7 | - | - |
| 6061 Al Alodined - Silicone | 7.3 | 8.5 | - | 5.3 | - | - |
| 6061 Al Alodined - DSE | 7.8 | 8.5 | - | 5.3 | - | - |
| 6061 Al Anodized - Krytox | 4.7 | 4.8 | - | 3.7 | - | - |
| 6061 Al Anodized - Silicone | 4.8 | 5.0 | - | 4.5 | - | - |
| 6061 Al Anodized - DSE | 6.5 | 6.7 | - | 5.7 | - | - |
| 7075 Alodined - Krytox | 5.7 | 7.7 | - | 4.7 | - | - |
| 7075 Alodined - Silicone | 5.7 | 9.2 | - | 4.3 | - | - |
| 7075 Alodined - DSE | 6.0 | 9.3 | - | 4.8 | - | - |
| 7075 Anodized - Krytox | 6.0 | 8.0 | - | 4.7 | - | - |
| 7075 Anodized - Silicone | 8.0 | 10.0 | - | 6.0 | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7075 Anodized - DSE | 5.3 | 9.8 | - | 4.2 | - | - |
| 303 SS - Krytox | - | 7.7 | 3.4 | 8.4 | 3.3 | 28.0 |
| 303 SS - Silicone | - | 12.5 | 4.5 | 4.3 | 3.7 | 24.6 |
| 303 SS -DSE | - | 8.2 | 1.3 | 0.4 | 2.4 | 15.0 |
| 304L SS - Krytox | 7.3 | 9.0 | 2.4 | 1.2 | 4.7 | 13.4 |
| 304L SS - Silicone | 8.5 | 10.3 | 5.2 | 3.2 | 7.1 | 12.0 |
| 304L SS - DSE | -12.3 | -15.8 | -12.0 | -18.3 | 4.1 | -16.1 |
| 304L SS-P Krytox | - | 6.3 | 4.6 | 6.7 | 5.0 | 6.1 |
| 304L SS-P Silicone | - | 8.2 | 6.1 | 8.0 | 3.0 | 8.9 |
| 304L SS-P DSE | - | 7.7 | 2.4 | 6.2 | 5.5 | 7.5 |
| Titanium - Krytox | 6.0 | - | - | 7.7 | - | 16.6 |
| Titanium - Silicone | 5.2 | - | - | 6.7 | - | 18.9 |
| Titanium - DSE | 6.5 | - | - | 5.3 | - | 18.2 |

***Table 4 – Contact Angles - Samples wiped 6X with HFE/IPA Azeotrope***

| Metal Alloy | Avg. Preclean CAº | Avg. After Wipe CAº | Difference CAº |
|---|---|---|---|
| 2024 Al - Krytox | 67.0 ±0.5 | 75.2 ±0.7 | 8.2 |
| 2024 Al - Silicone | 68.0 ±1.9 | 76.2 ±0.2 | 8.2 |
| 2024 Al - DSE | 68.5 ±0.2 | 80.5 ±0.7 | 12.0 |
| 2024 Al Anodized -Krytox | 62.6 ±1.8 | 71.6 ±2.4 | 9.0 |
| 2024 Al Anodized - Silicone | 62.6 ±0 | 70.0 ±1.4 | 7.3 |
| 2024 Al Anodized -DSE | 63.1 ±0.2 | 70.3 ±0.9 | 7.2 |
| 304L SS - Krytox | 78.3 ±1.5 | 85.6 ±1.2 | 7.3 |
| 304L SS - Silicone | 78.3 ±1.7 | 86.8 ±0.8 | 8.5 |
| 304L SS - DSE | 78.3 ±1.7 | 66.0 ±1.5 | -12.3 |
| 6061 Al Anodized - Krytox | 82.7 ±4.7 | 87.3 ±0 | 4.7 |
| 6061 Al Anodized - Silicone | 83.2 ±2.1 | 88.0 ±2.4 | 4.8 |
| 6061 Al Anodized - DSE | 82.5 ±0.2 | 89.0 ±0.5 | 6.5 |
| 7075 Alodined - Krytox | 86.8 ±0.7 | 92.5 ±2.1 | 5.7 |
| 7075 Alodined - Silicone | 83.8 ±1.2 | 89.5 ±0.2 | 5.7 |
| 7075 Alodined - DSE | 85.0 ±1.4 | 91.0 ±0.5 | 6.0 |
| 7075 Anodized - Krytox | 85.0 ±1.4 | 91.0 ±0.5 | 6.0 |
| 7075 Anodized - Silicone | 81.5 ±1.6 | 89.5 ±8.0 | 8.0 |
| 7075 Anodized - DSE | 81.2 ±0.2 | 86.5 ±1.2 | 5.3 |
| Titanium - Krytox | 64.3 ±0 | 70.3 ±0.9 | 6.0 |
| Titanium - Silicone | 62.2 ±2.1 | 67.3 ±2.4 | 5.2 |
| Titanium - DSE | 61.3 ±0.5 | 67.8 ±0.7 | 6.5 |

