

Using Gas Chromatography for Indoor-Air Quality Control in Conservation and Renovation Studios

**Tomasz Ligor
Piotr Gorczyca
Bogusław Buszewski**

Faculty of Chemistry, Nicolaus Copernicus University, Toruń, Poland

Investigations were carried out in the Department of Conservation of Painting and Polychrome Sculpture and in the Screen Printing Studio of the Faculty of Art at Nicolaus Copernicus University. Concentration of the vapours of organic solvents was measured in 2 workshops: the Art Conservation Studio and the Screen Printing Studio. This study attempts to evaluate the work environment in both studios by analysing the concentration of vapour solvents over 5 to 7 years of measurements. Volatile solvents—aliphatic and aromatic hydrocarbons, alcohols, esters and ketones—were detected in investigated workplaces. These compounds have a wide range of applications in cleaning and removing old varnishes, lacquers and paints; inhalation is the main route of exposure. Vapour was collected using an active sampling method.

volatile organic compounds (VOCs) air analysis gas chromatography (GC)
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1. INTRODUCTION

The problem of health risk resulting from exposure to volatile organic compounds (VOCs) present in the workplace is very important for physicians, employers, the local government and workers. VOCs are regarded as poisonous agents in the occupational environment [1]. The relationship between adverse health effects and exposure to VOCs was first recognized in the chemical industry, where there were high concentrations of a great number of compounds. For instance, in the USA, the National Institute of Occupational Safety and Health (NIOSH) estimated that in the late 1980s about 100,000 workers were likely to have some degree of toluene exposure. About 140,000 individuals have potential exposure to xylenes in their work [2]. So, it is a very important problem, considering the number of people exposed to VOCs. Many volatile solvents have various effects on the human body, from irritating and

acute effects to long-term effects, e.g., causing cancer. Exposure to solvents is a common problem in industry as well as in various art and conservation studios [3]. Volatile hydrocarbons, ketones, esters and alcohols are mostly used as solvents for paints, varnishes, lacquers, inks, glues, cleaning agents and removers.

Organic solvents represent a large, chemically heterogeneous group of compounds, which are widely used for dissolving water-insoluble materials. They may be grouped in the following classes: aliphatic, aromatic or halogenated hydrocarbons, alcohols, ketones, esters and its mixtures [4]. Due to wide applications of the solvents, occupational exposure is common. Inhalation is the main route of exposure. However, in some cases absorption through skin is possible.

Quite large quantities of chemicals are used in the process of creating works of art and in conservation processes. Very often we do not realize that the concentration is quite high because

we are used to the peculiar smell. The workplace conditions are rather associated with the kind of work—painting, etching, screen printing, conservation—than with the kind of materials and solvents that are used. The main problem is the awareness of the kind of chemicals that are used and their properties as well as their influence on human health. This requires an education on safety, an introduction of protective equipment and measurements of the concentration of agents in workplace air to see changes in concentration. In some art studios chemicals, e.g., solvents for cleaning, removing and impregnation, are permanently used. Investigations were carried out to determine the kind and quantities of solvents in workplace air in the aforementioned studios. An attempt was made to find factors that may influence the level of the concentration of agents in the air. Both the Art Conservation and Screen Printing Studios represent occupational environments with potentially high concentrations of toxic air pollutants.

A broad group of solvents used in diluting paints and removing varnishes is a source of those pollutants. The degree of exposure varies because restoration techniques need various materials.

The widespread use of organic solvents results from their properties, especially their ability to dissolve a significant number of water insoluble organic components. Due to the common use of organic solvents it is useful to discuss briefly their toxicological properties.

1.1. Toxicological Effects

Inhalation is the main route of exposure to volatile toxicants by humans. Therefore absorption of compounds may occur through direct skin contact with liquid chemicals too. The quantity of absorbed solvents by the lungs depends on pulmonary ventilation, pulmonary circulation rates and depth of respiration [1, 2]. Blood can transport the absorbed chemicals to organs where biotransformation takes place. Based on the route of exposure to solvents, a significant difference between the uptake and adverse effects can be observed. There are many solvents and there are many potential metabolic breakdown pathways that produce water-soluble metabolites [5].

A central nervous system (CNS) depression as well as irritation of the respiratory system and of the skin are the most common toxicity effects related to solvents in the workplace. A CNS depression is usually observed after short-term exposure to organic solvents. The lipophilic character of organic solvents is a feature that results in the tendency of these compounds to accumulate in lipid rich areas of the body such as the nervous system [4, 6].

