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Agata Stachowiak-Wencek, Włodzimierz Prądzyński

CONCENTRATION OF VOLATILE ORGANIC COMPOUNDS IN THE PRODUCTION HALLS OF A SELECTED FURNITURE MANUFACTURING PLANT

The aim of this study was to determine the concentrations of volatile organic compounds found in the air in five production halls at a furniture manufacturing plant. Tests were performed in production halls, where machining operations were performed both on wood and wood-based materials, in shop halls in which surface-finishing operations were performed, as well as a finished goods warehouse. A Tenax TA synthetic sorbent was used to adsorb compounds found in the air. Volatile substances were analysed by gas chromatography combined with mass spectrometry and thermal desorption. It was found that the microclimate in the examined production halls varied. Differences were observed not only in the type of compounds detected in the shop halls, but also in their amounts. The analysed air contained a broad spectrum of volatile compounds, mainly alcohols, glycols, aromatic hydrocarbons, aldehydes, esters and terpenes. The total concentration of volatile organic compounds (TVOC) found in the air in the examined production halls varied within a very broad range from 795 to 5113 μg/m^3. The concentrations of volatile organic compounds identified in the production halls were markedly lower than those specified by Polish legal regulations - the Ordinance of the Minister of Labour and Social Policy of 2002 (with later amendments).

Keywords: volatile organic compounds, air pollution, furniture industry, gas chromatography with mass spectrometry and thermal desorption (GC/MS/TD)

Introduction

We are exposed to dust, pollen, fungal and mould spores, as well as chemical pollutants, released by construction materials and interior design elements. It is difficult to reliably define which of the air pollutants found indoors cause only discomfort and which may lead to disease. Sick building syndrome (SBS) has been

Agata Stachowiak-Wencek, Poznan University of Life Sciences, Poznan, Poland
astachowiak@up.poznan.pl
Włodzimierz Prądzyński, Poznań University of Life Sciences, Poznan, Poland
wpradzynski@up.poznan.pl

discussed for years. Occupants of many facilities suffer from headaches, irritation of the eyes, nose and throat, attention span problems and/or fatigue. Mølhave [2003] presented the range of health effects caused by pollutions pollutants found in indoor air (table 1). An interesting point is that most symptoms disappear upon leaving the building. Their causes are complex, but one of them is connected with the presence of chemicals in the air. Agents suspected of causing 'sick building' symptoms include, for example, volatile organic compounds. Studies have shown that indoor air typically contains higher concentrations of pollutants than outdoor air [Andersson et al. 1997; Brinke et al. 1998; Wargocki et al. 1999; Mølhave 2003; Nielsen et al. 2007]. According to analyses conducted by the Environmental Protection Agency (EPA), the concentration of air pollutants inside buildings may be from 2 to 5 times greater than outdoor air.

Table 1. Classes of health effects found indoors [Mølhave 2003]
Tabela 1. Efekty zdrowotne spotykane w pomieszczeniach [Mølhave 2003]

Health effect *Efekty zdrowotne*	Symptoms of the disease *Objawy chorobowe*
Immune effects and other hypersensitivity *Efekty immunologiczne i inna nadwrażliwość*	Asthma *Astma* Allergy *Alegria* Non-specific hypersensitivity *Nadwrażliwość niesprecyzowana*
Respiratory effects (other than immunological) *Efekty dróg oddechowych (inne niż immunologiczne)*	–
Cellular effects *Efekty komórkowe*	Cancer *Rak* Other cellular effects including affecting reproduction *Inne efekty komórkowe, w tym oddziałujące na rozrodczość*
Neurogenic and sensory effects *Efekty neurogenne i sensoryczne*	Odor *Zapach* Irritation *Podrażnienie* Neurotoxic symptoms *Objawy neurogenne*
Cardiovascular effects *Wpływ na układ krążenia*	–

The quality of air in the workplace is as important as that of the air at home. Studies presenting the results of air analyses conducted at industrial or commercial facilities have indicated that air may contain several pollutants [Rufus et al. 2001a, b; Lee et al. 2002; Wu et al. 2004; Loh et al. 2006; Eklund et al. 2008].

However, air in industrial plants may be of particular importance. Technological operations performed at production plants and the materials used obviously have a significant effect on the microclimate of production halls and air polluted with volatile substances. World literature presents to a limited extent studies concerning VOC emissions and air pollution in industrial facilities, particularly the wood industry. When such analyses have been reported, they have typically concerned VOC emissions from materials used in the production process or finished products [Salthammer 1997; Salthammer et al. 1999; Roffael 2006; Ohlmeyer et al. 2008; Kirkeskov et al. 2009; Stachowiak-Wencek 2012].

