Candle Science & Testing

Report on the Ökometric Wax and Emissions Study

A new, internationally funded study on candle emissions has confirmed that well-made candles of all major wax types exhibit the same clean burning behavior, and pose no discernible risks to human health or indoor air quality.

The independent laboratory tests, conducted at the Bayreuth Institute of Environmental Research in Germany (Ökometric GmbH) and completed in late 2007, constitute the most extensive and rigorous scientific investigation of candle emissions to date.

In carrying out the tests, reference candles made from paraffin, soy wax, stearin, palm wax and beeswax were burned in a specialized testing chamber.

Emission gases were analyzed for more than 300 chemicals known or suspected of toxicity, health risks or respiratory irritation at elevated concentrations.

Targeted chemical groups included dioxins and furans, polycyclic aromatic hydrocarbons, short-chain aldehydes, and volatile organic compounds. Recorded emission levels were then compared to any known relevant indoor-air standards.

The study found all of the waxes burned cleanly and safely, with no appreciable differences in burning behavior. Their combustion byproducts were virtually identical in composition and quantity, with all emissions levels registering far below the most restrictive of any applicable indoor-air standards. (See Table 1 at right.)

A similar but less extensive study of paraffin, stearin and beeswax candles was conducted by the Bayreuth Institute in 1994.

By comparison, the 2007 study added soy and palm to the candle waxes tested, and expanded the target analytes to include an extensive number of volatile organic compounds as well as the polycyclic aromatic hydrocarbons, dioxins/furans and short-chain aldehydes investigated in 1994. No significant differences in candle emission behavior could be detected between the 1994 and 2007 investigations.

A global consortium of industry groups and companies sponsored the Ökometric study. Funding was provided by the Association of European Candle Manufacturers (AECM); the Asociacion Latino Americana de Fabricantes de Velas (ALAFAVE); Cargill, Incorporated; the European Wax Federation (EWF); the National Candle Association (NCA), and the National Petrochemical & Refiners Association (NPRA).

Sasol Wax GmbH and The International Group, Inc. contributed through the preparation and certification of the testing samples and provision of project management personnel.

For the 2007 study, the Ökometric investigators were also asked to undertake a preliminary look at the behavior of sooting candles and the formation of particulate matter. The results of these related investigations are discussed later in this report.

Study Methodology

All laboratory testing was conducted at the Ökometric facility in Bayreuth, Germany, using a burn chamber specifically developed for testing candles and producing uniform burning conditions comparable to real-room situations.

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Container candles consisting solely of a single base wax and wick (no fragrance or dyes) were made for each of the five waxes. The containers were approximately 70 mm wide by 90 mm high (2.75" x 3.5") and held approximately 170 grams (6 oz) of wax.

The five waxes were selected as representative of those most widely used in the global candle industry, and the wicks were appropriate to the different waxes. Care was taken to ensure that the reference candle systems burned efficiently and at comparable wax consumption rates.

For each wax type, nine test candles were burned simultaneously in the test chamber

Table 1: Summary of Reference Candle Emission Findings (All Wax Types)

TARGET COMPOUND	EMISSION RATES* (all waxes)	AVERAGE EMISSION RATE	AVERAGE AIR LEVEL**	STRICTEST INDOOR AIR STANDARD	% of STD
Dioxins/Furans	0.008 - 0.029pg I-TEQ/g	0.013 pg I-TEQ/g	0.005 pg I-TEQ/m^3	0.5 pg I-TEQ/m^3 [a]	1%
Total PAHs	2.737 - 3.966 ng/g	n/a	n/a	n/a	
Benzo[a]pyrene	0.004 - 0.017 ng/g	0.010 ng/g	0.004 ng/m^3	1.0 ng/m^3 [b]	<1%
Total VOCs	3.07 - 10.70 µg/g	5.36 µg/g	1.974 µg/m^3	200.0 µg/m^3 [a]	1%
Benzene	not detected	n/a	n/a	5.0 µg/m^3 [b]	--
Aldehydes					
Formaldehyde	0.66 – 1.77 µg/g	1.088 µg/g	0.397 µg/m^3	60.0 µg/m^3 [c]	<1%
Acetaldehyde	<0.10 – 0.70 µg/g	0.378 µg/g	0.137 µg/m^3	9.0 µg/m^3 [d]	<2%
Acrolein	not detected	n/a	n/a	0.02 µg/m^3 [d]	--
Propionaldehyde	<0.10 – 0.53 µg/g	0.338 µg/g	0.125 µg/m^3	10.0 µg/m^3 [c]	<2%

* Emission rates are per gram of wax consumed, based on an average of 9 candles burned simultaneously for each wax type.

