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FLAMMABILITY PARAMETERS OF CANDLES

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Abstract

The paper deals with the assessment of selected fire safety characteristics of candles. Weight loss of a candle during the burning process, candle burning rate, soot index, heat release rate and yield of carbon oxides were determined. Soot index was determined according to EN 15426: 2007 - Candles - Specification for Sooting Behavior. All samples met the prescribed amount of produced soot. Weight loss, heat release rate and the yield of carbon oxides were determined for one selected sample. While yield of CO increased during the measurement, the yield of CO_2 decreased by half in 40 minutes.

Key words

candle, soot index, weight loss, heat release rate, fire safety characteristics of candles

INTRODUCTION

Candles are generally a mixture of various hydrocarbons, coloured esters and fragrance (1). Basic materials used for candles include paraffin, stearin and beeswax (2). A wick is located along the centre of the candle. The principle of the wick is based on the capillary phenomenon. At the surface of the wick, the flammable vapours evaporate and burn (i.e. oxidize). Fuel consumption gradually shortens the candle. Studies show that the choice of a stronger wick usually results in a significant reduction of pourability, and, at the same time, an increase in the burning time, which results in increment of the usefulness of the candle. On the other hand, the disadvantage of stronger wicks is the enhanced soot production (3).

The study of candles focused on the analysis of the shape of a candle flame (4), the modelling of a burning candle (5), the measurement of light intensity (6), the time of candle burning, the influence of the shell and stand on candle flame (7) and the soot production (8, 9).

The main hazard of candles is that they are a possible low energy initiator of fire. An important safety characteristic is soot formation during combustion which we determined in accordance with EN 15426: 2007 - Candles - Specification for Sooting Behavior (10).

Soot is black powder composed mainly of unburnt carbon particles. It is formed as a by-product during incomplete combustion. Main cause of soot formation is the disruption of combustion process or diffusion of flame by air flow etc. Length of the wick has also impact on formation of soot during burning the candle i.e. if the wick is too long, all particles are not burnt, which results the soot production. The main factors affecting the production of soot are the fuel-oxygen ratio, temperature of the flame and critical fuel flow (2, 11).

According to the Environmental Protection Agency (EPA), incineration in the domestic households is a large source of fine particles (11). Insufficient air exchange causes the accumulation of soot. Candles are one of sources of soot accumulation (12). Soot is formed of respirable particles, and therefore is hazardous (13).

Amount of the soot released by burning candle can be expressed by the soot index (Si). It must not be exceeded for 1 hour of burning. Mean soot index per hour (Si_h) from three measurements of the same sample must not exceed the value of 1.0 h^{-1}, while none of these measurements shall exceed 2.0 h^{-1} during a visible combustion of candle. The soot release can be minimised, for example, by choosing the optimum length of wick, and the candle should not be placed in a place with a higher air flow rate (2).

For the exact assessment of initiating sources of fire, it is necessary to obtain information on the behaviour of burning candles. The aim of the contribution was to determine selected fire safety characteristics, such as the time dependence of weight loss and burning rate, the rate of heat release as well as the amount of carbon oxides produced by burning candles and the soot index which indicates the amount of produced soot during the burning.

MATERIALS AND METHODOLOGY OF EXPERIMENT

Five test samples of candles (from different manufacturers) were chosen for experimental determination of their fire safety characteristics (Table 1).

Table 1 Basic characteristics of testing samples of candles

Sample	Colour	Weight [g]	Height [mm]	Diameter [mm]	Shape	Height of wick [mm]
1.	white	60.00	78	40	conical	15
2.	bordeaux	63.00	70	38	conical	13
3.	white	51.58	240	22	conical	16
4.	red	54.84	240	22	conical	19
5.	gold	80.53	290	22	conical	16

Weight loss determination

Weight loss was determined using the Kern 620 analytical balance. The scale was connected via a serial port to a computer where the software read the actual sample weight at the ten second intervals. The sample was placed in a wire mesh cylinder to avoid uneven or impingement air flow. The measurement lasted until the sample was self-extinguished. For Sample 1, weight loss and the rate of weight loss were recorded on the cone calorimeter, while the amount of heat released was also monitored.

Soot index determination

Determination of the soot index was carried out according to EN 15246: 2007 by comparing the light transmission of the clean glass plate with the glass plate contaminated by the soot formed by burning candle. The sample was placed in the prescribed type of the cylinder (Fig. 1) as the diameter of all three samples of candles was less than 70 mm and their

initial weight was greater than 40 g. The Type 1 cylinder was used to provide a uniform flow of air around the sample, not to interfere with the burning of the sample (4).