Membrane and tissue irritation is another adverse effect of organic solvents. Cell membranes are composed principally of a protein-lipid matrix. Moreover, solvents at sufficient concentrations may dissolve or defat this matrix. These processes may cause irritation.

1.2. Alkanes

This group represents straight chain or branched hydrocarbons with no multiple bonds. Saturated aliphatic hydrocarbons (alkanes) have many members, which are potentially toxic. Typical hydrocarbons applied in commercially available solvents are low-molecular-weight alkanes (pentane, hexane, heptane, octane, nonane) with some CNS depressant, neurotoxic and irritant properties.

Liquid paraffins (higher than decane) are primary irritants capable—following repeated or prolonged exposure—of dermal irritations and dermatitis. Chronic exposure to some aliphatic hydrocarbons, especially hexane and heptane, can produce polyneuropathy [2, 6].

1.3. Aromatic Hydrocarbons

Aromatic hydrocarbons used as solvents cause more tissue irritation than the corresponding low-molecular-weight saturated hydrocarbons. These compounds are mildly irritant to mucous membranes at high concentrations and may cause dermatitis and skin irritation [7].

1.4. Alcohols

Alcohols are generally stronger CNS depressants and stronger irritants than similar alkanes. The irritant properties of alcohol decrease as molecular

weight increases. Alcohols rarely represent serious hazards in the workplace because their vapour concentrations are usually lower than those causing irritation. Ethyl alcohol in high concentrations is classified as a mild to moderate local irritant.

1.5. Ketones

Ketones are recognized as CNS depressants. However, these compounds are strong irritants to the eyes and respiratory passages. Toxic properties of ketones increase as molecular weight increases. Acetone is a widely used solvent and raw material in industrial processes. Skin irritation typically occurs after repeated prolonged contacts only. Generally, eye irritation is observed at 500 ppm. High concentrations of 2-butanone (MEK) are irritating to the eyes, nose and skin. CNS depression may result from prolonged exposure [4].

1.6. Aliphatic Esters

Lower-molecular-weight esters are more potent irritants than alcohols and are known to cause eye irritation and lacrimation. Esters are typically degraded in the bloodstream by plasma esterases to corresponding carboxylic acids and alcohols.

VOCs are frequently monitored with a sorption method based on trapping followed by thermal desorption or solvent (carbon disulphide) desorption [8, 9, 10, 11, 12, 13]. In this paper charcoal adsorbent followed by solvent desorption for monitoring occupational air in studios is described.

2. EXPERIMENTAL

2.1. Chemicals and Reagents

Chromatographic standards, toluene, pentane, hexane, heptane, octane, decane, alpha-pinene, 2-butanone, acetone, butyl and ethyl acetates, were purchased from Supleco and Riedel de Haen (Poznań, Poland). Methanol, ethanol, turpentine and petroleum ether were purchased from POCH (Gliwice, Poland). Carbon disulphide was purchased from Sigma Aldrich (Poznań, Poland).

2.2. Instrumentation

A Fisons 8000 series gas chromatograph (Fisons, Milan, Italy), equipped with an RTX-WAX capillary column (30 m × 0.25 mm × 0.25 µm) (Restek, Bellefonte, PA, USA), was used. The split-splitless injector and detector temperatures were 200 °C, column temperature was programmed as follows: 50 °C hold for 3 min and 5 °C/min ramp to 160 °C and hold 4 min. Injection volume 2 µl, condition: splitless 0.6 min., split ratio 1:25.

The monitoring of the workplace was carried out with a 224-EEX Air Check pump (SKC Ltd, Blandford, Dorset, UK). A UM-2 ultrasonic bath (Unitra-Unima, Olsztyn, Poland) and a Rotina 48 centrifuge (Tuttingen, Germany) were used for sample preparation.

2.3. Sampling

Sampling time depended on worker exposure. The airflow rate was set at 20 ml/min, at room temperature. Volatile organics in occupational air were sampled with a glass tube containing activated charcoal (SKC Ltd, Blandford, Dorset, UK). Samples were analysed immediately after sampling.