** Conversion of average emission rate to air volume, based on burning a candle for 4 hours in an unventilated 50m^3 room.

[a] IRK/AOLG I [b] EU ambient air [c] AGÖF Intervention [d] EPA Rfc *(see page 3 for descriptions)*

to obtain enough emissions to be detected and quantified. The exhaust gases were then sampled and analyzed according to recognized laboratory procedures and testing standards.

Chemicals Targeted for Analysis	
Dioxins & Furans	Seventeen tetra-octa chlorinated congeners
Polycyclic Aromatic Hydrocarbons	Acenaphthene Fluorene Phenanthrene Anthracene Fluoranthrene Pyrene Benz[a]anthracene Chrysene (+triphenylene) Benzo [b+j+k+] fluoranthene Benzo [a]pyrene Ideno [1, 2, 3-cd] pyrene Benzo [ghj]perylene Dibenz [ah+ac] anthracene
Short-Chain Aldehydes	Formaldehyde Acetaldehyde Propionaldehyde Acrolein
Volatile Organic Compounds	Aliphatic & aromatic hydrocarbons Chlorinated hydrocarbons Terpenes Esters and ketones Phthalates Aldehydes (> C_5) Alcohols and glycolethers Organic acids Others

Emission rates per gram of wax were averaged and converted to indoor air-volume levels to facilitate comparison to air quality standards. For purposes of the study, the air levels were calculated to correspond to the daily burning of one container candle for four hours in an unventilated 50 m^3 room.

Although the exclusion of any air exchange exaggerated the air concentration levels, it was used as a conservative means of accounting for improper burning practices in real-world situations (*e.g.* placing a candle in a draft or not trimming a wick).

The calculated air levels were then compared to any applicable U.S., European or World Health Organization air-quality standards, with evaluation based on the most stringent relevant standard.

Reference Candle Findings (Table 1)

All five of the reference candle systems generated emission rates comparable in composition and quantity, indicating no significant differences in their burning behaviors.

The calculated air concentration levels were also comparable for all of the reference candle types, registering far below the most restrictive of applicable air standards.

A more detailed discussion of the findings for each target compound group is below.

Volatile Organic Compounds

A total of 274 polar, semi-polar and non-polar VOCs were targeted for measurement in the study.

Volatile organic compounds (VOCs) are common indoor air pollutants emitted by a wide variety of household products and building materials. VOCs generally persist in home environments at much higher concentrations than outdoors, and thus are of concern for their potential impact on indoor air quality and health.

Although the laboratory test measured emission levels for each of the 274 target VOC compounds, the summed total of all VOCs detected (Total VOCs or TVOCs) was used to evaluate the findings in terms of an applicable indoor air standard.

In addition, benzene – a common pollutant associated with combustion and a known human carcinogen at high exposure levels – was singled out for separate evaluation.

The total VOC emissions from the reference candles were very low. TVOC levels for paraffin, soy, stearin and beeswax were comparable, ranging from 3.07 to 5.09 micrograms(μg) per gram of wax consumed. Palm wax exhibited a slightly higher emission rate of 10.70 μg/g wax, which was still far below any level of significance.

The closed-room TVOC air levels for all wax types averaged less than 2 percent of the applicable indoor air-quality standard.

Of the 274 individual VOCs to be measured, only 12 were detected in one or more of the reference candles. Of those, only benzaldehyde, benzonitril, acetophenone and 2,5-hexandione were detected in all samples, but at very low levels.

No benzene emissions were detected in any of the reference candle waxes. Similarly, no emissions of styrene, ethylbenzene, naphthalene or phthalates were detected in any of the reference candles.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are typically formed during the incomplete combustion of organic substances and enter the air in soot or attached to dust particles. Some PAHs are known to be toxic at elevated concentrations.

Thirteen key PAH compounds were sampled and analyzed for the study:

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acenaphthene; anthracene; benz[a]anthracene; benzo[a]pyrene; benzo[b+j+k]fluoranthrene; benzo[ghj] perylene; chrysene (+ triphenylene); dibenz[ah+ac]anthracene; fluoranthrene; fluorene; indeno[1,2,3-cd] pyrene; phenanthrene, and pyrene.

The total PAH emissions for all five of the reference-candle waxes were considered comparable, ranging from 2.737 - 3.966 nanograms (ng) per gram of wax.