Soot index was calculated from the obtained data according to the formula:

$$Si = \left(1 - \frac{E_3}{E_1}\right) \times 100 \ ,$$

where:
Si is the soot index,
E_3 is the illuminance of the measuring chamber with the sooted glass plate [lx],
E_1 is the illuminance of the measuring chamber with the cleaned glass plate [lx].

The mean soot index per hour (Si_h) is used to compare the samples with different burning time. It is calculated as the ratio of the soot index to the total measuring time according to:

$$Si_h = \frac{Si}{t_m} \ ,$$

where:
Si_h is the average soot index per hour [h^{-1}],
Si is the soot index,
t_m is the total measuring time [h].

Fig. 1 *Front view of a wire mesh cylinder and a glass plate for determination of soot index of burning candle*

Heat release rate and carbon oxides production rate

When burning, candles release a low yield of carbon oxides and heat in comparison with the (100x100) mm sheet materials tested on a cone calorimeter. To determine the yield of the heat and carbon oxides produced by burning candles, four candles were ignited by an external source at the same time. The resulting values were then calculated for one candle.

RESULTS AND DISCUSSION

Weight loss determination

The time dependence of weight loss and weight loss rate of burning candle No.1 is shown in Figure 2. The graph shows that linear character, indicating the homogeneous burning of the sample during the whole test. The average weight loss rate was 0.075 g min^{-1}.

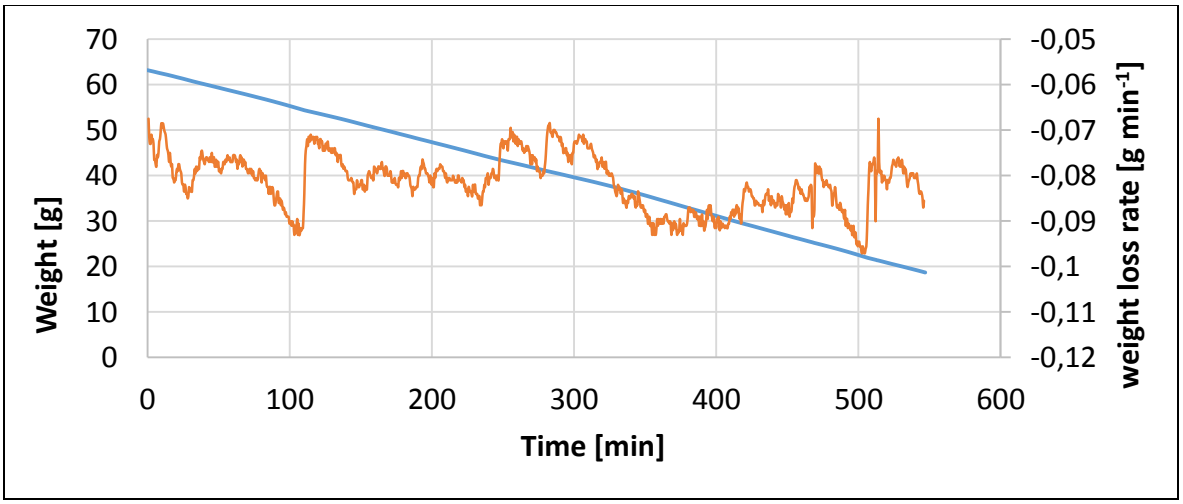

Fig. 2 *Time dependence of weight loss and weight loss rate of burning candle No. 1*

Figure 3 shows the dependence of weight loss on the burning time. All three graphs have a linear character, which indicates the homogeneous burning of the sample during the whole test. Calculated burning rate of candles are: candle No. 3 – 0.1 g min^{-1}, candle No. 4 – 0.115 g min^{-1}, candle No. 5 – 0.099 g min^{-1}.

Candle No. 3 burned almost without leaving the residue, which meant that wax did not melt during its burning (Figure 3). During the burning of candles no. 4 and no. 5 there was a significant melting of the wax on the sides of the candle.