In the wood industry, the air within production halls, paint shops, assembly rooms, warehouses or grinding shops may contain an extensive spectrum of compounds harmful to human health due to the operations performed there.

In the wood industry, volatile substances are emitted not only from finishing materials or binders, but also the basic raw material, i.e. wood.

A toxicological evaluation of substances may be performed on the basis of the relation between dose and effects [AgBB 2012]. The U.S. Environmental Protection Agency (U.S. EPA) generally uses reference concentrations (RfCs) to assess the risks from exposure to toxic substances for non-cancer effects. RfCs are supposed to represent lifetime inhalation with minimal appreciable risk. Frequently, a NO(A)EL ["no observed (adverse) effect level", i.e., the highest exposure level showing no significant effect of exposure] or LO(A)EL ["lowest observed (adverse) exposure level", showing such an effect], is used to calculate the RfCs [Mølhave 2003].

The most comprehensive evaluation system available for the workplace area is in the form of occupational exposure limit values (OELs) [AgBB 2012]. Occupational exposure limits have been developed in many countries for airborne exposure to gases, vapours and particulates.

In Poland, occupational exposure limits for airborne toxic substances have been determined by the Ordinance of the Minister of Labour and Social Policy on the Maximum Admissible Concentrations and Intensities of Harmful to Health Agents in the Working Environment. The official version was published in Dziennik Ustaw 2002, No. 217, item 1833, and modified subsequently in Dziennik Ustaw 2005, No. 212, item 1769; Dziennik Ustaw 2007, No. 161, item 1142; Dziennik Ustaw 2009, No. 105, item 873 and Dziennik Ustaw 2010, No. 141, item 950).

For airborne exposures, there are three types of limits in common use:

– **NDS – MAC(TWA): Maximum Admissible Concentration:** the time-weighted average concentration for a conventional 8-hour workday and a workweek defined in the Labour Code, to which workers may be exposed during their whole working life, without any adverse effects on their health or that of the next generations,

– **NDSCh – MAC(STEL): Maximum Admissible Short-Term Concentration:** the short-term exposure limit is an average concentration, to which workers may be exposed without any adverse health effects if it does not last longer than 15 minutes and does not occur more than twice during a workday, at intervals not shorter than 1 hour,
– **NDSP – MAC(C): Maximum Admissible Ceiling Concentration:** Ceiling concentration, which because of the threat to workers' health or life, should not be exceeded even instantaneously [http://www.ilo.org/safework/info/WCMS_151579/lang--en/index.htm].

The aim of this study was to determine the concentration of volatile organic compounds found in the production halls at a furniture manufacturing plant.

The scope of the study comprised quantitative and qualitative analyses of compounds contained in the air.

Materials and methods

Samples for analyses were collected at a furniture manufacturing plant producing case furniture.

The analyses were conducted on the air collected from five production halls, in which different technological operations were performed:

– Production hall 1: mechanical working of wood and wood-based materials, (dimensions: 23 × 41 × 4.5 m);
– Production hall 2: surface finishing operations. Three lacquering booths equipped with dry filters had been installed. The finishing operations were performed using manual pneumatic spray guns, (dimensions: 20 × 15 × 5.3 m);
– Production hall 3: surface finishing of furniture elements. An automated lacquering line had been installed in the production hall, (dimensions: 40 × 20 × 5.2 m);
– Production hall 4: machining operations, including the operation of element grinding after preliminary lacquering with undercoating varnish, preparing the surface for final lacquering, (dimensions: 40 × 59 × 6.5 m);
– Production hall 5: warehouse of finished products, (dimensions: 29 × 34 × 9 m).

In each room, the air for the analyses was collected from 5 randomly selected locations. The air for the analyses was collected in glass tubes filled with the Tenax TA solid sorbent at 120 mg (35/60mesh, by Alltech). A volume of 500 ml air was transferred through the sorbent layer at a rate of 50 ml/min. Air was sucked in with a FLEC Air Pump 1001, by Chematec Company. The samples were collected at a height of 1.5 m above floor level.

Chromatographic analysis: The volatile organic compounds adsorbed on the sorbent layer were released in a thermal desorber and next they were determined using gas chromatography coupled with mass spectrometry, according to the procedure presented in table 2.

