Pre-normative study of number concentrations of combustion particles generated by fossil and non-fossil fuels

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Introduction

Candle lights made of the fossil paraffin and non-fossil stearin form one of the most common open combustion sources that people use in the confinement of their private living rooms. The evaluation of the candle quality and consequently the characterization of the released aerosol of soot particles is still regulated and standardized with methods that relate to visual macroscopic effects, such as the deposition of candle soot on a glass plate [1][2]. In order to quantify the soot emission of a candle light, typically the opacity of the glass plate is determined before and after it has been exposed to candle soot for a given time at a given distance to the flame. Still, only the macroscopic amount of the soot is considered, not the characteristics of the actual combustion aerosol. With the booming market for alternative candle fuels such as beeswax or soya fat, the comparison of the composition the various combustions aerosols are becoming more and more important in order to avoid unnecessary contamination of the indoor living rooms with soot particles. This work compares the particle number concentration and size distribution from tea lights of different material. It is envisioned that this work gives raise to reconsideration of normative work related to the quantification of the combustion efficiency of candle lights.

Instrumentation

In order to count and measure the released soot particles, a combustion chamber has been built which is fed by particle-free compressed air. The air flow in the chamber is controlled in order not to interfere with the combustion flame of the candle light. The average air speed for flicker-free combustion is approx. 0.07 m/s. This corresponds also approximately to the measured air speed of the hot air convection speed.

The released soot particles are measured by a spectroscopic particle counter based on light scattering. The particle counter registers the particle number concentration by applying the light of a 633 nm laser. In order to determine the particle size, the principals of Mie scattering theory are applied to convert the intensity of the scattered light to a sphere equivalent diameter. Immediately after the candles have been lit, the combustion chamber is sealed and the measurement starts. The initial unavoidable contamination of the air with ambient particles is insignificant. The candles are left to burn for a period of 30 minutes, in order to include long-term effects after the wick has reached a stable condition for the combustion, both by its length and the combustion temperature. The sample flow through the instrument is set to approximately 5 cm^3/min, which allows isokinetic sampling of the undiluted combustion aerosol.

