Solvents for Ultrasonic Cleaning

by Bogdan Niemczewski*

The withdrawal of freons from ultrasonic cleaning in industry imposed by the Montreal Protocol and limitations for using chlorinated solvents, though not included in the Protocol but harmful to human health, have led to greater than expected difficulties in finding effective solvents. A substantial problem exists because all non-halogenated solvents are inflammable and thus are more or less fire hazardous. Presented here are the results of testing four high flash point solvents as to their applicability in ultrasonic cleaning. Three of them have acoustic properties sufficient for use in ultrasonic cleaning, but the fourth one proved to be unacceptable.

The present article is a continuation of the work previously presented in this journal,[1] the subject of which was selection of solvents for ultrasonic cleaning from the group of propylene glycol ethers. In this article, the test results for four solvents from outside this group are presented. The main criterion for accepting a solution for testing was that it have a high flash point (>55°C; >131°F). Ecological and health safety were, of course, also taken into consideration. Moreover, three of the four solvents selected [N-methylpyrrolidone, C_5H_9NO (NMP), diethylene glycol monoethyl ether, $C_2H_5(OCH_2CH_2)_2OH$ (carbitol) and diethylene glycol monomethyl ether, $CH_3(OCH_2CH_2)_2OH$ (methyl carbitol)] are totally soluble in water. Considering that these are low vapor pressure solvents, making it difficult to dry articles after cleaning, the process is simplified, as it is possible to introduce an additional water rinsing operation after cleaning, followed by traditional, simple drying. Unfortunately, the fourth solvent, a proprietary hydrocarbon mixture,** does not possess this valuable feature.

Nuts & Bolts: What This Paper Means to You

Because of health and environmental issues, halogen solvents, such as tetrachloroethylene (TCE), have been eliminated from surface cleaning processes, including ultrasonic cleaning. This has made it necessary to use other solvents which are often less effective but safer. In his last paper, in the October 2003 issue, the author studied propylene glycol ethers as substitutes. Here, he considers other solvent types to see if they are suitable for ultrasonic cleaning and compares them with the halogen solvents that they would replace.

Nevertheless, it was included in testing because it is representative of a very wide group of solvents, hydrocarbon mixtures, offered by various manufacturers for cleaning, including ultrasonic cleaning.

The solvents under test are intended to replace halogenated solvents. In prior work,[1] tetrachloroethylene was used as a halogenated solvent benchmark for test under the same conditions as for the other solutions. The same approach was taken in the current work, but in order to make a wider comparison, measurements of acoustical properties were also made for one of the common proprietary freons formerly used in industry.***

The basic physical properties of the five solvents tested are presented in Table 1.

Experimental procedure

The enhancement of cleaning processes by means of ultrasonics is possible because of two physical phenomena occurring in the liquid:

- Ultrasonic cavitation
- Liquid movement (agitation) induced by ultrasonics radiation pressure.

The cleaning solvent should be characterized by a high susceptibility to both phenomena. A low cavitation intensity will result in a low degree of substrate cleaning if the impurities are strongly adherent. On the other hand, low ultrasonic radiation pressure is the reason why ultrasonics are minimally effective in removing soluble impurities. If the intensities of both of these phenomena are low, the solvent is not suitable for ultrasonic cleaning.

The author has developed a method to measure cavitation and the effects of ultrasonic radiation pressure versus solvent temperature. This method was described in detail in prior work.[1] Since both the cavitation intensity and the radiation pressure effects depend on liquid temperature and the ratio of the liquid column height to one-half of the ultrasonic wavelength, measurements carried out by

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** *Clenvex AS105, Castrol International*
*** *DuPont Freon TE, E. I. DuPont de Nemours, Wilmington, DE*

Table 1
Selected Physical Properties of the Solvents

Solvent	Chemical name or composition	Boiling point °C	Flash point °C	Density (20°C) g/cm^3	Surface tension (20°C) mN/m	Vapor pressure (20°C) mbar	Solubility in water (20°C) g/100g
NMP	N Ð Methylpyrrolidone	204	91	1.03	41	0.32	∞
Carbitol	Diethylene Glycol Monoethyl Ether	201	102	0.99	31.7	< 0.1	∞
Methyl Carbitol	Diethylene Glycol Monomethyl Ether	194	96	1.02	34.7	0.25	∞
Clenvex AS 105	Mixture of paraffins and naphthenes	230-260	105	0.81	27	0.003	Insoluble
Freon TE	Azeotrope of trichlorotri-fluoroethane (96%) and ethanol (4%)	44,6	none	1.51	17.7	~ 380	-

this method are done at a minimum of seven heights of the liquid column (every 4 mm; 0.16 in.) and over the full temperature range in which ultrasonic cleaning is possible. Curves resembling irregular sinusoids are obtained. The areas occupied by the curves for all levels of a given liquid are characteristic of the intensity of the measured acoustic parameters.