Table 2. Operating conditions of the TD/GC/MS
Tabela 2. Parametry układu analitycznego TD/GC/MS

Elements of the system *Elementy układu*	Parameters *Parametry*
Thermal desorber *Termiczny desorber*	
Injector *Dozownik*	Thermal desorber connected to sorption microtrap; Purging gas: argon at 20 m^3min^{-1}; Purge time: 5 min *Termiczny desorber połączony z pułapką sorpcyjną;* *Gaz płuczący: argon 20 m^3min^{-1};* *Czas płukania: 5 min*
Microtrap *Mikropułapka*	Sorbent: 80 mg Tenax TA/30 mg Carbosieve III; Desorption temperature: 250°C for 90 s *Sorbent: 80 mg Tenax TA/30 mg Carbosieve III;* *Temperatura desorpcji: 250°C przez 90 s*
Gas chromatograph *Chromatograf gazowy*	TRACE GC, Thermo Quest.
Column *Kolumna*	RTX – 624 Restek Corporation, 60m x 0.32mm ID; D_f – 1.8 mm: 6% cyanopropylophenyl, 94% dimethylo-polysiloxane *RTX – 624 Restek Corporation, 60m x 0,32mm ID;* *D_f – 1,8 µm: 6% cyjanopropylofenyl, 94% dimetylopolisiloksan*
Detector *Detektor*	Mass spectrometer (SCAN: 10 – 350) *Spektrometr masowy (SCAN: 10 – 350)*
Carrier gas *Gaz nośny*	Helium: 100 kPa, ~2 cm^3min^{-1} *Hel: 100 kPa, ~2 cm^3min^{-1}*
Temperature setting *Program temperaturowy*	40°C during 2 min, 7°C min^{-1} to 200°C, 10°C min^{-1} to 230°C, 230°C for 20 min *40°C przez 2min, 7°C min^{-1} do 200°C, 10°C min^{-1} do 230°C, 230°C przez 20 min*

Qualitative and quantitative analyses: Compounds were identified by comparing the recorded mass spectra with spectra contained in the NIST MS Search library – program ver. 1.7, and confirmed by referring the mass spectra and retention times of the identified compounds to the spectra and retention times of the appropriate standards. The quantitative analysis of the volatile organic compounds emitted from the investigated surfaces was conducted by adding a reference standard 1-bromo-4-fluorobenzene (Supelco).

Results

The results of the analyses are given in fig. 1 and table 3.

