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Comparison of supercritical fluid extraction and Soxhlet extraction of organic compounds from carpet samples

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Abstract

Supercritical fluid extraction (SFE) and Soxhlet extraction were applied to a common set of samples to determine their relative efficiencies for the measurement of a variety of organic compounds and their comparability as laboratory techniques. For this test, a variety of carpet samples were extracted by both SFE and Soxhlet methods and the extraction solutions were analyzed via gas chromatography/mass spectrometry. The results relative to an internal standard spike were then compared statistically by their relative standard deviations, an *F*-test for precision, and their averages within a 95% confidence level. Compounds of possible environmental exposure concern were used as some of the selected compounds for comparison. © 1997 Elsevier Science B.V.

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1. Introduction

Sample preparation for the measurement of semi-volatile and non-volatile organic compounds (SVOCs and NVOCs) from solid matrices is generally accomplished with liquid extraction techniques using organic solvents followed by a concentration step wherein much of the solvent is evaporated. An aliquot of the reduced extraction liquid can then be analyzed with conventional chromatographic methods. Although simple soaking, ultrasonic shaking, or rinsing methods are sometimes employed, the most common laboratory procedure for the extraction step is the Soxhlet reflux method [1]. A typical application of Soxhlet extraction requires 250–500 ml of organic solvent for a 16–24 h extraction step; the

resulting solution is later evaporated to achieve a 1–2 ml sample.

An alternative to Soxhlet extraction is the use of supercritical fluid extraction (SFE), wherein a normally gaseous compound (typically carbon dioxide) is taken to a pressure and temperature above its critical point and used as an extraction solvent [2–4]. The supercritical fluid has higher solute diffusivity and lower viscosity than most commonly used organic solvents such as hexane and methylene chloride (MeCl₂), and it is thus a more efficient extraction fluid. Also, since supercritical fluids are typically gases at room temperature and atmospheric pressure, analytes are easily separated from the extraction fluid when the mixture is depressurized and bubbled through a small quantity of organic solvent (1–2 ml). These properties allow SFE to exhibit distinct advantages over Soxhlet extraction in

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that the enhanced efficiency allows much shorter extraction times (typically 30–60 min) and the ease of separation of analyte from the extraction matrix avoids sample handling and solvent disposal issues.

The potential for increased sample throughput, reduced sample handling, and reduced consumption of organic solvent makes SFE an attractive extraction method. SFE has already been applied to a variety of solid-phase extraction situations and found to be comparable to Soxhlet extraction in many cases [5–14].

The National Exposure Research Laboratory (NERL) of the US Environmental Protection Agency (EPA) has been developing SFE and Soxhlet extraction methodology for application to measurement of SVOC and NVOC air pollutants. One such project was the development of methods for the measurement of organic emissions of carpeting, which included a chamber/headspace method for volatile organic compounds and Soxhlet extraction methods for SVOCs [15]. The work described in this paper is a follow-up of this original carpet project. Here, carpet samples of interest were characterized with the Soxhlet and SFE methodologies and the results compared. The study of carpet samples as a basis for SFE/Soxhlet extraction comparison is convenient as there exists topical interest; and the wide variety of compounds from both new and used carpeting should present a good analytical challenge for both methods. Additionally, the information presented here may be used to guide the choice of methods for eventual routine analysis of carpeting and other indoor furnishings.

2. Experimental

The carpet samples were obtained from several sources and include new and used carpets. For

purposes of this paper, each carpet sample was given a three-letter code. These codes and a brief description are listed in Table 1.

The used carpet samples were typically 20×20 cm sections that had been cut from the center of very large samples and sealed for transport. The new samples were received as shipped to the customer. All samples were then subdivided for in-house use into 1×4 cm pieces for Soxhlet and SFE analysis and immediately sealed in inert containers. The carpet samples were spiked with an internal standard of 10 µg of 1-phenylcyclohexene (1-PC; Aldrich, Milwaukee, WI, USA) just prior to extraction.

