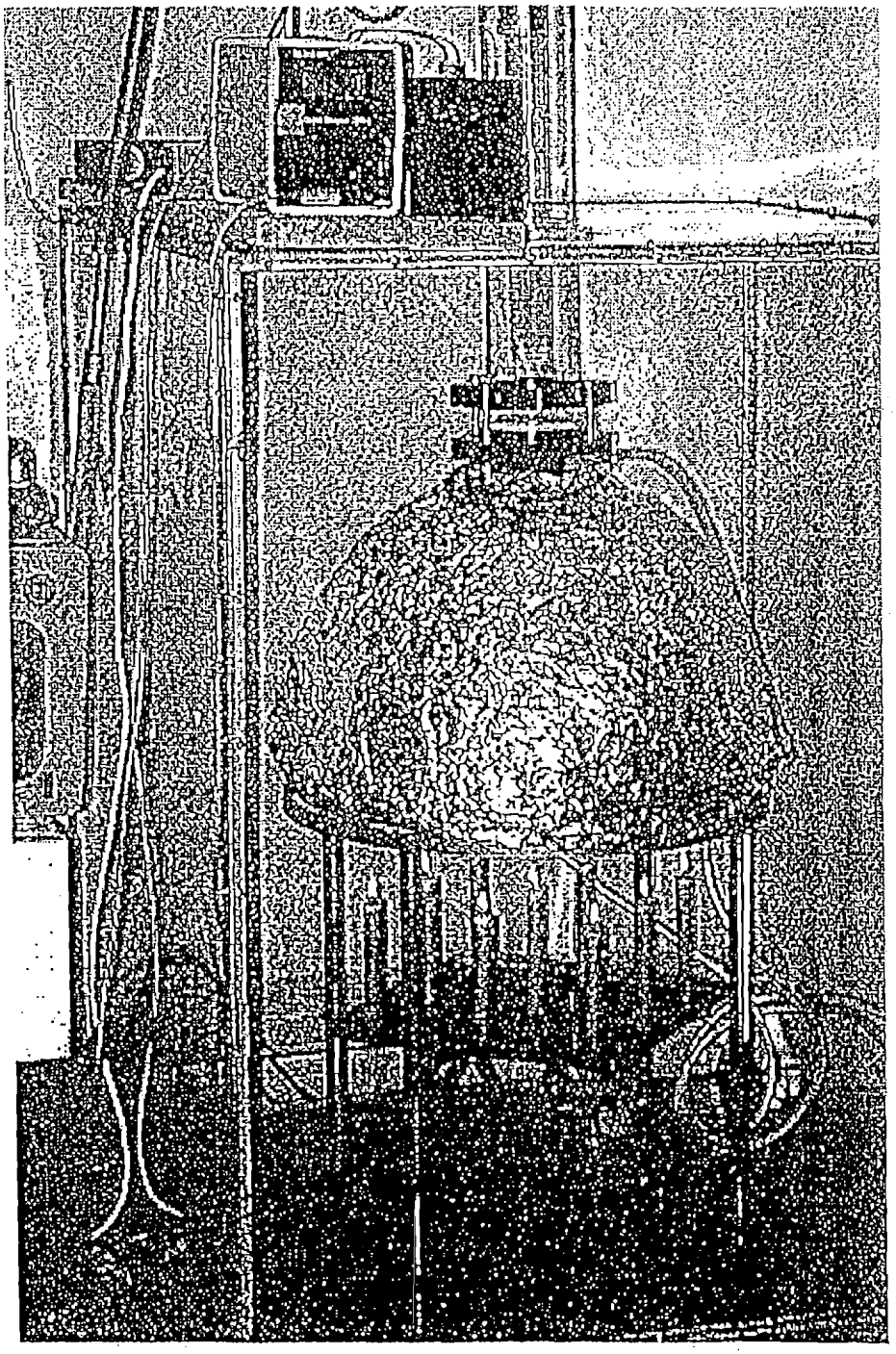
TRANSLATION

Determining and Evaluating the Emissions of PCDD/PCDF, PAH and Short-Chain Aldehydes in Combustion Gases of Candles