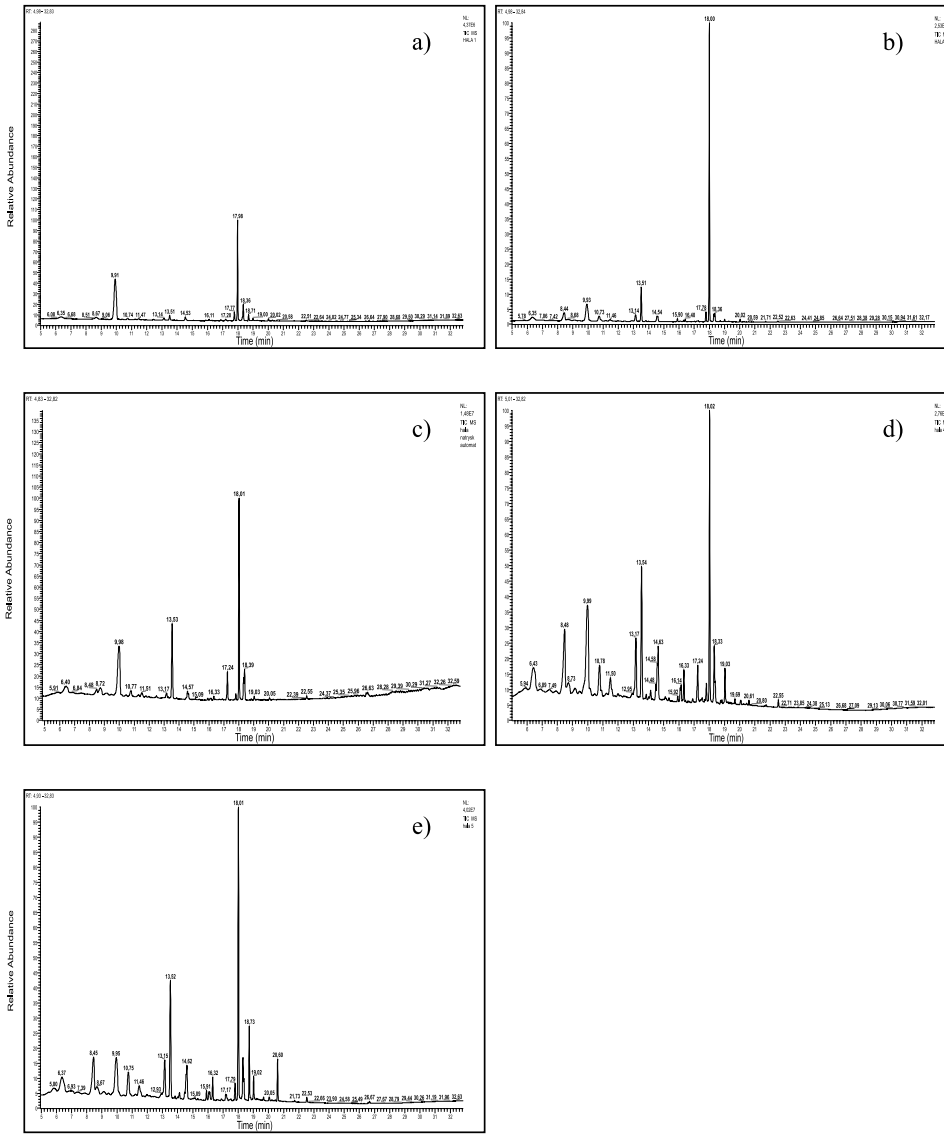

Fig. 1. Chromatograms of volatile organic compounds present in the air collected from: a) production hall 1; b) production hall 2; c) production hall 3; d) production hall 4; e) production hall 5

Rys. 1. Chromatogramy rozdziału lotnych związków organicznych obecnych w powietrzu pobranym z: a) hali produkcyjnej 1; b) hali produkcyjnej 2; c) hali produkcyjnej 3; d) hali produkcyjnej 4; e) hali produkcyjnej 5

Table 3. Concentration of volatile organic compounds found in the air of the production halls
Tabela 3. Stężenie lotnych związków organicznych występujących w powietrzu na terenie hal

Compound *Związek*	Compound concentration [µg/m^3] *Stężenie związku*									
	Hall 1 *Hala 1*		Hall 2 *Hala 2*		Hall 3 *Hala 3*		Hall 4 *Hala 4*		Hall 5 *Hala 5*	
	Value *Wartość*									
	Minimum *Minimalna* Maximum *Maksymalna*	Mean *Średnia*	Minimum *Minimalna* Maximum *Maksymalna*	Mean *Średnia*	Minimum *Minimalna* Maximum *Maksymalna*	Mean *Średnia*	Minimum *Minimalna* Maximum *Maksymalna*	Mean *Średnia*	Minimum *Minimalna* Maximum *Maksymalna*	Mean *Średnia*
1	2	3	4	5	6	7	8	9	10	11
Acetone *Aceton* CAS No. 67-64-1	– –	–	– –	–	– –	–	298 622	443	235 387	307
1-butanol *1-butanol* CAS No. 71-36-3	– –	–	225 511	336	34 55	47	326 552	412	278 354	315
Pentanal *Pentanal* CAS No. 110-62-3	– –	–	– –	–	– –	–	188 296	223	100 188	147
Toluene *Toluen* CAS No. 108-88-3	18 32	22	197 284	249	14 41	29	353 703	529	297 408	335
Tetrachloroethylene *Tetrachloroetylen* CAS No. 127-18-4	– –	–	– –	–	– –	–	55 64	62	30 52	45
n-butyl acetate *octan n-butylu* CAS No. 123-86-4	28 38	37	141 199	179	22 37	31	163 245	200	100 170	139

Table 3. Continued
Tabela 3. Ciąg dalszy

1	2	3	4	5	6	7	8	9	10	11
Hexanal *Heksanal* CAS No. 66-25-1	–	–	32 38	37	14 23	19	152 342	287	–	–
n-butyl ether *eter n-butylu* CAS No. 142-96-1	–	–	62 79	71	–	–	19 38	29	–	–
Ethylbenzene *Etylobenzen* CAS No. 100-41-4	–	–	–	–	4 6	5	56 88	67	45 67	56
m,p-xylene *m,p-ksylen* CAS No. 108-38-3 CAS No. 106-42-3	–	–	24 39	34	8 14	11	162 193	171	124 187	133
1-methoxy-2-propyl acetate *Octan 1-metoksy-2--propylu* CAS No. 108-65-6	–	–	33 40	38	–	–	–	–	–	–
o-xylene *o-ksylen* CAS No. 95-47-6	–	–	–	–	–	–	31 37	33	18 25	23
ά-pinene *ά-pinen* CAS No. 7785-70-8	100 152	139	200 290	244	71 92	82	67 151	101	87 116	97
2-butoxyethanol *2-butoksyetanol* CAS No. 111-76-2	472 625	509	3524 4090	3806	599 701	623	901 1899	1447	801 1401	1091

