



Comparing Alternatives for Hand Wipe and Cold Cleaning

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Several solvent blends have been developed for solvent-based, hand wipe, and cold cleaning applications, which typically require quick drying times and good worker-exposure characteristics. The blends described demonstrate improved cleaning performance for a wide range of soils and good compatibility with many substrates. Their solubility characteristics are described and compared to traditional cleaning solvents. The vapor hazard ratio (VHR) is used to compare the relative inhalation hazards of these solvents and their traditional counterparts. This method of comparing the inhalation hazards combines a solvent's exposure limit and vapor pressure to give a realistic reflection of worker exposure hazard. Additionally, when evaluating a solvent's impact on the environment, including vapor pressure into the evaluation gives a more realistic picture of that solvent's impact.

Why Replace Your Cold-Cleaning or Hand-Wipe Solvent?

Solvents that evaporate quickly such as acetone, methyl ethyl ketone (MEK), methyl propyl ketone (MPK), or isopropyl alcohol (IPA) are popular cleaners for the removal of many soils. Their low costs combined with performance characteristics and fast evaporation rates have made them appealing cleaners. However, as environmental and fire-safety regulations become more stringent, the demand has increased for cleaning agents which are safer, perform better, and have less environmental impact. Several solvent blends are described here that were developed to meet the needs of today's industry. The blends listed below are currently approved for use in a variety of applications by airframe or aircraft engine manufacturers.

Blend A: composed of aliphatic hydrocarbons, non-linear alcohols, and high purity terpenes. This blend is able to dissolve a variety of soils, including waxes, oils, greases, adhesives, and welding flux residues. For certain soils, it can be a more powerful, more versatile cleaner than other alternatives.

Blend B: composed of highly refined isoparaffinic hydrocarbons and linear alcohols. The product's broad solvency and relatively fast evaporation make it ideal for hand cleaning a wide range of lubrication fluids and cutting oils. It is an ideal replacement for isopropanol (IPA) in hand wipe or immersion cleaning applications where cleaning performance, safety, and/or VOC emissions need to be improved.

Blend C: a very low residue terpene-based solvent designed for hand-wipe cleaning applications. It is a blend of high purity terpenes with selected polar solvents giving it high solvency and low surface residue on evaporation.

Blend D: a blend of food-grade citrus terpenes designed to provide strong cleaning performance, low odor, quick evaporation, and minimal non-volatile residue for this type of cleaner. This composition is especially effective for cleaning tars, asphalt, or baked-on flux residue.

Blend E: a blend of aliphatic hydrocarbons formulated to offer an excellent combination of low-odor, minimum residue, and broad range of solvency. This blend is good for cleaning a variety of soils and has a slightly higher flash point.

Blend F: a blend of aliphatic hydrocarbons and alcohols. This blend is good for cleaning a variety of soils and has a slightly higher flash point.

Cleaning Performance

The five blends discussed above are effectively used in a variety of applications. These products can dissolve many soils, which include but are not limited to: tape residues, conductive adhesives, adhesives for wood bonding, wax, pitch, oils, greases, sealants, mold release agents, lubricants, welding flux residues, and inks.

Nonvolatile Residue

Fast-drying solvents are frequently required to leave “no residue” after cleaning. But, what does “no residue” really mean? It means that the amount of residue remaining does not interfere with subsequent parts processing or the function of the part in the final assembly. Vacuum deposition, plating, and painting are all applications that are especially sensitive to small amounts of residue remaining on surfaces.

Non-volatile residue is a test frequently used to measure the amount of residue left after drying a known quantity of solvent. The precision of this test is affected by both the sample volume and the precision of the balance used. Listed in Table 1 below are residue data for the blends described here and some commercially available solvents.