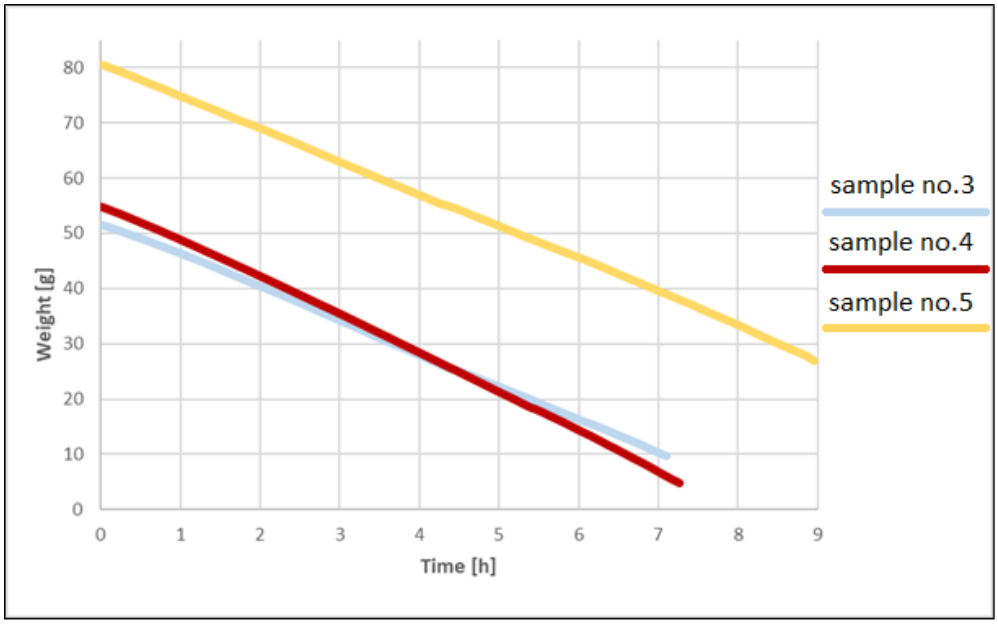

Fig. 3 *Time dependence of weight loss of burning candles Nos.3, 4 and 5*

Soot index

Owing to their dimensions, all five samples were tested in three phases according to EN 15246: 2007 standard. Burning duration of the candles was compared to the burning times during the determination of their weight loss, with the experiment terminating at 10 mm of the non-burnt part of the sample. From the measured data, the soot index and the mean soot index per hour of each sample were calculated. The results can be seen in Figure 4.

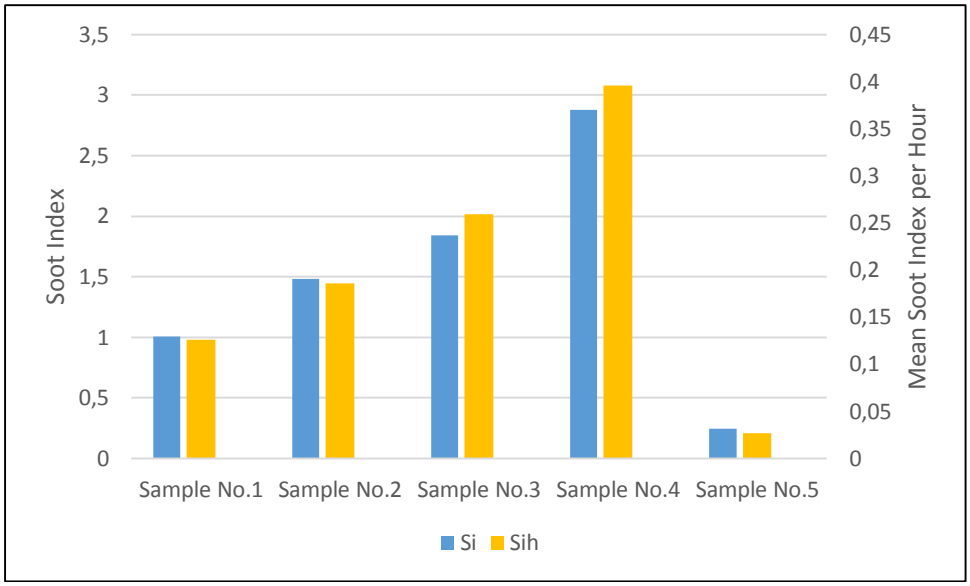

Fig. 4 *Soot index (Si), mean soot index per hour (Si_h) of candles No.1 – 5*

All five samples of candles meet the mentioned standard as none of them exceed the value of mean soot index per hour (2 h^{-1}). The Si and Si_h values of candles No. 3 and No. 4 were different. This is probably due to the colour treatment of the sample No. 4

Heat release rate and production of carbon oxides

The rate of heat release as well as the amount of carbon oxides production of candles No. 1 was determined by cone calorimeter. The yield of carbon oxides was determined by the infrared analysers connected to the cone calorimeter.