Table 3. Continued
Tabela 3. Ciąg dalszy

1	2	3	4	5	6	7	8	9	10	11
1-butoxy-2-propanol *1-butoksy-2-propanol* CAS No. 5131-66-8	30 45	40	–	–	–	–	15 20	16	257 371	341
3-carene *3-karen* CAS No. 13466-78-9	14 28	16	32 72	56	15 26	18	–	–	23 45	28
Limonene *Limonen* CAS No. 138-86-3	–	–	5 8	5	–	–	22 29	24	78 146	97
Σ unidentified compounds *Σ związków niezidentyfikowanych*	29 47	32	51 67	58	169 282	214	521 899	671	225 342	294
TVOC: Minimum *Minimalna* Maximum *Maksymalna*	691 967		4526 5717		950 1277		3329 6178		2698 4259	
TVOC: Mean *Średnia*	795		5113		1079		4715		3448	

The total concentration of volatile organic compounds (TVOC) found in the air in the examined production halls varied within a very broad range from 795 to 5113 μg/m^3.

The highest concentration of volatile organic compounds was found in the air collected from production hall 2 containing 3 spraying booths equipped with dry filters, in which the finishing process of the elements was performed using manual spray guns. The lowest VOC concentration was recorded in production hall 1, in which machining operations on wood and wood-based materials was performed. Relatively low VOC concentrations were also recorded in production hall 3, in which the automated finishing line operated. The concentration of VOCs in production hall 3 was at a medium level amounting to 1079 μg/m^3 almost 5 times lower than in the facility (production hall 2), in which the surface finishing process was performed using manual spray guns in lacquering booths. A high VOC concentration was also recorded in the air in production hall 4 and in the warehouse of products (in production hall 5). In production hall 4, in which mechanical working was performed, including e.g. the grinding of elements after lacquering with an undercoating varnish, the VOC concentration was on average 4715 μg/m^3. The concentration of VOC in the warehouse of finished products was lower, amounting on average to 3448 μg/m^3.

In the air collected from the analysed production halls, a broad spectrum of compounds was identified, mainly including alcohols, glycols, aromatic hydrocarbons, aldehydes, esters and terpenes. The narrowest spectrum of volatile organic compounds was found in production hall 1, while it was broadest for production halls 4 and 5. 2-butoxyethanol, was a characteristic compound found in all the production halls. Its concentration varied between production halls, ranging from 509 to 3806 μg/m^3. 2-butoxyethanol is a compound emitted from water-borne lacquers [Stachowiak-Wencek, Prądzyński 2011]. As it is given off by company materials, the surface finishing process of furniture products at the discussed plant was carried out 70% using water-borne products, and for the other 30%, using solvent products mainly from the group of polyurethane products, while nitrocellulose products accounted for a slight percentage of the process. As it results from company materials the surface finishing process of furniture products at the discussed plant was performed in 70% using water-borne products, and in the other 30% with solvent products mainly from the group of polyurethane products, while nitrocellulose products accounted for a slight percentage of the process.

In all the production halls, analyses also detected toluene, n-butyl acetate and terpenes. The concentration of toluene varied within a very broad range from 22 to 529 μg/m^3. The lowest concentration was recorded in production hall 1, in which machining operations were performed, the highest in production hall 4, in which machining operations were also performed, although with the difference that the production hall elements were ground after the first stage of lacquering. A high toluene content was also found in the air from production halls 2 and 5, at 249

and 335 μg/m^3, respectively. In production hall 3, in which the lacquering line adapted to the application of water-borne products operated, the concentration of toluene was 29 μg/m^3.

The concentration of n-butyl acetate in the production halls ranged on average from 31 to 200 μg/m^3. The greatest amount of this compound was recorded in production hall 4. In production halls 2 and 3, in which surface finishing was performed, the concentration of n-butyl acetate ranged from 31 to 179 μg/m^3.

Moreover, in all five production halls the analyses showed the presence of terpenes in the air, mainly α-pinene, 3-carene and limonene, i.e. natural compounds coming from wood. The lowest concentrations of these compounds were detected in production hall 3 (100 μg/m^3), while they were highest in production hall 5 (222 μg/m^3).

In almost all the production halls, except for production hall 1, the presence of 1-butanol was found in the air. Its lowest concentration, amounting to 47 μg/m^3, was recorded in production hall 3, in which the lacquering line operated. High concentrations of 1-butanol from 315 to 412 μg/m^3 were found in the other three facilities.

