



Catalytic Air Freshening Diffusers Based on Isopropyl Alcohol - A Major Source of Acetone Indoors

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ABSTRACT

Air fresheners are used in indoor environments for perfuming the ambience and/or masking unpleasant smells. There are several types of air fresheners on the market including those belonging to the family of catalytic diffusers. The fuel of these devices is frequently 2-methylpropanol, which, while operating, is oxidised to acetone. The acetone emission of a catalytic diffuser was measured for two fragrances under controlled laboratory conditions as well as in a private household. Emission rates were 530 mg/h and 660 mg/h respectively. Acetone concentrations of approximately 700 $\mu\text{g}/\text{m}^3$ were measured in a private household three hours after the diffuser was extinguished. Besides isopropyl alcohol, one of the two fragrances contained 2-methylpropanol as a fuel component, which is oxidised to 2-methylpropanal. The emission rate for 2-methylpropanal was 11 mg/h. Catalytic diffusers containing isopropyl alcohol as fuel were identified as being a major indoor source of acetone. Although not a legal requirement, the secondary formation of acetone should be included in product information along with a list of product constituents. As an alternative, a less easily oxidisable solvent could be used.

Keywords: Catalytic diffuser; Air freshener; Acetone, 2-Methylpropanal; IAQ.

INTRODUCTION

Past studies have identified a variety of building and consumer products as sources of indoor air pollution (Wallace, 2001; Edwards *et al.*, 2006; Habib *et al.*, 2006; Singer *et al.*, 2006a, b; Su *et al.*, 2007). Air fresheners are an example of consumer products widely used to perfume indoor environments and mask unpleasant smells and judging by the number of such items on offer via the internet and in regular shops, catalytic diffusers in particular are an increasingly popular type of air freshener. Generally, air fresheners contain dissolved terpenoid fragrances which volatilise during product application and use. The characteristics of the emissions from these products are sometimes not thoroughly established and/or reported, however (Steinemann *et al.*, 2011). Moreover, air fresheners may contain chemicals that can react with other air contaminants (Nazaroff and Weschler, 2004) or, in the case of catalytic diffusers, may be oxidised to form potentially harmful secondary products such as carbonyls.

Studies conducted in the past investigated mainly the fragrance composition (Liu *et al.*, 2004; Nazaroff and

Weschler, 2004; Singer *et al.*, 2006a, b; Jo *et al.*, 2008; Lamas *et al.*, 2010; Lin, 2011) of air fresheners, and the ability of the terpenoids they contain to form terpene reaction products in the presence of ozone (Nazaroff and Weschler, 2004; Singer *et al.*, 2006b; Lamorena and Lee, 2008; Steinemann *et al.*, 2011; Wolkoff *et al.*, 2013). To the knowledge of the authors, no work published to date has reported on acetone emissions from catalytic diffusers as an oxidation product of fragrance components as described in the current investigation.

The purpose of this study was therefore to establish the characteristics of these commonly used domestic devices as regards acetone emissions. Two fragrances were investigated and their respective acetone emission rates determined. Acetone concentrations were measured under realistic conditions, with the catalytic diffuser being used in a private house.

METHODS AND MATERIAL

Air Freshener

The type of air freshener investigated belongs to the family of catalytic diffusers. These are commonly composed of a container that holds a liquid fuel with active substances in solution in which a wick is placed that leads the mixture to a ceramic piece or burner provided with a catalyst on its surface.

The presence of the catalyst activates a combustion

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reaction of the mixture composed of fuel (solvent) and active substances (typically a mixture of terpenes) without the presence of a flame. The heat generated causes evaporation of the active substances dissolved in the mixture. A flame is only required to initiate the catalytic process by heating the ceramic to 150°C and is extinguished after approximately 2 minutes. The alcohol (fuel) from the reservoir is oxidised by the hot ceramic in the presence of air, generating heat (approximately 50°C) and allowing the cycle to continue.

The diffuser was activated for both the chamber experiments as well as for the real-world scenario measurements following the instructions described in the accompanying information leaflet: the diffuser was filled two-thirds with the fragrance liquid; the wick was then placed in the container and left for 20 minutes for equilibration, allowing the wick to soak up the active components; the burner was then lit and the flame was allowed to burn for 2 minutes before it was extinguished; the catalytic process was stopped by capping the diffuser after 30 minutes as recommended by the manufacturer. The diffuser is therefore intended for discontinuous use.

For the determination of the emission rate (ER) during the chamber experiments, the burner head was capped after approximately 4 hours.

Two different fragrances were tested. They were described as having scents of grapefruit (Fragrance A) and pine (Fragrance B). The labels of these two fragrances do not report the detailed composition of the products. Due to flammability risks labels only indicate a content of 95% of isopropyl alcohol.