Soxhlet extractions were performed using 200 ml of MeCl₂ in most cases. A piece of carpet from each sample was placed in MeCl₂ to determine if excessive solvent attack would occur and thereby interfere with the extraction procedure. LCO was the only carpet that displayed significant problems with MeCl₂. The Soxhlet extracts were allowed to reflux for 16–18 h. Blank extracts were also prepared. The resulting extraction solution was then rotary evaporated to about 5 ml. It was then transferred to a test tube and reduced in volume to about 1 ml under a stream of dry N₂.

SFE extractions were performed using a 5-ml stainless steel extraction cell and CO₂ as the extraction fluid. Extractions were performed at typical SFE conditions of 400 atm and 40°C in two stages (1 atm=101 325 Pa). The first was a static extraction for 40 min, followed by a 30–40 min dynamic extraction at a supercritical CO₂ flow-rate of 1 ml/min. The extracts were collected in 3–4 ml MeCl₂ and the volume was subsequently reduced to 1 ml under a stream of dry N₂.

Each extracted sample aliquot of 1 µl was analyzed on a Hewlett-Packard GC-MS 5890 Series II/S971A equipped with a fused-silica chromatography column (30 m×0.25 mm I.D.) coated with 1.0

Table 1
Carpet sample descriptions

Code	Description
NWB	New, light blue with colored specks, short looped pile with grid and SBR backing from personal residence
PLM	Used, rose, medium length tufted pile with grid and SBR backing
DRW	Used, white, medium length tufted pile with grid and SBR backing
FTZ	Used, brownish gray loop pile with grid and SBR backing
LCO	New, gray/blue, black pattern, short tufted pile carpet tiles with hard plastic backing

Table 2
Gas chromatographic conditions

Parameter	
Injection port temperature	250°C
Injection mode	On-column
Injection volume	1 µl
Column	30 m×0.25 mm
Film thickness	1.0 mm
Carrier gas	Helium (99.9999%)
Carrier gas flow-rate	2.0 ml/min
Oven temperature, initial	40°C, hold for 1 min
Oven temperature, final	250°C, hold for 10 min
Oven temperature ramp rate	5°C/min
Mass spectrometer temperature	260°C
Solvent delay	5.0 min

µm film thickness of Crossbond 6% cyanopropylphenyl–94% dimethyl polysiloxane (Restek, Bellefonte, PA, USA). A 1-m retention gap of 0.32 mm I.D. deactivated fused-silica column (Alltech Associates, Deerfield, IL, USA) was also used. The chromatographic conditions used for these analyses are given in Table 2. Chromatographic data were acquired and processed with a Hewlett-Packard HP Vectra 386/25 computer station. Selected compounds were given coded identifiers, and these are listed in Table 3. The alkanes, the 2-(2-hydroxypropoxy)-1-propanol, and the 1,1'-oxybis-2-propanol were tentatively identified through ≥80% quality matches to compounds in the mass spectral library of compounds (Wiley). The other selected compounds were confirmed by analyzing standard solutions of Dursban (AccuStandard, New Haven, CT, USA),

4-phenyl-cyclohexene (4-PC; Chemsampco, Gray Court, SC, USA), caprolactam (Aldrich USA), dibutylated hydroxytoluene (BHT; Aldrich), 2-phenoxyethanol (Aldrich), 2,4-bis(1,1-dimethylethyl)phenol (Aldrich), phenol (US EPA Repository, Research Triangle Park, NC, USA) and 1,1'-biphenyl (Supelco, Bellefonte, PA) and comparing their retention times and mass spectra to those of the analytes.

3. Results and discussion

SFE and Soxhlet extraction yielded similar results in terms of the numbers and types of compounds extracted from the carpet matrix. This is illustrated by two typical chromatograms, shown in Fig. 1.