2.4. Sample Preparation

The tube was composed of two charcoal layers (beds): a sampling (100 mg of charcoal) and a breakthrough layer (50 mg). Each of the two layers was extracted and analysed separately. The air was passed through an adsorption tube using a pump. Volatile compounds, which were adsorbed in the trap tube, were extracted in carbon disulphide by ultrasonication. Longer sonication (>15 min) did not improve the efficiency. For charcoal separation centrifugation was applied. Using typical filtration methods (cellulose filters or membrane discs) to separate carbon particles was impractical due to the low volume of the solvent and the high volatility of carbon disulphide.

The analytical procedure for the two charcoal layers (sample preparation) was as follows:

- Charcoal bed was placed in an autosampler vial and 1 ml of carbon disulphide was added;

- After the vial was closed charcoal was extracted by ultrasonication for 15 min;
- The carbon disulphide solution was separated from charcoal by centrifugation at 3,500 rpm for 10 min;
- The decanted solution was transferred into another vial and was analysed with gas chromatography with a flame ionization detector.

2.5. Calibration

A standard solution containing target compounds was prepared by sequential dilutions of the stock solution. A calibration curve was established for each compound. The precision of the analysis was examined for an external calibration method. Calibration standards were analysed before each batch of samples was analysed.

2.6. Breakthrough

The breakthrough layers were analysed in order to verify the loss of volatile compounds. The breakthrough volume was defined as air volume when the amount of analyte collected in the breakthrough layer reached a certain percentage (typically 5%) of the total amount collected by the charcoal tube [8]. The breakthrough layers were analysed in all the experiments to verify that all the compounds were completely retained by the main layer. The breakthrough volume was dependent on the concentration of the compounds examined and also on the concentration of the other constituents of the mixture [9, 14, 15]. In our investigations the breakthrough layer did not contain significant amounts of the compounds in question (below 1%). Therefore, the target compounds were well retained by the main layer without breakthrough in the charcoal tubes used in all samples.

3. RESULTS AND DISCUSSION

Two art studios were selected for this investigation: the Screen Printing Studio and the Art Conservation Studio. The main characteristics obtained from the inspection of the buildings are shown in Table 1.

The present method was applied to determine vapour of solvents in the workplace. The time and frequency of sampling were applied according to the Act of the Ministry of Health of April 20, 2005 [16]. If the concentration of chemical agents in workplace air is in the range of 0.1–0.5 of the value of time-weighted average limits (MAC-TWA), control measurements should be made every 2 years. If the concentrations are in the range of 0.5–1.0 of the maximum admissible concentration (MAC), value measurements should be made every year.

In each workplace, compounds were identified on the basis of retention information. Quantification was performed by constructing calibration curves. Correlation coefficients for the determined compounds ranged from .9985 for petroleum ether to 0.9997 for toluene. The precision of the analysis, represented as relative standard deviation (*RSD*), ranged from 1.8 to 3.6% for toluene and turpentine, respectively (Table 2). Thus, it can be concluded that this method, based on the Polish Standard was appropriate for routine analysis.

MACs for an 8-hr working day and a 40-hr working week are regulated by the Act of the Minister of Work and Social Affairs of Poland of November 29, 2002 [17]. The values for selected compounds were compared with the concentration obtained during control measurements and are listed in Tables 3 and 4. In all cases sampling time was the same as the time of exposure. TWA concentration is useful for estimating chemical exposure:

TABLE 1. Workplace Characteristics

Laboratory	Dimensions l × w × h (m)	Cubature (m ³)	Ventilation System	Surface Material Wall/Floor
Serigraphy	14.6 × 5.8 × 3.1	262.5	Gravimetric (natural) and supply	Acrylate paint/PVC floor covering
Old paint	12.2 × 3.5 × 3.6	153.7	Exhaust ventilation	Acrylate paint/PVC floor covering

Notes. PVC—polyvinyl chloride.