Blend or Solvent	A	B	C	D	E	F	Acetone	IPA	Mineral Spirits
NVR (ppm)	84	5	15	660	1	23	15	11	1

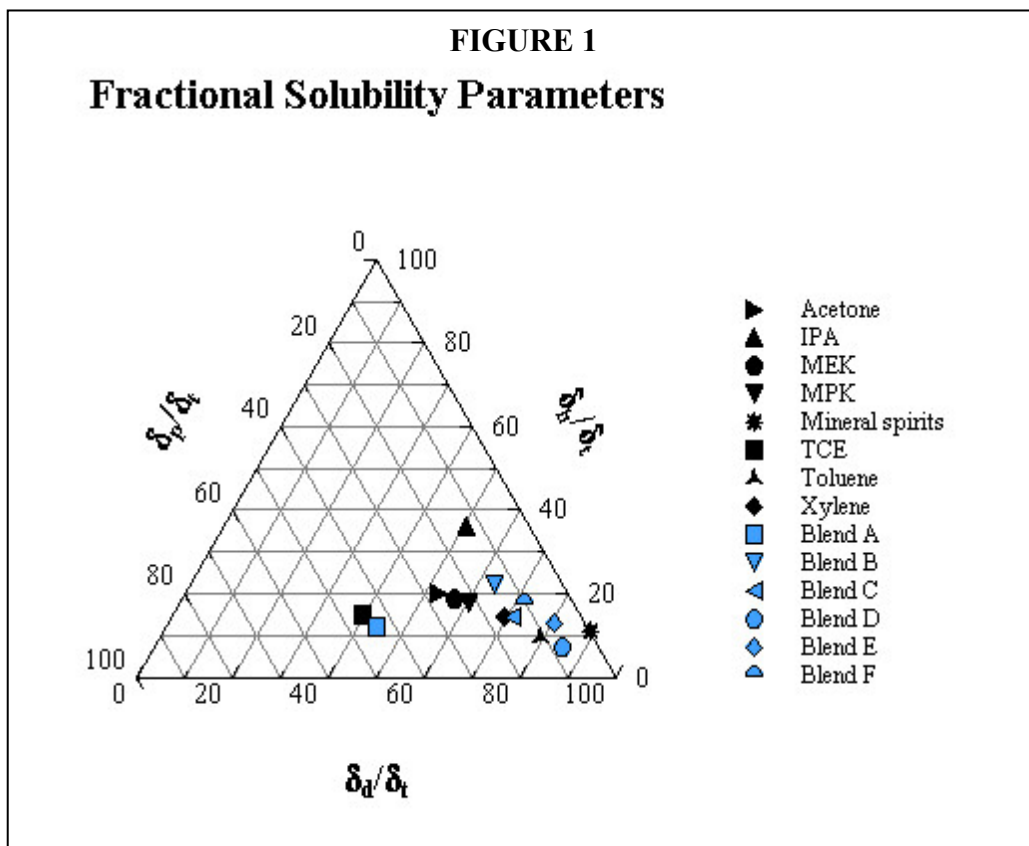
When replacing a fast-drying solvent, remember that any alternative with a flash point higher than the currently used solvent will dry more slowly. What appears to be a residue may actually be solvent that is not completely dry. If a slower dry time is unacceptable, the drying time can be accelerated by blowing off the part with compressed (or heated) air.

Hanson Solubility Parameters

Choosing a method to compare cleaning performance of alternative solvents can be a difficult task, and there are several approaches. Actually testing the alternative solvents for their ability to clean specific soils is the most reliable method. However, it requires a large number of solvents to be available for testing and can be very time-consuming and difficult to ensure test conditions remain consistent for each test. Other methods of evaluating a solvent’s solubility characteristics include Kauri-Butanol (Kb) values and solubility parameters. This type of data can narrow the available solvents to those most similar to the solvent currently used. Though easy to obtain, Kb values are

poor measures of solubility for anything except kauri resin and similar soils. Hildebrand and Hanson solubility parameters are more rigorous methods of evaluating solubility, but are much better than Kb value comparisons for matching a current solvent's "cleaning ability," especially when the soils are varied and dissimilar to kauri resin.