The most commonly occurring compounds were 1,1'-oxybis-2-propanol, 2-(2-hydroxypropoxy)-1-propanol, and BHT. The first two compounds are most likely related to the production of carpet as a common component of the backing material, because it was present in all of the carpet extracts. BHT is used as an antioxidant in a variety of commercial products, ranging from foodstuffs to synthetic rubbers and plastics and as an antiskinning agent in inks and paints [16], and as such is a fairly ubiquitous material, although it is listed on several state hazardous and toxic materials lists [17]. Other compounds identified from these extracts that may raise potential exposure concerns and that are listed on federal and state lists of hazardous or toxic materials [17] were

Table 3
Compound codes and compound names

Compound code	Compound name
Alkanes ^a	Selected alkanes, all >C ₁₂
BDEP	2,4-Bis(1,1-dimethylethyl)phenol
BHT	Dibutylated hydroxytoluene <i>or</i> 2,6-bis(1,1-dimethylethyl)-4-methylphenol
1,1'-BP	1,1'-Biphenyl
CAP	Caprolactam
DRSB	Dursban <i>or</i> Chlorpyrifos
HPP ^a	2-(2-Hydroxypropoxy)-1-propanol
OBP ^a	1,1'-Oxybis-2-propanol
1-PC	1-Phenylcyclohexene (internal standard)
4-PC	4-Phenylcyclohexene
2-PE	2-Phenoxyethanol
PHNL	Phenol

^aTentatively identified through mass spectral library (Wiley) matching.

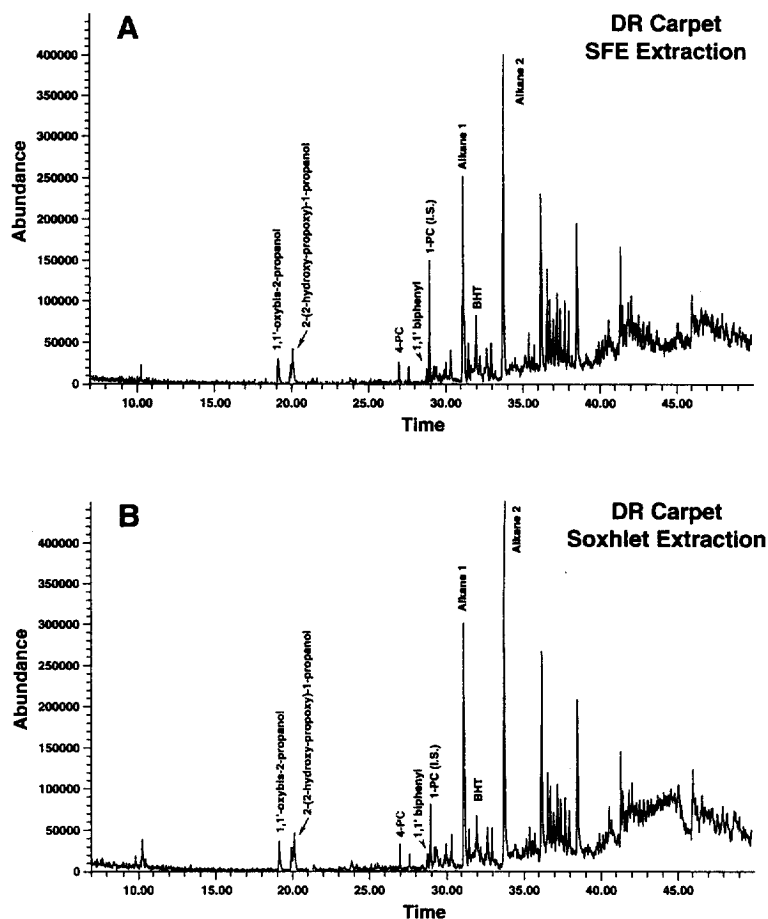


Fig. 1. Total ion chromatogram for SFE and Soxhlet extractions of carpet sample.

caprolactam, 2-phenoxy-ethanol, Dursban, phenol, 1,1'-biphenyl, and 4-PC. All of these compounds have sources that can be associated with carpet samples.