In the air in production halls 2, 3 and 4, hexanal was also detected. The concentration of hexanal in these facilities ranged from 19 to 287 μg/m^3. However, in production halls 3, 4 and 5, ethylbenzene was found. Its concentration varied in range from 5 to 67 μg/m^3.

In production hall 2, n-butyl ether and 1-methoxy-2-propyl acetate were also detected. These compounds were not found in the other facilities. In turn, acetone, pentanal, tetrachloroethylene and 1-butoxy-2-propanol were recorded only in production halls 4 and 5.

Discussion

Table 4 presents the occupational exposure limits for substances harmful to the health which were identified in the production halls in the tested furniture plant. Table 4 also includes information concerning the health effects caused.

When comparing the recorded quality testing results of the air found in the furniture plant to the occupational exposure limits (both NDS and NDSCh) determined by the Minister of Labour and Social Policy, it may be noted that in the examined production halls the concentrations of the detected compounds were much lower. The admissible levels were not exceeded for any of the identified compounds whose concentrations were determined. For example, the NDS value for 2-butoxyethanol, a compound found in all production halls in the largest quantities, is 98 000 μg/m^3. In the production halls, the concentration of this compound ranged from 472 (the minimum value detected in hall 1) to 4090 μg/m^3 (the maximum value recorded in hall 2), i.e. it was almost 24 times lower (for the maximum value) than the threshold considered a safe level, which should cause no negative effects on the health of the employees working there.

Table 4. Occupational exposure limits for substances identified in the air of the examined production halls and caused health effects

Tabela 4. Najwyższe dopuszczalne stężenia dla substancji zidentyfikowanych w powietrzu badanych hal produkcyjnych i powodowane przez nie efekty zdrowotne

Compound *Związek*	Occupational exposure limits *Najwyższe dopuszczalne stężenia*			Symptoms *Symptomy*
	NDS [µg/m^3]	NDSCh [µg/m^3]	NDSP [µg/m^3]	
1	2	3	4	5
Acetone *Aceton* CAS No. 67-64-1	600 000	1800 000	–	Irritation of eyes, nose and throat; headaches, dizziness, central nervous system depression; dermatitis *Podrażnienie oczu, nosa, gardła; bóle głowy, zawroty głowy, depresja ośrodkowego układu nerwowego*
1-butanol *1-butanol* CAS No. 71-36-3	50 000	150 000	–	Irritation of eyes, nose and throat, headaches, dizziness, drowsiness, corneal inflammation, blurred vision, lacrimation, photophobia, dermatitis; possible auditory nerve damage, hearing loss; central nervous system depression *Podrażnienie oczu, nosa, gardła; bóle głowy, zawroty głowy, senność, zapalenie rogówki, niewyraźne widzenie, łzawienie, światłowstręt, zapalenie skóry, możliwe uszkodzenie nerwów słuchowych, utrata słuchu, depresja ośrodkowego układu nerwowego*
Pentanal *Pentanal* CAS No. 110-62-3	118 000	300 000	–	Irritation of eyes, skin, nose and throat *Podrażnienie oczu, skóry, nosa, gardła*
Toluene *Toluen* CAS No. 108-88-3	100 000	200 000	–	Irritation of eyes and nose; lassitude (weakness, exhaustion), confusion, euphoria, dizziness, headaches; dilated pupils, lacrimation, anxiety, muscle fatigue, insomnia; paresthesia; dermatitis; liver damage, kidney damage *Podrażnienie oczu, nosa; zmęczenie (słabość, przemęczenie), dezorientacja, euforia, zawroty głowy, bóle głowy; rozszerzenie źrenic, łzawienie, stany lękowe, niepokoju, zmęczenie mięśni, bezsenność, parestezja, zapalenie skóry, wątroby, uszkodzenie nerek*