TABLE 2. Calibration Parameters and Precision of Method

Compound	Concentration Range (mg/ml)	Correlation Coefficient <i>r</i>	RSD (%)
Acetone	0.01–12.00	.9993	2.5
Ethyl alcohol	0.03–26.00	.9990	2.1
Ethyl acetate	0.01– 5.00	.9991	1.9
Butyl acetate	0.02–6.00	.9988	2.2
2-Butanone	0.01–6.00	.9989	2.3
Iso-propyl alcohol	0.01–5.00	.9991	2.3
Dichloromethane	0.09–10.20	.9989	2.8
Turpentine	0.06–7.80	.9986	3.6
Toluene	0.01–9.10	.9997	1.8
<i>o</i> -Xylene	0.02–8.30	.9990	2.1
<i>m</i> -Xylene	0.03–8.50	.9991	2.5
<i>p</i> -Xylene	0.02–8.60	.9989	2.2
Petroleum ether	0.04–13.10	.9985	3.3

Notes. RSD—relative standard deviation. It was determined for the lowest concentration of each calibration solution.

$$TWA = \frac{\text{exposure time} \times \text{concentration}}{8 \text{ hrs}} \quad (1) \qquad \frac{c_1}{MAC_1} + \frac{c_2}{MAC_2} + \dots + \frac{c_n}{(MAC_n)}, \quad (2)$$

In a workplace with more than one pollutant, a more global evaluation can be obtained by calculating the cumulative threshold limit value given as

where c_1, c_2, \dots, c_n are the concentrations of substances 1, 2, ..., n , and which has to be lower than 1 or equal to 1.

TABLE 3. Concentrations of Solvent Vapours in a Screen Printing Studio (1996–2002)

Place of Sampling	Compound	Exposure Time (min)	Average Concentration (mg/m ³)	RSD (%)	TWA (mg/m ³)	MAC-TWA (mg/m ³)	Cumulative Threshold
December 10, 1996							
(I) employee	Petroleum ether	205	337.52	1.4	143.41	300	
	Toluene	205	7.23	1.3	3.04	100	0.33
(II) employee	Petroleum ether	126	208.71	1.8	54.82	300	
	Toluene	126	4.75	1.2	1.24	100	0.11
(III) employee	Petroleum ether	220	101.81	2.1	45.82	300	
	Toluene	220	64.12	1.1	28.87	100	0.378
(IV) employee	Petroleum ether	170	69.91	2.3	24.51	300	
	Toluene	170	61.23	1.3	21.44	100	0.25
May 20, 1997							
(I) employee	Toluene	144	0.28	2.6	0.12	100	
	Petroleum ether	144	0.69	2.9	0.36	300	0.00192
(II) employee	Toluene	150	0.55	1.6	0.31	100	
	Petroleum ether	150	10.47	2.5	6.52	300	0.0161
May 10, 1999							
(I) employee	Acetone	250	8.56	1.1	4.42	600	
	Toluene	250	70.61	0.9	36.74	100	
	n-Butyl acetate	250	2.59	1.2	1.35	200	0.3744
February 28, 1998							
(I) employee	Toluene	81	57.17	1.5	9.64	100	
	Acetone	81	13.20	1.4	2.24	600	0.107
(II) employee	Toluene	138	32.62	1.1	9.38	100	
	Acetone	138	10.03	1.6	2.88	600	0.107

TABLE 3. (continued)

Place of Sampling	Compound	Exposure Time (min)	Average Concentration (mg/m ³)	RSD (%)	TWA (mg/m ³)	MAC-TWA (mg/m ³)	Cumulative Threshold
(III) employee	Toluene	137	23.96	1.4	6.84	100	0.08
	Acetone	137	8.11	1.6	2.31	600	
(IV) employee	Toluene	66	71.24	1.3	9.80	100	0.12
	Acetone	66	31.98	1.2	4.40	600	
(V) employee	Toluene	203	95.23	1.4	40.26	100	0.484
	Acetone	203	40.08	1.3	16.95	600	
April 4, 2000							
(I) employee	Toluene	146	46.35	1.6	14.09	100	0.487
	Acetone	146	5.06	1.9	1.09	600	
	Petroleum ether	146	327.09	2.6	99.49	300	
	n-Butyl acetate	146	4.31	1.4	1.31	200	
	Xylenes	146	2.63	1.8	0.79	100	
(II) employee	Toluene	162	42.48	1.2	14.31	100	0.557
	Acetone	162	3.40	1.6	0.55	600	
	Petroleum ether	162	356.01	2.5	120.15	300	
	n-Butyl acetate	162	4.17	1.4	1.43	200	
	Xylenes	162	3.39	1.4	1.12	100	
January 30, 2002							
(I) employee	Toluene	190	17.44	1.3	6.90	100	1.77
	Isopropanol	190	8.24	1.2	3.26	900	
	2-Butanone	190	0.53	1.8	0.21	200	
	Ethyl acetate	190	1.59	1.5	0.63	200	
	Acetone	190	3.61	1.6	1.43	600	
	Petroleum ether	190	2115.91	2.2	837.51	300	
(II) employee	Toluene	204	23.57	1.2	10.02	100	1.82
	Isopropanol	204	7.73	1.3	3.29	900	
	2-Butanone	204	0.55	1.9	0.24	200	
	Ethyl acetate	204	1.31	1.7	0.56	1000	
	Acetone	204	5.49	1.1	2.33	600	
	Petroleum ether	204	2000.92	2.6	850.43	300	
(III) employee	Toluene	268	17.12	1.5	9.56	100	1.64
	Isopropanol	268	13.80	1.3	7.71	900	
	2-Butanone	268	0.47	2.0	0.26	200	
	Ethyl acetate	268	1.15	1.7	0.64	200	
	Acetone	268	6.72	1.1	3.75	600	
	Petroleum ether	268	1341.52	2.5	749.04	300	
January 31, 2002							
(I) employee	Toluene	164	0.67	2.0	0.23	100	0.003
	Isopropanol	164	0.13	1.9	0.05	900	
	2-Butanone	164	0.57	2.2	0.19	200	