Main Ingredients–Determination of Fragrances

The main components of the two fragrances investigated were determined by injecting the undiluted fragrances into a gas chromatographic system coupled to a mass selective detector (GC-MS). The GC separation was achieved with an Agilent 5975CN gas chromatographic system coupled to an Agilent 7890A MS detector (Agilent Technologies, Inc., Santa Clara, CA, USA) and a J&W Scientific capillary column (DB-624, 30m × 0.25 mm ID, 1.4 µm film thickness). Gas chromatographic settings: injector temperature: 250°C; constant flow mode, 1 mL/min He; split ratio 1:25; injection volume: 0.5 µL. The temperature programme was 4 min isothermal at 40°C, 4°C/min to 90°C, 15°C/min to 260°C, 5 min isothermal at 260°C. Total runtime: 32.8 min. The mass selective detector was set to scan-mode (30–530 amu).

Sampling

Measurement in Private House - A Realistic Scenario

The catalytic diffuser was tested under realistic conditions in a private house. The diffuser was activated in the living room located on the ground floor following the procedure described under 2.1. The living room has a floor area of approximately 50 m² and a height of 2.7 m, resulting in a volume of approximately 135 m³. Samples were collected in the living room at a distance of approximately 1 m from the diffuser and in the bedroom on the first floor. The first floor is not separated by doors from the ground floor. Investigations were carried out in December and the room

was not aired during the tests, thus simulating typical use of the diffuser during wintertime. Only fragrance A (grapefruit scent) was tested. The average ventilation rate inside the house has not been determined.

Control samples were collected in both the living room and the bedroom before lighting the diffuser. After ignition of the diffuser, samples were taken at defined time intervals (living room: 0/70/140 mins; bedroom: 30/110 mins). Approximately 45 litres of air were collected at a sampling rate of approximately 1.5 L/min on Sep-Pak DNPH-silica cartridges (Sep-Pak DNPH-Silica cartridges, Plus Short Body 360 mg, Part No. WAT037500, Waters Corporation, Milford, MA 01757, USA).

Emission Rates (ER) Determination in Chamber Tests

The emission rate was determined for both fragrances A and B. The catalytic diffuser was placed in the middle of a 30 m³ walk-in environmental chamber (Fig. 1). The chamber allows precise control of temperature, relative humidity and air exchange rate. The air exchange rate was set by introduction of defined volumes of air per unit of time and this was verified by means of tracer gas dilution tests (ASTM E741, 2011). The exclusive use of stainless steel, glass and 'non-stick' poly-tetrafluoroethylene (PTFE) polymer coatings in the interior of the chamber minimises pollutant adsorption and re-emission by the inner walls. The chamber is filled with ultra-clean pre-dried and filtered 'zero' air. The chamber was run at an indoor-realistic air exchange rate of 0.5 h⁻¹. The temperature was set at 23°C and relative humidity at 50%. Homogeneity of the atmosphere inside the chamber is ensured by 3 internal fans. The uncapped diffuser was left for 4h inside the chamber for equilibration before lighting the burner.

The catalytic diffuser was activated as described in 2.1. Three litre air-samples at a flow rate of approximately 1.5 L/min were collected from the chamber (sampling point in chamber wall at approximately 1 m from diffuser and a height of approximately 1 m from the ground) at defined time intervals after extinguishing the flame. Blank samples were additionally taken from the chamber before and after the four hour equilibration period (before lighting the burner). All samples were collected on Sep-Pak DNPH-silica cartridges (Sep-Pak DNPH-Silica cartridges, Plus Short Body 360 mg, Part No. WAT037500, Waters Corporation, Milford, MA 01757, USA).

Sample Preparation and Analysis (DNPH-Cartridges)

The cartridges were eluted with acetonitrile into a 5 mL volumetric flask and analysed against external calibration with a HPLC system coupled to a diode array detector following ISO 16000-3 (2001). The liquid chromatographic system (HPLC) used consisted of an Agilent Series 1100 system (Agilent Technologies, Inc., Santa Clara, CA, USA), composed of a G1312A binary pump, a G1379A degassing device, a G1329A Autosampler and a G1315B Diode Array Detector set at 360 nm. The chromatographic separation was performed on a Waters Nova-Pak C18, 60 Å, 4 µm (3.9 × 300) mm column (Waters Corp., Milford, MA, USA) and a mobile phase composed of acetonitrile, tetrahydrofuran

