Second Evaluation of Combustion Gases in Scented Paraffin ~~Scented~~ Candles for Toxicologically Relevant Hazardous Substance Classes

Report of Results

Commissioned by:
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Research Report

Introduction:

In a letter of 7/02/1998 the Association of German Candle Manufacturers, Frankfurt am Main, commissioned our institute to perform a study of the combustion gases of a type of scented candle with respect to the toxins polychlorinated dibenzo-p-dioxins and ~~dibenzoduranes~~ dibenzofuranes (PCDD/PCDF), polycyclic aromatic hydrocarbons (PAH) and short-chain aldehydes (formaldehyde, acetaldehyde, acrolein, and propionaldehyde).

The analyses were performed in January 1999. The study subjects were paraffin candles of type OFA 5603 (wick R 18/3"S") with an 8% addition of scent from the one-sixth mixed group. This group includes a mixture of the 77 most commonly used scents, which were tested already in the first study (report of October 1997). In that study the same candle type was used with a 1.5% component of the same scent blend.

The present study is thus primarily for purposes of comparison to the first study.

The objective of the study was to determine the contents of PCDD/PCDF, PAH and aldehydes that can emerge given a defined combustion of the above cited candles in a standardized test apparatus under realistic conditions. The tests were therefore performed analogously to the study performed in 1994 for the Association of German Candle Manufacturers, in which paraffin, stearin and beeswax candles were analyzed. For results and description, see Schwind, K.-H., Hosseinpour, J., Fiedler H., Lau C., Hutzinger O. (1994); Determination and Evaluation of Emissions of PCDD/PCDF, PAH and Short Chain Aldehydes in the Combustion Gasses of Candles. [Bestimmung und Bewertung der Emissionen von PCDD/PCDF, PAK und kurzkettigen Aldehyden in den Brandgasen von Kerzen] UWSF – Z. Umweltchem. Ökotox. 6, 243-46.

The evaluation of the results of the candles studied here is therefore analogous to the system presented in that publication, with an additional comparison of the data to the findings for candles with a 1.5% scent component.

Summary:

The study showed that the combustion emissions of the candles pose no significant risk potential to the consumer of the candle and are safe.

For the substances detected in the candle type, the contents in emissions were always less than 0.6% of the concentrations stipulated for occupational safety. For the model scenario of a 4-hour combustion of 30 candles, the values for benz(a)pyrene and formaldehyde were substantially lower than for comparable cigarette combustion. For PCDD/PCDF these values were above those of a cigarette; however, a comparison to daily ingested quantity showed a negligible proportion of 0.54%.

Comparison to the same candle type with only a 1.5% scent component reveals substantially higher contents of all tested substances, which is quite probably the result of different combustion behaviors. This would also be consistent with previous tests in which no significant toxin elevation could be observed given an optimal combustion.

Results:

~~Combustion~~ Analysis of Combustion Gases

During the combustion of the candles in the test chamber, it could be observed that partial sooting occurred. During combustion outside the chamber using the same candles without scents, the same observation could be made. In addition, the candles with an 8% scent component burn notably more rapidly. It can thus be assumed that this poor combustion behavior influences the analysis.

Table 1: Measured quantities of PCDD/PCDF, PAH and aldehydes produced per g candle wax and comparison to reference values

analyzed substances	candle 8% scented oil	candle 1.5% scented oil	reference value stearin	reference value paraffin	reference value beeswax
PCDD/PCDF (pg I-TE/g)	0.026	0.008	0.027	0.015	0.004
PAH (ng/g) benzo(a)pyrene	0.014	0.011	<0.01	0.01	<0.02
aldehydes (ng/g) formaldehyde acetaldehyde acrolein propionaldehyde	219 <300 <100 <100	94 <1200 <400 <400	- - - -	- - - -	- - - -

Table 2: Measured concentrations of PCDD/PCDF, PAH and aldehydes in the ~~emission~~ exhaust gases of the combustion apparatus and comparison to reference values

analyzed substances	candle 8% scented oil	candle 1.5% scented oil	reference value stearin	reference value paraffin	reference value beeswax
PCDD/PCDF (pg I-TE/m^3)	0.30	0.07	0.340	0.183	0.038
PAH (ng/m^3) benzo(a)pyrene	0.16	0.10	<0.16	0.12	<0.15
aldehydes (mg/m^3) formaldehyde acetaldehyde acrolein propionaldehyde	0.003 <0.010 <0.005 <0.005	0.001 <0.010 <0.005 <0.005	0.006 <0.001 0.009 <0.001	0.017 <0.001 <0.001 <0.001	0.005 <0.001 <0.001 <0.001

Analogously to the previous tests, the concentrations of most of the tested substances are near or even below the detectable limit. In this measurement range, a wider distribution of measurement data is expected, and so the interpretation of an individual measurement result must be seen against this background. For all evaluation parameters the content of emitted hazardous substances of the candle with 8% scent is significantly above the comparison value of the candle with 1.5% scent. The cause here may be the suboptimal combustion when the scent proportion is too high.