The candles were placed on the specimen holder and placed in the top of a square with dimensions (80 x 80) mm. The samples thus prepared long with the specimen holder were placed on the weighing device of the cone calorimeter. The rate of suction of the combustion products in the exhaust hood of cone calorimeter was set to 24 $l.s^{-1}$. The candle knobs were initiated by a flame and data of heat release and carbon oxides production were continuously recorded at the 5 s intervals.

Time dependence of the heat release rate is shown in Figure 5, and time dependence of the carbon oxides production rate is shown in Figure 6. According to these results, we can say that the burning process of samples was completed in the beginning of the test. In the initial stages of burning, the amount of produced CO_2 and the heat release rate were higher, while the amount of produced CO was lower than in the later stages of testing. This is likely to be attributed to the conical shape of the top of the candle, whose radius was decreasing upwards. The smaller radius of the wax cone corresponded to the smaller cross-sectional area. As the wick thickness did not change, the efficiency of the wax burning could be higher. After 45 minutes, the amount of produced CO_2 and the heat release rate decreased, and the amount of produced CO increased as the burning process was stabilized. Average values of these parameters are shown in Table 2.

Table 2 Average values of the carbon oxides production rates and heat release rate calculated for one candle

	CO production rate [µg.s^{-1}]	CO_2 production rate [mg.s^{-1}]	Heat release rate [W]
Phase 1 burning time to 45 min	16.77	2.78	54.66
Phase 2 Burning time from 45 min	28.4	1.46	43.79