TABLE 3. (continued)

Place of Sampling	Compound	Exposure Time (min)	Average Concentration		TWA (mg/m ³)	MAC-TWA (mg/m ³)	Cumulative Threshold
			(mg/m ³)	RSD (%)			
(II) employee	Toluene	184	0.78	2.0	0.29	100	
	Isopropanol	184	0.26	2.5	0.10	900	
	2-Butanone	184	0.54	2.0	0.21	200	
	Ethyl acetate	184	0.32	2.2	0.12	200	0.005
(III) –employee	Toluene	232	1.21	1.8	0.58	100	
	Isopropanol	232	0.22	2.0	0.11	900	
	2-Butanone	232	0.26	2.1	0.13	200	
	Acetone	232	0.25	2.4	0.12	600	0.008
December 20, 2002							
(I) employee	Petroleum ether	157	69.34	2.8	22.68	300	
	Ethanol	157	1.76	2.0	0.58	1000	0.05
(II) employee	Petroleum ether	217	221.32	2.3	100.05	300	
	Acetone	217	14.27	1.1	6.45	600	0.21

Notes. RSD—relative standard deviation, TWA—time-weighted average, MAC—maximum admissible concentration. Exposure time = sampling time.

TABLE 4. Concentrations of Solvent Vapours in an Art Conservation Studio (1997–2001)

Place of Sampling	Compound	Exposure Time (min)	Average Concentration		TWA (for an 8-hr working day) (mg/m ³)	MAC-TWA (mg/m ³)	Cumulative Threshold
			(mg/m ³)	RSD (%)			
February 3, 1997							
(I) employee	Petroleum ether	113	5.18	2.9	1.91	300	
(II) employee	Petroleum ether	120	1.46	3.1	0.53	300	
November 20, 1996							
(I) employee	Toluene	220	0.21	2.0	0.09	100	
(II) employee	Toluene	226	15.54	1.4	7.75	100	
	Acetone	226	24.50	1.3	12.25	600	
	Petroleum ether	226	37.52	2.4	18.75	300	
	Dichloromethane	226	6.54	2.0	2.48	20	1.04
(III) employee	Toluene	230	0.96	1.8	0.48	100	
	Acetone	230	3.00	2.1	1.50	600	
	Petroleum ether	230	36.64	2.9	18.30	300	
	Dichloromethane	230	8.41	1.8	4.20	20	0.283
February 3, 1998							
(I) employee	Turpentine	145	4.32	1.9	1.61	300	
October 29, 1998							
(I) employee	Toluene	205	4.87	1.3	20.05	100	
	Ethylbenzene	205	1.55	1.6	0.64	100	
	Xylenes	205	1.24	1.8	0.51	100	0.031
(II) employee	Toluene	205	1.42	1.4	0.60	100	
	Ethylbenzene	205	0.21	2.1	0.21	100	
	Xylenes	205	0.41	1.8	0.17	100	0.0044
December 1, 1998							
(I) employee	Xylenes	177	0.43	1.7	0.01	100	
	Toluene	177	0.45	1.4	0.16	100	
	Isopropanol	177	0.58	1.9	0.21	900	
	Ethanol	177	0.77	1.9	0.29	1000	0.002