**Table 5 – Coupons wiped 3X with HFE/IPA Azeotrope**

| Metal Alloy | Avg. Preclean CAº | Avg. After Wipe CAº | Difference CAº |
|---|---|---|---|
| 2024 Al - Krytox | 84.2 ±0.2 | 94.8 ±0.7 | 10.6 |
| 2024 Al - Silicone | 85.2 ±1.2 | 95.0 ±0 | 9.8 |
| 2024 Al - DSE | 84.2 ±0.2 | 96.5 ±0.7 | 12.3 |
| 2024 Al Alodine -Krytox | 86.3 ±1.4 | 93.6 ±0.9 | 7.3 |
| 2024 Al Alodine - Silicone | 86.8 ±1.2 | 93.2 ±0.2 | 6.3 |
| 2024 Al Alodine - DSE | 85.2 ±3.1 | 89.8 ±1.2 | 4.7 |
| 2024 Al Anodized - Krytox | 59.3 ±2.4 | 86.7 ±0.9 | 27.3 |
| 2024 Al Anodized - Silicone | 63.3 ±0.9 | 83.0 ±1.4 | 20.7 |
| 2024 Al Anodized -DSE | 61.0 ±0.9 | 89.2 ±1.6 | 28.2 |
| 303 SS - Krytox | 64.5 ±1.6 | 72.2 ±3.5 | 7.7 |
| 303 SS - Silicone | 62.5 ±0.7 | 75.0 ±0.9 | 12.5 |
| 303 SS - DSE | 65.3 ±0 | 73.5 ±2.1 | 8.2 |
| 304L SS - Krytox | 78.2 ±1.4 | 87.2 ±1.3 | 9.0 |
| 304L SS - Silicone | 78.2 ±2.3 | 88.5 ±1.3 | 10.3 |
| 304L SS - DSE | 79.6 ±0.8 | 63.7 ±2.6 | -15.9 |
| 304L SS-P - Krytox | 81.3 ±0 | 87.7 ±1.4 | 6.3 |
| 304L SS-P - Silicone | 79.2 ±1.2 | 87.3 ±0.5 | 8.2 |
| 304L SS-P – DSE | 81.2 ±0.7 | 88.8 ±0.2 | 7.7 |
| 6061 Al - Krytox | 81.7 ±0.5 | 84.0 ±0.9 | 2.3 |
| 6061 Al - Silicone | 82.3 ±0 | 86.8 ±1.2 | 4.5 |
| 6061 Al - DSE | 81.8 ±0.2 | 86.3 ±1.9 | 4.5 |
| 6061 Al Alodined - Krytox | 86.0 ±0.9 | 94.0 ±0.9 | 8.0 |
| 6061 Al Alodined - Silicone | 87.0 ±0.5 | 95.5 ±1.2 | 8.5 |
| 6061 Al Alodined - DSE | 85.5 ±1.6 | 94.0 ±0.5 | 8.5 |
| 6061 Al Anodized - Krytox | 81.0 ±2.3 | 85.8 ±0.7 | 4.8 |
| 6061 Al Anodized - Silicone | 82.8 ±0.2 | 87.8 ±0.2 | 5.0 |
| 6061 Al Anodized - DSE | 80.5 ±0.7 | 87.2 ±0.7 | 6.7 |
| 7075 Alodined - Krytox | 86.7 ±0.9 | 94.3 ±1.4 | 7.7 |
| 7075 Alodined - Silicone | 86.7 ±0 | 95.8 ±0.7 | 9.2 |
| 7075 Alodined - DSE | 86.5 ±0.2 | 95.8 ±1.6 | 9.3 |
| 7075 Anodized - Krytox | 75.8 ±1.2 | 83.8 ±0.2 | 8.0 |
| 7075 Anodized - Silicone | 73.7 ±2.8 | 83.7 ±3.8 | 10.0 |
| 7075 Anodized - DSE | 73.8 ±0.2 | 83.6 ±0.9 | 9.8 |

**Table 6 - Contact Angles - Coupons cleaned 6X with Isopropyl Alcohol**

| Metal Alloy Contaminant | Avg. Preclean CAº | Avg. After Wipe CAº | Difference CAº |
|---|---|---|---|
| 2024 Al - Krytox | 86.3 ±1.2 | 92.7 ±0.8 | 6.4 |
| 2024 Al - Silicone | 76.4 ±1.4 | 87.0 ±0.9 | 10.6 |
| 2024 Al - DSE | 79.1 ±2.0 | 83.4 ±0.5 | 4.3 |
| 2024 Al Alodine -Krytox | 82.1 ±3.7 | 82.6 ±1.2 | 0.5 |
| 2024 Al Alodine - Silicone | 81.7 ±2.8 | 86.5 ±2.7 | 4.8 |
| 2024 Al Alodine - DSE | 78.3 ±0.7 | 83.9 ±1.2 | 5.6 |
| 2024 Al Anodized - Krytox | 56.1 ±1.5 | 80.8 ±5.3 | 24.7 |
| 2024 Al Anodized - Silicone | 48.6 ±6.0 | 77.7 ±4.2 | 29.1 |
| 2024 Al Anodized - DSE | 49.6 ±5.9 | 86.1 ±1.3 | 36.5 |
| 303 SS - Krytox | 62.4 ±4.3 | 65.8 ±7.9 | 3.4 |
| 303 SS - Silicone | 64.4 ±4.3 | 68.9 ±5.1 | 4.5 |
| 303 SS -DSE | 66.0 ±2.2 | 67.3 ±1.5 | 1.3 |
| 304L SS - Krytox | 66.1 ±2.2 | 68.5 ±2.3 | 2.4 |
| 304L SS - Silicone | 74.9 ±2.4 | 80.1 ±3.3 | 5.2 |
| 304L SS - DSE | 71.3 ±4.1 | 69.9 ±2.5 | -1.4 |
| 304L SS-P - Krytox | 74.4 ±1.7 | 79.0 ±3.5 | 4.6 |
| 304L SS-P - Silicone | 75.5 ±2.0 | 81.6 ±3.8 | 6.1 |
| 304L SS-P - DSE | 74.9 ±2.9 | 77.3 ±3.4 | 2.4 |

**Table 7 – Contact Angles - Coupons cleaned 6X with HFE-7100**

| Metal Alloy-Contaminant | Avg. Preclean CAº | Avg. After Wipe CAº | Difference CAº |
|---|---|---|---|
| 2024 Al - Krytox | 85.6 ±1.2 | 94.3 ±0.3 | 8.7 |
| 2024 Al -Silicone | 76.5 ±2.7 | 85.8 ±3.4 | 9.3 |
| 2024 Al - DSE | 83.1 ±1.7 | 86.8 ±4.2 | 3.7 |
| 2024 Al Alodine - Krytox | 85.4 ±0.8 | 93.2 ±0.5 | 7.8 |
| 2024 Al Alodine - Silicone | 82.5 ±1.1 | 90.1 ±1.9 | 7.6 |
| 2024 Al Alodine - DSE | 79.7 ±3.4 | 85.7 ±3.6 | 6.0 |
| 2024 Al Anodized - Krytox | 43.1 ±5.8 | 82.9 ±4.9 | 39.8 |
| 2024 Al Anodized - Silicone | 44.8 ±3.0 | 89.6 ±1.8 | 44.8 |
| 2024 Al Anodized - DSE | 50.5 ±4.5 | 89.8 ±3.7 | 39.3 |
| 303 SS - Krytox | 64.2 ±1.4 | 67.5 ±2.7 | 3.3 |
| 303 SS - Silicone | 65.2 ±2.9 | 68.9 ±3.5 | 3.7 |
| 303 SS - DSE | 66.1 ±1.9 | 68.5 ± 3.0 | 2.4 |

| | | | |
|---|---|---|---|
| 304L SS - Krytox | 69.4 ±1.6 | 74.1 ±2.9 | 4.7 |
| 304L SS - Silicone | 76.1 ±2.1 | 83.2 ±2.7 | 7.1 |
| 304L SS - DSE | 76.4±1.5 | 64.4 ±2.9 | -12.0 |
| 304L SS-P - Krytox | 77.2 ±1.3 | 82.2 ±2.2 | 5.0 |
| 304L SS-P - Silicone | 75.7 ±2.3 | 78.7 ±3.4 | 3.0 |
| 304L SS-P - DSE | 75.7 ±4.4 | 81.2 ±1.6 | 5.5 |