Quantitative comparisons of the two extraction techniques were based on pre-extraction spiking of the carpet samples with the internal standard, 1-PC. (The 1-PC was chosen because of its similarity to the commonly occurring carpet compound 4-PC, a source of 'new carpet smell'.) Pre-extraction spiking is commonly conducted to minimize matrix effects associated with complex or problematic matrices such as carpet. This assumes that similar matrix effects will be experienced for all of the extracted components including the internal standard. It was assumed that the relative amounts of the internal

standard and selected compounds would be the same for each sample, and thus a comparative measure of the two methods could be made by ratioing the results obtained from the analytes and the internal standard. The values used in these comparisons were obtained by extracting specific mass spectral ion chromatograms for selected components (Table 3), integrating the peaks for these ions, and ratioing these values to those similarly obtained for 1-PC. These ratios were then used to compare SFE and Soxhlet extraction.

Comparisons of these two extraction techniques for carpet were based on several statistical parameters. Those were relative standard deviation (R.S.D.), precision as determined by the statistical *F*-test, and comparison of the means at the 95% confidence

level. From the tables associated with each of these parameters, general trends can be observed that will give an overall view of the comparison of SFE to Soxhlet extraction. Discussion of the individual compounds and how they support the general trends is presented below.

Table 4 shows the comparisons of the R.S.D.s for each sample. In most cases the R.S.D. is within 30%, and many R.S.D.s are within 20%, which can be considered good repeatability, given the relative

complexity of the matrices. Variations in R.S.D.s between carpet types can be attributed to the variations in the carpets due to composition and history (new vs. used). Those carpets that were previously installed would be expected to have the greatest variations because of non-uniform distribution of contaminants such as might occur with spills, traffic wear, or post-manufacturing topical applications (pesticides, fungicides, cleaning fluids, etc.). This may be especially true in the older PLM carpet

Table 4
Extraction results for carpet samples: compounds listed in elution order

Compound	1-PC ratios for SFE			1-PC ratios for Soxhlet		
	Average ($n=3$)	S.D.(s)	R.S.D. (%)	Average ($n=5$)	S.D.	R.S.D. (%)
<i>NWB sample</i>						
OBP	2.53	±0.46	18.3	5.52	±1.04	18.9
HPP	3.63	±0.66	18.0	7.43	±1.76	23.7
4-PC	2.13	±0.57	26.9	2.32	±0.30	13.2
CAP	5.53	±0.64	11.5	10.40	±1.05	10.1
Alkane (>C ₁₂)	0.68	±0.04	5.6	0.77	±0.07	8.8
BHT	0.28	±0.01	4.1	0.35	±0.06	18.1
BDEP	0.96	±0.08	8.9	1.15	±0.15	13.3
	Average ($n=4$)	S.D.(s)	R.S.D. (%)	Average ($n=5$)	S.D.	R.S.D. (%)
<i>PLM sample</i>						
PHNL	0.78	±0.48	60.6	3.08	±1.02	18.9
OBP	0.93	±0.30	33.1	4.08	±0.93	23.7
HPP	1.52	±0.39	25.9	6.77	±2.02	13.2
2-PE	0.70	±0.21	29.8	2.40	±0.44	10.1
Alkane (>C ₁₂)	0.28	±0.10	36.0	1.30	±0.14	8.8
BHT	2.63	±1.20	45.6	2.58	±0.64	18.1
DRSB	0.56	±0.31	55.1	0.79	±0.24	13.3
	Average ($n=5$)	S.D.(s)	R.S.D. (%)	Average ($n=5$)	S.D.	R.S.D. (%)
<i>DRW sample</i>						
OBP	1.14	±0.34	30.3	1.13	±0.24	21.2
HPP	2.20	±0.63	28.7	2.51	±0.45	18.1
4-PC	0.82	±0.29	35.6	1.07	±0.22	20.5
1,1-BP	0.33	±0.07	20.0	0.45	±0.07	14.9
Alkane 1 (>C ₁₂)	2.17	±0.22	10.1	3.42	±1.02	29.9
BHT	1.01	±0.08	8.0	0.63	±0.31	48.7
Alkane 2 (>C ₁₂)	3.29	±0.30	9.3	4.23	±1.33	31.5
	Average ($n=4$)	S.D. (s)	R.S.D. (%)	Average ($n=4$)	S.D.	R.S.D. (%)
<i>FTZ sample</i>						
OBP	1.01	±0.15	14.9	1.70	±0.17	10.2
HPP	2.74	±0.28	10.3	4.30	±0.20	4.5
Alkane 1 (>C ₁₂)	1.40	±0.29	20.7	1.46	±0.23	15.8
4-PC	1.88	±0.23	12.2	2.19	±0.48	22.0
Alkane 2 (>C ₁₂)	4.06	±0.75	18.4	4.60	±0.25	5.5
BHT	0.80	±0.29	36.1	0.87	±0.10	11.2
Alkane 3 (>C ₁₂)	4.52	±0.96	21.2	5.51	±0.32	5.8

