TECHSPRAY

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TECH SPRAY, L. P.

Technical White Paper

Standardized Criteria for Testing HCFC-141b Aerosol Replacements

The most widely used aerosol solvent in the electronics industry is going away. The EPA has phased out HCFC-141b, introduced as a replacement cleaner to CFC chemistry in the early 90's. An estimated 9 million pounds of HCFC-141b was used for cleaning last year alone. New replacements are now available which unlike the conversion from CFC's, perform better, are more eco-friendly, and are more efficient in terms of total usage cost.

December 31, 2002 was the last date to manufacture HCFC-141b. Title VI of the Clean Air Act directs the Environmental Protection Agency (EPA) to protect the ozone layer through several regulatory and voluntary programs. Acting under this directive, and to meet the requirements of the Montreal Protocol, the EPA stopped all production for domestic consumption of HCFC-141b due to its ozone depletion factor. As a result, many companies have begun the search for a new solvent of choice to replace this popular cleaner.

HCFC-141b was popular because of its non-flammability, rapid evaporation, good cleaning efficiency, and moderate plastic compatibility. A proper evaluation of alternatives must consider these as well as other aspects. Standardized and objective criteria are needed to isolate the best aerosol replacement.

The following decisive factors must be investigated before a solvent can truly be considered as a viable replacement. The first four are the most critical, so an HCFC-141b aerosol replacement must pass all four to be considered.

1. EPA SNAP approved
2. Non-flammable in aerosol
3. Not a California PROP 65 listed chemical
4. Exposure limit appropriate for aerosol use

Once the alternative passes these criteria it must be evaluated for suitability in the user's specific applications. The following are basic criteria used to distinguish various solvents and their uses.

5. Cleaning efficiency as good or better than HCFC-141b
6. Kauri Butanol Value (Kb)
7. No ozone depletion potential
8. No noxious fumes
9. Evaporation
10. Low Surface tension
11. Plastic compatibility similar to or better than HCFC-141b
12. Low VOC content
13. Low global warming potential

Criteria 1:
SNAP Listed

The product must be SNAP listed to be considered a viable replacement. EPA created the Significant New Alternatives Policy (SNAP) Program under section 612 of the Clean Air Act Amendments. SNAP evaluates the overall risk to human health and the environment posed by alternatives to Class I and Class II ozone depleting substances. Substitutes are reviewed on the basis of ozone depletion potential, global warming potential, toxicity, flammability, and the use specific exposure potential as described in the March 18, 1994 final SNAP rule (59 FR 13044). Lists of acceptable and unacceptable substitutes are updated periodically in the Federal Register. Compounds listed as pending or have applied for approval may be used after a 90-day period. However the user must be aware that the EPA may not ultimately approve the process or compound.

Criteria 2:
Non-flammable

In the electronics and industrial industries, many aerosol-cleaning products are used on live circuits or the substrate is powered down, cleaned, and immediately powered back up -- often still wet. In those cases, the product must be non-flammable when used in an aerosol. Furthermore, it is always safer to use non-flammable products when they are available. An aerosol product is non-flammable if it propagates a flame of less than 18 inches when sprayed through a standing flame. A flammable aerosol should not be considered as a viable HCFC-141b replacement.[i]

Criteria 3:
Not Prop 65 listed

The third pass/fail criterion is based on Proposition 65 chemical list. Prop 65 lists chemicals that to the state of California, are "known to cause cancer or reproductive toxicity." The proposed product must not be on this list. In the table below (fig. 1), if any of the ingredients in a blend are Prop 65 listed, then the product is not considered an HCFC-141b replacement.

Criteria 4:
Exposure Limit Appropriate for Aerosol Application

In contrast to sealed cleaning systems, aerosols, by the nature of the delivery method, have greater exposure potential. Because of this, it is inadvisable to use an aerosol solvent that falls below 50ppm (parts per million). The value assigned for this was the lowest value of any chemical in the composition of the blend.