**Table 8 – Contact Angles - Coupons cleaned 3X with Isopropyl Alcohol**

| Metal Alloy-Contaminant | Avg. Preclean CAº | Avg. After Wipe CAº | Difference CAº |
|---|---|---|---|
| 2024 Al Anodized -Krytox | 54.1 ±5.3 | 70.3 ±2.1 | 16.2 |
| 2024 Al Alodine -Krytox | 84.4 ±1 | 90.8 ±1.7 | 6.4 |
| 2024 Al Alodine - Silicone | 85.2 ±2.7 | 94.5 ±4.3 | 9.3 |
| 2024 Al Alodine - DSE | 86.3 ±1.0 | 93.7 ±3.4 | 7.4 |
| 2024 Al Anodized - Silicone | 50.7 ±4.2 | 89.3 ±1.8 | 38.6 |
| 2024 Al Anodized - DSE | 51.9 ±8.6 | 85.5 ±2.9 | 33.6 |
| 6061 Al - Krytox | 83.6 ±4.0 | 85.7 ±3.3 | 2.1 |
| 6061 Al - Silicone | 83.2 ±2.4 | 87.8 ±3.3 | 4.6 |
| 6061 Al - DSE | 82.4 ±1.0 | 88.9 ±1.5 | 6.5 |
| 6061 Al Anodized - Krytox | 82.7 ±0 | 86.3 ±0 | 3.7 |
| 6061 Al Anodized - Silicone | 80.8 ±1.2 | 85.3 ±1.9 | 4.5 |
| 6061 Al Anodized - DSE | 81.3 ±0.9 | 87.0 ±0.5 | 5.7 |
| 7075 Alodine - Krytox | 87.5 ±1.6 | 92.2 ±1.2 | 4.7 |
| 7075 Alodine - Silicone | 89.0 ±0.9 | 93.3 ±0.5 | 4.3 |
| 7075 Alodine - DSE | 87.3 ±0 | 92.2 ±0.7 | 4.8 |
| 7075 Anodized - Krytox | 77.5 ±0.7 | 82.2 ±0.2 | 4.7 |
| 7075 Anodized - Silicone | 77.8 ±1.2 | 83.8 ±1.2 | 6.0 |
| 7075 Anodized - DSE | 78.0 ±0.5 | 82.2 ±0.2 | 4.2 |
| 303 SS - Krytox | 66.6 ±2.5 | 75.0 ±2.6 | 8.4 |
| 303 SS - Silicone | 63.0 ±1.7 | 67.3 ±1.5 | 4.3 |
| 303 SS - DSE | 52.6 ±1.5 | 53.0 ±2.6 | 0.4 |
| 304L SS–P - Krytox | 78.4 ±2.9 | 85.1 ±6.8 | 6.7 |
| 304L SS–P - Silicone | 81.9 ±0.1 | 89.9 ±1.3 | 8.0 |
| 304L SS–P - DSE | 82.0 ±1.0 | 88.2 ±1.2 | 6.2 |
| 304L SS - Krytox | 75.3 ±1.5 | 76.5 ±3.1 | 1.2 |
| 304L SS - Silicone | 71.9 ±2.4 | 75.1 ±1.0 | 3.2 |
| 304L SS - DSE | 77.5 ±1.0 | 59.2 ±1.4 | -18.3 |
| Titanium - Krytox | 69.7 ±0.5 | 77.5 ±3.2 | 7.8 |
| Titanium - Silicone | 61.6 ±0.4 | 68.3 ±2.0 | 6.8 |
| Titanium - DSE | 67.5 ±2.5 | 72.9 ±4.9 | 5.3 |

**Table 9 – Contact Angles - Coupons cleaned 3X with HFE-7100**

| Metal Alloy-Contaminant | Avg. Preclean CAº | Avg. After Wipe CAº | Difference CAº |
|---|---|---|---|
| 2024 Al - Krytox | 84.3 ±0 | 96.2 ±1.6 | 11.8 |
| 2024 Al - Silicone | 84.2 ±0.7 | 98.0 ±0.9 | 13.8 |
| 2024 Al - DSE | 84.0 ±0.5 | 97.7 ±0 | 13.7 |
| 2024 Al Alodine - Krytox | 86.9 ±1.0 | 97.1 ±1.7 | 10.2 |
| 2024 Al Alodine - Silicone | 85.9 ±2.9 | 91.8 ±1.7 | 5.9 |
| 2024 Al Alodine - DSE | 86.2 ±3.3 | 93.8 ±3.6 | 7.6 |
| 2024 Al Anodized -Krytox | 57.1 ±6.5 | 84.3 ±4.3 | 27.2 |
| 2024 Al Anodized - Silicone | 51.4 ±1.9 | 83.7 ±2.5 | 32.3 |
| 2024 Al Anodized - DSE | 53.3 ±6.2 | 89.7 ±1.0 | 36.4 |
| 6061 Al - Krytox | 84.8 ±2.5 | 87.4 ±5.0 | 2.6 |
| 6061 Al - Silicone | 81.8 ±1.6 | 86.7 ±1.8 | 4.9 |
| 6061 Al - DSE | 84.3 ±1.5 | 89.6 ±1.4 | 5.3 |
| 303 SS - Krytox | 60.3 ±1.5 | 88.3 ±2.1 | 28.0 |
| 303 SS - Silicone | 64.0 ±2.6 | 88.6 ±2.1 | 24.6 |
| 303 SS - DSE | 67.6 ±2.3 | 82.6 ±3.1 | 15.0 |
| 304L SS–P -Krytox | 82.9 ±1.0 | 89.0 ±1.7 | 6.1 |
| 304L SS–P -Silicone | 82.6 ±2.3 | 91.5 ±1.8 | 8.9 |
| 304L SS–P - DSE | 79.9 ±2.3 | 87.4 ±1.1 | 7.5 |
| 304L SS Krytox | 71.0 ±1.8 | 84.4 ±2.0 | 13.4 |
| 304L SS - Silicone | 74.7 ±1.7 | 86.7 ±2.3 | 12.0 |
| 304L SS - DSE | 79.2 ±1.0 | 63.1 ±4.2 | -16.1 |
| Titanium - Krytox | 71.5 ±2.0 | 88.2 ±0.8 | 16.6 |
| Titanium - Silicone | 68.8 ±1.6 | 87.7 ±4.3 | 18.9 |
| Titanium - DSE | 67.0 ±2.6 | 85.2 ±3.0 | 18.2 |

**Table 10 – Sandwich Corrosion Test Results**

| Metal | Average Corrosion Rating IPA | Average Corrosion Rating $H_20$ | Average Corrosion Rating HFE |
|---|---|---|---|
| 7075 Al - Bare | 1 | 4 | 1 |
| 6061 Al – Bare | 1 | 3 | 1 |
| 2024 Al - Bare | 1 | 1 | 0 |
| 2024 Al - Anodized | 0 | 0 | 0 |
| 2024 Al - Alodined | 1 | 0 | 0 |
| 303 Stainless Steel Type 303se | 1 | 0 | 0 |
| 303 Stainless Steel Type 303 | 1 | 0 | 0 |
| 301 Stainless Steel | 1 | 0 | 0 |
| 304L Stainless Steel Bare | 1 | 0 | 0 |
| 304L Stainless Steel Passivated | 1 | 0 | 0 |
| Titanium 6Al4V | 0 | 0 | 0 |
| Beryllium | 0-1 | 3 | 0-1 |