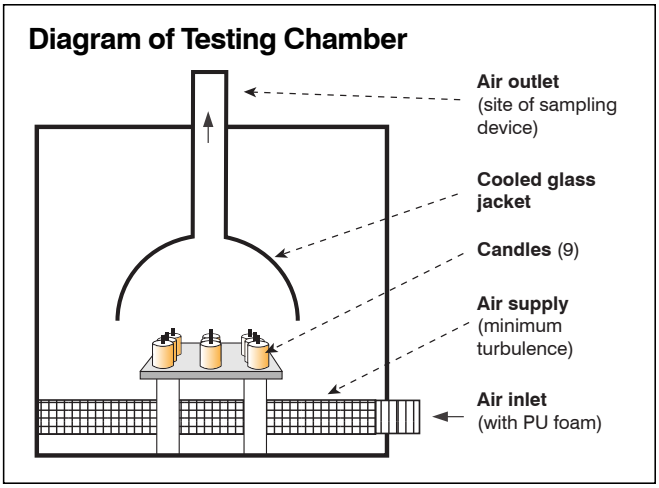
Because PAH compounds cannot be summed to a single toxicity equivalent, benzo[a]pyrene was selected as a benchmark compound for evaluation, since it is a common combustion byproduct and probable human carcinogen that has been studied extensively.

Test results showed the benzo[a]pyrene levels to be among the lowest of all PAH compounds detected in the reference candle emissions, ranging from 0.004 to 0.017 ng/g wax.

Closed-room benzo[a]pyrene air levels for the reference candles were less than 1 percent of the most restrictive air standard.

Dioxins and furans

Seventeen chlorinated dioxin and furan congeners were singled out for sampling and analysis. Dioxins and furans encompass a large group of chlorinated hydrocarbons that bio-accumulate and are highly persistent in the environment. They are typically formed by industrial processing, waste incineration, herbicide manufacturing and



About the Air-Quality Standards Used in the Study

Air standards applicable to the study's target compounds were compiled by Ökometric to evaluate the potential impact of candle emissions on indoor air quality. In certain instances, only one applicable air standard was found to exist.

For each target compound, the most restrictive applicable standard was selected as the evaluation benchmark (see table at right).

Target Compound	Strictest Standard
Dioxins/furans	IRK/AOLG I
Total VOC	IRK/AOLG I
Benzo[a]pyrene	EU value
Benzene	EU value
Formaldehyde	AGÖF II
Propionaldehyde	AGÖF II
Acetaldehyde	RfC (EPA)
Acrolein	RfC (EPA)

Because these benchmark standards were issued by different authoritative bodies using different criteria, they are briefly described below to clarify their distinctions.

IRK/AOLG I – These values were developed by the German Federal Environmental Agency's commission for indoor air hygiene (IRK) and the German state public health authorities (AOLG). The IRK/AOLG I value is considered a level likely to be without appreciable risk of deleterious effects during a lifetime.

EU Value – Published by the European Parliament and the Council of the European Union, the EU values represent target levels to avoid, prevent or reduce harmful effects on human health and the environment as a whole. They will become effective in the EU beginning in 2010.

AGÖF II – AGÖF is a German consortium of companies specializing in indoor air-quality issues. It publishes recommended thresholds based on statistical analysis of its database of air levels typically found in German buildings. The consortium does not collect or evaluate toxicological data. AGÖF II is considered an intervention level.

EPA RfC – The reference concentration (RfC) level of the U.S. Environmental Protection Agency (EPA) represents an estimate of the daily inhalation exposure for the general population, including sensitive individuals, which is likely to be without an appreciable risk of deleterious effects during a lifetime.

combustion. Many dioxins and furans are highly toxic.

Dioxin and furan emissions from all of the reference candles were very low. Paraffin, soy, palm and stearin produced almost identical amounts, ranging from 0.008 to 0.011 picograms (pg) per gram of wax. Beeswax was somewhat higher at 0.029 pg/g wax.

The average closed-room dioxin/furan air levels for the reference candles measured less than 1 percent of the most stringent applicable air standard.

Short-chain aldehydes

Aldehyde compounds are commonly formed by the combustion of hydrocarbons. Four short-chain aldehydes – formaldehyde, acetaldehyde, propionaldehyde, and acrolein – were targeted for sampling and analysis. All are considered respiratory irritants that may pose significant health risks at high exposure levels in indoor air.

No acrolein emissions were detected in any of the tested candle samples. Of the remaining three target aldehydes, formaldehyde was found to be the predominant compound among all wax types. The formaldehyde emissions ranged from 0.66 – 1.17 μg/g of wax for paraffin, soy, stearin and beeswax. Palm wax was somewhat higher, at 1.77 μg/g wax, but still far below any level of concern.