sample. The best results were obtained from the only new carpet sample tested, NWB; a more uniform distribution of the extracted components in this new carpet might explain why it yielded the least variation in results. Also for this carpet, a trend can be seen for the SFE results. The later-eluting compounds in the SFE extract have lower R.S.D.s than those eluting earlier, whereas no such trend is evident in the Soxhlet extract. This may be due to the volatility of these compounds or the trapping efficiency of the MeCl₂ used in collecting the SFE effluent. This trend is also evident in the DRW carpet sample.

The two methods were compared in precision for each sample constituent by applying a standard *F*-test at the 5% significance level to the standard deviations of the means. The *F*_{calc} values in Table 5 were obtained from the standard deviations(s) in Table 4 by using the equation

$$F_{\text{calc}} = s_{\text{larger value}}^2 / s_{\text{smaller value}}^2$$

The *F*_{crit} values were obtained from standard statistics tables for *F*_{crit} values (at a 5% significance level). These values are dependent on the number of degrees of freedom for the methods represented by

Table 5
Comparison of the precision for each sample (*F*-test) for SFE vs. Soxhlet

Compound	<i>F</i> _{calc} ^a	< or >	<i>F</i> _{crit} ^a	Statistically significant differences in precision? (Y/N)
<i>NWB sample</i>				
OBP	5.1	<	39.2	No
HPP	7.1	<	39.2	No
4-PC	3.6	<	10.6	No
CAP	2.7	<	39.2	No
Alkane (>C ₁₂)	3.2	<	39.2	No
BHT	32.8	<	39.2	No
BDEP	3.1	<	39.2	No
<i>PLM sample</i>				
PHNL	4.6	<	15.1	No
OBP	9.1	<	15.1	No
HPP	26.0	>	15.1	Yes
2-PE	4.4	<	15.1	No
Alkane (>C ₁₂)	1.8	<	15.1	No
BHT	3.6	<	10.0	No
DRSB	1.7	<	10.0	No
<i>DRW sample</i>				
OBP	2.1	<	9.6	No
HPP	1.9	<	9.6	No
4-PC	1.8	<	9.6	No
1,1-BP	1.0	<	9.6	No
Alkane 1 (>C ₁₂)	21.6	>	9.6	Yes
BHT	14.4	>	9.6	Yes
Alkane 2 (>C ₁₂)	19.0	>	9.6	Yes
<i>FTZ sample</i>				
OBP	1.3	<	15.4	No
HPP	2.1	<	15.4	No
Alkane 1 (C ₁₂)	1.6	<	15.4	No
4-PC	4.4	<	15.4	No
Alkane 2 (>C ₁₂)	8.8	<	15.4	No
BHT	8.6	<	15.4	No
Alkane 3 (>C ₁₂)	8.9	<	15.4	No

*F*_{crit} obtained from standard statistical tables using the numbers of degrees of freedom of the numerator and denominator.

^a
$$F_{\text{calc}} = s_{\text{larger value}}^2 / s_{\text{smaller value}}^2$$

the s values in the numerator and denominator. The F_{calc} and F_{crit} values are then compared to one another. If the F_{calc} value is less than ($<$) the F_{crit} value then the two methods are considered to have comparable precisions. Thus the results in Table 5 indicate that SFE and Soxhlet extractions for most of the selected compounds have no statistically significant differences in precision. This means that even with relatively large R.S.D.s, SFE and Soxhlet extraction exhibit similar extraction capabilities for

these compounds and are affected similarly by the matrix characteristics.