**Table 11 – Immersion Corrosion Test Results**

| Metal | Avg. Sample Weights Before Exposure (g) | Solvent | Avg. Sample Weights After Exposure(g) | Weight Difference (g) |
|---|---|---|---|---|
| Bare 7075 Aluminum Alloy | 1.4236 ±0.0090 | IPA | 1.4236 ±0.0090 | 0.0000 |
| | 1.4252 ±0.0071 | HFE | 1.4252 ±0.0072 | 0.0000 |
| Alodined 7075 Aluminum Alloy | 0.7780 ±0.0.0204 | IPA | 0.7777 ±0.0203 | -0.0003 |
| | 0.7824 ±0.0717 | HFE | 0.7824 ±0.0719 | 0.0000 |
| | 0.7573 ±0.0484 | Azeotrope | 0.7572 ±0.0483 | 0.0001 |
| Bare 2024 Aluminum Alloy | 1.4195 ±0.0086 | IPA | 1.4192 ±0.0086 | -0.0003 |
| | 1.4215 ±0.0067 | HFE | 1.4213 ±0.0067 | -0.0002 |
| Bare 6061 Aluminum Alloy | 1.3368 ±0.0073 | IPA | 1.3366 ±0.0072 | -0.0002 |
| | 1.3459 ±0.0134 | HFE | 1.3458 ±0.0133 | -0.0001 |
| Bare 303 SS | 3.6816 ±0.0094 | IPA | 3.6815 ±0.0093 | -0.0001 |
| | 3.6757 ±0.0069 | HFE | 3.6756 ±0.0069 | -0.0001 |
| Passivated 304L SS | 3.8494 ±0.0249 | IPA | 3.8493 ±0.0249 | -0.0001 |

| | | | | |
|---|---|---|---|---|
| | 3.8381 ±0.0185 | HFE | 3.8380 ±0.0249 | -0.0001 |
| Bare 303se SS | 4.9351 ±0.2058 | IPA | 4.9349 ±0.2058 | -0.0002 |
| | 4.8516 ±0.3993 | HFE | 4.8516 ±0.3994 | 0.0000 |
| Bare 301 SS | 3.9436 ±0.0036 | IPA | 3.9435 ±0.0036 | -0.0001 |
| | 3.9421 ±0.0146 | HFE | 3.9420 ±0.0157 | -0.0001 |
| Bare 304L SS | 3.8286 ±0.01291 | IPA | 3.8285 ±0.01286 | -0.0001 |
| | 3.8343 ±0.0234 | HFE | 3.8342 ±0.0233 | -0.0001 |
| 6AL4VTitanium Alloy | 2.2279 ±0.0212 | IPA | 2.2279 ±0.0212 | 0.0000 |
| | 2.2387 ±0.0127 | HFE | 2.2386 ±0.0126 | -0.0001 |