TABLE 4. (continued)

Place of Sampling	Compound	Exposure Time (min)	Average Concentration (mg/m ³)	RSD (%)	TWA (for an 8-hr working day) (mg/m ³)	MAC-TWA (mg/m ³)	Cumulative Threshold
December 1, 1998							
(II) employee	Xylenes	180	1.85	2.1	0.70	100	
	Toluene	180	1.67	1.8	0.62	100	
	Isopropanol	180	0.36	2.2	0.14	900	
December 21, 1998							
(I) employee	Ethanol	180	0.11	2.7	0.04	1000	0.0143
	Toluene	192	0.39	1.9	0.16	100	
	Isopropyl alcohol	192	2.80	1.3	1.12	900	
	Ethyl acetate	192	0.92	2.0	0.37	200	0.0045
(II) employee							
	Toluene	192	0.40	2.3	0.09	100	
	Isopropyl alcohol	192	0.70	2.4	0.17	900	0.0011
November 23, 2000							
(I) employee							
	Toluene	105	0.48	2.4	0.10	100	
	Acetone	105	1.87	2.2	0.40	600	
	Ethanol	105	1.69	2.3	0.36	100	
	Turpentine	105	1.01	3.2	0.22	300	0.0028
(II) employee							
	Toluene	105	0.46	1.8	0.10	100	
	Acetone	105	3.75	1.4	0.82	600	
	Ethanol	105	4.03	1.2	0.88	1000	
	Turpentine	105	3.93	2.7	0.86	300	0.0053
(III) employee							
	Toluene	273	4.93	1.2	2.80	100	
	Ethanol	273	9.35	1.1	5.32	1000	
	Ethyl acetate	273	4.24	1.0	2.41	200	0.045
(IV) employee							
	Toluene	279	0.81	1.3	0.47	100	
	Ethanol	279	142.38	1.1	82.76	1000	
	Ethyl acetate	279	4.08	1.3	2.37	200	0.098
November 29, 2001							
(I) employee							
	Acetone	239	1.99	1.2	0.99	600	
	Toluene	239	1.40	1.2	0.70	100	
	Xylenes	239	2.64	1.3	1.31	100	
	Ethylbenzene	239	0.24	1.7	0.12	100	
	Methanol	239	2.14	1.1	1.06	100	
	Petroleum ether	239	5.83	2.9	2.90	300	0.033
(II) employee							
	Acetone	110	33.55	1.0	7.68	600	
	Toluene	110	1.20	1.3	0.27	100	
	Xylenes	110	1.14	1.5	0.26	100	
	Ethylbenzene	110	1.16	1.3	0.26	100	
	Methanol	110	2.11	1.3	0.48	100	
	Petroleum ether	110	4.37	2.9	1.00	300	0.029

Notes. RSD—relative standard deviation, TWA—time-weighted average, MAC—maximum admissible concentration. Exposure time = sampling time.

Concentrations of solvent vapour varied widely according to the means of renovation or mechanical cleaning and removal using different commercially available solvents or their mixtures.

Volatile chemicals can be emitted by paint, resins, glues, and lacquers and varnishes. Cleaning procedures and filling in missing coating material are typical emission sources.

3.1. Alkanes

Petroleum ether, which is frequently used in both studios, is a common example of a solvent based on mixtures of aliphatic hydrocarbons. The concentration of petroleum ether vapours was relatively low (0.53–18.75 mg/m³) in the Art Conservation Studio. In these concentrations the vapours of petroleum ether are not irritating

to the respiratory tract. Moreover, the skin can be splashed, which is typical for manual cleaning and removing old paint layers. In this case defatting of the skin was observed. Generally, concentrations of this solvent in the Screen Printing Studio were at a higher level (0.36–850.43 mg/m³) than in the Art Conservation Studio. Overexposure was detected in 2002 during careless washing of matrices in the open air, not using a laboratory hood. Control measurements carried over three employees indicated concentrations exceeding 2.5-fold MAC-TWA. Such a situation appeared only once during the 5 years of the study. In the second control measurement in 2002, no petroleum ether vapours in the air were detected. The next measurements in this studio, also in 2002, did not demonstrate excess concentrations; however, the concentrations of petroleum ether ranged from 22.68 to 100.05 mg/m³.