The overall makeup of the aldehyde emissions varied to some extent among the reference candle systems. Formaldehyde, for example, was the only aldehyde detected for paraffin, while acetaldehyde was a prominent secondary aldehyde with soy. For the palm, stearin and beeswax candles, both the acetaldehyde and propionaldehyde emissions were generally apportioned equally as secondary aldehydes.

The average aldehyde air levels ranged from <1 percent (formaldehyde) to <2 percent (acetaldehyde and propionaldehyde) of the most stringent applicable air standards.

Sooting Candles (Table 2)

A secondary objective of the study was to begin investigating the relationship between sooting and emission gases. To accomplish this, identically sized container candles were made from the same paraffin and soy waxes used for the reference candles, but they were intentionally over-wicked to produce greater amounts of soot. The wax consumption rates of the two sooting systems were comparable to each other.

These "high-soot" candles were then tested and analyzed for the same emission gases as the reference candles. Funding constraints permitted the production and testing of only two high-soot candle systems — paraffin and soy.

These were selected because they were deemed the most representative of container candle waxes in the commercial marketplace, and presented an opportunity to compare the sooting behavior of a long-used and studied candle wax with the most popular of the relatively new vegetable-based waxes.

Even though the high-soot candles generally produced greater levels of emissions than the reference candles, they were still far below the most stringent of the applicable air-quality standards.

Emission behaviors of the sooting soy and paraffin candles were very similar to that of their reference candle counterparts, although interesting differences were noted with the TVOC and aldehyde emissions.

Volatile Organic Compounds

The VOC profiles of the high-soot candles were essentially the same for the reference candles. However, the total VOC (TVOC) emissions for the high-soot soy and paraffin samples (1.79 and 2.84 μg/g) were lower than for their respective reference counterparts (3.07 and 4.08 μg/g wax). The reasons

Table 2: High-Soot Candle Emission Rates

TARGET COMPOUND	HIGH-SOOT CANDLES*
Dioxins/Furans	0.034 - 0.057 pg I-TEQ/g
Total PAHs	13.873 – 15.586 ng/g
Benzo[a]pyrene	0.021 - 0.027 ng/g
Total VOCs	1.79 – 2.84 μg/g
Benzene	0.06 – 0.12 μg/g
Aldehydes	
Formaldehyde	2.23 – 3.11 μg/g
Acetaldehyde	2.07 – 2.73 μg/g
Acrolein	not detected
Propionaldehyde	0.54 – 0.74 μg/g

* Soy and paraffin only; rates calculated per gram of wax consumed, based on an average of 9 candles burned simultaneously for each wax type.

for this seeming incongruity will likely be the subject of future industry research.

Of the 274 individual VOCs targeted for measurement in the study, eight were detected in one or both of the high-soot candles. Benzaldehyde, n-octane, benzene and 2,5-hexadione were detected at low levels in both of the high-soot systems, with the benzene hovering just above the detection level.

"Even though the high-soot candles generally produced greater levels of emissions than the reference candles, they were still far below the most stringent of the applicable air-quality standards."

Polycyclic Aromatic Hydrocarbons

Both the high-soot and reference candles exhibited very similar PAH profiles, although the total PAH emissions from the high-soot samples were notably greater than the corresponding reference candles. Total PAH emissions for the high-soot soy and paraffin candles were 13.873 and 15.586 ng/g (compared to 3.363 and 3.713 ng/g for the corresponding reference candles).

The benchmark benzo[a]pyrene emissions still remained very low, averaging 0.024 ng/g for the high-soot candles versus 0.010 ng/g for the reference soy and paraffin.

Dioxins and Furans

The dioxin and furan emissions for both the high-soot and reference candles revealed comparable formation patterns. The total dioxin and furan rates of the high-soot soy and paraffin candles measured 0.034 and 0.057 pg I-TEQ/g respectively, compared to 0.009 and 0.008 pg I-TEQ/g for the corresponding reference samples.

Short-Chain Aldehydes

The high-soot paraffin and soy candles generated notably higher aldehyde emissions than the corresponding reference candles. Although the total aldehyde emission amounts for the high-soot candles were virtually the same, their aldehyde profiles were different from one another, as well as from their counterpart reference candles.

Formaldehyde was the dominant aldehyde with the high-soot paraffin candles at 3.11 μg/g, followed by acetaldehyde at 2.07 μg/g and propionaldehyde at 0.74 μg/g of wax. Only formaldehyde was detected in the reference paraffin candles.

Acetaldehyde was the dominant aldehyde for the high-soot soy candles at 2.73 μg/g, followed by formaldehyde at 2.23 μg/g, and propionaldehyde at 0.54 μg/g wax. This was an inverse of the formaldehyde-acetaldehyde pattern in the reference soy candles.