The same ultrasonic cleaning conditions were used here as in the earlier work:[1] one operating at a nominal frequency of 25 kHz (Condition A) and two cleaners operating at a nominal frequency of 40 kHz (Conditions B and C). One of the 40 kHz cleaners (Condition B) operated at approximately the same power as Condition A. The power used in Condition C was about doubled. It should be emphasized that power applied to a cleaner may only be approximated. In the tests described here, differences for different solvents were much larger than what was observed in the previous study, because of a larger difference in consumption of electrical current by the generators. The consumption of electrical current was recorded along with the other parameters. The voltage was controlled by means of autotransformers. Therefore it was possible to determine average power consumption for each solvent.

The cleaners used in the tests were industrial cleaners in 30 L (4.0 gal) tanks. At the beginning, the cleaner tanks were filled with 22 L (3.0 gal) of solvent and then the quantity of liquid was sequentially lowered in 4-mm (0.16-in.) steps. The test methodology is given in the earlier paper.[1]

Results & discussion

Figures 1 - 4 show the results of the cavitation intensity measurements and the effects of ultrasonic radiation pressure versus temperature for the four solvents studied. The areas marked with the letters A, B and C correspond to the 25 kHz cleaner, the 40 kHz

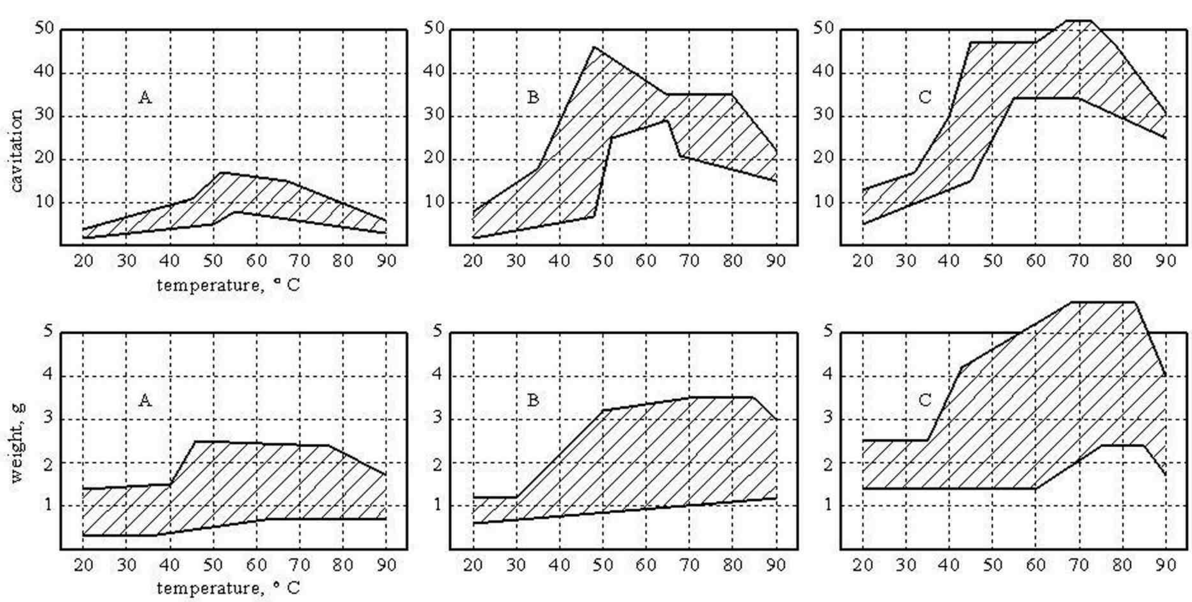

Figure 1—Results of measurements for NMP. The upper diagrams show areas occupied by all the curves (at different liquid levels) at measurements of average cavitation intensity of the liquid in the tank (measured in comparative units) versus temperature. The lower diagrams show areas occupied by all the curves (at different liquid levels) at measurement of ultrasonic radiation pressure effects, measured as apparent loss of weight of the radiometer reflector: A–25 kHz; B–40 kHz (low power); C–40 kHz (high power).