3.2. Aromatic Hydrocarbons

Toluene is the most frequently used aromatic solvent. This agent is usually present in the workplace, particularly in the Screen Printing Studio. Toluene—as a principal component of solvent mixtures—is commonly used for cleaning matrices. The observed concentration of toluene changed from 0.09 to 7.75 mg/m³ and from 0.12 to 40.26 mg/m³ in the Art Conservation and Screen Printing Studios, respectively. The highest concentration of toluene (40.26 mg/m³) was detected in February 2000. Nevertheless, the detected concentration exceeded MAC-TWA (100 mg/m³). Other employees in the Screen Printing Studio were exposed to lower concentrations (9.38–9.80 mg/m³). The maximum concentrations detected during other years, were as follows: 28.87 mg/m³ (1996), 0.31 mg/m³ (1997), 9.80 mg/m³ (1999), 0.58 mg/m³ (2002). In these concentrations the vapour of toluene is mildly irritating to mucous membranes.

Other representatives of alkyl-substituted benzenes such as dimethylbenzenes (xylenes) and ethylbenzene were less frequently detected in the air. Concentrations of xylenes (calculated as a sum of *o*-, *m*- and *p*-isomers) were in the range of 0.79–1.12 mg/m³ and 0.17–1.31 mg/m³ in the Screen Printing and Art Conservation Studios,

respectively. Ethylbenzene was rarely found in the Art Conservation Studio. Moreover, the concentration of this compound was at the level of 0.21–0.64 mg/m³.

3.3. Methyl, Ethyl and Isopropyl Alcohols

In both studios, vapours of aliphatic alcohols such as iso-propyl alcohol and ethanol were seldom identified. Ethanol was usually used in the Art Conservation Studio and its concentration in laboratory air was at the level of 0.04–82.76 mg/m³. However, it was not detected in the Screen Printing Studio. Isopropanol was identified in both studios. The concentrations of iso-propyl alcohol were low, in the range of 0.05–7.71 mg/m³ and 0.14–0.17 mg/m³ in the Screen Printing and Art Conservation Studios, respectively. Vapours of methyl alcohol were identified only in the air of the Art Conservation Studio at concentrations in the range of 0.48–1.06 mg/m³. The concentration of alcohols never exceeded MAC-TWA.

3.4. Acetone and 2-Butanone

Acetone is an extremely useful organic solvent due to its volatility and particularly good solving properties. That is why vapours of acetone were identified in most samples. Average concentration ranged from 0.12–16.95 mg/m³ (in the Screen Printing Studio) to 0.40–7.68 mg/m³ (in the Art Conservation Studio). Probably the high concentration of acetone resulted from its properties as it effectively dissolves various resins, glues and paint remover. Vapours of 2-butanone were observed in Screen Printing only, and their concentrations were below 0.19 mg/m³.

3.5. Aliphatic Esters

Ethyl acetate is the most frequently used ester. This chemical is usually detected at low concentrations. Typical concentrations of ethyl acetate were in the range of 0.37–2.41 mg/m³ (Art Conservation) and 0.12–0.63 mg/m³ (Screen Printing). Butyl acetate was found only in the Screen Printing Studio (1.31–1.35 mg/m³). Figures 1 and 2 illustrate a comparison of the volatile solvents most common in both studios.

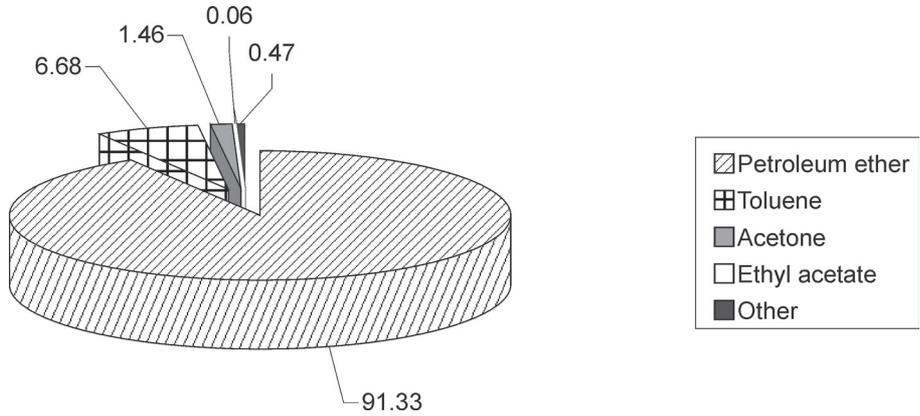


Figure 1. Percentage fraction of volatile compounds in a Screen Printing Studio (1996–2002).