Table 4. Continued
Tabela 4. Ciąg dalszy

1	2	3	4	5
Tetrachloroethylene *Tetrachloroetylen* CAS No. 127-18-4	60 000	480 000	–	Irritation of eyes, skin, nose, throatand respiratory system; nausea, dizziness, incoordination; headaches, drowsiness; skin erythema (skin redness); liver damage; (potential occupational carcinogen) *Podrażnienie oczu, skóry, nosa, gardła, systemu oddechowego, nudności, zawroty głowy, zaburzenia koordynacji, bóle głowy, senność, rumień skóry (zaczerwienienie skóry), uszkodzenie wątroby, (potencjalny zawodowy czynnik rakotwórczy)*
n-butyl acetate *Octan n-butylu* CAS No. 123-86-4	200 000	950 000	–	Irritation of eyes, skin and upper respiratory system; headaches, drowsiness, narcosis *Podrażnienie oczu, skóry, górnych dróg oddechowych, bóle głowy, senność*
Hexanal *Heksanal* CAS No. 66-25-1	40 000	80 000	–	Irritation of eyes, nose and throat; headaches, dizziness *Podrażnienie oczu, nosa, gardła; bóle głowy, zawroty głowy*
n-butyl ether *Eter n-butylu* CAS No. 142-96-1	–	–	–	Irritation of upper respiratory tract, coughing, shortness of breath, effect on central nervous system, narcotic effect, irritation of skin and eyes, redness, itching, and pain *Podrażnienie górnych dróg oddechowych, kaszel, duszność, wpływ na centralny układ nerwowy, efekt narkotyczny, podrażnienie skóry i oczu, zaczerwienienie, świąd i ból*
Ethylbenzene *Etylobenzen* CAS No. 100-41-4	200 000	400 000	–	Irritation of eyes, skin, mucous membrane; headaches; dermatitis; narcosis, coma *Podrażnienie oczu, skóry, błon śluzowych, ból głowy, zapalenie skóry, narkoza, śpiączka*
m,p-xylene *m,p-ksylen* CAS No. 108-38-3 CAS No. 106-42-3	100 000	–	–	Irritation of eyes, skin, nose and throat; dizziness, excitability, drowsiness, incoordination, staggering gait; corneal vacuolization; anorexia, nausea, vomiting, abdominal pain; dermatitis *Podrażnienie oczu, skóry, nosa, gardła, zawroty głowy, podniecenie, senność, brak koordynacji ruchów, chwiejny chód, wakuolizacja rogówki, brak łaknienia, nudności, wymioty, bóle brzucha, zapalenie skóry*
1-methoxy-2-propyl acetate *Octan 1-metoksy-2--propylu* CAS No. 108-65-6	–	–	–	Irritation of upper respiratory tract, coughing, dizziness, drowsiness, headaches, nausea, sore throat, dry skin, irritation of the eyes, redness, pain. *Podrażnienie górnych dróg oddechowych, kaszel, zawroty głowy, senność, bóle głowy, nudności, ból gardła, suchość skóry, podrażnienie oczu, zaczerwienienie, ból*

Table 4. Continued
Tabela 4. Ciąg dalszy

1	2	3	4	5
o-xylene *o-ksylen* CAS No. 95-47-6	100 000	–	–	Irritation of eyes, skin, nose and throat; dizziness, excitability, drowsiness, incoordination, staggering gait; corneal vacuolization; anorexia, nausea, vomiting, abdominal pain; dermatitis *Podrażnienie oczu, skóry, nosa, gardła, zawroty głowy, podniecenie, senność, brak koordynacji ruchów, chwiejny chód, wakuolizacja rogówki, brak łaknienia, nudności, wymioty, bóle brzucha, zapalenie skóry*
ά-pinene *ά-pinen* CAS No. 7785-70-8	–	–	–	Irritation of upper respiratory tract, eyes and skin, allergy, possible damageor irritation of mucous membrane *Podrażnienie górnych dróg oddechowych, oczu, skóry, alergia, możliwe uszkodzenia lub podrażnienie błony śluzowej*
2-butoxyethanol *2-butoksyetanol* CAS No. 111-76-2	98 000	200 000	–	Irritation of eyes, skin, nose and throat; hemolysis, hematuria, central nervous system depression, headaches; vomiting *Podrażnienie oczu, skóry, nosa, gardła, hemoliza, krwiomocz, depresja ośrodkowego układu nerwowego, bóle głowy, wymioty*
1-butoxy-2-propanol *1-butoksy-2-propanol* CAS No. 5131-66-8	–	–	–	Irritation of eyes and skin *Podrażnienie oczu i skóry*
3-carene *3-karen* CAS No. 13466-78-9	–	–	–	Irritation of upper respiratory tract, eyes and skin, allergy *Podrażnienie górnych dróg oddechowych, oczu, skóry, alergia*
Limonene *Limonen* CAS No. 138-86-3	–	–	–	Irritation of eyes and skin, redness, pain *Podrażnienie oczu, skóry, zaczerwienienie, ból*

Source: Rozporządzenie Ministra Pracy i Polityki Społecznej [2002], ChemSpider | Search and share chemistry [2013]; PAN Pesticides Database: Chemical Active Ingredient Search [2013]; The National Institute for Occupational Safety and Health (NIOSH) [2013]; Material Safety Data Sheets – Pharmco-Aaper [2013]
Źródło: Rozporządzenie Ministra Pracy i Polityki Społecznej [2002], ChemSpider | Search and share chemistry [2013]; PAN Pesticides Database: Chemical Active Ingredient Search [2013]; The National Institute for Occupational Safety and Health (NIOSH) [2013]; Material Safety Data Sheets – Pharmco-Aaper [2013]