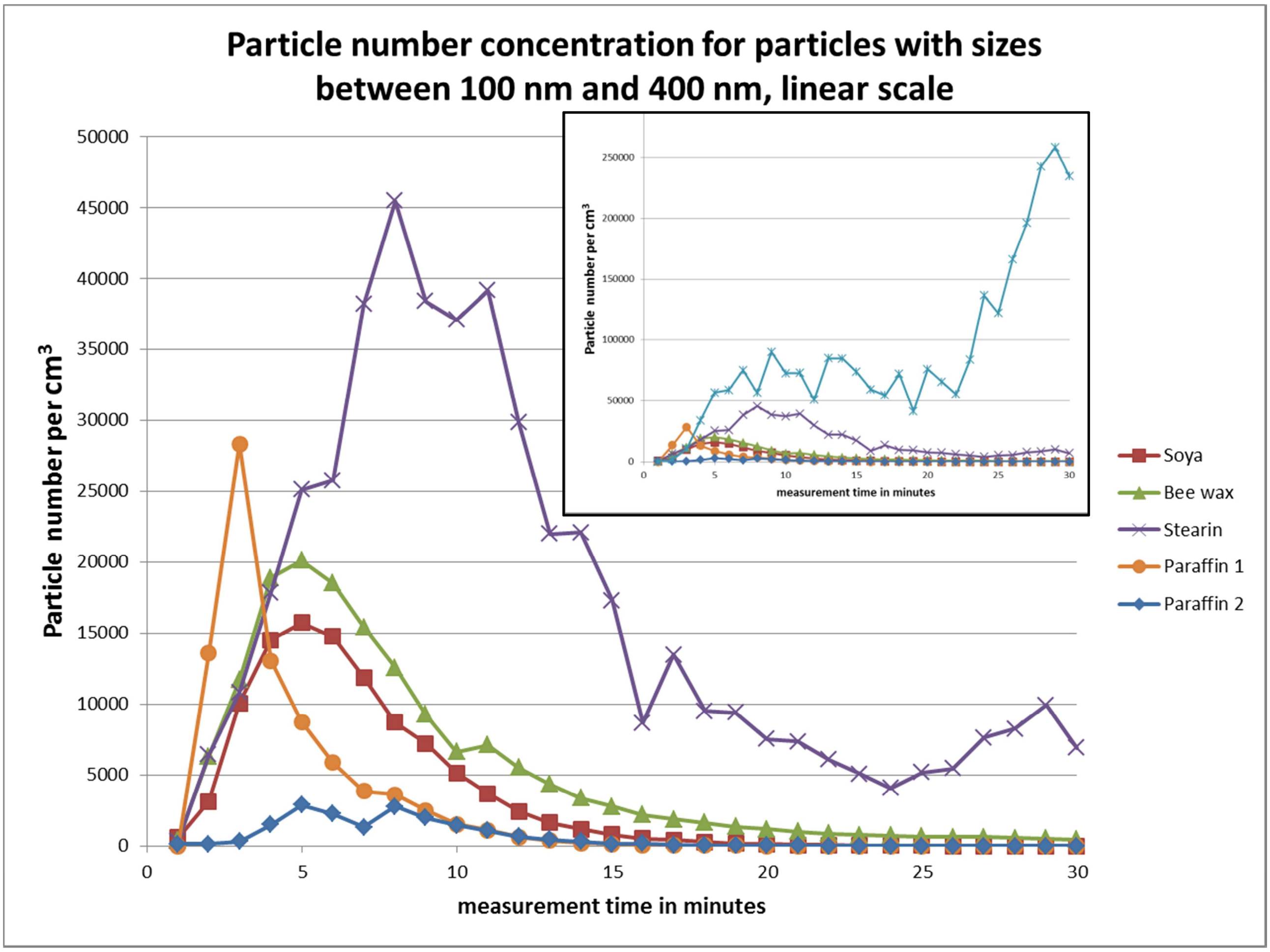

Figure 1: Particle number concentration for different candle materials, linear scale. The total combustion time was 30 minutes. Large image: particle number concentration for tea lights. Inlay: The particle number concentration of a birthday cake candle is 5 times higher than the highest amount of the tea lights.

Results

A total of four different materials have been analyzed: tea lights made of stearin, paraffin, soya fat and bees wax. In addition, one birthday candle made of bees wax has been used. Figure 1 shows the particle number concentrations per minute of the measurement. The stated particle number is the cumulative number between 100 nm and 400 nm. As can be seen in figure 2, particle sizes above 400 nm did not be observed during the measurements.

Figure 1 clearly indicates that stearin generates the highest number of combustion particles. Even after the initial stabilizing period after ignition of the wick, the particle number concentration settles at a constant level of approx. 7000 #/cm^3. The other materials show a fast decrease of particle number after the initial period of 10 minutes. Bees wax tends to a slow decrease, with a possible asymptotic approach to a constant level (this must be proved by a longer measurement period). Soya fat particles are quickly reduced after ignition, and seem to reach an insignificant level after 30 minutes.