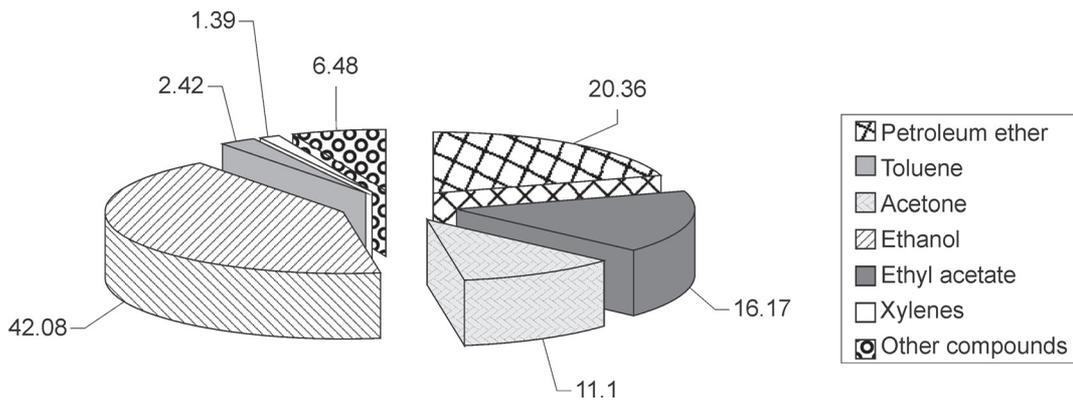


Figure 2. Percentage fraction of volatile compounds in an Art Conservation Studio (1997–2001).

Petroleum ether was the most common solvent used in the Screen Printing Studio (Figure 1). Measurements carried out over the 7 years showed its contribution to the total content of solvent vapor concentration at the level of about 90%. It was detected whenever the measurements were taken. Petroleum ether is a mildly harmful solvent to human at the concentrations observed in that studio (except for that accidental overexposure). However, long-lasting (over several years) occupational exposure to this solvent may result in some neurological effects. Toluene was detected at a lower concentration than ether and its contribution to the total content of solvent vapor concentration was about 6%, whereas the contribution of other solvents, e.g., acetone and butyl acetate, was about 2%.

In the Department of the Conservation of Painting and Polychrome Sculpture the composition of solvent vapours differs from those

mentioned earlier as a result of the kind of work done in this studio (Figure 2). Ethanol was the most common solvent detected over the 5 years of monitoring. The level of petroleum ether in the Art Conservation Studio was lower than in the other studio: it stood at about 20% of the total concentration. The contribution of other solvents in the total concentration was as follows: toluene 16%, acetone 11%, xylene and ethyl acetate 10%.

4. CONCLUSIONS

Depending on the type of job, duties and work schedule, individuals' exposure to solvents varies over time. Typical exposure is limited to 2–4 hrs per day. However, other time schedules are also possible. In both studios (Screen Printing and Art Conservation) nearly all employees were exposed.

The investigation of air quality in both studios during a 6-year period confirmed a relative tendency towards a decrease in the concentrations of pollutants. The results were a consequence of the systematic safety education carried out by our Safety Department, applying protection solutions (high efficiency exhaust and fume-hood), control of concentrations of pollutants and working in accordance with safety rules. Petroleum ether, acetone and toluene were the most frequently detected compounds. The concentration of those compounds was below the MAC-TWA limits. However, the concentration of petroleum ether exceeded the MAC-TWA value 1.5-fold. It was an incidental but serious example of overexposure in the Screen Printing Studio observed in January, 2002, which can be explained by a high intensity of renovation processes at that time. However, this assumption cannot be proved because no parallel investigation of solvent consumption has been carried out. On the other hand, January is a month of a low outdoor temperature and systematic ventilation (open windows) is avoided.

The results confirm the necessity for systematic safety education especially when users are non-chemists, for the use of protection equipment, for working in accordance with safety rules, and for controlling concentrations of pollutants at the workplace. Compliance with all those rules leads to reduced exposure and it makes the workplace safer.

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