The low concentrations of the volatile organic compounds found in the air of the examined production halls are most probably a consequence of the furniture surface finishing technology adopted in that production plant. Water-borne products are mostly applied in that plant in furniture surface finishing, such as e.g. UV-hardened products. In hall no. 1, in which the operating lacquering line was equipped with a UV drying tunnel, the concentration of volatile organic compounds was one of the lowest (min. 950 $\mu g/m^3$, max. 1277 $\mu g/m^3$, mean 1079 $\mu g/m^3$).

A quantitative assessment of the occupational risk associated with exposure to chemical factors may be conducted only for those substances, for which the occupational exposure limits were specified in the respective regulations. For the relatively large number of identified compounds, these values have not been determined to date. This pertains to such compounds as n-butyl ether, 1-methoxy--2-propyl acetate and 1-butoxy-2-propanol, as well as terpenes - compounds commonly found in wood and wood-based processing plants, i.e. α-pinene, 3-carene and limonene.

However, these compounds, as shown in table 4, may have a negative effect on the health of workers. Long-term, repeated exposure and inhalation of these compounds, even at slight concentrations, may cause irritation of the eyes, skin, nose and throat, dizziness, excitability, drowsiness, incoordination, nausea, vomiting, abdominal pain, depression, as well as allergies, and they may irritate the mucous membrane.

Moreover, the maximum admissible ceiling concentration (NSDP) values have not been specified for any of the identified compounds.

We need to be aware that workers are exposed to VOC not only in the work place, but these compounds are also found in housing facilities. As research has shown, organic pollutant levels in housing facilities may be close to the level detected in the examined production halls [Krause et al. 1987; Wallace et al. 1991; Brown et al. 1994; Wiglusz 2000; Guo et al. 2003].

Conclusions

1. The VOC content in the air in a production hall, in which the manufacturing process was conducted, varied both in terms of the amounts of the compounds contained and their types.
2. The total concentration of all volatile compounds (TVOC) recorded in the tested production halls varied in a very broad range from 795 to 5113 $\mu g/m^3$.
3. In the air collected from the production halls, a broad spectrum of compounds was detected, mainly alcohols, glycols, aromatic hydrocarbons, aldehydes, esters and terpenes.
4. The application of automated lacquering lines contributed to an improvement in the air quality in the facilities in which this equipment operated.

5. The concentrations of volatile organic compounds identified in the examined production halls were markedly lower than those specified by the Polish legal regulations – the Ordinance of the Minister of Labour and Social Policy of 2002 (with later amendments).

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STĘŻENIE LOTNYCH ZWIĄZKÓW ORGANICZNYCH NA TERENIE HAL PRODUKCYJNYCH W WYBRANYM ZAKŁADZIE PRZEMYSŁU MEBLARSKIEGO

Streszczenie

Celem pracy było określenie stężenia lotnych związków organicznych występujących w powietrzu na terenie pięciu hal produkcyjnych w zakładzie przemysłu meblarskiego. Badaniu poddano hale, w których przeprowadzano zarówno obróbkę mechaniczną drewna i tworzyw drzewnych, jak i hale, w których wykonywano operacje uszlachetniania powierzchni oraz magazyn wyrobów gotowych. Adsorpcję związków obecnych w powietrzu przeprowadzano na sorbencie syntetycznym Tenax TA. Lotne substancje analizowano techniką chromatografii gazowej w połączeniu ze spektrometrią mas i termiczną desorpcją. Stwierdzono, że mikroklimat badanych hal produkcyjnych był zróżnicowany, tak pod względem rodzaju, jak ilości występujących w nich związków. Całkowite stężenie lotnych związków organicznych zmieniało się w bardzo szerokim zakresie, od 795 do 5113 $\mu g/m^3$. W badanym powietrzu występowały głównie związki należące do alkoholi, glikoli, węglowodorów aromatycznych, aldehydów estrów i terpenów. Stężenie zidentyfikowanych w halach produkcyjnych lotnych związków organicznych kształtowało się na zdecydowanie niższym poziomie niż to regulują polskie przepisy prawne, rozporządzenie Ministra Pracy i Polityki Socjalnej z 2002 roku (z późniejszymi zmianami).

Słowa kluczowe: lotne związki organiczne, zanieczyszczenie powietrza, meblarstwo, chromatografia gazowa ze spektrometrią mas i termiczną desorpcją GC/MS/TD)