Criteria 5:
Cleaning Efficiency as Good or Better than HCFC-141b

The cleaning efficiency is calculated and recorded relative to 141b. To perform this test four coupons are contaminated with four different soils. Each contaminant is then cleaned with 141b in aerosol form and the percentage of the contaminant removed is recorded. This procedure is repeated for the test solvent and the amount of contaminant removed is then recorded. The value given in table 1 (fig 1) is the test solvents' performance relative to 141b. (HCFC-141b was given a value of 1 for cleaning efficiency.[ii]) Every solvent must be aerosolized the same to ensure every solvent is tested under the same conditions.

Criteria 6:
Kauri Butanol Value

A Kauri Butanol (Kb) value is a measure of solvent power of hydrocarbon solvents -- another test for cleaning effectiveness. Kauri gum is readily soluble in butanol and insoluble in hydrocarbons. Therefore the Kb value is the measure of the volume of solvent required to produce turbidity in a standard solution of Kauri gum dissolved in butanol. High Kauri Butanol values indicate relatively strong solvency. Naphtha's usually have a Kb value of about 30, while toluene is around 105.[iii]

Criteria 7:
No Ozone Depletion Potential

The Ozone Depletion Potential (ODP) should be reviewed when considering HCFC-141b replacement chemistry. This is particularly important because HCFC-141b is being phased out because it has an ODP value of 0.11. The ideal replacement should have a minimal potential to avoid future government intervention and negative ecological impact. When there is a blend of two or more chemicals and each has an ODP value, record the highest individual ODP value for the blend.

Criteria 8:
No Noxious Fumes

In an aerosol cleaning application, the surrounding air may become saturated with atomized aerosol vapor. Many times cleaning is performed at an isolated workstation with minimal airflow. In these instances, air quality is critical. Therefore, another criterion that is used to determine a replacement is odor. A subjective test is used where the products are ranked from one to ten with a score of ten being the most offensive.[iv]

Criteria 9:
Evaporation Rate as Good or Better than HCFC-141b

Whether cleaning a part or reworking a bad component on a printed circuit board, down time and production time is critical. In a cleaning operation, the ideal product will clean the part and then dry immediately. A relative evaporation rate is indicative of the compounds ability to dry. The evaporation was done relative to Trichloroethylene. In this test the dry time of the test material is divided by the dry time of the reference solvent and this gives the relative evaporation rate. If the product evaporated in the same time the result would be 1. A number of less than one means that a same amount of a comparative solvent will dry faster.[v]

Criteria 10:
Surface Tension of less than 25 dynes/cm

Surface tension is the phenomenon that creates an inward pull or internal pressure on a liquid, which tends to restrain the liquid from flowing. This is what makes water bead up instead of spreading out indefinitely. Water has a surface tension of 73 dynes/cm. A surface tension of less than 25 dynes/cm is considered ideal for precision cleaning. A low surface tension gives the solvent the ability to flow in, around and under various parts for more efficient cleaning. This becomes especially important on highly populated boards or boards with minimal clearance.[vi]

Criteria 11:
Plastic Compatibility Similar to HCFC-141b

Plastics compatibility was the next test with results ranked on a relative scale from zero to eight (zero being 100% compatible, eight non-compatible). Plastic parts and components are commonplace as an integral part of many printed circuit boards and many more electronics are encased in plastic. Plastic will react very differently when in contact with a solvent depending upon whether the plastic is stressed or non-stressed. Therefore, the plastic was tested both stressed and non-stressed. The two scores are then averaged for each plastic tested. For example, we tested 14 different plastics with 42 possible points (14x3). We then took the total score each solvent received and divided that number by 42 with the perfect score being 0. Therefore the lower the number the more compatible with a variety of plastics the solvent will be. The plastics tested were ABS, Nylon 6, Nylon 6/6, Polycarbonate, HDPE, LDPE, C.E. phenolic, PMMA, POM, PP, PS, PTFE, PVC plasticized, and PVC rigid.[vii]

Criteria 12:
Low VOC

Volatile Organic Compound (VOC) is any volatile compound of carbon, excluding carbon monoxide, methane, carbon dioxide, carbonic acid, ammonium carbonate, metallic carbides or carbonates, and exempt compounds. VOC's and the secondary photochemical oxidant products have a potential to cause damage to the environment and human health. As a result, a Low Volatile Organic Compound (VOC) is favorable with an exempt compound being optimal. Since many solvents are volatile organics, any value of less than 1200 grams per liter for the blend is considered desirable.