Comparison of the means at the 95% confidence level (Table 6) shows that there are statistically significant differences in the means for some compounds, and in these instances, the means for the Soxhlet extracts are higher. This indicates that the two techniques extract different amounts of compounds from the carpet relative to 1-PC and that the extraction efficiency of MeCl_2 in the Soxhlet ex-

Table 6
Comparison of the SFE and Soxhlet averages at the 95% confidence level

Compound	$ X_1 - X_2 $	$<$ or $>$	U	Statistically significant difference in the averages? (Y/N)
<i>NWB sample^a</i>				
OBP	3.00	$>$	1.59	Yes
HPP	3.80	$>$	2.66	Yes
4-PC	0.19	$<$	0.74	No
CAP	4.88	$>$	1.67	Yes
Alkane ($>C_{12}$)	0.10	$<$	0.11	No
BHT	0.06	$<$	0.09	No
BDEP	0.19	$<$	0.24	No
$t = 2.447$, $n_{\text{SFE}} = 3$, $n_{\text{Sox}} = 5$, $df_T = 6$				
<i>PLM sample</i>				
PHNL	2.30	$>$	1.43	Yes
OBP	3.15	$>$	1.26	Yes
HPP	5.25	$>$	2.65	Yes
2-PE	1.70	$>$	0.62	Yes
Alkane ($>C_{12}$)	1.02	$>$	0.21	Yes
BHT	0.05	$<$	1.58	No
DRSB	0.23	$<$	0.46	No
$t = 2.365$, $n_{\text{SFE}} = 4$, $n_{\text{Sox}} = 5$, $df_T = 7$				
<i>DRW sample</i>				
OBP	0.01	$<$	0.50	No
HPP	0.31	$<$	0.93	No
4-PC	0.25	$<$	0.43	No
1,1-BP	0.11	$<$	0.11	No
Alkane 1 ($>C_{12}$)	1.25	$>$	1.25	Yes
BHT	0.38	$>$	0.38	Yes
Alkane 2 ($>C_{12}$)	0.94	$<$	1.63	No
$t = 2.306$, $n_{\text{SFE}} = 5$, $n_{\text{Sox}} = 5$, $df_T = 8$				
<i>FTZ sample</i>				
OBP	0.68	$>$	0.28	Yes
HPP	1.56	$>$	0.42	Yes
Alkane 1 ($>C_{12}$)	0.06	$<$	0.45	No
4-PC	0.31	$<$	0.65	No
Alkane 2 ($>C_{12}$)	0.55	$<$	0.97	No
BHT	0.08	$<$	0.37	No
Alkane 3 ($>C_{12}$)	1.00	$<$	1.23	No
$t = 2.447$, $n_{\text{SFE}} = 4$, $n_{\text{Sox}} = 4$, $df_T = 6$				

$$U = t s_{\text{pooled}} [(n_{\text{SFE}} + n_{\text{Sox}}) / n_{\text{SFE}} n_{\text{Sox}}]^{1/2}, s_{\text{pooled}} = [(df_{\text{SFE}} s_{\text{SFE}}^2 + df_{\text{Sox}} s_{\text{Sox}}^2) / df_{\text{SFE}} df_{\text{Sox}}]^{1/2}, t = t \text{ value at 95\% confidence level at a given } df_{\text{Total}} = n_{\text{SFE}} + n_{\text{Sox}} - 2; df = \text{degrees of freedom} = n - 1.$$

traction is greater than that of supercritical CO₂ for these compounds. This is to be expected since the extraction 'solvents' have different extraction properties, which are governed by their chemical characteristics and behavior.