**Table 12– Materials Compatibility of Other Materials**

**1st Round**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Samples A= 186 Sylgard | Samples B= 184 Sylgard | Samples C= Wilethane 44 | Samples D= Epoweld 8173 | Samples E= Nitrile Gloves | | | |
| Samples F= PVC Gloves | Samples G= Butyl Gloves | Samples H= Silastic J | Samples I=Barco Bond | Samples J=O-Ring | | | |
| Samples K= Polyethylene Terephthalate Shim Stock | | | | | | | |
| | | | | | | | |
| **Sample** | **Chemical** | **Start Weight** | **End Weight 1** | **End Weight 2 (5 min)** | **End Weight 3 (10 min)** | **End Weight 4 (180 min)** | **Difference in Start and End Weight 4** |
| 1A | IPA | 1.3167 | 1.3204 | 1.3178 | 1.3172 | 1.3155 | -0.0012 |
| 2A | IPA | 1.1356 | 1.1389 | 1.1365 | 1.1359 | 1.1349 | -0.0007 |
| 3A | HFE | 1.0614 | 1.0733 | 1.0664 | 1.065 | 1.061 | -0.0004 |
| 4A | HFE | 1.2217 | 1.2331 | 1.2269 | 1.2254 | 1.2216 | -1E-04 |
| 5A | IPA/HFE | 0.9671 | 0.9796 | 0.9722 | 0.971 | 0.967 | -1E-04 |
| 6A | IPA/HFE | 1.445 | 1.4593 | 1.452 | 1.4508 | 1.4448 | -0.0002 |
| | | | | | | | |
| 1B | IPA | 1.0892 | 1.0954 | 1.091 | 1.0902 | 1.0883 | -0.0009 |
| 2B | IPA | 0.1567 | 1.1631 | 1.1588 | 0.1579 | 0.1562 | -0.0005 |
| 3B | HFE | 0.9808 | 0.9917 | 0.9857 | 0.9841 | 0.9808 | 0 |
| 4B | HFE | 0.822 | 0.8306 | 0.827 | 0.8255 | 0.8222 | 0.0002 |
| 5B | IPA/HFE | 0.7656 | 0.776 | 0.7712 | 0.7694 | 0.7654 | -0.0002 |
| 6B | IPA/HFE | 1.0415 | 1.0589 | 1.0498 | 1.0476 | 1.042 | 0.0005 |
| | | | | | | | |
| 1C | IPA | 1.6586 | 1.6613 | 1.6606 | 1.6601 | 1.6597 | 0.0011 |
| 2C | IPA | 1.7178 | 1.7202 | 1.7194 | 1.7194 | 1.7185 | 0.0007 |
| 3C | HFE | 1.6876 | 1.6877 | 1.6875 | 1.6873 | 1.6874 | -0.0002 |
| 4C | HFE | 1.7983 | 1.7985 | 1.7984 | 1.7984 | 1.7983 | 0 |
| 5C | IPA/HFE | 1.5085 | 1.5085 | 1.5084 | 1.5084 | 1.5082 | -0.0003 |
| 6C | IPA/HFE | 1.5996 | 1.5997 | 1.5994 | 1.5994 | 1.599 | -0.0006 |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1D | IPA | 0.9918 | 0.9916 | 0.9915 | 0.9916 | 0.9916 | -0.0002 |
| 2D | IPA | 0.8206 | 0.8217 | 0.8211 | 0.8212 | 0.821 | 0.0004 |
| 3D | HFE | 0.9818 | 0.9815 | 0.9817 | 0.9817 | 0.9817 | -1E-04 |
| 4D | HFE | 0.7238 | 0.7237 | 0.7238 | 0.7238 | 0.7238 | 0 |
| 5D | IPA/HFE | 0.7497 | 0.7495 | 0.7495 | 0.7494 | 0.7493 | -0.0004 |
| 6D | IPA/HFE | 0.714 | 0.7139 | 0.7137 | 0.7138 | 0.714 | 0 |
| | | | | | | | |
| 1E | IPA | 0.042 | 0.0419 | 0.0419 | 0.0418 | 0.0417 | -0.0003 |
| 2E | IPA | 0.0702 | 0.0702 | 0.0702 | 0.0701 | 0.07 | -0.0002 |
| 3E | HFE | 0.0525 | 0.0524 | 0.0523 | 0.0523 | 0.0523 | -0.0002 |
| 4E | HFE | 0.0553 | 0.055 | 0.0551 | 0.055 | 0.055 | -0.0003 |
| 5E | IPA/HFE | 0.0594 | 0.0592 | 0.0591 | 0.0591 | 0.059 | -0.0004 |
| 6E | IPA/HFE | 0.0817 | 0.0815 | 0.0814 | 0.0814 | 0.0811 | -0.0006 |
| | | | | | | | |
| 1F | IPA | 0.1208 | 0.1179 | 0.1177 | 0.1178 | 0.1169 | -0.0039 |
| 2F | IPA | 0.0739 | 0.0714 | 0.0714 | 0.0713 | 0.0704 | -0.0035 |
| 3F | HFE | 0.0908 | 0.0905 | 0.0904 | 0.0904 | 0.0904 | -0.0004 |
| 4F | HFE | 0.0749 | 0.0745 | 0.0746 | 0.0745 | 0.0746 | -0.0003 |
| 5F | IPA/HFE | 0.09 | 0.0895 | 0.0894 | 0.0893 | 0.089 | -0.001 |
| 6F | IPA/HFE | 0.0801 | 0.0796 | 0.0796 | 0.0795 | 0.0793 | -0.0008 |
| | | | | | | | |
| 1G | IPA | 0.199 | 0.1987 | 0.1988 | 0.1988 | 0.1988 | -0.0002 |
| 2G | IPA | 0.1609 | 0.1608 | 0.1608 | 0.1608 | 0.1608 | -1E-04 |
| 3G | HFE | 0.1744 | 0.1743 | 0.1743 | 0.1743 | 0.1743 | -1E-04 |
| 4G | HFE | 0.147 | 0.1469 | 0.1469 | 0.1469 | 0.1469 | -1E-04 |
| 5G | IPA/HFE | 0.1993 | 0.1992 | 0.1993 | 0.1993 | 0.1993 | 0 |
| 6G | IPA/HFE | 0.1642 | 0.1641 | 0.1641 | 0.1641 | 0.1641 | -0.0001 |
| | | | | | | | |
| 1H | IPA | 1.4337 | 0.4376 | 1.4348 | 1.4342 | 1.4333 | -0.0004 |
| 2H | IPA | 1.2059 | 0.2087 | 0.2069 | 0.2063 | 1.2056 | -0.0003 |
| 3H | HFE | 0.9473 | 0.9577 | 0.9517 | 0.9504 | 0.948 | 0.0007 |
| 4H | HFE | 1.033 | 1.0411 | 1.0371 | 1.0359 | 1.0336 | 0.0006 |
| 5H | IPA/HFE | 0.9436 | 0.9524 | 0.9476 | 0.9466 | 0.9437 | 1E-04 |
| 6H | IPA/HFE | 1.0295 | 1.0365 | 1.0333 | 1.0325 | 1.0296 | 1E-04 |
| | | | | | | | |
| 1I | IPA | 0.8202 | 0.82 | 0.82 | 0.82 | 0.82 | -0.0002 |
| 2I | IPA | 0.52 | 0.5193 | 0.5192 | 0.5192 | 0.5192 | -0.0008 |
| 3I | HFE | 0.4317 | 0.4316 | 0.4316 | 0.4316 | 0.4317 | 0 |
| 4I | HFE | 0.6472 | 0.6469 | 0.6469 | 0.6469 | 0.6469 | -0.0003 |
| 5I | IPA/HFE | 0.4342 | 0.4342 | 0.4341 | 0.4341 | 0.4341 | -1E-04 |
| 6I | IPA/HFE | 0.419 | 0.4189 | 0.4189 | 0.4189 | 0.4189 | -1E-04 |
| | | | | | | | |
| 1J | IPA | 0.0785 | 0.0785 | 0.0785 | 0.0785 | 0.0785 | 0 |
| 2J | IPA | 0.0703 | 0.0704 | 0.0704 | 0.0704 | 0.0704 | 0.0001 |
| 3J | HFE | 0.1059 | 0.1059 | 0.1059 | 0.1059 | 0.1059 | 0 |
| 4J | HFE | 0.0633 | 0.0633 | 0.0633 | 0.0633 | 0.0633 | 0 |
| 5J | IPA/HFE | 0.0908 | 0.0908 | 0.0908 | 0.0908 | 0.0908 | 0 |
| 6J | IPA/HFE | 0.0975 | 0.0975 | 0.0975 | 0.0975 | 0.0975 | 0 |
| | | | | | | | |
| 1K | IPA | 0.0384 | 0.0384 | 0.0384 | 0.0384 | 0.0384 | 0 |
| 2K | IPA | 0.042 | 0.0419 | 0.0419 | 0.042 | 0.042 | 0 |
| 3K | HFE | 0.021 | 0.0209 | 0.021 | 0.021 | 0.021 | 0 |
| 4K | HFE | 0.0112 | 0.0111 | 0.0111 | 0.0111 | 0.0111 | -1E-04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5K | IPA/HFE | 0.0216 | 0.0216 | 0.0216 | 0.0216 | 0.0216 | 0 |
| 6K | IPA/HFE | 0.0146 | 0.0145 | 0.0145 | 0.0145 | 0.0145 | -1E-04 |