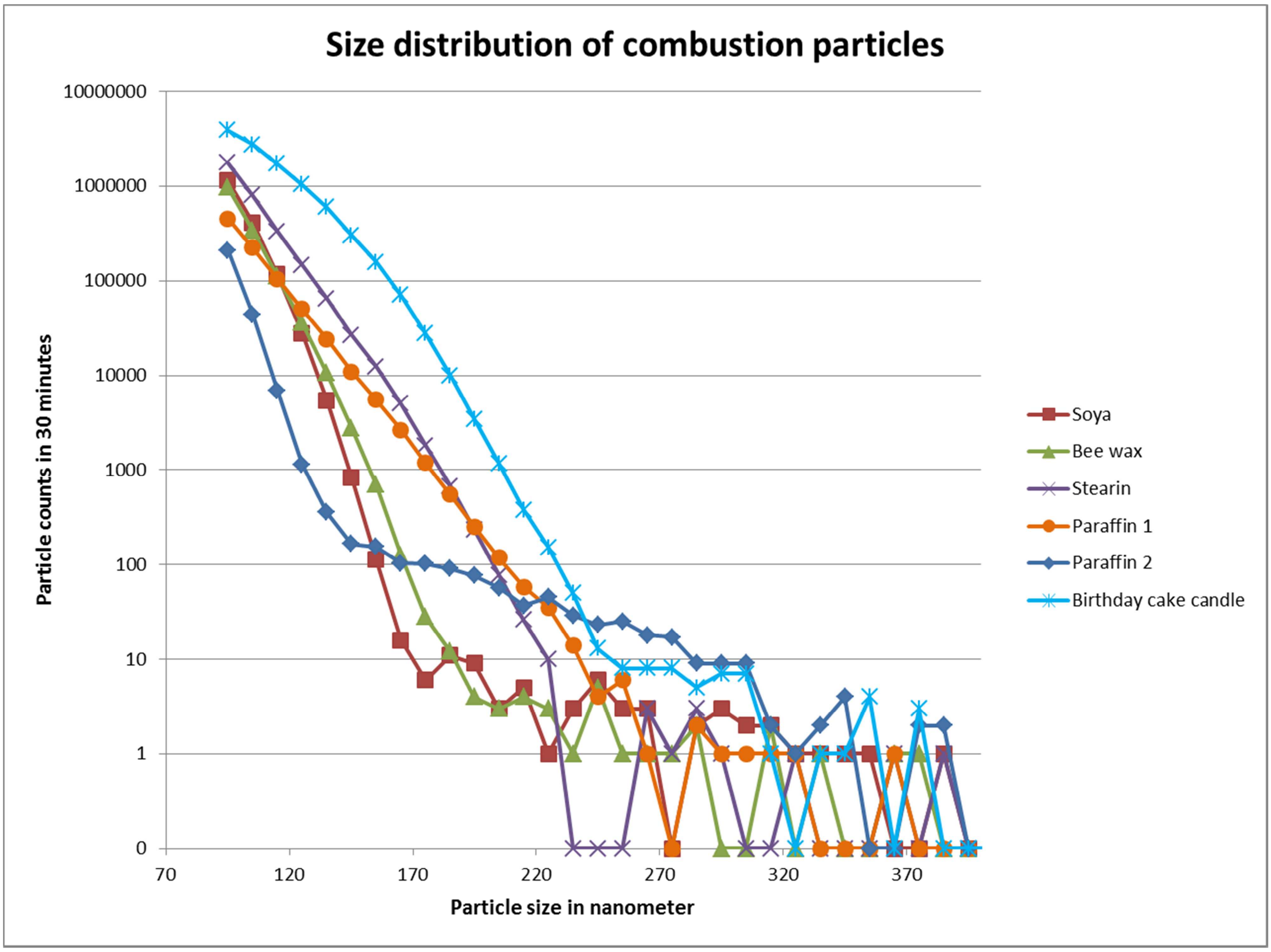

Figure 2: Particle size distributions for different candle materials for the total combustion period of 30 minutes.

The two paraffin tea lights generate the least amount of particles. The combustion of a birthday cake candle generates a huge amount of particles compared to the other 4 tea lights, see inlay in figure 1. The maximum amount of produced particles peaks at about 5 times the value for the stearin tea light. As the wick of the birthday cake candle is completely consumed during the thirty minutes of the experiments, this indicates that the combustion of the wick is responsible for the particle generation.

Acknowledgements

The work presented here has been executed within the support program "videnkupon" of the Danish Ministry of Science, Innovation and Higher Education for SME and members of the Danish Advanced Technology Group GTS.