SFE and Soxhlet extractions yielded comparable results for caprolactam from the new carpet sample, NWB, and 2-phenoxyethanol, Dursban, and phenol from an older carpet sample, PLM, as evidenced in Tables 4 and 5. Caprolactam was found only in carpet NWB. Caprolactam, a mutagen and teratogen [18], is a solvent for high-molecular-mass polymers such as those found in carpets, is highly soluble in water, and has a relatively high vapor pressure (1.9×10^{-3} mmHg at 25°C), which may explain why it was found only in the sample of pristine (uninstalled) carpet. The results in Tables 4 and 5 show that SFE and Soxhlet techniques were comparable in the ability to extract caprolactam from the NWB carpet. The 2-phenoxyethanol, Dursban, and phenol were all found in the same carpet sample (PLM). 2-Phenoxyethanol is used as a bactericide and insect repellent, Dursban is an insecticide, and phenol is found in a variety of cleaning and antiseptic products; all of these compounds may have been applied to the carpet at some time after installation. Tables 4 and 5 show high R.S.D.s for the SFE and the Soxhlet techniques for the PLM carpet (Table 4), but little significant difference in precision relative to the internal standard (Table 5). This means that while there may be wide variations in the amount of material extracted relative to an internal standard, the variations are comparable for both methods.

The presence of these compounds may, in itself, indicate why these variations occurred. If this carpet had been subjected to the types of materials or treatments associated with these compounds, it would be reasonable to expect that the treatment was not uniformly distributed across the carpet, even in a relatively small area. This in turn would lead to the observed differences in the relative amount of recovered material. The 1,1-biphenyl and 4-PC results would tend to support this explanation. 1,1'-Biphenyl was found in only one carpet sample (DRW) and is used in organic synthesis and as a fungicide, both of which could explain its presence. The results in Tables 4–6 for 1,1'-biphenyl again demonstrate that SFE is comparable to Soxhlet extraction. The 4-PC

was found in three of the four carpets. As previously mentioned, it is commonly linked to new carpet smell and is associated with human health effects such as skin rashes and eye, respiratory, and mucous membrane irritation [19]. It is a by-product in the manufacture of styrene-butadiene (SBR) latex, which is used as the backing material for these carpets. The reason none was observed in the PLM carpet may be linked to the treatment or age of this carpet relative to the other carpet samples. Again, in Tables 4–6 for 4-PC, SFE compares favorably with Soxhlet extraction in all three samples in terms of precision and extracted quantities relative to the internal standard.

The alkanes were selected as a group because of their prevalence in these carpet samples. No attempt was made to determine which alkane was present because of the difficulty of distinguishing one from another except as a function of their retention times and relative peak heights for a particular extract. Therefore, in general terms, the results of comparing alkanes as a group show varying degrees of comparability between SFE and Soxhlet extraction. These variations are most likely due to many of the reasons mentioned for the other selected compounds.

The comparability of results from SFE extraction and from Soxhlet extraction was marked by one notable exception. Two of the carpet samples (NWB, FTZ) contained a compound that was tentatively identified from the Soxhlet extracts as urea. This compound was not detected in the SFE extracts of either of these carpets. This was most likely due to the difference in the extraction capabilities of the two 'solvents', MeCl₂ versus supercritical carbon dioxide, for this compound.

Extraction of the LCO carpet sample proved to be especially difficult by both techniques. First, the carpet completely disintegrated in the MeCl₂, and another solvent, hexane, had to be used in the Soxhlet extraction. Even with the use of a less chemically aggressive solvent, the Soxhlet extracts overwhelmed the GC-MS system to the extent that no useful chromatographic information could be gathered, even with dilution of the sample. Similar results, though to a lesser extent, were seen for the SFE extracts. This was not expected because supercritical CO₂ is generally less chemically aggressive as a solvent than the solvents used in Soxhlet

extractions. The large amount of nonchromatographable material extracted from this carpet may have been components of the thick plastic backing of these carpet tiles.

4. Conclusions

These comparisons have shown that SFE in general compares favorably to Soxhlet extraction in an analytically challenging situation. And because the SFE technique offers other advantages such as shorter extraction times and less solvent exposure and disposal, SFE can be a viable alternative to Soxhlet extraction. Although these results were obtained with a limited set of samples and cannot be construed as representative of all carpets, this comparison has also shown that SFE and Soxhlet extraction yield comparable results for measuring compounds that pose environmental exposure concerns such as 4-PC, phenol, and Dursban.

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