Criteria 13:
Global Warming Potential

The final criterion is the Global Warming Potential (GWP). The ideal replacement would not be a global warmer with a GWP rating of 0. GWP represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of carbon dioxide. All GWP values shown are calculated over a 100-year time horizon. As CO_2 is the standard it is assigned a value of 1, and water is assigned a value of 0. Most Hydro fluorocarbons (HFC) and Hydro chlorofluorocarbons (HCFC) have GWP's ranging from 93 to 12,100. For the purposes of this study the results listed are the highest value for any single ingredient.

Conclusions

Having evaluated over 100 different solvents and solvent blends, trans-1,2-dichloroethylene (trans), produced by PPG, showed the best overall performance across all categories. Trans is a rapidly evaporating, moderately priced solvent that exhibits excellent cleaning power. Blended with various non-flammable solvents, trans provides the backbone for nearly every viable alternative.

The best performing blend was found to be 80% trans and 20% HFC-245fa. This non-flammable aerosol performs better than comparable HCFC-141b based blends with 32% greater cleaning power (see fig. 1, **Techspray® G3™**). The Techspray® G3™ has the highest percentage of Trans of any of the products tested. The high amount of Trans optimizes cleaning efficiency with minimal cost impact, while maintaining a low odor, good evaporation rate, and a good surface tension.

HCFC-225 fits the criteria of being VOC exempt, somewhat plastic compatible, and a good cleaner. Unfortunately, it is expensive relative to HCFC-141b and the other solvents and blends tested.

Trans/4310/365 marketed by DuPont as **Vertrel®** KCD-9587 and Micro Care as **Heavy Duty Degreaser C** has lower surface tension and VOC percentage but is not as good of a cleaner.

nPB is inexpensive and an effective cleaner, but has a toxicity level that may be of concern when used outside a sealed system. Furthermore nPB is still pending SNAP approval and may not be approved for all applications.

Genesolv® S-TZ is an azeotropic Trans/245 blend with only 13% Trans. This product had the fastest evaporation rate, the lowest VOC content, but has the worst cleaning ability of all solvents and blends tested.

Trichloroethylene is a solvent that has been in the cleaning industry for many years with many positive characteristics; however, due to its Prop 65 listing, we did not feel it would be an acceptable drop-in replacement for HCFC-141b.

The last product looked at was a **hydrocarbon** blend. These products are inexpensive, good cleaners, moderate odor and very plastics compatible. However, a flammable aerosol cannot be considered as a drop in replacement for a non-flammable product being phased out.

Steve Cook
Laboratory Manager
Tech Spray, L. P.

Figure 1: Aerosol testing results (Green indicates significantly superior performance compared to HCFC-141b, red indicates significantly inferior performance)

Criteria	Solvent (Pure or Blend)	141b	Techspray G3	HCFC AK225	Vertrel KCD-9587	nPB	Genesolv S-TZ	TCE	Hydro-carbon
	Cost (relative to 141b)	-	Slightly Higher	Much Higher	Slightly Higher	Slightly Higher	Slightly Higher	Lower	Lower
Critical Criteria (Alternatives Must Meet to be Considered Acceptable)									
1	SNAP listed	Yes	Yes	Yes	Yes	Unknown*	Yes	Yes	Yes
2	Non Flammable Aerosol	√	√	√	√	√	√	√	X
3	Prop 65 listed	√	√	√	√	√	√	X	√
4	Toxicity TWA (ppm)	500	200	50	200	25*	200	100	50
Evaluative Criteria (Alternatives Must be Evaluated Against Applications)									
5	Cleaning Efficiency Relative to 141b	1	1.32	0.70	0.65	1.36	0.06	1.34	1.35
6	Kb Value	56	91.84	31	20.73	125	NA**	133.7	29
7	ODP	0.11	0	0.03	0	0.006	0	0	0
8	Odor (10 most Offensive)	3.7	5.2	3.4	8	9.7	5.4	8.0	6.3
9	Relative Evaporation Rate <=TCE	0.27	0.44	0.31	0.19	0.6	0.22	1	2.04
10	Surface Tension	18.4	21.8	18.8	14.1	25.9	15.3	29.5	28
11	Plastic Compatibility	2.38	3.6	3.1	3.1	2.86	1.43	2.86	0
12	VOC content	Exempt	1024	Exempt	446	1330	166.4	1462	690
13	GWP***	630	790	620	150	0	790	0	0