References

[1] ASTM F2326 - 04(2009) Standard Test Method for Collection and Analysis of Visible Emissions from Candles as They Burn

[2] CEN standard EN 15426 – "Candles – Specification for Sooting Behaviour"

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Ministry of Science, Innovation and Higher Education

Introduction

Candle lights made of the fossil paraffin and non-fossil stearin form one of the most common open combustion sources that people use in the confinement of their private living rooms. The evaluation of the candle quality and consequently the characterization of the released aerosol of soot particles is still regulated and standardized with methods that relate to visual macroscopic effects, such as the deposition of candle soot on a glass plate [1][2]. In order to quantify the soot emission of a candle light, typically the opacity of the glass plate is determined before and after it has been exposed to candle soot for a given time at a given distance to the flame. Still, only the macroscopic amount of the soot is considered, not the characteristics of the actual combustion aerosol. Yet there are many approaches to characterize the combustion aerosol of candles in a more rigorous way [3]-[5]. With the booming market for alternative candle fuels such as beeswax or soya fat, the comparison of the composition the various combustions aerosols are becoming more and more important in order to avoid unnecessary contamination of the indoor living rooms with soot particles, see figure 1.

This work compares the particle number concentration and size distribution from tea lights of different material, see figure 1. It is envisioned that this work gives raise to reconsideration of normative work related to the quantification of the combustion efficiency of candle lights.

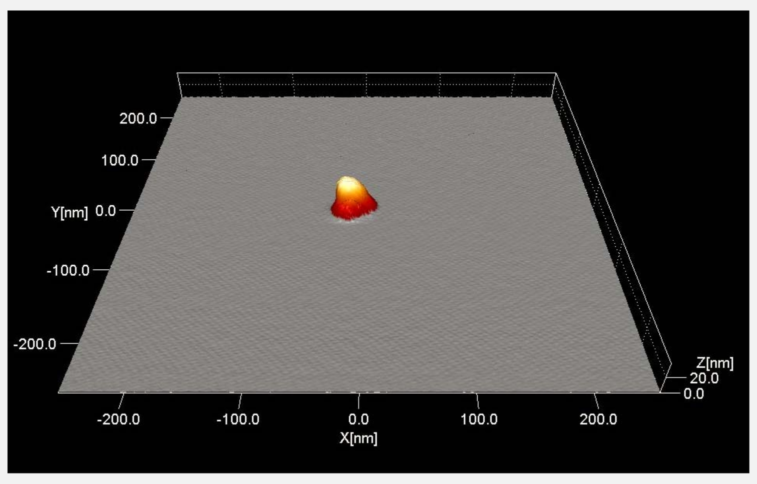

Figure 1: A classic primary soot particle from a propane combustion (3D Atomic Force Microscopy)

Figure 2: Candles materials from left to right: Soya fat, stearin, bees wax (birthday cake candle), paraffin, bees wax

[1] ASTM F2326 - 04(2009) Standard Test Method for Collection and Analysis of Visible Emissions from Candles as They Burn

[2] CEN standard EN 15426 – “Candles – Specification for Sooting Behaviour”

[3] David J. Silver , “Occupational exposure to ultrafine particles and polycyclic aromatic hydrocarbons from candle emissions, dissertation (2006), University of South Florida

[4] Karamatollah Rezaei, Tong Wang, and Lawrence A. Johnson, “Combustion Characteristics of Candles Made from Hydrogenated Soybean Oil”, JAOCS (2002), Vol. 79, no. 8

[5] Matthew D. Wright, A. Peter Fews, Paul A. Keitch, and Denis L. Henshaw, "Small-Ion and Nano-Aerosol Production During Candle Burning: Size Distribution and Concentration Profile with Time." Aerosol Science and Technology (2007), 41:475–484

Experimental set-up

In order to count and measure the released soot particles, a combustion chamber has been built which is fed by particle-free compressed air, see figure 3. The air flow in the chamber is laminar and controlled in order not to interfere with the combustion flame of the candle light. The average air speed for flicker-free combustion is approx. 0.07 m/s.

The released soot particles are measured by a spectroscopic particle counter based on light scattering. The particle counter registers the particle number concentration by applying the light of a 633 nm laser. In order to determine the particle size, the principals of Mie scattering theory are applied to convert the intensity of the scattered light to a sphere equivalent diameter, see figure 4. Diameters between 80 nm and 8000 nm can be measured. Immediately after the candles have been lit, the combustion chamber is sealed and the measurement starts. The initial unavoidable contamination of the air with ambient particles is insignificant. The candles are left to burn for a period of 30 minutes, in order to include long-term effects after the wick has reached a stable condition for the combustion, both by its length and the combustion temperature.