Solubility parameters are derived from the energy necessary to convert a liquid to a gas. This energy is expressed in terms of the bonds or forces holding a liquid together.^{1,2} Hanson solubility parameters divide the energy into three parts: dispersion forces (interactions between atoms), dipole–dipole forces (interactions between molecules), and hydrogen bonding forces (interactions between molecules containing a hydrogen and an electronegative group). These forces are symbolized as δ_d , δ_p , and δ_h , respectively.¹ Solubility parameters are helpful when looking for a new solvent since they mathematically describe the similarity of intermolecular structures of two liquids. When the intermolecular and atomic interactions of two liquids are similar, the liquids are miscible, because the intermolecular spacing is similar and allows for mixing. Consider the example of oil and water. Water molecules are polar and held together tightly by hydrogen bonding, whereas oil molecules are not polar and do not hydrogen bond. Their differences do not allow mixing, and mutual solubility is poor.



In addition to published tables of these data for many solvents, there are also many published methods for calculating these parameters. The Hanson solubility data for the solvents described in this paper are tabulated in Table 2. These data are expressed as fractional parameters or percentages of the total (δ_t). This allows us to graph the data on a Teas (or Triangular) graph, which is a more convenient way to depict the three parameters.

Solvent or Blend	δ_d/δ_t	δ_p/δ_t	δ_h/δ_t
Acetone	0.8140	0.4109	0.3101
Isopropanol (IPA)	0.7517	0.1931	0.5310
Methyl ethyl ketone (MEK)	0.8571	0.3651	0.2778
Methyl propyl ketone (MPK)	0.8871	0.3226	0.2581
Mineral Spirits	0.9709	0.0000	0.1165
Trichloroethylene (TCE)	0.6961	0.7843	0.2549
Toluene	0.9435	0.1290	0.1129
Xylene	0.9342	0.2171	0.1908
Blend A	0.8954	0.1511	0.2433
Blend B	0.8664	0.1908	0.2977
Blend C	0.9735	0.0885	0.0796
Blend D	0.9124	0.1830	0.1790
Blend E	0.9059	0.1255	0.2228
Blend F	0.9382	0.0710	0.1504

Environmental

Emissions of volatile organic compounds (VOCs) are now regulated in many parts of the world. While a few solvents, such as acetone, are exempt from VOC regulations in the United States, fast evaporating solvents are among the major sources of VOC emissions. Table 3 lists vapor pressures for a number of solvents used for wiping and immersion cleaning. The advantage to solvents with lower vapor pressures, hence slower evaporation rate, is that their VOC emissions can be reduced. For example, IPA evaporates approximately 7 times faster than Blend A under actual batch cleaning conditions. (See data in the Economics section.) This means that using Blend A to replace IPA can reduce VOC emissions by as much as 86%.

Safety

Although fast evaporating, low flash point solvents have been used as cleaning agents for decades, manufacturers are becoming more concerned about the flammability of these processes. Typical room-temperature processes operate at approximately 25°C (77°F), well above acetone's -20°C (-4°F) and IPA's 12°C (53°F) closed-cup flash points. This means that the vapors from a room temperature process can be ignited if oxygen is available (as it always is in the form of air) and if an ignition source is introduced.

Processes using blends with higher flash points, such as the blends described here, are considerably safer. For example, a process using Blend A in typical room-temperature settings remains well below the cleaner's 41°C (105°F) closed-cup flash point. Under controlled-temperature conditions, in which the solvent is kept at room temperature (below its flash point), the amount of Blend A vapor present is

approximately one-fourth the amount required for ignition. As a result, its vapors cannot be ignited when the liquid is at normal room temperatures, and it can be said that this mixture is too lean to burn.³

Toxicity

The ingredients in Blends A through F were carefully selected to provide low toxicity without sacrificing performance, economy, or convenience. Under normal conditions, their vapors are not irritating to the eyes, skin, or respiratory tract. The recommended exposure limits for these blends and the American Conference of Governmental Industrial Hygienists (ACGIH) recommended threshold limit value time-weighted average (TLV-TWA) for a variety of other solvents are listed in Table 3. While the ACGIH TLVs and the U.S. Occupation Safety and Health Association (OSHA) permissible exposure limits (PELs) provide a way to compare potential toxicity hazards between solvents, use of these values alone does not provide enough information to judge potential exposure hazards.