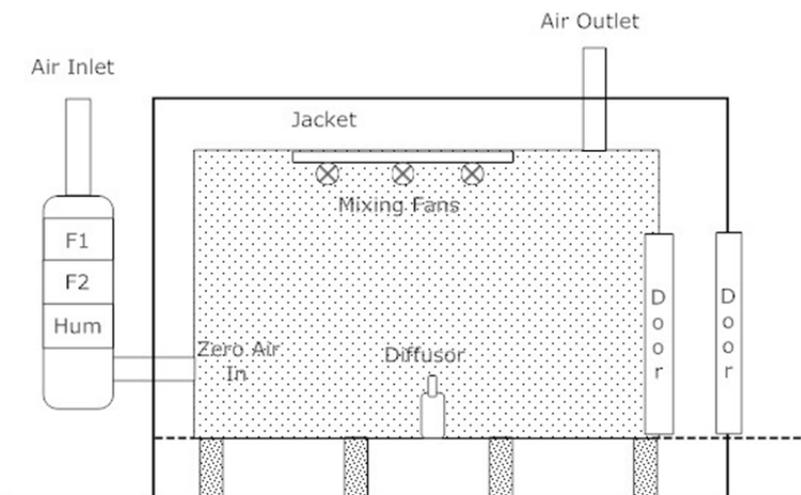


Fig. 1. Scheme of walk-in environmental chamber. Heaters/coolers in the insulated jacket permit accurate temperature setting inside the chamber. Ceiling-mounted fans provide homogeneous pollutant and temperature distribution. Outside air is dried, filtered for particles (F1) and pollutants (F2, activated charcoal filters) before entering the chamber as ultra-clean air. Controlled humidification is achieved by steam injection into the dry airflow immediately before entering the chamber (Hum).

and water which allowed separation of acetone-DNPH from acrolein-DNPH.

Quality Assurance/Control for Acetone and 2-Methylpropanal Measurements

Quality control included the sampling of duplicate air samples and the analysis of blank DNPH-cartridges. Duplicates were considered acceptable when the difference between the two calculated concentrations was lower than 10%. Sample loss was avoided by adapting the amount of sampled air to sorbent capacity. A distinct peak of unconverted 2, 4-dinitrophenylhydrazine was visible in all chromatograms. Sampling flows of 1.5 L/min, as applied in the current study, are reported in the manufacturer's leaflet to achieve collection efficiencies of > 95%. Collected air volumes were measured with a calibrated experimental gas meter (Wet Type V2A Series, Elster-Instromet GmbH, Mainz-Kastel, Germany). Cartridges were stored in a dark and cool place before analysis and were eluted and analysed within 48 hours of sample collection.

RESULTS AND DISCUSSION

Main Ingredients - Determination of Fragrance Composition and Hypothesis for Acetone-Formation

While employing catalytic diffusers in the context of terpene-ozone reaction chamber studies, we regularly detected unexpectedly high concentrations of acetone in the chamber air. Not knowing the source of these elevated acetone concentrations, we suspected acetone was part of the fragrance itself. Therefore, we determined the main components of the two liquid fragrances investigated by gas chromatography coupled to a mass-selective detector. Results are shown in Fig. 2. The main components of fragrance A were α -pinene, β -myrcene, D-limonene and 3-carene. These terpenes are dissolved in isopropyl alcohol. The

main components of fragrance B were α -pinene, camphene, 4-carene, D-limonene, eucalyptol and isobutylacetate. The gas-chromatogram of fragrance B shows two major solvent (fuel) peaks: isopropyl alcohol and 2-methylpropanol.

Results show that the original fragrances contain neither acetone nor 2-methylpropanal. Their occurrence in air can therefore not be attributed to diffusion/evaporation effects of the product. They are formed during the operation of the diffuser, rather than already being present in the fragrance itself. Looking at the main components identified in the gas-chromatogram, isopropyl alcohol and 2-methylpropanol are the reduced alcohols of acetone and 2-methylpropanal respectively. The principle of operation of the diffusers is based on catalysis, which produces acetone and 2-methylpropanal by dehydrogenation (oxidation) of the respective alcohols while passing over the catalyst.

For qualitative confirmation, the diffuser was filled with pure isopropyl alcohol, activated in a 450 litre chamber following the procedure described in 2.1 and the presence of acetone measured by sampling on DNPH-covered silica cartridges and consequent analysis with HPLC-DAD (see 2.4). High amounts of acetone were detected in the chamber air.

Determination of Emission Rates for Acetone and 2-Methylpropanal

Once it had been ascertained that acetone and 2-methylpropanal were formed by catalytic oxidation of the corresponding alcohols, the emission rates from the diffuser for both chemicals were determined. For this purpose, the diffuser was placed in an environmental walk-in chamber which was maintained at a specified temperature, relative humidity and ventilation rate (see 2.3.2). As the air in the chamber was fully mixed by internal fans, the acetone and 2-methylpropanal concentrations measured were representative of air concentrations in the chamber. The

emission rate of a specific compound is defined as the total mass of a chemical emitted from a product per hour and

was calculated following Eq. (1) where c is the measured substance concentration in the chamber:

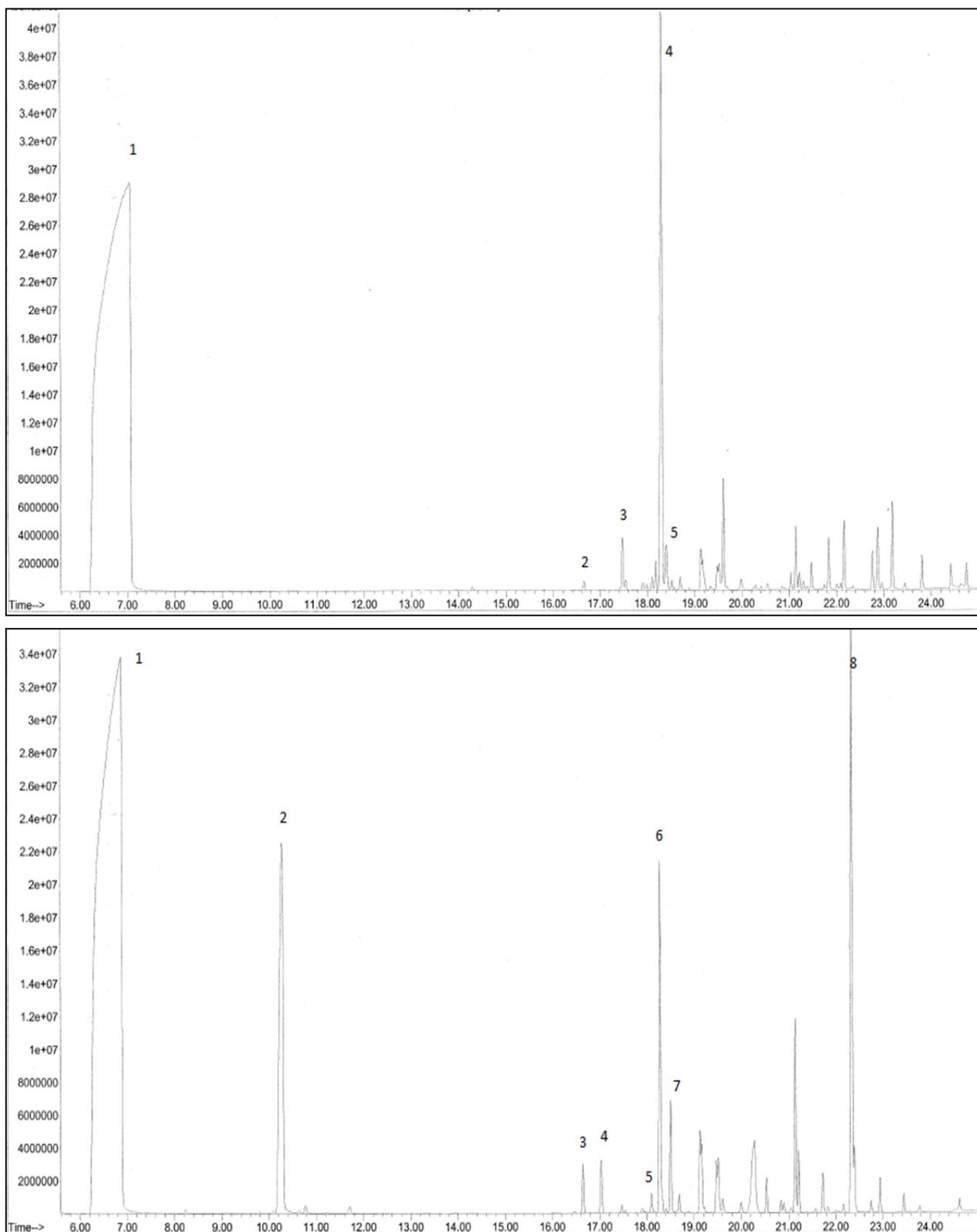


Fig 2. Composition fragrances. Fragrance A (top): (1) isopropyl alcohol, (2) α -pinene, (3) β -myrcene, (4) D-limonene, (5) 3-carene. Fragrance B (bottom): (1) isopropyl alcohol, (2) 2-methylpropanol, (3) α -pinene, (4) camphene, (5) 4-carene, (6) D-limonene, (7) eucalyptol, (8) isobutylacetate.

$$ER \text{ [mg/h]} = c \text{ (mg/m}^3\text{)} \times \text{chamber volume (m}^3\text{)} \times \text{air exchange rate (h}^{-1}\text{)} \quad (1)$$

Air samples were drawn from the chamber at defined time-intervals. The course of the acetone and 2-methylpropanal concentrations for both fragrances is depicted in Fig. 3. Emission rates were calculated when the concentrations reached the steady-state status. Emission rates for acetone were 530 mg/h and 660 mg/h for fragrances A and B respectively. 2-Methylpropanal was detected only in fragrance B and its emission rate was 11 mg/h.