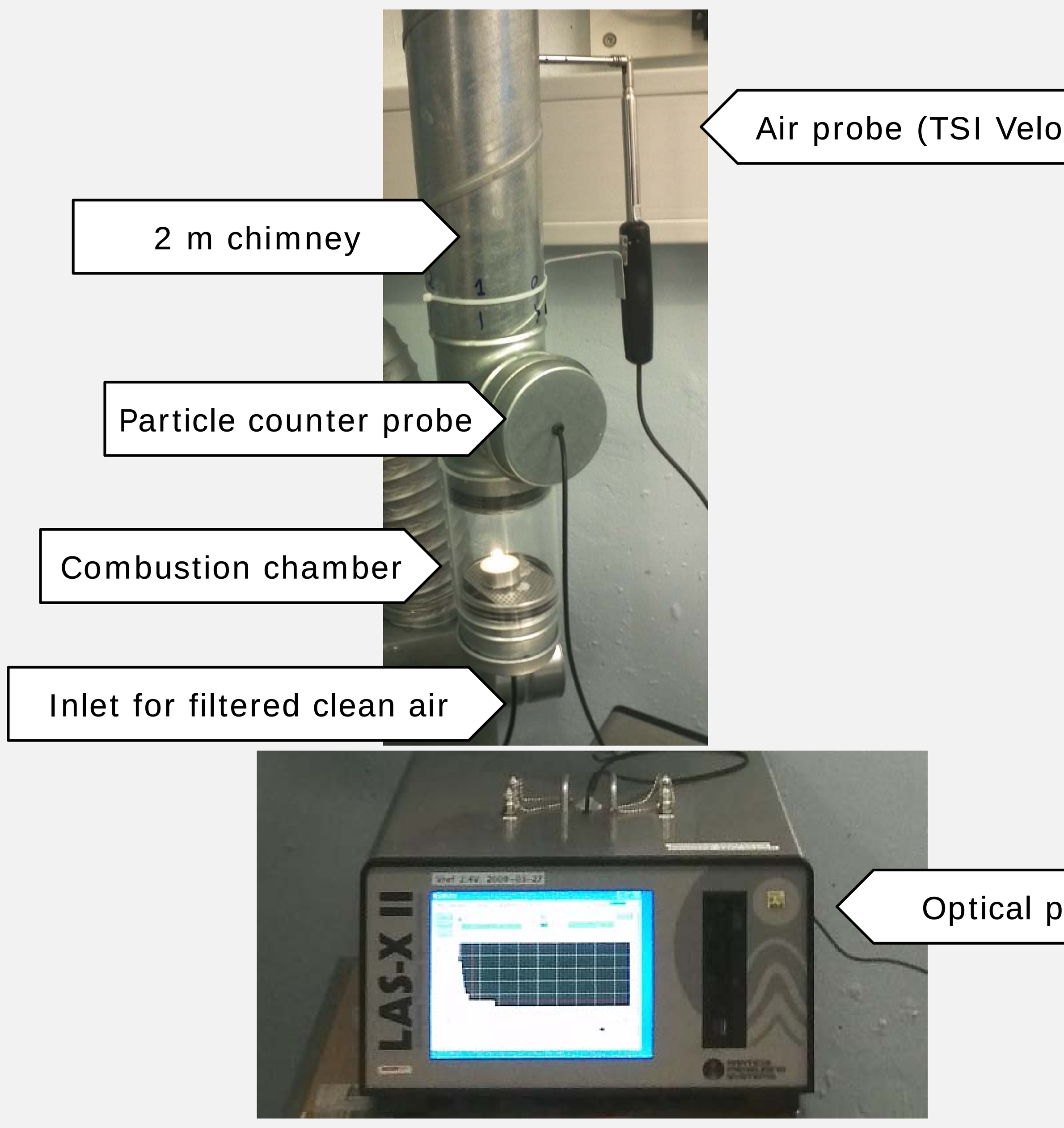

Figure 3: Particle free combustion chamber with air probe and optical particle sizer