Vapor Hazard Ratio⁴ (VHR) is a more realistic way to compare the relative inhalation hazards of various solvents used for cold cleaning than comparing only exposure limits. Since a higher vapor pressure indicates increased exposure to a solvent, the exposure limit alone does not adequately convey the relative hazards of solvents. That is, a solvent that has an exposure limit of 400 ppm might be thought safer than one with an exposure limit 50 ppm. However, if the solvent with a 400-ppm limit has a significantly higher vapor pressure, and therefore evaporation rate, then the 400-ppm solvent might actually be more hazardous, as it is more likely to actually reach its exposure limit. The same comparison can be made with two solvents having the same exposure limit but very different vapor pressures. Although the two solvents have the same exposure limit and might be viewed as equally safe (or hazardous), the solvent with the higher vapor pressure will be more hazardous due to the likelihood of increased exposure to its vapors. Vapor Hazard Ratio factors in vapor pressure as follows:

$$\text{Vapor Hazard Ratio} = \frac{\text{Vapor Pressure (mm Hg)} \times 10^6}{760 \text{ mm Hg} \times \text{Exposure Limit (ppm)}}$$

The vapor is normalized to atmospheric pressure (760 mm Hg), and the factor 10^6 is used to bring the VHR into whole numbers. Higher numbers indicate higher risk.

Table 3 shows several cleaning solvents and their corresponding VHRs.

Solvent	Exposure Limit (ppm)⁵	Vapor Pressure (mm Hg)	VHR
Mineral Spirits	100	3	39
<i>d</i> -Limonene	50 ⁶	2	53
Xylene	100	20	263
MEK	200	70	460
MPK	250	35	184
Acetone	500	248	652
Toluene	50	28	737
IPA	400	44	145
Blend A	250 ⁵	2	11
Blend B	250 ⁵	5	26
Blend C	250 ⁵	2	11
Blend D	250 ⁵	2	11
Blend E	500 ⁵	1	3
Blend F	250 ⁵	2	11

Economics

A “use-cost analysis” is helpful for determining the economic impact of using a slower evaporating solvent. A use-cost analysis of Blend A compared with isopropanol and acetone is presented. Assume standard grade acetone costs about \$2.60 per gallon and IPA approximately \$2.80 per gallon in 55-gallon drums. By comparison, Blend A costs about \$12.00 per gallon in 55-gallon drums. Relative use-cost can be determined by evaluating the differences in evaporation rates, maximum soil loading, drag-out, and process cycle time.

Blend A	Isopropanol	Acetone
0.4 ml/minute	2.6 ml/minute	14 ml/minute
0.006 gal/hour	0.042 gal/hour	0.22 gal/hour
0.051 gal/8-hour shift	0.33 gal/8-hour shift	1.7 gal/8-hour shift
\$0.61/8-hour shift	\$0.92/8-hour shift	\$4.42/8-hour shift

The data shown in the Table 4 are from laboratory studies with IPA simulating open-tank cleaning processes. The data for acetone has been extrapolated from the difference in evaporation rates for IPA and acetone. These data show that, under the same conditions, an acetone bath evaporates about 35 times faster, and an IPA bath evaporates approximately 7 times faster, than a bath containing Blend A. So, despite their higher per-gallon price, the use cost for solvent blends can be economical even when replacing low cost, commodity chemicals.

Drying enhancement techniques, such as unheated, forced air, can accelerate the drying time for these slower evaporating solvent blends in applications where dry parts are needed immediately.

TABLE 5. Properties Overview

Solvent	Flash Point (°F)	VOC Content	HAP	VHR	Vapor Pressure (25°C)	Specific Gravity	SARA
Acetone	-4	Exempt	No	652	231 mm Hg	0.79	Regulated
MEK	19	100%	Yes	460	91 mm Hg	0.80	Regulated
MPK	45	100%	No	184	35.4 mm Hg	0.81	Regulated
Toluene	45	100%	Yes	737	28.4 mm Hg	0.86	Regulated
IPA	54	100%	No	145	45.4 mm Hg	0.78	Regulated
Xylene	77	100%	Yes	92	7.99 mm Hg	0.86	Regulated
Mineral Spirits	102	100%	No	39	3.0 mm Hg	0.60	Not regulated
<i>d</i> -limonene	117	100%	No	53	1.6 mm Hg	0.84	Not regulated
Blend A	105	100%	No	11	2 mm Hg	0.80	Not regulated
Blend B	111	100%	No	26	5 mm Hg	0.82	Not regulated
Blend C	117	100%	No	11	2 mm Hg	0.84	Not regulated
Blend D	120	100%	No	11	2 mm Hg	0.86	Not regulated
Blend E	145	100%	No	3	1 mm Hg	0.82	Not regulated
Blend F	145	100%	No	11	2 mm Hg	0.83	Not regulated