Determining and Evaluating the Emissions of PCDD/PCDF, PAH and Short-Chain Aldehydes in Combustion Gases of Candles

- Examination of Waxes and Wicks
- Determining Emissions of Candle Combustion Gases
- Toxicological Evaluation

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Abstract: In the framework of a program investigating the pollutant emissions of paraffin, stearin and beeswax candles without coloring and lacquer additives, both waxes and wicks as well as the combustion gases of these candles were examined for their toxicologically especially relevant pollutant classes of PCDD/PCDF, PAH and short-chain aldehydes. Even with an assumed "worst-case scenario" and allowing for governmental limits and specifications, the toxicological evaluation arrived at the result that the examined candles do not cause any additional health risk.

1 Introduction

Providing atmosphere at festive events, candles radiate warmth, tranquility and comfort. Sales and production figures reflect their great popularity. Presently, for example, about 90,000 tons of candles are produced annually alone in the Federal Republic of Germany [1]. The three wax types used in the German candle production are paraffin, stearin and beeswax, with paraffin wax accounting for 90% of the wax consumption for candles. Stearin has a share of several percent, the market share of beeswax (nearly 1000 tons annually) is estimated at about 1% [2]. Expressed at times, the assumption that the com-

bustion emissions of paraffin candles show toxicologically a more unfavorable picture than the emissions from beeswax and stearin candles - which therefore are said to deserve preference - points to the necessity of systematic examination.

To be able to sufficiently answer these and other questions from scientific aspects, a study program was conducted which also covered the candle raw materials - waxes and wicks - and the combustion gases of these raw materials without additives of coloring and lacquers. While PCDD/PCDF and the major precursor compounds were searched for in the waxes and wicks, the combustion gases were analyzed for their toxicologically relevant pollution of PCDD/PCDF, PAH and short-chain aldehydes. For reason of comparability, all of the paraffin, beeswax and stearin candles tested measured 245 mm in length and 20 mm in diameter. The wax grades of the specimens are in the relevant grad spectrum typical and popular in the German candle production. The same is true for the grades of wicks used [2]. The specimen composition of just wax and wick, i.e., without decorative additives such as coloring, lacquers, glitter and the like, were chosen deliberately so as to obtain representative measuring results for the inevitable major ingredients of any candle, namely wax and wick. This procedure makes it possible to pursue with further measuring programs in the near future the question which effects are being caused by the use of coloring, lacquers and other decorative elements. While such decorated candles have so far been the object of several specific pollutant examinations [3], continuing the present measuring program and using the test equipment developed, however, guarantees defined, reproducible measuring conditions at which more accurately distinguished information can be obtained.

2 Analysis of Candle Raw Materials

At the start of the work, the candle raw materials - paraffin, stearin and beeswax as well as the pertaining wicks - were examined for any contamination by PCDD/PCDF, chlorobenzols, chlorophenols and several selected pesticides.

The analysis of the various wax types for PCDD/PCDF contaminations showed for paraffin 0.59 ng/kg I-TE (toxicity equivalent), for stearin 1.62 ng/kg I-TE, and for the examined beeswax 10.99 ng/kg I-TE. The sum concentrations of chlorophenol in bees-

wax range with 256 µg/kg above those of stearin and paraffin. The chlorobenzol contaminations differ only slightly from one another in all three wax types (refer to Tbl. 1).

The analysis of candle wicks (refer to Tables 2, 3) showed that the three wick types differ from one another only insignificantly with respect to the examined pollutant classes. The PCDD/PCDF values range here between 0.08 and 0.18 ng/kg I-TE (toxicity equivalent). The sum concentrations of chlorophenol range between 0.74 and 1.23 µg/kg, the sum values for chlorobenzol fluctuate between 0.34 and 0.67 µg/kg. The two dichlorodiphenyltrichloroethane (DDT) isomers were found with concentrations of 6 µg/kg respectively 13 µg/kg merely in the wick material of the paraffin candles.