Evaluation

Comparison of the Detected Emission Values to Limit Values

The emission values are compared to existing limit, standard, and orientation values by calculating how much of the limit value is exhausted by the candle emission.
This is done according to the following formula:

% of the limit value = (emission value of the candle/limit value)*100%

The bases of evaluation were the MAK value (Maximum Workplace Concentration; highest permitted concentration at the workplace given regular and long-term exposure (daily 8 h, 40 h work week)) and the TRK value (Technical Standard Concentration for carcinogenic substances).

analyzed substances	**quantity in the emission of candle with 8% scented oil**	**TRK value**	**% exhaustion of TRK value**	**MAK value**	**% exhaustion of MAK value**
PCDD/PCDF (pg I-TE/m^3)	0.30	50	0.6		
benzo(a)pyrene (ng/m^3)	0.16	2000	0.008		
formaldehyde (mg/m^3)	0.003			0.6	0.5
acetaldehyde (mg/m^3)	<0.010			90	<0.011
acrolein (mg/m^3)	<0.005			0.25	<2

analyzed substances	% exhaustion of TRK or MAK value	reference value 1.5% scent oil	reference value stearin	reference value paraffin	reference value beeswax
PCDD/PCDF (pg I-TE/m^3)	0.6	0.14	0.7	0.4	0.08
benzo(a)pyrene (ng/m^3)	0.008	0.005	0.008	0.006	0.0075
formaldehyde (mg/m^3)	0.5	0.17	1.0	2.8	0.8
acetaldehyde (mg/m^3)	<0.011	<0.011	0.001	0.001	0.001
acrolein (mg/m^3)	<2	<2	3.6	0.4	0.4

Interpretation:
The values for the substances PCDD/PCDF, benz(a)pyrene and formaldehyde were below the MAK or TRK value by at least a factor of 200. Nevertheless these values are somewhat worse than the values for the candle with 1.5% scent.

Determination of the "Critical Volume"

The "critical volume" serves for evaluating how much a released quantity of hazardous substances can be diluted without crossing the limit value. The values are given in l, so that a value above 1,000 l means that the emissions would have to be diluted by this corresponding additional volume of air in order to maintain the limit value. A volume below 1,000 l means that the limit value will be exceeded when the substances concentrate at this volume. The following calculation applies:

critical volume = (released hazardous substances/limit value)

The released quantity of hazardous substances is based on the simultaneous combustion of 30 candles for a period of 4 h (modeled on Christmas; corresponds to a burned wax quantity of approx. 600 g. or 150 g for gel wax candles), and the TRK and MAK values serve as limit values.

analyzed substances	**released substance quantity given 30 candles with 8% scent**	**critical volume in l**	**comparison value stearin in l**	**comparison value paraffin in l**	**comparison value beeswax in l**
PCDD/PCDF	15.6 pg I-TE	312	324	180	48
benzo(a)pyrene	8.4 ng	4.2	3	3	6
formaldehyde	0.131 mg	218	3	10	4
acetaldehyde	<0.18 mg	<2	-	-	-
acrolein	<0.06 mg	<240	-	-	-

Interpretation:

For the candles with 8% scent, the values for critical volume that were detected already reached the corresponding limit values given concentration by a factor of 20. These values are again somewhat worse than for the candles with 1.5% scent.

Comparison of Combustion Gases To Cigarette Smoke

The hazardous substance quantity released by candle combustion will now be compared to the load produced by cigarette smoke.

The scenario described above (simultaneous combustion of 30 candles for 4 h in a room with a size of 50 m^3) for the candles is compared to the published data for the smoke of one cigarette.

analyzed substances	**released substance quantity given 30 candles with 8% scent**	**airborne concentration candle combustion**	**airborne concentration cigarette smoke**
PCDD/PCDF	15.6 pg I-TE	0.312 pg I-TE/m^3	0.002 pg I-TE/m^3
benzo(a)pyrene	8.4 ng	0.168 ng/m^3	2.6 ng/m^3
formaldehyde	0.131 mg	0.00262 mg/m^3	0.0305 mg/m^3
acetaldehyde	<0.18 mg	<0.0036 mg/m^3	Not specified
acrolein	<0.06 mg	<0.0012 mg/m^3	0.0185 mg/m^3

Interpretation:

For benz(a)pyrene and acrolein the load associated with candles is substantially below the air concentration produced by a cigarette, but for PCDD/PCDF the value is higher. It must be taken into account that only one cigarette was used in the comparison. The candle is naturally somewhat worse than the comparison candle with 1.5% scent.

Ingestion Of PCDD/PCDF With Inhaled Air

Based on the PCDD/PCDF value for the cigarette being exceeded in the section above, in this section the share of ingestion through respiration in relation to total daily ingestion will be calculated for the scenario described.