The calculated emission rates of > 500 mg/h for acetone and of around 10 mg/h for 2-methylpropanal were significant. Saarela *et al.* (1994) found emission rates of acetone for 27 different flooring materials, typically used indoors, were 14 $\mu\text{g/m}^2/\text{h}$ (mean) and 31 $\mu\text{g/m}^2/\text{h}$ (maximum). Considering a flooring surface of 90 m^2 , emission rates of 1.3 and 2.8 mg/h are obtained respectively. In comparison, emission rates calculated for the catalytic diffuser are approximately 160 times higher.

Determination of Acetone Concentration under Realistic Conditions

To assess the impact of the catalytic device on a realistic indoor environment, it was deployed in a private house, following the instructions provided by the manufacturer (see 2.3.1). Only fragrance A (grapefruit scent) was tested in this setup. Air samples were collected both in the living room where the diffuser was located (ground floor) and a bedroom located on the first floor. Windows were kept closed during the whole experiment, simulating typical use of the

catalytic diffuser during wintertime. Results are shown in Fig. 4.

Interestingly, the acetone concentration measured in the bedroom located on the first floor is slightly higher compared to that measured in the living room where the diffuser was placed. This might be explained by the fact that the first floor is not separated by any barrier (e.g., doors) from the living room and the tendency of air heated by radiators to move upwards to the first floor by heat-convection.

Results show that even approximately three hours after capping the catalytic diffuser, the acetone concentration was still around $700 \mu\text{g/m}^3$. Although not measured, concentrations for time periods > 3 h can be roughly estimated following the regression curve equation (Eq. (2), for bedroom) extrapolated from the curve in Fig. 4:

$$c \text{ (Acetone, } \mu\text{g/m}^3\text{)} = -642.6 \ln(x) + 4185.5 \quad (2)$$

where x is the time since the diffuser was capped (mins).

Using Eq. (2), it can be estimated that concentrations corresponding to that before starting the diffuser in this specific house would be reached after approximately 11 hours. Assuming a realistic situation where the catalytic diffuser is activated around 8 pm, acetone would therefore be completely removed the next day around 7 am. The given scenario does not represent a realistic worst case scenario since the total dilution volume of the open plan design of the house chosen in this study is considerably higher than if the device was used in a closed room.

Acetone has a relatively low toxicity potential. With respect to sensory irritation (nasal pungency and eye irritation)

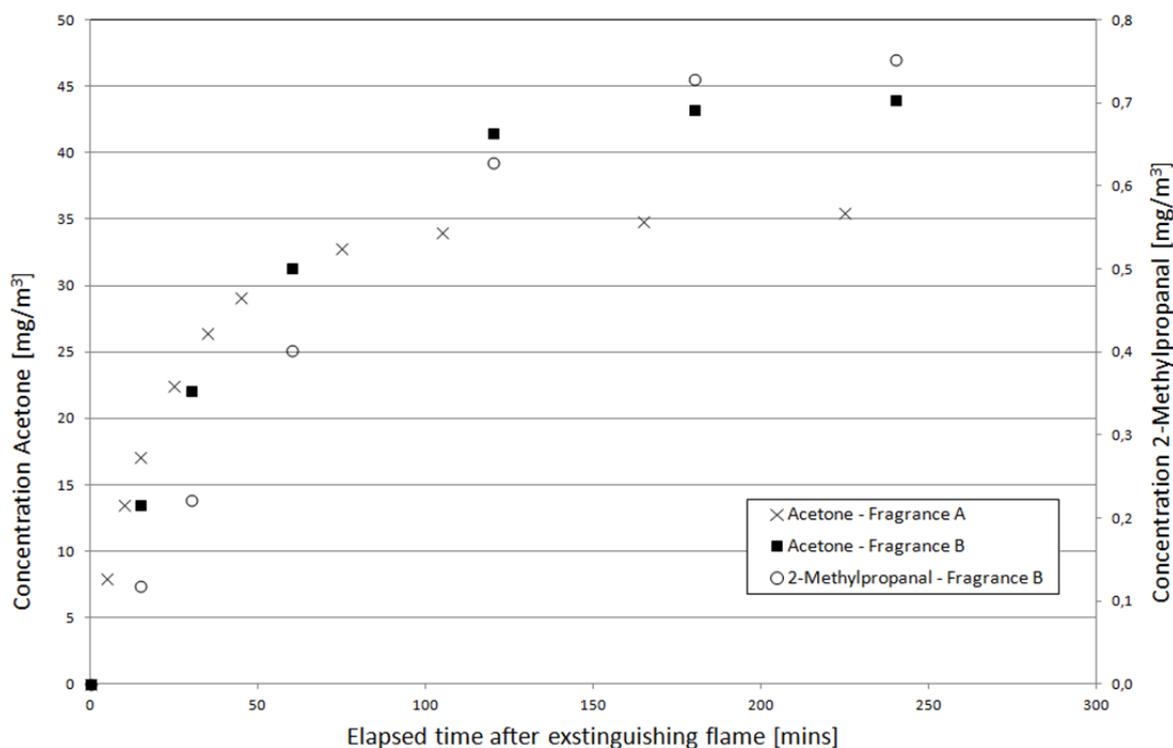


Fig. 3. Chamber experiments. Measured acetone and 2-methylpropanal-concentrations after extinguishing the flame (air exchange rate 0.5 h^{-1}).

