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APPLICATION NOTE
SMALL SCALE COMBUSTION
PPS-M sensor

Background and problem

Gravimetric measurements are considered the reference method for determining particle mass (PM) emission from small-scale combustion devices and standards for this kind of measurement are under development. However, this method is labour-intensive and does not provide any real-time data. Knowledge about where most PM is generated during a combustion cycle is essential in development. Other real-time instruments available in the market do not fulfil such criteria. ExIS AB in collaboration with SP Technical Research Institute of Sweden and a leading stove manufacturer carried out a measurement campaign to explore the suitability of Pegasor PPS-M sensor for this application.

Summary and solution

In summary, the stand-alone Pegasor M-sensor (and the integrated version Mi3) proves its suitability for measuring PM from small scale combustion device, provided that the following crucial points and conditions are taken into consideration:

- The particle size distribution from a wood burning small scale combustion device may vary extensively during and between the cycles. Initial combustion cycles before the system is fully warmed up show the maximum variation and are prone to give higher deviation between the Pegasor M-sensor and gravimetric data. After warm up the particle size distribution during and between the cycles stabilizes, becomes consistent and consequently the correlation with gravimetric results improve.
- Majority of the particle emission is in the size range of 120 nm but there is often a tendency for a bimodal size distribution with a second peak at smaller size. This small peak can result in an abnormally high electrometer signal, but due to the small size of the particles their contribution to mass is very low. The standard trap voltage setting of 400 V is not sufficient to avoid this peak. Setting the sensors trap voltage at 1 000 V gave the best result.
- The standard mass calibration factor in Pegasor M-sensor’s software interface is not suitable for this application and a new one should be calculated based on actual gravimetric measurements from that particular combustion device, or else an approximate factor can be provided by Pegasor.
- The ratio between Pegasor M-sensor PM and gravimetric measurement remained consistent during the tests carried out as basis for this application note and the variation was less than 15 % over a range of (average) cycle concentrations by one order of magnitude between the lowest and the highest.
- The stand-alone Pegasor M-sensor is best suited for relatively clean burning conditions, such as in normal operation of a stove. At abnormal operating conditions with very high concentrations the integrated Pegasor Mi3 is better, since the built-in dilution system can be used to reduce concentrations prolonging the cleaning interval.
- A heated sampling line for Pegasor M-sensor is recommended to avoid condensation of volatiles, nucleation of nano particles and to improve accuracy.
- Isokinetic sampling is not needed, because majority of the particles are very small (mostly <1μm) and do not cause any error due to continuous sampling for gravimetric measurement.

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Experiment details

Particle size distribution from a wood burning stove was measured with an ELPI instrument (Dekati, FIN) in conjunction with Pegasor M-sensor and gravimetric sampling. Where in Pegasor M-sensor used a heated sampling line set at 200°C and the ELPI used heated sampling line set at same temperature with a single stage ejector dilution set up giving a sample flow of about 6lpm, Fig 1 Experimental setup. Pegasor M-sensor's trap voltage was set at 1 000 V so as to get a low end cut-off point higher than the 23 nm achieved with the standard 400 V trap setting. As expected the size distribution was bimodal and showed high levels of variation during the initial combustion cycles and then stabilized, although the variation in the size distribution between the different stages of the same combustion cycle remained at large.