3 Performing Burn Tests

A test chamber with a volume of 1.2 m^3 was developed for the candle burn tests; it allows a reproducible candle burn under conditions approaching reality, with minimal turbulences and defined rates of air exchange. Nine candles each were burned simultaneously in each burn test (refer to Fig. 1). The candle burn took place in burn cycles approaching reality. The candles were extinguished by blowing out, two hours after lighting with a gas lighter; the gases of seconds of aftersmoking were absorbed as well by the collection filter. The next cycle was started after a one-hour pause. Three burn cycles each were conducted to determine the PCDD/PCDF and PAH emissions from the burn gases. In measuring the aldehyde emissions, only one cycle each was run for reasons of sampling.

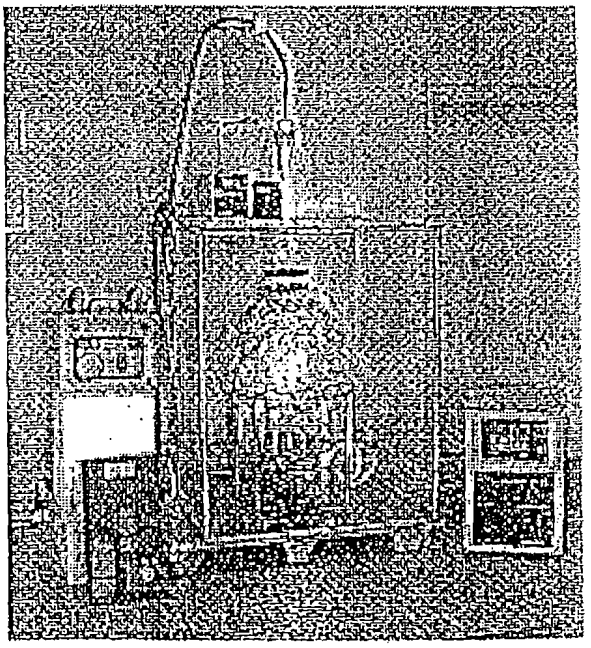

Fig. 1: Test setup for determining the pollutant emissions in the candle burn.

Table 1: PCDD/PCDF, Chlorophenol and Chlorobenzol Contaminations in the Examined Waxes

Wax Type	PCDD/PCDF I-TE* Value in [nanogram/kg]	Chlorophenols Sum Value in [nanogram/kg]	Chlorobenzols Sum Value in [nanogram/kg]
Paraffin	0.59	14.8	0.13
Beeswax	10.99	256.2	0.12
Stearin	1.62	32.3	0.33

*Toxicity equivalent

Table 1: PCDD/PCDF, Chlorophenol and Chlorobenzol Contaminations in the Examined Wicks

Wick Type	PCDD/PCDF I-TE Value in [nanogram/kg]	Chlorophenols Sum Value in [nanogram/kg]	Chlorobenzols Sum Value in [nanogram/kg]
For paraffin candles	0.18	1.23	0.67
For beeswax candles	0.08	0.74	0.35
For stearin candles	0.12	0.94	0.34

Table 3: Pesticide Concentrations in the Examined Wicks

Type of Wick	Pesticides [µg/kg]	
For paraffin candles	alpha-HCH	< 0.5
	gamma-HCH	< 0.5
	o,p'-DDT	6.0
	p,p'DDT	13.0
For beeswax candles	alpha-HCH	< 0.5
	gamma-HCH	< 0.5
	o,p'-DDT	< 1.0
	p,p'DDT	< 1.0
For Stearin Candles	alpha-HCH	< 0.5
	gamma-HCH	< 0.5
	o,p'-DDT	< 1.0
	p,p'DDT	< 1.0

4 Results of Burn Tests

The combustion gases of the respective candles were analyzed for PCDD/PCDF, PAH and short-chain aldehydes. For exact determination of the pollutant quantities emitted by the candles, blank tests were conducted for each of the substance classes examined. The relevant blank value was then deducted from the value of the corresponding burn test. The concentrations compiled in Tables 4–6 are corrected by the relevant blank value. All concentration references by unit (amount of substance/m^3) correspond to the emissions of nine candles.