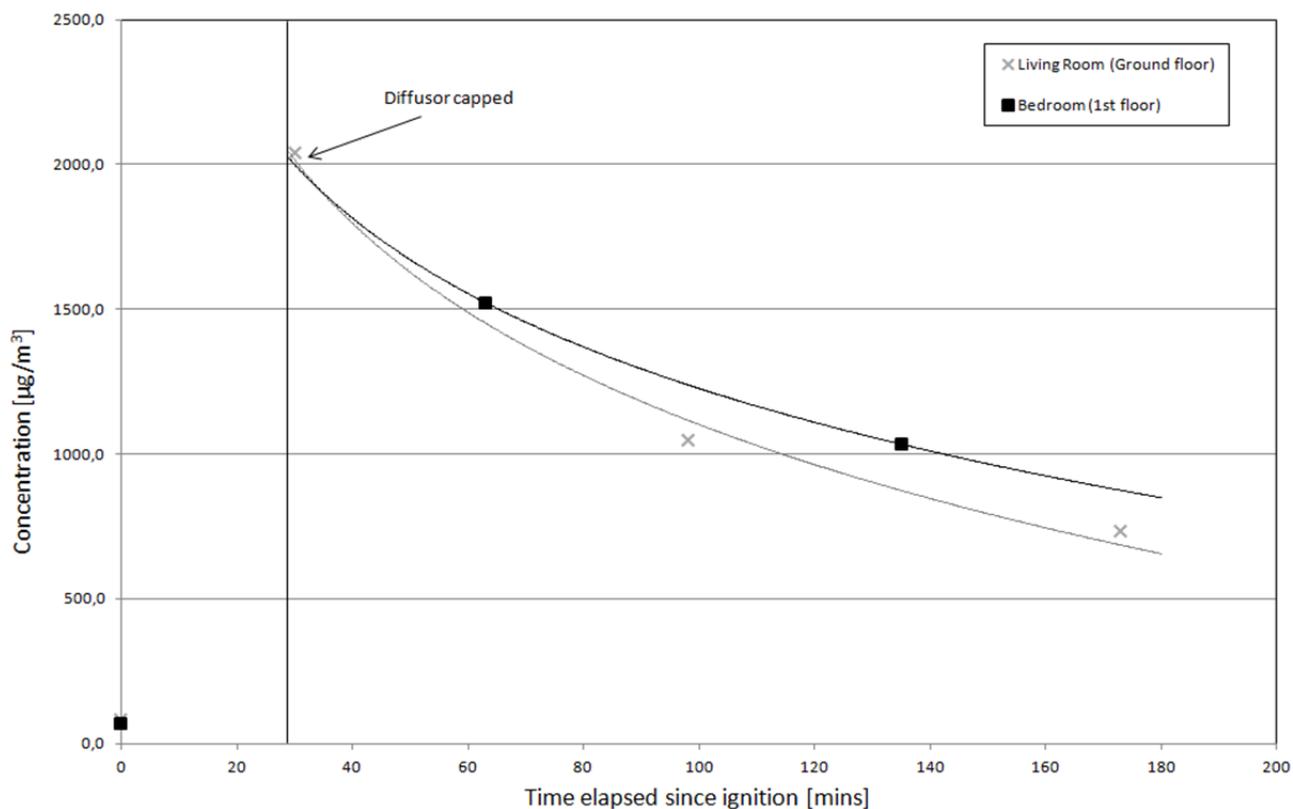


Fig. 4. Acetone concentration in living room (ground floor) and bed-room (1st floor) of private house (Fragrance A). Concentrations of control-samples taken before lighting the diffusor are plotted at t_0 .

levels between 10000 and 40000 ppm were reported (Arts *et al.*, 2002). The odour threshold ranges from 20 to 400 ppm (Arts *et al.*, 2002). Currently no indoor air guideline value has been released for acetone, however concentrations measured in this study can be compared with a variety of occupational limit values: the European occupational exposure limit (European Commission, 2000) for an 8-hour Time Weighted Average (TWA) is set at 500 ppm (1200 mg/m³). The American Conference of Governmental Industrial Hygienists (ACGIH, 2001) has adopted a 500 ppm (1200 mg/m³) Threshold Limit Value (TLV) for acetone for an 8-hour Time Weighted Average (TWA) exposure and a STEL (Short Term Exposure Limit) of 750 ppm (1800 mg/m³). The Occupational Safety and Health Administration PEL (Permissible Exposure Limit) for acetone is 1000 ppm (2400 mg/m³). The recommended airborne exposure limit (REL) adopted by NIOSH (1988) is 250 ppm (600 mg/m³) averaged over a 10-hour working shift.