**Table 13 – Materials Compatibility of Other Materials**
**2nd Round**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Samples A= Coax Wire Polyimide Insulation | Samples B= EN-7 Polyurethane Encapsulation | Samples C= PET-90 Polyurethane Encapsulation | Samples D= CF3262 Samples | Samples D2= CF3262 copper end | Samples E= Compression Pad # BBN-3725-F82 | | |
| Samples F= Compression Pad # BBN-3586-E82 | Samples G= Compression Pad # BBN-4267 B84 | Samples H= Compression Pad # BBN-2848 J80 | Samples I= Aft det holdown #530851 | Samples J= Aft det hold down #326799 | Samples K= Aft det hold down #607526 | | |
| Samples L= Fwd det hold down #834223 | Samples M= Fwd det hold down #396294 | Samples N= Cable Protector 422078 WS N468459Cylce 21 | Sample O=tube protector | | | | |
| | | | | | | | |
| **Sample** | **Chemical** | **Start Weight** | **End Weight 1** | **End Weight 2 (5 min)** | **End Weight 3 (10 min)** | **End Weight 4 (180 min)** | **Difference in Start and End Weight 4** |
| 1A | IPA | 0.1022 | 0.1033 | 0.1025 | 0.1022 | 0.1022 | 0 |
| 2A | IPA | 0.1053 | 0.1063 | 1055 | 0.1053 | 0.1052 | -0.0001 |
| 3A | IPA | 0.1065 | 0.1078 | 0.1067 | 0.1066 | 0.1064 | -0.0001 |
| 4A | HFE | 0.0999 | 0.1 | 0.0999 | 0.0999 | 0.0999 | 0 |
| 5A | HFE | 0.1014 | 0.1014 | 0.1014 | 0.1014 | 0.1014 | 0 |
| 6A | HFE | 0.926 | 0.933 | 0.926 | 0.926 | 0.926 | 0 |
| | | | | | | | |
| 1B | IPA | 0.3794 | 0.38 | 0.3796 | 0.3195 | 0.3794 | 0 |
| 2B | IPA | 0.3625 | 0.3633 | 0.3628 | 0.3627 | 0.3624 | -1E-04 |
| 3B | IPA | 0.4599 | 0.4608 | 0.4605 | 0.4602 | 0.4599 | 0 |
| 4B | HFE | 0.3986 | 0.3986 | 0.3985 | 0.3985 | 0.3986 | 0 |
| 5B | HFE | 0.4077 | 0.4078 | 0.4077 | 0.4077 | 0.4076 | -1E-04 |
| 6B | HFE | 0.4252 | 0.4252 | 0.4252 | 0.4252 | 0.4252 | 0 |
| | | | | | | | |
| 1C | IPA | 0.6427 | 0.6469 | 0.6444 | 0.6438 | 0.6434 | 0.0007 |
| 2C | IPA | 0.6379 | 0.6417 | 0.6397 | 0.6391 | 0.6386 | 0.0007 |
| 3C | IPA | 0.5055 | 0.5088 | 0.5068 | 0.5064 | 0.5061 | 0.0006 |
| 4C | HFE | 0.5359 | 0.5362 | 0.536 | 0.5359 | 0.5364 | 0.0005 |
| 5C | HFE | 0.624 | 0.6242 | 0.6241 | 0.624 | 0.6246 | 0.0006 |
| 6C | HFE | 0.6889 | 0.6892 | 0.689 | 0.689 | 0.6896 | 0.0007 |
| | | | | | | | |
| 1D2 | IPA | 0.9599 | 0.9601 | 0.96 | 0.9599 | 0.9599 | 0 |
| 2D2 | IPA | 0.7064 | 0.7066 | 0.7065 | 0.7064 | 0.7064 | 0 |
| 3D2 | IPA | 1.1229 | 1.123 | 1.123 | 1.1228 | 1.1228 | -1E-04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4D2 | HFE | 1.1057 | 1.1057 | 1.1057 | 1.1056 | 1.1057 | 0 |
| | | | | | | | |
| 1E | IPA | 0.1609 | 0.2036 | 0.187 | 0.1756 | 0.1603 | -0.0006 |
| 2E | IPA | 0.1592 | 0.2338 | 0.205 | 0.1879 | 0.1584 | -0.0008 |
| 3E | IPA | 0.1442 | 0.1868 | 0.1675 | 0.1536 | 0.1434 | -0.0008 |
| 4E | HFE | 0.1651 | 0.3465 | 0.2352 | 0.197 | 0.1644 | -0.0007 |
| 5E | HFE | 0.1265 | 0.2479 | 0.163 | 0.1427 | 0.1252 | -0.0013 |
| 6E | HFE | 0.147 | 0.226 | 0.1676 | 0.1528 | 0.1463 | -0.0007 |
| | | | | | | | |
| 1F | IPA | 0.1138 | 0.1393 | 0.1161 | 0.1139 | 0.1133 | -0.0005 |
| 2F | IPA | 0.1095 | 0.1443 | 0.1208 | 0.1146 | 0.1091 | -0.0004 |
| 3F | IPA | 0.1111 | 0.1325 | 0.1148 | 0.1107 | 0.1105 | -0.0006 |
| 4F | HFE | 0.1356 | 0.19 | 0.1365 | 0.1351 | 0.1351 | -0.0005 |
| 5F | HFE | 0.1116 | 0.1604 | 0.1131 | 0.1113 | 0.1112 | -0.0004 |
| 6F | HFE | 0.1131 | 0.1669 | 0.1172 | 0.1127 | 0.1127 | -0.0004 |
| | | | | | | | |
| 1G | IPA | 0.1302 | 0.2334 | 0.196 | 0.1759 | 0.1293 | -0.0009 |
| 2G | IPA | 0.1191 | 0.1943 | 0.169 | 0.1521 | 0.1183 | -0.0008 |
| 3G | IPA | 0.1277 | 0.2116 | 0.189 | 0.1647 | 0.1269 | -0.0008 |
| 4G | HFE | 0.1371 | 0.293 | 0.1665 | 0.1374 | 0.1366 | -0.0005 |
| 5G | HFE | 0.1553 | 0.2318 | 0.1556 | 0.1167 | 0.1159 | -0.0394 |
| 6G | HFE | 0.156 | 0.34 | 0.2556 | 0.1818 | 0.1547 | -0.0013 |
| | | | | | | | |
| 1H | IPA | 0.1134 | 0.181 | 0.1599 | 0.1401 | 0.113 | -0.0004 |
| 2H | IPA | 0.1432 | 0.2164 | 0.1947 | 0.1739 | 0.1428 | -0.0004 |
| 3H | IPA | 0.1041 | 0.153 | 0.1377 | 0.1238 | 0.1038 | -0.0003 |
| 4H | HFE | 0.1028 | 0.21 | 0.1198 | 0.1024 | 0.1026 | -0.0002 |
| 5H | HFE | 0.1046 | 0.1371 | 0.1044 | 0.104 | 0.1042 | -0.0004 |
| 6H | HFE | 0.1204 | 0.2166 | 0.1617 | 0.1208 | 0.1199 | -0.0005 |
| | | | | | | | |
| 1I | IPA | 0.223 | 0.2254 | 0.223 | 0.2227 | 0.2223 | -0.0007 |
| 2I | IPA | 0.2614 | 0.2632 | 0.2613 | 0.261 | 0.2608 | -0.0006 |
| 3I | IPA | 0.2618 | 0.2633 | 0.2619 | 0.2617 | 0.2613 | -0.0005 |
| 4I | HFE | 0.3434 | 0.3528 | 0.3467 | 0.3455 | 0.3429 | -0.0005 |
| 5I | HFE | 0.1877 | 0.1927 | 0.1898 | 0.189 | 0.1873 | -0.0004 |
| 6I | HFE | 0.2629 | 0.2701 | 0.2658 | 0.2646 | 0.2623 | -0.0006 |
| | | | | | | | |
| 1J | IPA | 0.2546 | 0.2572 | 0.2548 | 0.2544 | 0.2542 | -0.0004 |
| 2J | IPA | 0.2133 | 0.2152 | 0.2134 | 0.2131 | 0.2128 | -0.0005 |
| 3J | IPA | 0.2114 | 0.214 | 0.2116 | 0.2112 | 0.2108 | -0.0006 |
| 4J | HFE | 0.2775 | 0.2843 | 0.2795 | 0.279 | 0.2771 | -0.0004 |
| 5J | HFE | 0.2345 | 0.2416 | 0.2375 | 0.2361 | 0.234 | -0.0005 |
| 6J | HFE | 0.1382 | 0.1425 | 0.1405 | 0.1393 | 0.1377 | -0.0005 |
| | | | | | | | |
| 1K | IPA | 0.2541 | 0.2557 | 0.2541 | 0.2539 | 0.2537 | -0.0004 |
| 2K | IPA | 0.3168 | 0.3197 | 0.3171 | 0.3167 | 0.3163 | -0.0005 |
| 3K | IPA | 0.2545 | 0.2573 | 0.2547 | 0.2543 | 0.2539 | -0.0006 |
| 4K | HFE | 0.3663 | 0.3763 | 0.37 | 0.3682 | 0.3659 | -0.0004 |
| 5K | HFE | 0.3239 | 0.3316 | 0.3272 | 0.3254 | 0.3232 | -0.0007 |
| 6K | HFE | 0.2364 | 0.2423 | 0.2395 | 0.2378 | 0.2358 | -0.0006 |
| | | | | | | | |
| 1L | IPA | 0.0302 | 0.0306 | 0.0301 | 0.0299 | 0.0299 | -0.0003 |
| 2L | IPA | 0.0426 | 0.0433 | 0.0424 | 0.0424 | 0.0424 | -0.0002 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3L | IPA | 0.0431 | 0.0437 | 0.0429 | 0.43 | 0.0429 | -0.0002 |
| 4L | HFE | 0.0342 | 0.0366 | 0.035 | 0.0346 | 0.0342 | 0 |
| 5L | HFE | 0.0357 | 0.038 | 0.036 | 0.0357 | 0.0354 | -0.0003 |
| 6L | HFE | 0.0384 | 0.0402 | 0.0391 | 0.0385 | 0.0382 | -0.0002 |
| | | | | | | | |
| 1M | IPA | 0.0572 | 0.058 | 0.0572 | 0.0572 | 0.0571 | -0.0001 |
| 2M | IPA | 0.0453 | 0.0459 | 0.0452 | 0.0451 | 0.0451 | -0.0002 |
| 3M | IPA | 0.0368 | 0.0375 | 0.0368 | 0.0367 | 0.0368 | 0 |
| 4M | HFE | 0.0531 | 0.0558 | 0.0541 | 0.0535 | 0.0533 | 0.0002 |
| 5M | HFE | 0.0362 | 0.0384 | 0.0369 | 0.0366 | 0.0361 | -0.0001 |
| 6M | HFE | 0.0589 | 0.0618 | 0.0598 | 0.0594 | 0.0587 | -0.0002 |
| | | | | | | | |
| 1N | IPA | 0.0098 | 0.0097 | 0.0096 | 0.0095 | 0.0097 | -1E-04 |
| 2N | IPA | 0.0105 | 0.0105 | 0.0106 | 0.0103 | 0.0105 | 0 |
| 3N | IPA | 0.0105 | 0.0104 | 0.0104 | 0.0104 | 0.0105 | 0 |
| 4N | HFE | 0.0137 | 0.0134 | 0.0134 | 0.0135 | 0.0135 | -0.0002 |
| 5N | HFE | 0.0111 | 0.0109 | 0.0109 | 0.0109 | 0.0111 | 0 |
| 6N | HFE | 0.0098 | 0.0098 | 0.0098 | 0.0098 | 0.0098 | 0 |
| | | | | | | | |
| 1O | IPA | 0.0343 | 0.0342 | 0.0341 | 0.0341 | | -0.0343 |
| 2O | IPA | 0.0263 | 0.0261 | 0.0262 | 0.0262 | | -0.0263 |
| 3O | IPA | 0.0244 | 0.0241 | 0.0242 | 0.0243 | | -0.0244 |
| 4O | HFE | 0.028 | 0.0279 | 0.028 | 0.0279 | | -0.028 |
| 5O | HFE | 0.0267 | 0.0265 | 0.0265 | 0.0264 | | -0.0267 |
| 6O | HFE | 0.0396 | 0.0394 | 0.0394 | 0.0394 | | -0.0396 |