A respiration volume of 2 m^3 over 4 h was assumed. The total daily ingestion of PCDD/PCDF equals 115 pg l-TE, of which 1.5 pg l-TE is through respiration.

analyzed substances	**ingested substance quantity for 30 candles with 8% scent**	**% of daily ingested quantity (115 pg l-TE = 100%)**	**extra load added to respiratory intake (1.5 pg l-TE = 100%)**
PCDD/PCDF	0.624 pg I-TE	0.54%	41.6%

Interpretation:
Despite the higher comparison value relative to the cigarette, the proportion associated with the described combustion scenario can be seen as negligible. Although the additional contribution to respiratory intake equals 41.6%, over a year's time it is insignificant, because the described "usage" of the candles does not occur on a daily basis.

Bayreuth, March 15, 1999

[signature] [signature]

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Appendix: Individual Results

PCDD/PCDF

Candle Type: Paraffin OFA 5603, wick Wedo R 18/3"S"
plus 8% scent one-sixth mixed group
Lab #: 346/98-1
Sample Volume: 25.455 m^3
Burned Candle Mass: 294.7 g/6h (9 candles)
Burned Candle Mass/h: 5.46 g (1 candle)

	Quantity pg/sample	**I-TE pg/sample**	**Quantity pg/m^3**	**Quantity pg/g wax burned**
Total TCDD	27		1.06	0.092
2,3,7,8-TCDD	3	3.00	0.12	0.010
Total PeCDD	11		0.43	0.037
1,2,3,7,8-PeCDD	1	0.50	0.04	0.003
Total HxCDD	14		0.55	0.048
1,2,3,4,7,8-HxCDD	1	0.10	0.04	0.003
1,2,3,6,7,8-HxCDD	3	0.30	0.12	0.010
1,2,3,7,8,9-HxCDD	2	0.20	0.08	0.007
Total HpCDD	14		0.55	0.048
1,2,3,4,6,7,8-HpCDD	11	0.11	0.43	0.037
OCDD	18	0.02	0.71	0.061
Total PCDD	84	4.23	3.30	0.285
Total TCDF	398		15.64	1.351
2,3,7,8-TCDF	23	2.30	0.90	0.078
Total PeCDF	76		2.99	0.258
1,2,3,7,8-PeCDF	5	0.25	0.20	0.017
2,3,4,7,8-PeCDF	10	5.00	0.39	0.034
Total HxCDF	40		1.57	0.136
1,2,3,4,7,8-HxCDF	7	0.70	0.27	0.024
1,2,3,6,7,8-HxCDF	4	0.40	0.16	0.014
1,2,3,7,8,9-HxCDF	<1	0.10	<0.04	<0.003
2,3,4,6,7,8-HxCDF	3	0.30	0.12	0.010
Total HpCDF	11		0.43	0.037
1,2,3,4,6,7,8-HpCDF	8	0.08	0.31	0.027
1,2,3,4,7,8,9-HpCDF	<3	0.03	<0.12	<0.010
OCDF	<10	0.01	<0.39	<0.034
Total PCDF	535	9.17	21.02	1.815
Total I-TE		13.40	0.53	0.045
I-TE blank value		5.68	0.22	0.019
I-TE caused by candles		**7.72**	**0.30**	**0.026**

PAH

Candle Type: Paraffin OFA 5603, wick Wedo R 18/3"S"
plus 8% scent one-sixth mixed group
Lab #: 346/98-1
Sample Volume: 25.455 m^3
Burned Candle Mass: 294.7 g/6h (9 candles)
Burned Candle Mass/h: 5.46 g (1 candle)

	Quantity ng/sample	**I-TE ng/sample**	**Quantity ng/m^3**	**Quantity ng/g wax burned**
acenaphthene	40	30	0.39	0.034
fluorene	171	52	4.67	0.404
phenanthrene	3430	600	111.18	9.603
anthracene	469	72	15.60	1.347
fluoranthene	308	52	10.06	0.869
pyrene	262	44	8.56	0.740
benz(a)anthracene	43	<10	1.30	0.112
chrysene (+triphenylene)	163	<10	6.01	0.519
benzo(b+j+k)fluoranthene	59	<10	1.92	0.166
benz(a)pyrene	14	<10	0.16	0.014
indeno(1,2,3-cd)pyrene	<10	<10	<0.03	<0.004
benzo(ghi)perylene	<10	<10	<0.03	<0.004
dibenz(ah+ac)anthracene	<10	<10	<0.03	<0.004
Total analyzed PAH	4989	920	159.94	13.819

The data in ng/m^3 and ng/g burned wax are blank value corrected.

Aldehydes

Candle Type: Paraffin OFA 5603, wick Wedo R 18/3"S"
plus 8% scent one-sixth mixed group
Lab #: 346/98-1
Sample Volume: 0.056 m^3 substream
4.649 m^3 whole stream
Burned Candle Mass: 71.0 g/experiment

	Quantity ng/sample	**Blank Value ng/sample**	**Quantity mg/m^3**	**Quantity mg/g wax burned**
formaldehyde	212	25	0.003	219
acetaldehyde	317	330	<0.010	<300
acrolein	<250	<250	<0.005	<100
propionaldehyde	<250	<250	<0.005	<100

The data in mg/m^3 and ng/g burned wax are blank value corrected.