Acetone concentrations measured in this study in the private house are approximately 300-fold lower compared to workplace exposure limits listed above and, even extrapolating from the working population to the general population, would still leave a large safety margin.

However, compared to acetone concentrations typically measured in office- and residential indoor environments where people (including children) on average spend 2/3 of a day (Leech *et al.*, 2002; Brasche and Bischof, 2005), the concentrations measured in the private house in this study are far higher. In the frame of the AIRMEX study (Geiss *et*

al., 2011) where a variety of volatile organic compounds were measured in public buildings, schools and private houses in various European cities, median acetone concentrations of 19.5 µg/m³ and 31 µg/m³ were measured for offices/classrooms and private houses respectively. Baez *et al.* (2003) measured acetone levels ranging from 17 to 89 µg/m³ (arithmetic mean) in private houses, museums and offices in Mexico City and Xalapa. During the “Relationship of Indoor, Outdoor, and Personal Air (RIOPA) study” (Liu *et al.*, 2006) a median acetone concentration of 8 µg/m³ was measured in 353 private houses in the United States. Values measured in the above described studies are on average approximately 30 times lower than the acetone concentration measured two hours after extinguishing the flame of the catalytic diffusor in the current study. This demonstrates that the use of isopropyl alcohol based catalytic diffusers strongly contributes to the accumulation of acetone indoors. Generally, emissions of volatile organic compounds into indoor air should be kept as low as possible. The rationale is that the lower the concentrations of pollutants the lower the risk that the pollutant itself or the pollutant in a mixture contributes to the deterioration of perceived air quality and wellbeing.

CONCLUSIONS

Air fresheners based on catalytic diffusion and containing isopropyl alcohol as fuel were identified as being a major indoor source for acetone. Although the measured

concentrations are far below guideline values for occupational environments, consideration should be given to the fact that people spend large periods of time in their homes and the importance of the indoor environment for human health. Given that the private indoor environment can only be partially regulated, because it is the private sphere of the occupants, it is important, for the purpose of risk reduction, to provide information on chemical constituents for all types of products. In the specific case of catalytic diffusers, the secondary formation of acetone should be included in product information, along with a list of product constituents. Isopropyl-alcohol could be replaced with a less easily oxidisable solvent to avoid the formation of acetone or other secondary pollutants.