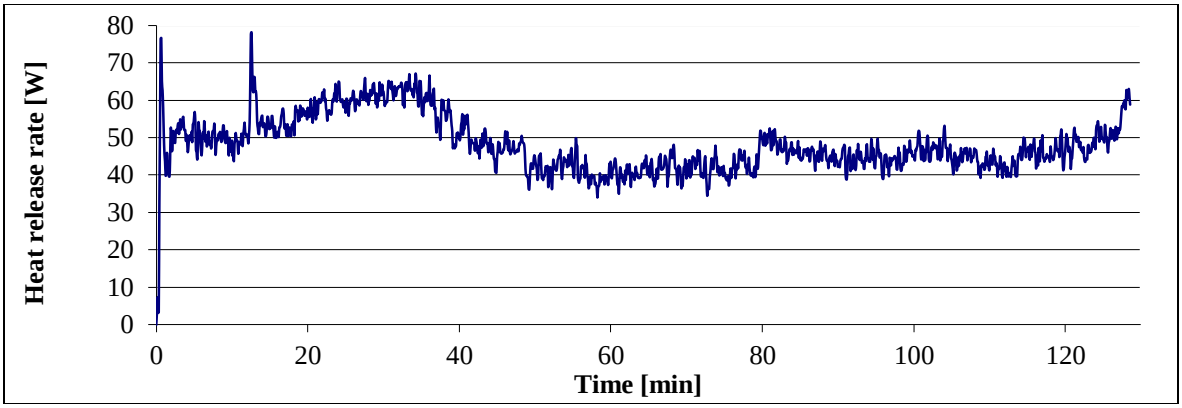

Fig. 5 *Time dependence of the heat release rate of sample no.1*

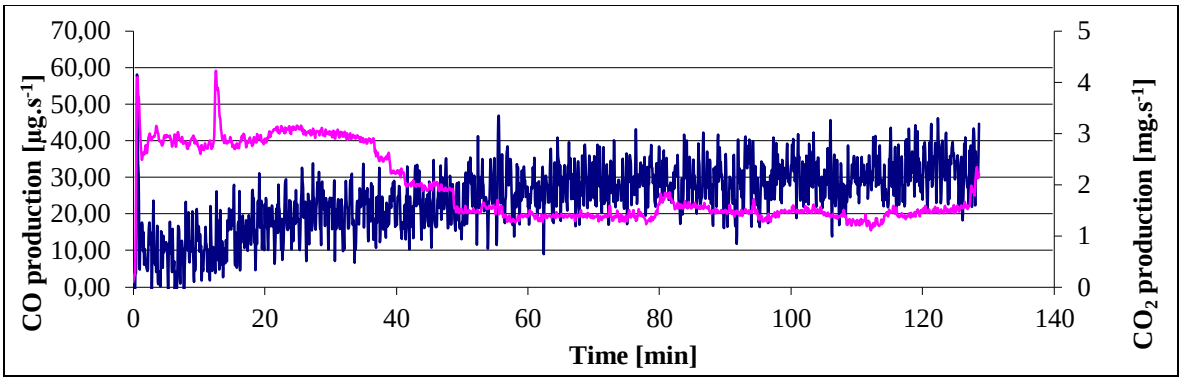

Fig. 6 *Time dependence of the CO and CO_2 production rate of candle no.1*
Note: blue line - CO production rate, violet - CO_2 production rate

CONCLUSION

The selected fire safety parameters for five types of candles were experimentally established. The mass loss at burning of all five candles has a linear character. The calculated mass loss rate was in the range from 0.075 g.min^{-1} to 0.115 g min^{-1}. The highest mass loss rate of 0.115 g min^{-1} was determined for candle No. 4 and the smallest mass loss rate of 0.075 g.min^{-1} for candle No. 1

Soot index indicates the amount of the soot produced during the burning of the sample. The calculated soot index varied from 0.2446 of candle No. 5 to 2.8781 of candle No. 4. According to EN 15246: 2007, the mean soot index per hour (Si_h) should not exceed 2 h^{-1}. None of the samples exceeded the established limit.

Heat release rate and carbon oxides production during the candle burning were determined for candle No.1. In the initial burning phase (approximately 45 minutes), the

average heat release rate was 54.66 W, the average CO production rate was 16.77 μg s^{-1} and the average production rate of CO_2 was 2.78 mg s^{-1}. After the flame stabilization, the heat release rate decreased to 43.79 W, the CO_2 production rate decreased to 1.46 mg s^{-1} and the CO production rate increased to 28.4 μg s^{-1}.

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References:

1. AKARE, A. A. 2009. *Investigating the links between smoke points, sooting thresholds, and particle number and size*. PhD Thesis. M. Phil. Thesis. St. Edmund's College, Cambridge University. (Available at March 2014).
2. MATTHAI, M., PETEREIT, N. 2003.The Quality Future for the Candle-a Burning Issue. *SOFW JOURNAL*, **129**(12), pp. 58-63.
3. Odetka in Europe: Knoty, Copyright © 2016 Odetka a.s., [online]. [2017.03.24]. Available at: < http://www.odetka.cz/net20/cz/knoty.aspx#cojeknot. >
4. SUNDERLAND, P. B. et al. 2011. Analysis and measurement of candle flame shapes. *Proceedings of the Combustion Institute*, **33**(2), pp. 2489-2496.
5. GRITTER, L. T. et al. 2010. *Analysis of Burning Candle*. [online]. [2017.03.22]. Available at: < https://www.comsol.se/paper/download/62922/koppenhoefer2_paper.pdf >
6. MATTHÄI, M. et al. 2011. Measuring Light Intensity of Candles of Various Compositions. *SÖFW-Journal*, 137. 12 p.
7. GAI ENGINEERS. *Candle Burning Study*. September 2011, Stoughton, MA, 29 p.
8. ALLAN, K. 2007. *Laminar smoke points of candle flames*. PhD Thesis.
9. ALLAN, K. M., et al. 2009. Laminar smoke points of wax candles. *Combustion Science and Technology*, **181**(5), pp. 800-811.
10. *EN 15426:2007 Candles – Specification for sooting behaviour*. November 2007, 14 p.
11. *NCA Issues Guide* [online]. Washington DC: National Candle Association, 2013.
12. United States Environmental Protection Agency, "EPA's Revised Particulate Matter Standards". Office of Air and Radiation, Office of Air Quality Planning and Standards, [online]. 1997, [2017.03.21]. Available at: www.epa.gov
13. HUYNH, C. K. et al. 1991. Impact of thermal proofing of a church on its indoor air quality: the combustion of candles and incense as a source of pollution. Science of the total environment, pp. 241-251.
14. United States Environmental Protection Agency, "Health and Environmental Effects of Particulate Matter". Office of Air and Radiation, Office of Air Quality Planning and Standards, [online]. 1997, [2017.03.22]. Available at: www.epa.gov

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