Particulate Measurements

In addition to the emission gas testing, Ökometric investigators were also asked to characterize the particulate matter emitted from both the reference and high-soot candles, using scanning electron microscopy (SEM) and gravimetric analysis.

The difference in particulate amounts emitted by the reference and high-soot candles was especially dramatic. With the reference candles, the particulate/condensate levels ranged from 6-10 μg/g for the paraffin, soy, palm and stearin candles, to 33 μg/g for beeswax. In contrast, the high-soot soy and paraffin candles generated particulates/ condensates of 146 μg/g and 273 μg/g of wax.

SEM analysis of the particulates generated by both the reference and high-soot candles found small and nearly spherical particles, with extreme variability in the agglomerated particles (see photos at right).

However, none of the primary collected particulates exceeded 100 nanometers in diameter, and no significant difference in the formation patterns could be observed among the different wax types.

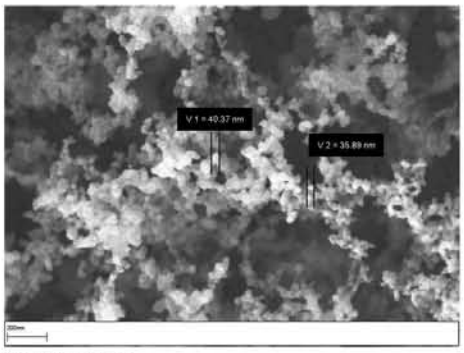
Study investigators also noted that it was difficult to determine the size distribution of the agglomerated particles using SEM. Anticipated follow-on studies are expected to further improve understanding of soot formation and its impact on candle emission patterns and behavior.

Significance of Study

The 2007 Ökometric study has greatly expanded the body of credible scientific data on candle emissions and burning behavior. In addition to demonstrating that the combustion byproducts of all major candle waxes are virtually identical in composition and quantity, the study reconfirms the lack of health or air-quality concerns with candles.

A formal paper on the Ökometric study will be submitted to a peer-reviewed journal for publication.

This report is published jointly by the Association of European Candle Manufacturers (AECM); Asociacion Latino Americana de Fabricantes de Velas (ALAFAVE); Cargill, Incorporated; European Wax Federation (EWF); National Candle Association (NCA); National Petrochemical & Refiners Association (NPRA); Sasol Wax GmbH, and The International Group, Inc. © 2008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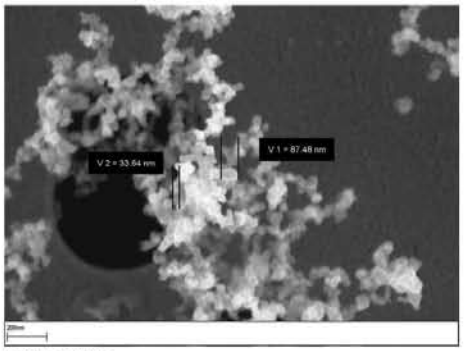
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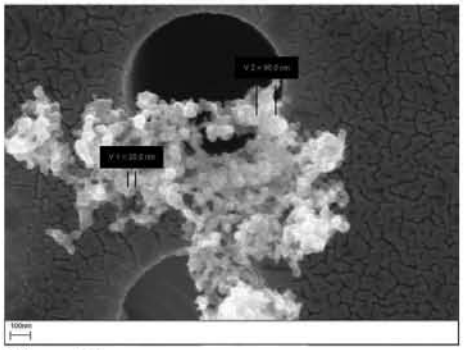
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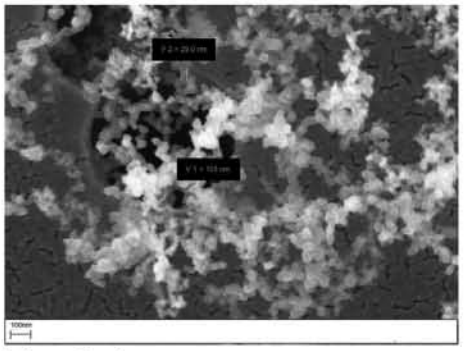
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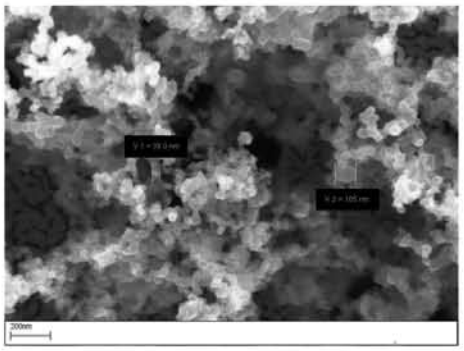
Reference Beeswax