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REFERENCES

- ACGIH (2001). American Conference of Governmental Industrial Hygienists, Acetone: TLV - Chemical Substances 7th Edition — Documentation.
- Arts, J.H.E., Mojet, J., van Gemert, L.J., Emmen, H.H., Lammers, J.H.C.M., Marquart, J., Woutersen, R.A. and Feron, V.J. (2002). An Analysis of Human Response to the Irritancy of Acetone Vapors. *Crit. Rev. Toxicol.* 32: 43–66.
- ASTM Standard E741 (2011). Standard Test Method for Determining air Change in a Single Zone by Means of a Tracer Gas Dilution, ASTM International, West Conshohocken, PA, 2011, www.astm.org.
- Baez, A., Padilla, H., Garcia, R., del Carmen Torres, M., Rosas, I. and Belmont, R. (2003). Carbonyl Levels in Indoor and Outdoor Air in Mexico City and Xalapa, Mexico. *Sci. Total Environ.* 302: 211–226.
- Brasche, S. and Bischof, W. (2005). Daily Time Spent Indoors in German Homes - Baseline Data for the Assessment of Indoor Exposure of German Occupants. *Int. J. Hyg. Environ. Health* 208: 247–253.
- Edwards, R.D., Schweizer, C., Llacqua, V., Lai, H.K., Jantunen, M. and Bayer-Oglesby, L. (2006). Time Activity Relationships to VOC Personal Exposure Factors. *Atmos. Environ.* 40: 5685–5700.
- European Commission (2000). Directive 2000/39/EC of 8 June 2000 Establishing a First List of Indicative Occupational Limit Values in Implementation of Council Directive 98/24/EC on the Protection of the Health and Safety of Workers from the Risk Related to Chemical Agents at Work, Official Journal of the European Communities, L142/p. 47 (16/6/2000).
- Geiss, O., Giannopoulos, G., Tirendi, S., Barrero-Moreno, J., Larsen, B.R. and Kotzias, D. (2011). The AIRMEX Study - VOC Measurements in Public Buildings and Schools/Kindergartens in Eleven European Cities: Statistical Analysis of the Data. *Atmos. Environ.* 45: 3676–3684.
- Habib, R.R., El-Masri, A. and Heath, R.L. (2006). Women's Strategies for Handling Household Detergents. *Environ. Res.* 101: 184–194.
- ISO 16000-3 (2001). Indoor Air - Part 3: Determination of Formaldehyde and other Carbonyl Compounds - Active Sampling Method, Geneva, Switzerland, International Organisation for Standardisation.
- Jo, W.K., Lee, J.H. and Kim, M.K. (2008). Head-Space, Small-Chamber and In-Vehicle Tests for Volatile Organic Compounds (VOCs) Emitted from Air Fresheners for the Korean Market. *Chemosphere* 70: 1827–1834.
- Lamas, J.P., Sanchez-Prado, L., Garcia-Jares, C. and Llompart, M. (2010). Determination of Fragrance Allergens in Indoor Air by Active Sampling Followed by ultrasound-Assisted Solvent Extraction and Gas Chromatography-Mass Spectrometry. *J. Chromatogr. A* 1217: 1882–1890.
- Lamorena, R.B. and Lee, W. (2008). Influence of Ozone Concentration and Temperature on Ultra-Fine Particle and Gaseous Volatile Organic Compound Formations Generated during the Ozone-Initiated Reactions with Emitted Terpenes from a Car Air Freshener. *J. Hazard. Mater.* 158: 471–477.
- Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S. and Raizenne, M.E. (2002). It's about Time: A Comparison of Canadian and American Time-Activity Pattern. *J. Exposure Anal. Environ. Epidemiol.* 12: 427–432.
- Lin, T.S. (2011). Indoor Air Pollution: Unusual Sources. *Encycl. Environ. Health* 201–207.
- Liu, W., Zhang, J., Zhang, L., Turpin, B.J., Weisel, C.P., Morandi, M.T., Stock, T.H., Colome, S. and Korn, L.R. (2006). Estimating Contributions of Indoor and Outdoor Sources to Indoor Carbonyl Concentrations in Three Urban Areas of the United States. *Atmos. Environ.* 40: 2202–2214.
- Liu, X.Y., Mason, M., Krebs, K. and Sparks, L. (2004). Full-Scale Chamber Investigation and Simulation of Air-Freshener Emissions in the Presence of Ozone. *Environ. Sci. Technol.* 38: 2802–2812.
- Nazaroff, W.W. and Weschler, C.J. (2004). Cleaning Products and air Fresheners: Exposure to Primary and Secondary Air Pollutants. *Atmos. Environ.* 38: 2841–2865.
- NIOSH (1988). The National Institute for Occupational Safety and Health, Occupational Safety and Health Guideline for Acetone.
- Saarela, K., Tirkkonen, T. and Tähtinen, M. (1994). *Preliminary Data Base for Material Emissions*, NKB Committee and Work Report 1994: 04E, ISBN 951-47-9858-9, Painatuskesku Oy, Helsinki.
- Singer, B.C., Destailats, H., Hodgson, A.T. and Nazaroff, W.W. (2006a). Cleaning Products and Air Fresheners: Emissions and Resulting Concentrations of Glycol Ethers and Terpenoids. *Indoor Air* 16: 179–191.
- Singer, B.V., Coleman, B.K., Destailats, H., Hodgson, A.T., Lunden, M.M., Weschler, C.J. and Nazaroff, W.W. (2006b). Indoor Secondary Pollutants from Cleaning Products and air Freshener Use in the Presence of Ozone. *Atmos. Environ.* 40: 6696–6710.
- Steinemann, A.C., MacGregor, I.C., Gordon, S.M.,

- Gallagher, L.G., Davis, A.L., Ribeiro, D.S. and Wallace, L.A. (2011). Fragranced Consumer Products: Chemicals Emitted, Ingredient Unlisted. *Environ. Impact Assess. Rev.* 31: 328–333.
- Su, H.J., Chao, C.J., Chang, H.Y., Wu, P.C. (2007). The Effects of Evaporating Essential Oils on Indoor Air Quality. *Atmos. Environ.* 41: 1230–1236.
- Wallace, L.A. (2001). Assessing Human Exposure to Volatile Organic Compounds. In *Indoor Air Quality Handbook*, Spengler, J.D., McCarthy, J.F. and Samet, J. (Eds.), Mc Graw-Hill, New York, (Chapter 33).
- Wolkoff, P., Larsen, S.T., Hammer, M., Kofoed-Sorensen, V., Clausen, P.A. and Nielsen, G.D. (2013). Human Reference Values for Acute Airway Effects of Five Common Ozone-Initiated Terpene Reaction Products in Indoor Air. *Toxicol. Lett.* 216: 54–64.

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