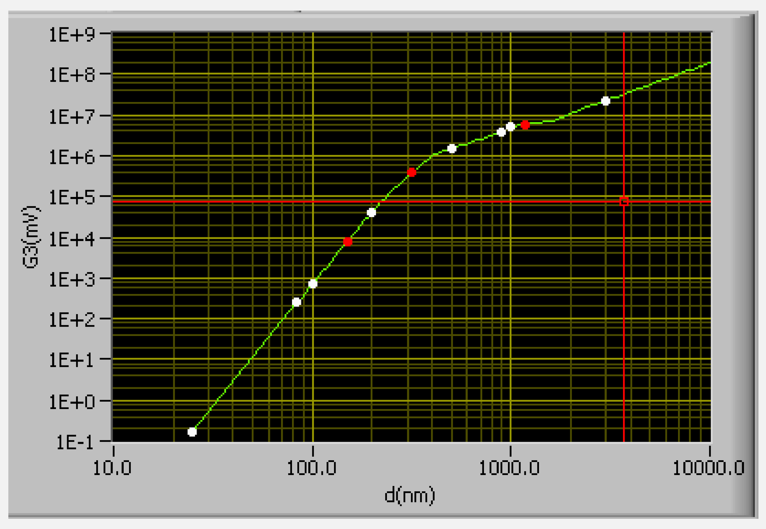

Figure 4: Typical calibration curve based on Mie scattering that relates particle size (x-axis) to observed scatter intensity of the laser light

Results and conclusions

Figure 5 shows the particle number concentrations per minute of the measurement. The particle number is the cumulative number between 100 nm and 400 nm. As can be seen in figure 8, particle sizes above 400 nm did not be observed during the measurements.

Figure 5 clearly indicates that stearin generates the highest number of combustion particles. Even after the initial stabilizing period after ignition of the wick, the particle number concentration settles at a constant level of approx. 7000 #/cm³. The other materials show a fast decrease of particle number after the initial period of 10 minutes. Bees wax tends to a slow decrease, with a possible asymptotic approach to a constant level (this must be proved by a longer measurement period). Soya fat particles are quickly reduced after ignition, and seem to reach an insignificant level after 30 minutes.

The two paraffin tea lights generate the least amount of particles, yet they show different long term behavior in the logarithmic plot, see figure 6. Paraffin 1 drops to almost zero particles, while paraffin 2 settles on a constant level of approx. 5 #/cm³.

The combustion of a birthday cake candle (center in figure 2) generates a huge amount of particles compared to the other 4, see figure 7. This indicates that the combustion of the wick is responsible for the particle generation. The wick of the birthday cake candle is 3 times longer than that of the tea lights, and it is completely consumed during the period of 30 minutes.