Although the beeswax used for the candles showed higher PCDD/PCDF and chlorophenol contaminations than paraffin and stearin waxes, the PCDD/PCDF emissions in the burn tests, with 4 femtogram/g of wax burned, are the lowest (refer to Table 4). The conditions of combustion in the candle flame were apparently suited to reduce PCDD and PCDF. The corresponding emission values for paraffin and stearin candles range slightly higher.

Table 4: PCDD/PCDF Emissions from Candle Burn Tests Corrected by Blank Value

Burn Test	I-TEQ* Values [picogram/g wax burned]	I-TEQ* Values [picogram/m^3]
Paraffin candles	0.015	0.183
Beeswax candles	0.004	0.038
Stearin candles	0.027	0.340

*Toxicity equivalent

The PAH emission values found in the burn tests are shown in Table 5. Since the PAH must not be included in the scheme of toxicity equivalent factors (TEF), due to the different working mechanism of the PCDD/PCDF and on account of the metabolic conversion of several of their representatives, any possible hazard potential needs to be estimated for the individual compound. Suitable as a reference substance, e.g., is benzopyrene. The benzopyrene emission in the combustion gases of all three candle types is less than 0.02 nanogram/g of wax burned.

Table 5: PAH Emissions from Candle Burn Tests Corrected by Blank Value

Burn Test Paraffin Candles		Burn Test Beeswax Candles		Burn Test Stearin Candles	
PAH [nanogram/g wax burned]		PAH [nanogram/g wax burned]		PAH [nanogram/g wax burned]	
Naphthalene	152.05	Naphthalene	4.33	Naphthalene	3.36
Acenaphthylene	<0.08	Acenaphthylene	<0.06	Acenaphthylene	<0.06
Acenaphthene	<0.08	Acenaphthene	<0.17	Acenaphthene	<0.02
Fluorene	<0.03	Fluorene	<0.05	Fluorene	<0.07
Phenanthrene	2.81	Phenanthrene	<0.13	Phenanthrene	<0.11
Anthracene	0.19	Anthracene	0.05	Anthracene	0.30
Fluoroanthene	0.35	Fluoroanthene	0.20	Fluoroanthene	0.28
Pyrene	0.20	Pyrene	0.03	Pyrene	0.11
Benzoanthracene	0.01	Benzoanthracene	<0.01	Benzoanthracene	0.01
Chrycene (+triphenylene)	0.05	Chrycene (+triphenylene)	0.01	Chrycene (+triphenylene)	0.02
Benzo(b+j+k)fluoroanth.	0.05	Benzo(b+j+k)fluoroanth.	0.05	Benzo(b+j+k)fluoroanth	<0.01
Benzopyrene	0.01	Benzopyrene	<0.02	Benzopyrene	<0.01
Indeno(1,2,3-cd)pyrene	0.03	Indeno(1,2,3-cd)pyrene	0.04	Indeno(1,2,3-cd)pyrene	0.11
Benzo(ghi)perylene	0.03	Benzo(ghi)perylene	0.05	Benzo(ghi)perylene	0.12
Dibenz(ah+ac)anthracene	0.07	Dibenz(ah+ac)anthracene	0.09	Dibenz(ah+ac)anthracene	0.10
Naphthalene	1810.41	Naphthalene	41.38	Naphthalene	42.75
Acenaphthylene	<0.93	Acenaphthylene	<0.61	Acenaphthylene	<0.79
Acenaphthene	<0.91	Acenaphthene	<1.63	Acenaphthene	<0.24
Fluorene	<0.31	Fluorene	<0.47	Fluorene	<0.88
Phenanthrene	33.51	Phenanthrene	<1.22	Phenanthrene	<1.41
Anthracene	2.28	Anthracene	0.49	Anthracene	3.87
Fluoroanthene	4.16	Fluoroanthene	1.88	Fluoroanthene	3.50
Pyrene	2.37	Pyrene	0.29	Pyrene	1.41
Benzoanthracene	0.12	Benzoanthracene	<0.11	Benzoanthracene	0.11
Chrycene (+triphenylene)	0.63	Chrycene (+triphenylene)	0.05	Chrycene (+triphenylene)	0.20
Benzo(b+j+k)fluoroanth.	0.55	Benzo(b+j+k)fluoroanth.	0.51	Benzo(b+j+k)fluoroanth.	0.87
Benzopyrene	0.12	Benzopyrene	<0.15	Benzopyrene	<0.16
Indeno(1,2,3-cd)pyrene	0.33	Indeno(1,2,3-cd)pyrene	0.36	Indeno(1,2,3-cd)pyrene	1.45
Benzo(ghi)perylene	0.33	Benzo(ghi)perylene	0.45	Benzo(ghi)perylene	1.52
Dibenz(ah+ac)anthracene	0.79	Dibenz(ah+ac)anthracene	0.88	Dibenz(ah+ac)anthracene	1.32