**Table 14 – Materials Compatibility of Other Materials**
**3rd Round**

| Samples A= White Chalky Pieces | Samples B= Black with Metal | Samples C= Long Black Pieces | Samples D= AA61583 | | | | |
|---|---|---|---|---|---|---|---|
| **Sample** | **Chemical** | **Start Weight** | **End Weight 1** | **End Weight 2 (5 min)** | **End Weight 3 (10 min)** | **End Weight 4 (180 min)** | **Difference in Start and End Weight 4** |
| 1A | IPA | 13.6736 | 13.9306 | 13.898 | 13.86 | 13.752 | 0.0784 |
| 2A | IPA | 12.6012 | 12.8446 | 12.81 | 12.7809 | 12.6839 | 0.0827 |
| 3A | IPA/HFE | 14.7729 | 15.366 | 15.2121 | 15.0095 | 14.8792 | 0.1063 |
| 4A | IPA/HFE | 11.8117 | 12.2481 | 12.124 | 12.038 | 11.8782 | 0.0665 |
| 5A | HFE | 9.6825 | 10.1912 | 10.037 | 9.977 | 9.738 | 0.0555 |
| 6A | HFE | 6.4452 | 6.757 | 6.6337 | 6.5974 | 6.4743 | 0.0291 |
| | | | | | | | |
| 1B | IPA | 7.4537 | 7.4545 | 7.4539 | 7.4537 | 7.4532 | -0.0005 |
| 2B | IPA | 9.0789 | 9.0793 | 9.0789 | 9.0786 | 9.0785 | -0.0004 |
| 3B | IPA/HFE | 8.9434 | 8.947 | 8.9437 | 8.9434 | 8.9421 | -0.0013 |
| 4B | IPA/HFE | 7.9657 | 7.9665 | 7.9658 | 7.9656 | 7.965 | -0.0007 |
| 5B | HFE | 8.6858 | 8.6873 | 8.6858 | 8.6852 | 8.6846 | -0.0012 |
| 6B | HFE | 8.0342 | 8.0355 | 8.0347 | 8.0343 | 8.0341 | -1E-04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1C | IPA | 33.16 | 33.1554 | 33.1545 | 33.1545 | 33.1524 | -0.0076 |
| 2C | IPA/HFE | 28.0529 | 28.048 | 28.0474 | 28.0472 | 28.0462 | -0.0067 |
| 3C | HFE | 28.9928 | 28.9911 | 28.991 | 28.9909 | 28.9904 | -0.0024 |
| | | | | | | | |
| 1D | IPA | 0.5962 | 0.6681 | 0.6299 | 0.6121 | 0.5914 | -0.0048 |
| 2D | IPA | 0.6128 | 0.6375 | 0.6198 | 0.6148 | 0.6095 | -0.0033 |
| 3D | IPA | 0.6787 | 0.7143 | 0.6858 | 0.6786 | 0.6734 | -0.0053 |
| 4D | HFE | 0.7413 | 0.7677 | 0.7487 | 0.7453 | 0.7382 | -0.0031 |
| 5D | HFE | 0.6518 | 0.6918 | 0.6591 | 0.6557 | 0.6484 | -0.0034 |
| 6D | HFE | 0.7906 | 0.8241 | 0.7970 | 0.7939 | 0.7873 | -0.0033 |
| 7D | Azeo | 0.6712 | 0.7214 | 0.6841 | 0.6778 | 0.6683 | -0.0029 |
| 8D | Azeo | 0.7130 | 0.7654 | 0.7268 | 0.7200 | 0.7089 | -0.0041 |
| 8D | Azeo | 0.5890 | 0.6132 | 0.5962 | 0.5927 | 0.5864 | -0.0026 |
| | | | | | | | |