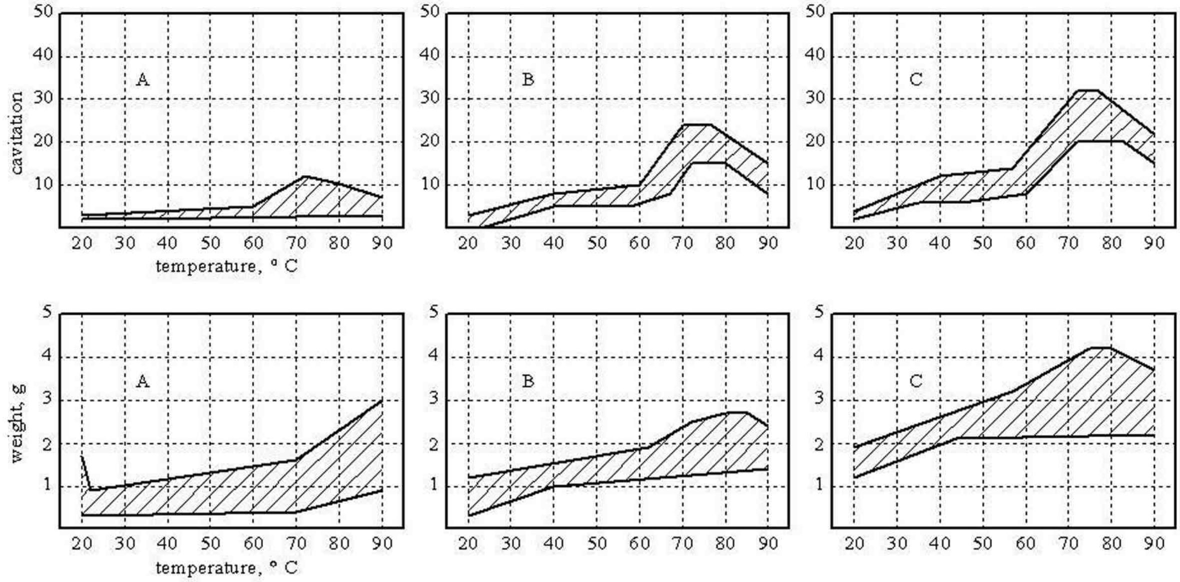

Figure 2—Results of measurements for carbitol. Marking as in Fig. 1.

cleaner (lower power) and the 40 kHz cleaner (higher power), respectively. These results can be compared with the earlier results for tetrachloroethylene and propylene glycol ethers.[1] The data for the proprietary freon is shown in Fig. 5. In view of the large difference between boiling points, the freon results are not fully comparable, because they do not take into account the influence of temperature on the solubility of impurities.

As was the case with propylene glycol ethers,[1] we explicitly observed lower cavitation at 25 kHz as compared to 40 kHz, at about the same applied power. This confirms the previously formulated conclusion that the lower ultrasonic frequencies are not suitable for cleaning in organic solvents. Further, the effects of ultrasonic radiation pressure at 25 kHz are somewhat worse.

The NMP cavitation intensity (Fig. 1) is higher than in the other nine tested liquids, including $CH_3O[CH_2CH(CH_3)O]_2H$, dipropylene glycol methyl ether (DPM), from the previous study.[1] As far as the intensity of solvent movement under the influence of ultrasonic radiation pressure is concerned, NMP matches tetrachloroethylene and yields precedence only to freon. It thus may be said that the acoustic properties of NMP are very favorable for its application in the processes of ultrasonic cleaning. Moreover, it is a very strong solvent, having a high Kauri-Butanol Value (>300). Its negative feature is, unfortunately, its low ability to dissolve grease impurities. However, the optimal temperature range for application of NMP is very wide, 45 to 85°C (113 to 185°F).

The results obtained for carbitol (Fig. 2) closely resemble those obtained earlier for TPM[1] Both these solvents reach similar cavitation intensities and similar effects of radiation pressure in the same temperature ranges. Thus carbitol is fully suitable for use in ultrasonic cleaning, the optimal temperature range being 70 to 85°C (158 to 185°F.).

Methyl carbitol (Fig. 3) is not inferior to carbitol as regards its acoustic properties, and its optimal temperature range is 55 to 85°C (131 to 185°F). It would be a solvent recommended for ultrasonic cleaning were it not for the fact that the manufacturer puts the following warning on its methyl carbitol containers: "Possible risk of