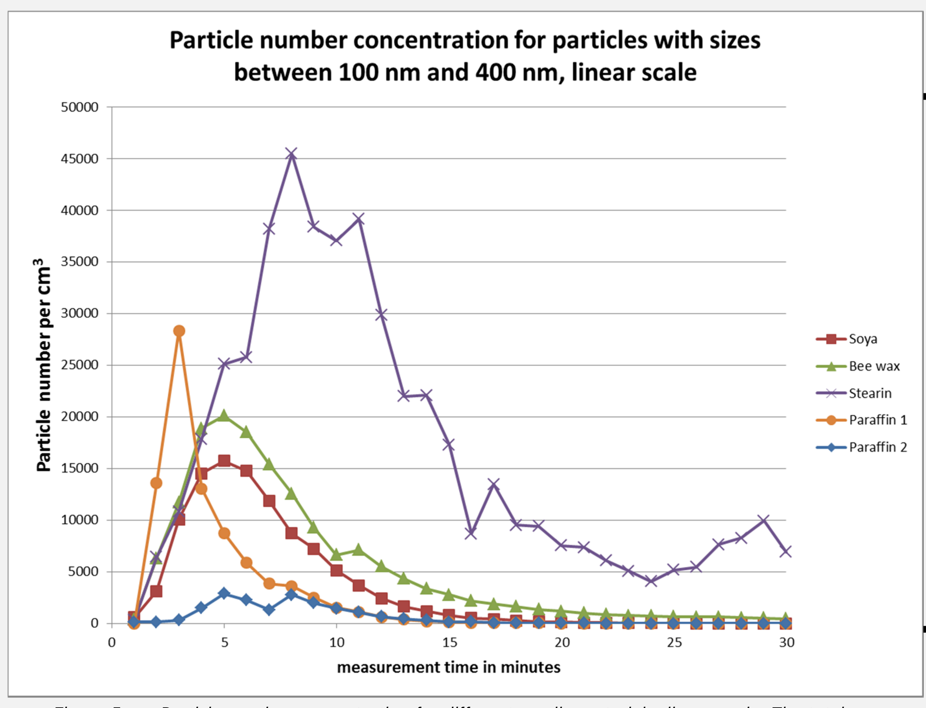

Figure 5: Particle number concentration for different candle materials, linear scale. The total combustion time was 30 minutes. The measurements started immediately after ignition.

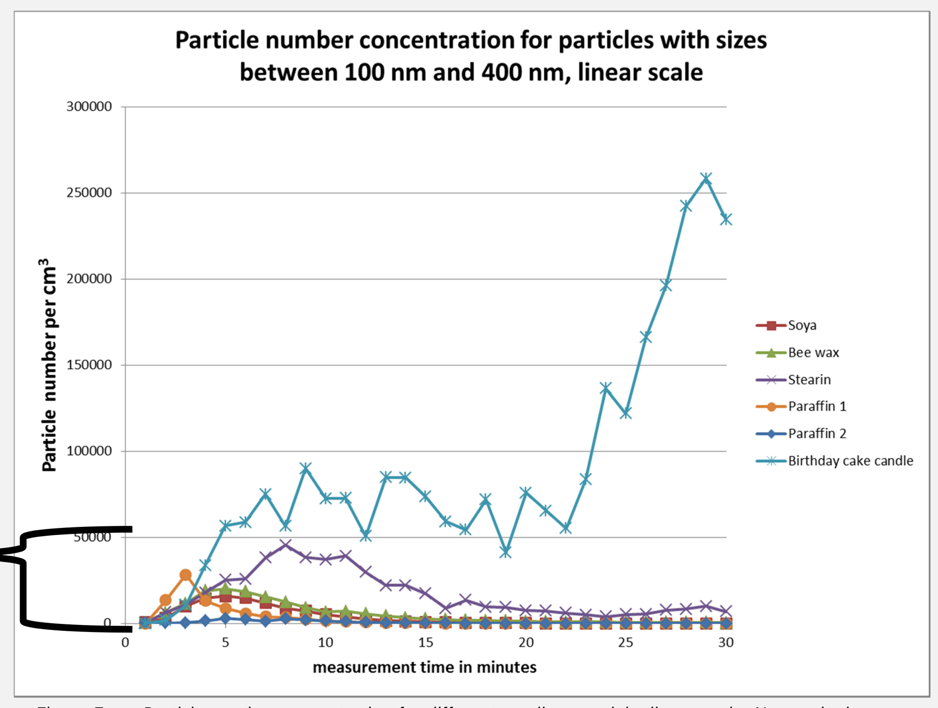

Figure 7: Particle number concentration for different candle materials, linear scale. Now a single birthday cake candle is plotted on top of the measurements from figure 5.