Methods of Use and How to Control Emissive Losses

The blends discussed here can be applied with a wipe cloth, by immersion (dip), by flooding, and in non-aqueous cleaning equipment for use with combustible/flammable solvents. Suitable process equipment is commercially available from several leading equipment vendors. Immersion processes incorporating vacuum distillation for solvent recovery/reuse reduce waste and overall solvent usage.

Use of bags and other airtight containers: Solvent emissive loss control methods, such as storage of soiled shop cloths in sealed plastic bags or in airtight metal cans, are significantly more effective with lower evaporating solvents.⁷ Highly volatile solvents such as MEK or acetone evaporate so rapidly that little benefit may come from such emission control methods.

Use of extraction systems that recover solvent from wipes: For large users of shop cloths (10,000 or more per week), a relatively new and novel cleaning/recycling system may be cost effective. Shop cloths should be managed as discussed above to maximize the amount of solvent left on the dirty cloths. The used cloths are cleaned in the same solvent used for cleaning on the shop floor and dried in a vacuum dryer where the remaining solvent is reclaimed. The dirty solvent used to launder the shop cloths can be recycled in a vacuum distillation unit. This system is reported to save as much as 89% of solvent purchases, elimination of an outside laundering service, and reduction of liquid waste disposal fees by 95%.⁸

Conclusion

Solvent blends can be a cost-effective choice for many applications. Compared to alternatives, these blends can be as effective as traditional solvents, offer more process flexibility, reduce VOC emissions, be safer for employees, and cost less to use.

Acknowledgements

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References

¹ C.M. Hanson, *Hansen Solubility Parameters: A User's Handbook*, CRC Press, Boca Raton, FL 1999 (and references therein).

² A.F.M. Barton, *Handbook of Solubility Parameters and Other Cohesion Parameters*, CRC Press, Boca Raton, FL 1983 (and references therein); J.L. Gardon and J.P. Teas, Solubility Parameters, in *Treatise on Coatings, Vol. 2, Characterization of Coatings: Physical Techniques, Part II*, R.R. Meyers and J.S. Long, Eds., Marcel Dekker, New York, 1976, chap. 8 (and references therein); H. Burrell, Solubility Parameters for Film Formers, *Off. Dig. Fed. Soc. Paint Technol.*, 27(369), 726-758, 1972; H. Burrell, A Solvent Formulating Chart, *Off. Dig. Fed. Soc. Paint Technol.*, 29(394), 1159-1173, 1957; H. Burrell, The Use of the Solubility Parameter Concept in the United States, *VI Federation d'Associations de Techniciens des Industries des Peintures, Vernis, Emaux et Encres d'Imprimerie de l'Europe Continentale, Congress Book*, 21-30, 1962.

³ Using the lower explosive limit (LEL) values for the various components of Blend A, all of which are similar, the LEL of Blend A at room temperature and atmospheric pressure is approximately 10,000 parts per million (1%). Its vapor pressure is approximately 2 mm Hg at room temperature, which corresponds to approximately 2,600 ppm. Thus, it cannot be ignited at normal room temperatures.

⁴ N. Kob and G. Altnau, "Vapor Hazard Ratio—Assessment for Solvent Risk Comparisons", *CleanTech Magazine*, May 2001, pp 30-37.

⁵ ACGIH threshold limit values (TLVs) and OSHA permissible exposure limits (PELs) are the time-weighted average concentrations to which workers may be repeatedly exposed during an 8-hour period.

⁶ Manufacturer's estimated exposure limit.

⁷ Technical Bulletin, "CONTEC Presaturated Wiper Implementation," Contec, Spartanburg, SC 29304 (1999).

⁸ C. Salerno, "A Dry Idea", *CleanTech Magazine*, January 2002, pp 26-29.