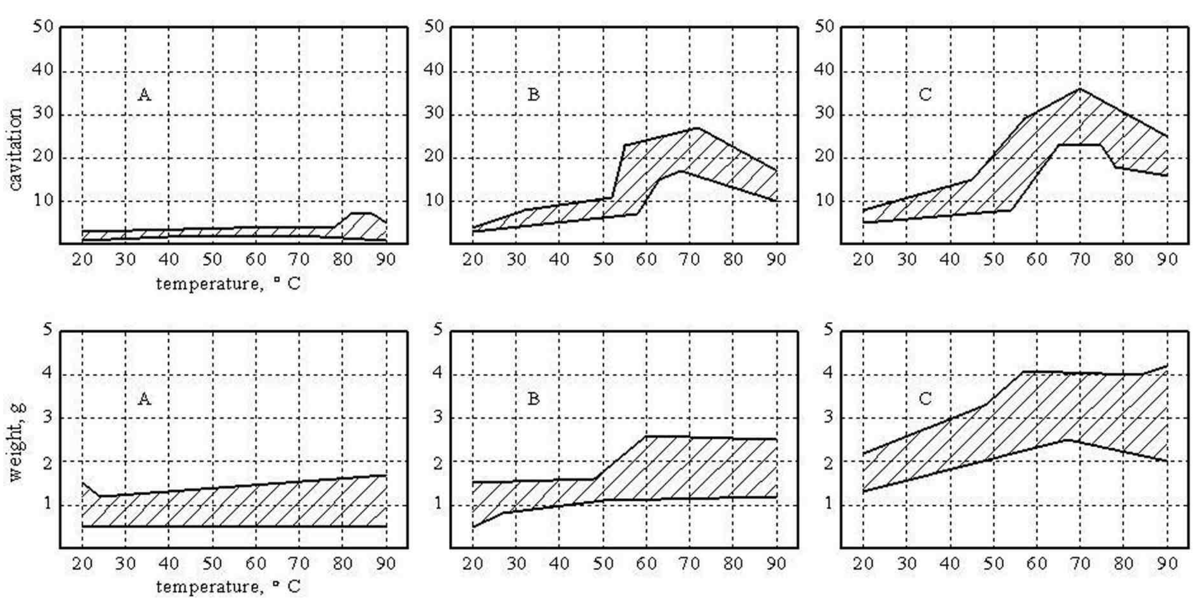

Figure 3—Results of measurements for methyl carbitol. Marking as in Fig. 1.

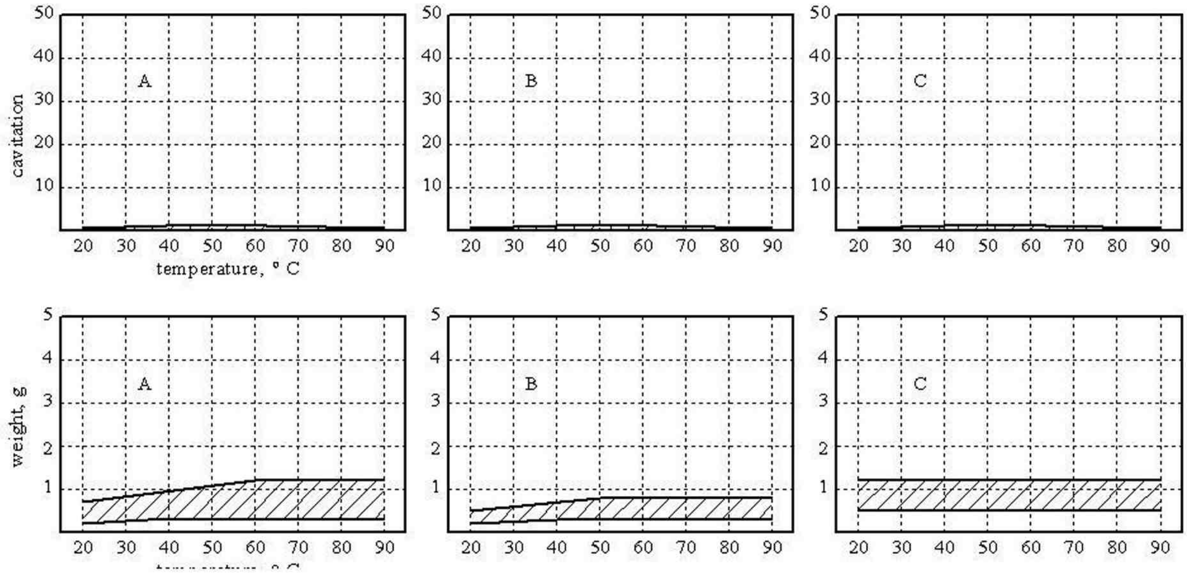

Figure 4—Results of measurement for the proprietary hydrocarbon solvent. Marking as in Fig. 1.

harm to the unborn child. Wear suitable protective clothing. For industrial use only." This warning significantly diminishes the attractiveness of methyl carbitol.

The results for the proprietary hydrocarbon mixture are shown in Fig. 4. From the results, it should not be used for ultrasonic cleaning. Both cavitation and the effects of radiation pressure reach extremely low values regardless of frequency or ultrasonic power.