* *EPA has recommended nPB be SNAP approved in Federal Register EPA 40 CFR Part 82 published on Tuesday June 3, 2003. However, a final ruling is not expected until Fall 2004.*

** *Initial boiling point below 40°C, which falls outside the scope of ASTM D 1133*

*** *Values given are the I.P.C.C. values listed in the most current EPA website at http://www.epa.gov/ozone/geninfo/gwps/html.*

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[i] Testing for aerosol flammability was performed in compliance with ASTM D 3065.

[ii] The cleaning was done in compliance with Mil-PRF-29608. In this standard, four different contaminants are used to contaminate four different coupons.

a. MIL-C-81309 (corrosion preventative)
b. MIL-H-83282 (hydraulic fluid)
c. VV-D-1078 (silicone damping fluid)
d. J-STD-004, Type R (rosin soldering flux)

Five drops of a test soil is applied to each of the three panels with a pipette or eyedropper and spread with a brush. This procedure is repeated for each of the test soils. The MIL-C-81309 coupons are then be baked at 105°C +/- 1°C (221° +/- 2°F) for one hour. Panels coated with flux in accordance with the J-STD-004 are dried at room temperature for 1 hour. Panels coated with fluids in accordance with MIL-H-83282 and VV-D-1078 are tested wet.

The soiled panels are then placed approximately 45° from horizontal. The compound under test is sprayed for 5 seconds across each panel and allowed to evaporate for 10 minutes. The bottom edge and the reverse side of the panel is wiped to remove displace soil.

The cleaning efficiency calculation is expressed as cleaning efficiency.

The coupons must be cleaned, dried and weighed prior to contamination. Record this weight as W1. After the panels are soiled as explained above, record this as W2. After the panels are sprayed and wiped, reweigh the panels and record this as W3.

% Cleaning efficiency = W2-W3/W2-W1 x 100

All four contaminants were cleaned using a 141b aerosol. The cleaning efficiency of 141b was assigned a value of 1.

[iii] All Kb values are tested and calculated in compliance with ASTM D 1133.

[iv] To perform this test, take blind aerosol samples of the finished products and allow each test subject to spray a substrate for two seconds. You then ask each person to rank the odor from one to ten. Add the results and divide by the number of participants to get the mean average. A minimum of five participants is recommended, and more will increase the repeatability of the results.

[v] The relative evaporation was tested and recorded in accordance with ASTM D 1901.

[vi] The test equipment used was a Surface Tensiometer.

[vii] Non-stressed test plastic is placed approximately 45° from horizontal. The specific plastic under test is sprayed for 5 seconds and allowed to dry. Immediately after the solvent evaporates, check the coupon for texture changes and pliability. To do this, physically grab the coupon checking for softness, stickiness, and fragility. The plastic was then given a score from 0 to 3.

0 = No effect on plastic coupon
1 = Slightly effected
2 = Moderately effected and compatibility for this plastic type in question
3 = Highly effected and is probably not suitable for this type of plastic

To test the plastic in stressed condition, use a jig in compliance with ASTM-D 543. The plastic is bent at an approximate 30° angle, sprayed for five seconds, and scored by the same criteria as explained above.

PO Box 949
Amarillo, Texas 79105-0949
www.techspray.com
Toll-Free: 800.858.4043
Fax: 806.372.8750
Email: tsales@techspray.com