5. Toxicological Evaluation

Basing on the available results and allowing for limits and specifications [4-14] (maximum workplace concentration [MWC] values, carcinogenic limit concentration [CLC] values, World Health Organization [WHO] air quality specifications, Association of German Engineers [VDI] specifications for maximum immission concentrations and others), an additional health hazard due to candle burning is not possible even with an assumed "worst-case scenario" (30 candles burning for 4 hours in a room with 50 m^3

and no air exchange during that time – which is an extreme situation reflecting the maximal load ceiling with all negative factors occurring simultaneously).

Table 6: Aldehyde Emissions from Candle Burn Tests Corrected by Blank Values

Burn Test	Aldehyde [nanogram/g wax used]		Aldehyde [milligram/m^3]	
Paraffin candles	Formaldehyde	14.1	Formaldehyde	0.017
	Acetaldehyde	<0.1	Acetaldehyde	<0.001
	Acrolein	0.1	Acrolein	<0.001
	Propionaldehyde	<0.1	Propionaldehyde	<0.001
Beeswax candles	Formaldehyde	4.7	Formaldehyde	0.005
	Acetaldehyde	<0.3	Acetaldehyde	<0.001
	Acrolein	<0.1	Acrolein	<0.001
	Propionaldehyde	<0.1	Propionaldehyde	<0.001
Stearin candles	Formaldehyde	3.7	Formaldehyde	0.006
	Acetaldehyde	<0.4	Acetaldehyde	<0.001
	Acrolein	5.4	Acrolein	0.009
	Propionaldehyde	<0.1	Propionaldehyde	<0.001

The PAH and aldehyde emissions of 9 paraffin, beeswax or stearin candles burning at the same time range by a multiple below the value produced by a burning cigarette [15]. The dioxin inhalation in such room air is negligible by the average annual inhalation rate. No significant contribution either derives from using the examined candles, not even in rooms with poor or no ventilation at all, as regards the average overall inhalation of PCDD/PCDF.

An additional health risk by way of "inhaled absorption of candle emissions" does toxicologically not derive from the examined substances.

6 Conclusions

The measuring program has shown that the burning emissions of the examined candles do not represent a potential health hazard to the candle user. The burn emissions of the examined paraffin, stearin an beeswax candles show no significant differences with respect to the pollutant classes examined. Candles made from paraffin are toxicologically

just as innocuous as beeswax or stearin candles. These conclusions apply also to the three wick types used.

It should be noted, though, that exclusively noncolored candles without decorative additives were used in the test program. Therefore, further examinations with colored and enameled candles need to be performed.

The test results obtained may serve as a scientific basis for the assessment of the quality and environmental compatibility of candle products.

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