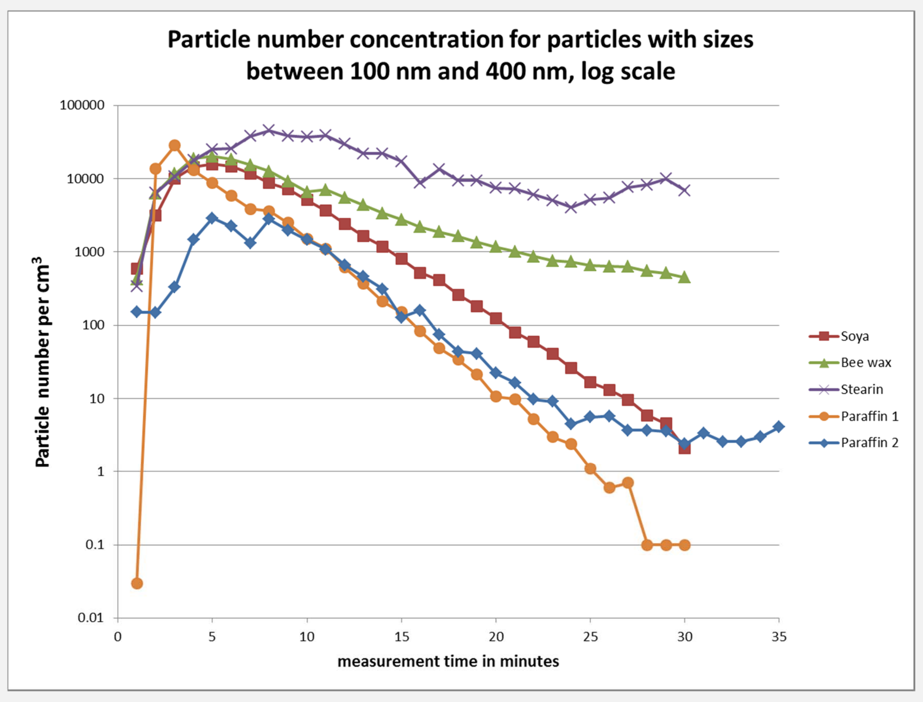

Figure 6: Particle number concentration for different candle materials, logarithmic scale. Note that the x-axis now shows 35 minutes, in order to reveal the asymptotic for paraffin 2.

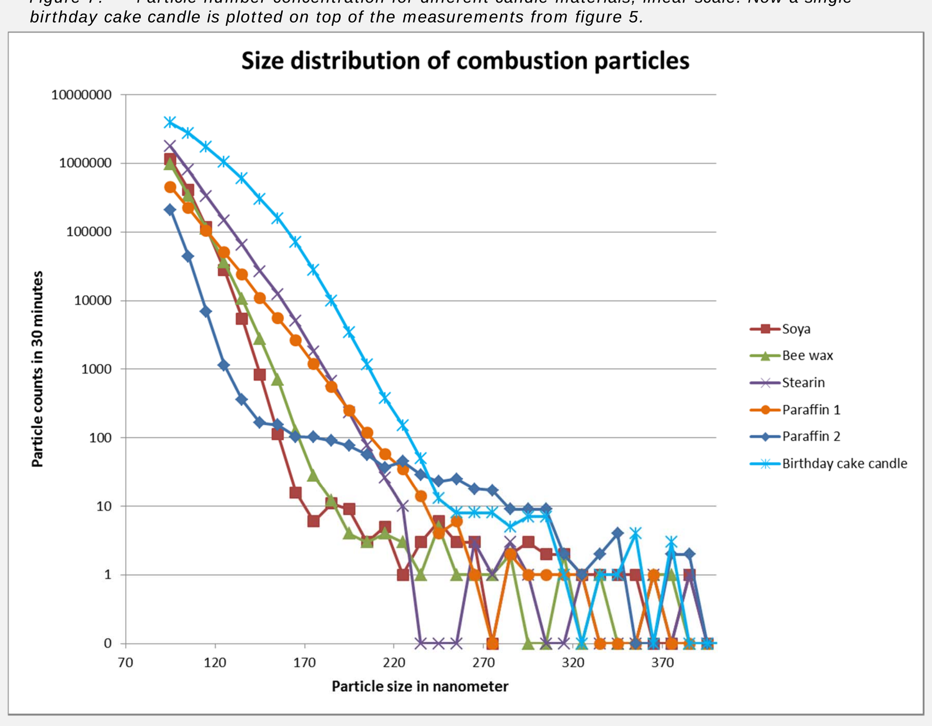

Figure 8: Particle size distributions for different candle materials for the total combustion period of 30 minutes.

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