In order to assure that the material selected was not an exception among hydrocarbon solvents, the author also examined other proprietary hydrocarbon mixtures. All other hydrocarbon solvent mixtures were found to be unsuitable for use in ultrasonic cleaning.

The results for the freon material are shown in Fig. 5. As can be seen, the good cleaning results were achieved primarily through high radiation pressure and not cavitation. The cavitation intensity at 40 kHz was moderate and almost nil at 25 kHz. The radiation pressure for the freon in cleaner condition C reached 6.9 g, the highest value of all solvents studied.

Average power consumption values for each of the five liquids are compiled in Table 2. It is interesting to note that NMP, distinguished by the highest acoustic parameters, consumed electrical power much above the average 350 and 700 W levels. On the other hand, the proprietary hydrocarbon solvent consumed power well below the average. Freon is not considered here because the temperature ranges in which the measurements were taken are not comparable. Such results are comprehensible if we are aware of the fact that for inducing cavitation and solvent agitation, energy must be consumed.

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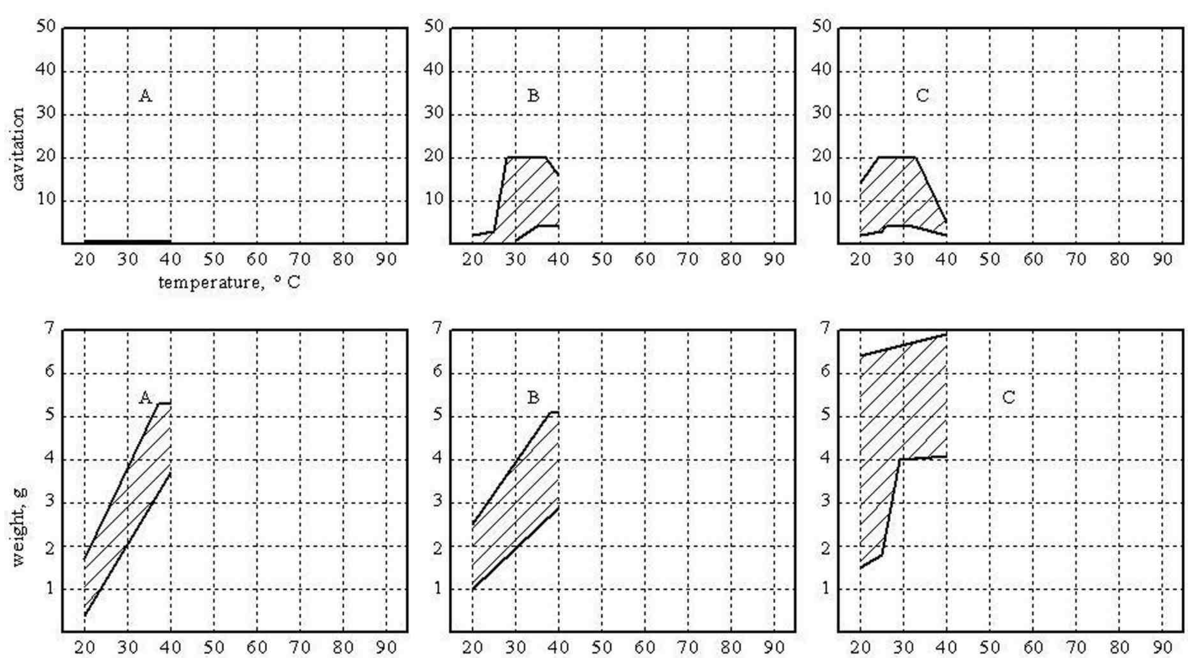

Figure 5—Results of measurement for freon. Marking as in Fig. 1.

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Table 2
Average Electrical Power Drawn by the Generators in the Five Solutions Studied

Solvents	Average electrical power, W Cleaner frequency, kHz		
	25 (A)	40 (B)	40 (C)
NMP	382	423	817
Carbitol	357	364	707
Methyl Carbitol	345	385	739
Clenvex AS 105	368	334	655
Freon TE	430	300	582

Conclusions

The initial requirement to be met by a solvent used for cleaning is, of course, good solubility for the given impurity. Having met this requirement and using a cleaner operating at about 40 kHz (and not at 25 kHz), three of the solvents tested in this work may be successfully used in ultrasonic cleaning, N-methylpyrrolidone (NMP), carbitol and methyl carbitol. However, there are serious reservations about the latter material owing to its being possibly hazardous to human health. Hydrocarbon solvent mixtures are not recommended by the author for use in ultrasonic cleaning.

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