Figures

Figure 1 – Contact Angle Differences – IPA versus Neat HFE-7100

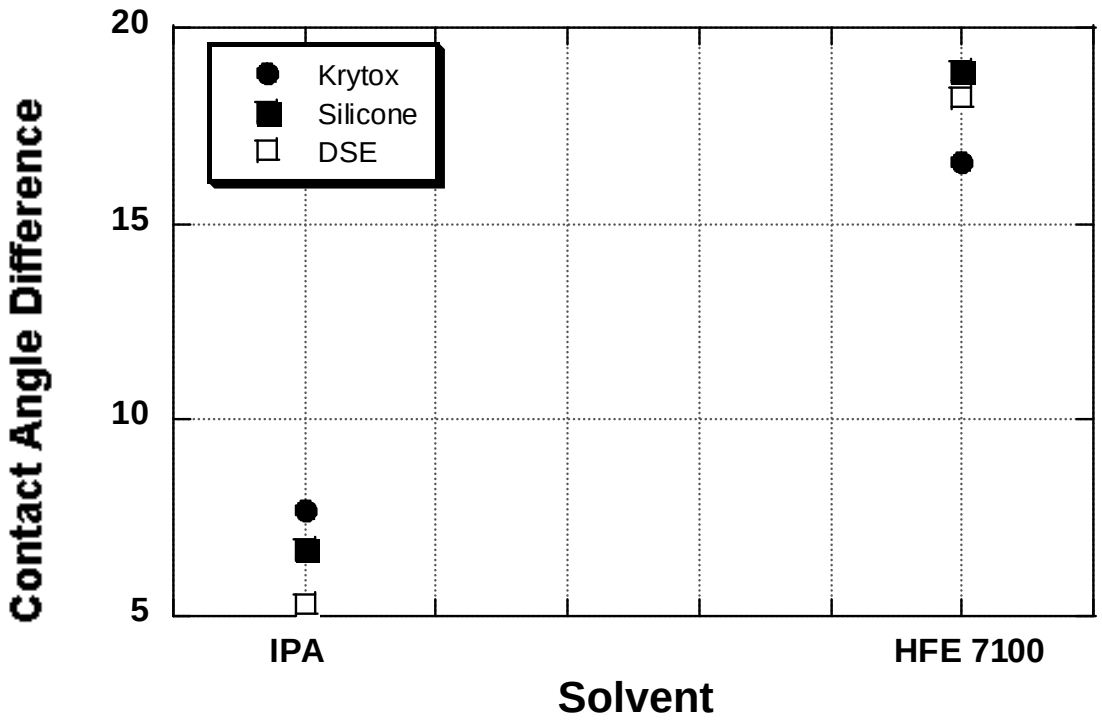
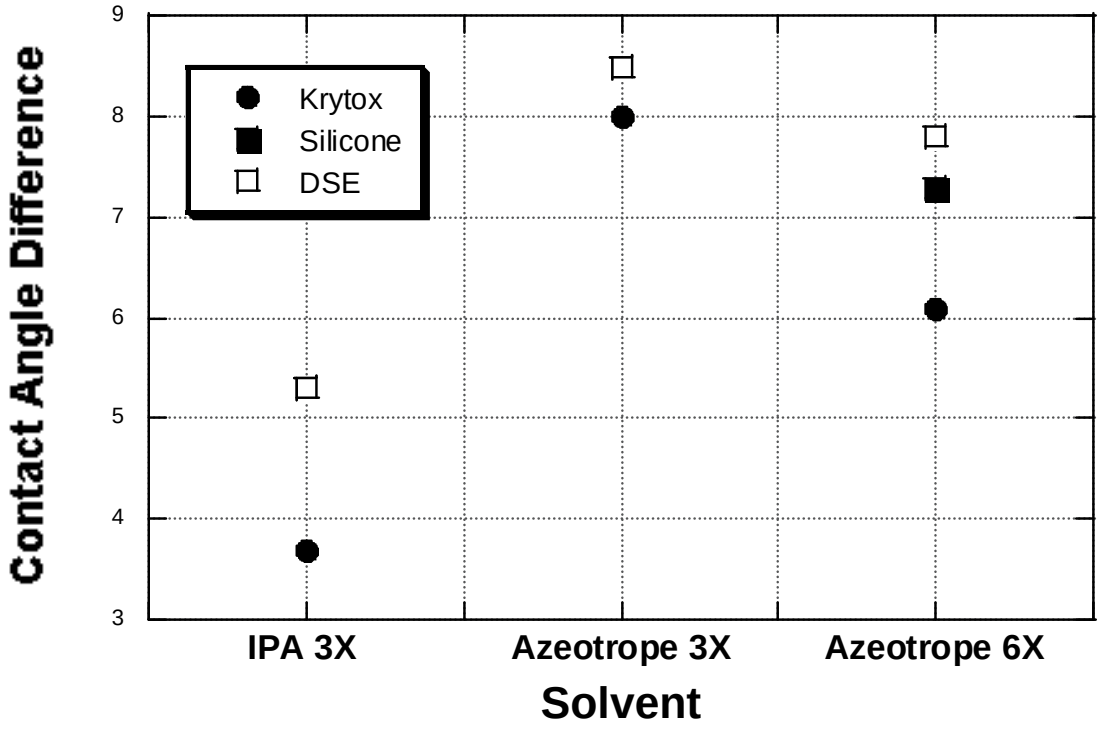


Figure 2 – Contact Angle Differences – IPA versus HFE/IPA Azeotrope



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