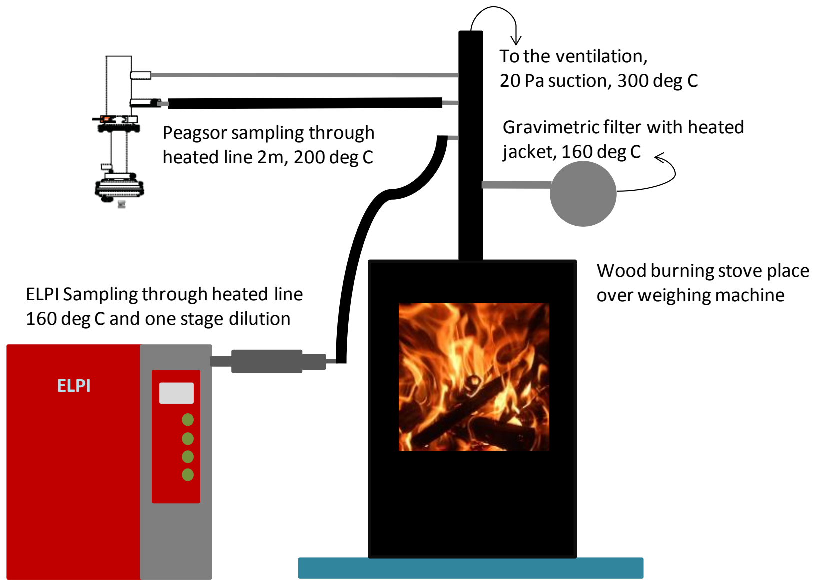

Figure 1 Experimental setup

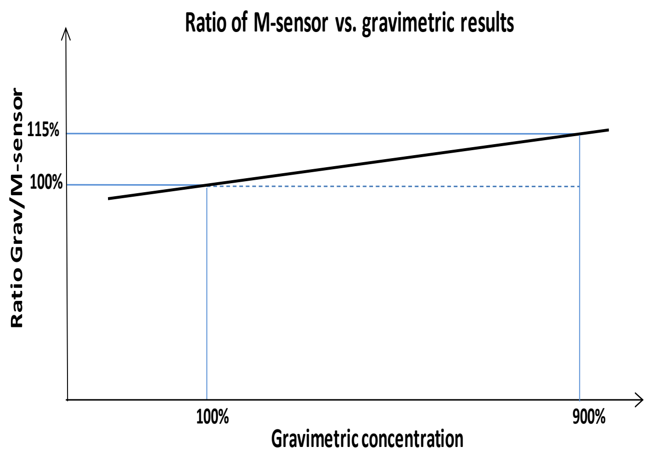

Figure 2 Ratio of Pegasor M-sensor vs. gravimetric results

For most of the cycles the ratio between Pegasor M-sensor's PM and gravimetric measurement is consistent when using 1 000 V and variations remain within 15%, as shown in figure 2. This was seen although the PM as average for a combustion cycle varied as much as one order of magnitude from test to test, due to different settings of the stove. The 100% mark corresponds to the average soot emission expected from a contemporary wood burning stove. This value was identified from the recent literature on soot emission from wood burning stove and matched closely with the results from the experiment. The 900% mark indicates extreme conditions such as deprived oxygen supply and the soot emission at these conditions were much higher than the reference value, but still below the maximum threshold for the sensor. This is a good indicator of a robust setting of the instrument (trap voltage) and provision for a reliable PM calibration.

Figure 3 from one of the earliest combustion cycle (cycle 2 out of 14) when the stove was cold, a tendency for a bi-modal particle size distribution is clearly seen with relatively higher values of PN compared to the later combustion cycles. Figure 4 from one of the later cycle (cycle 5 out of 14), a bi-modal distribution is not seen at all and in general, more consistent particle size distribution between the different stages of the combustion. This particular cycle 5 is a good representative of the characteristics of most of the combustion cycles that are carried out under "good" operating conditions. Similarly, the concentration of particles below 100 nm and the total PN were also substantially lower for cycle 5 than cycle 2.

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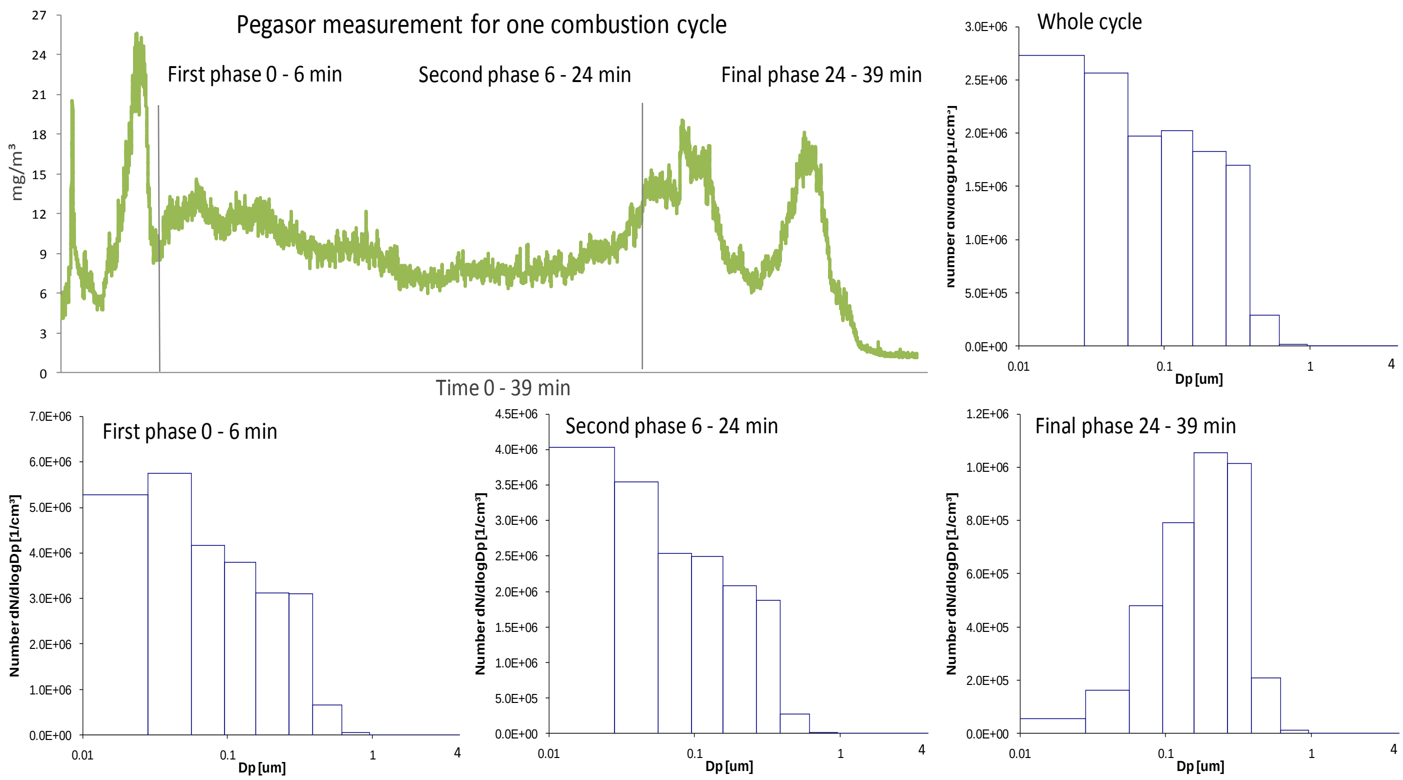

Figure 3 Pegasor M-sensor and ELPI measurements for Cycle 2

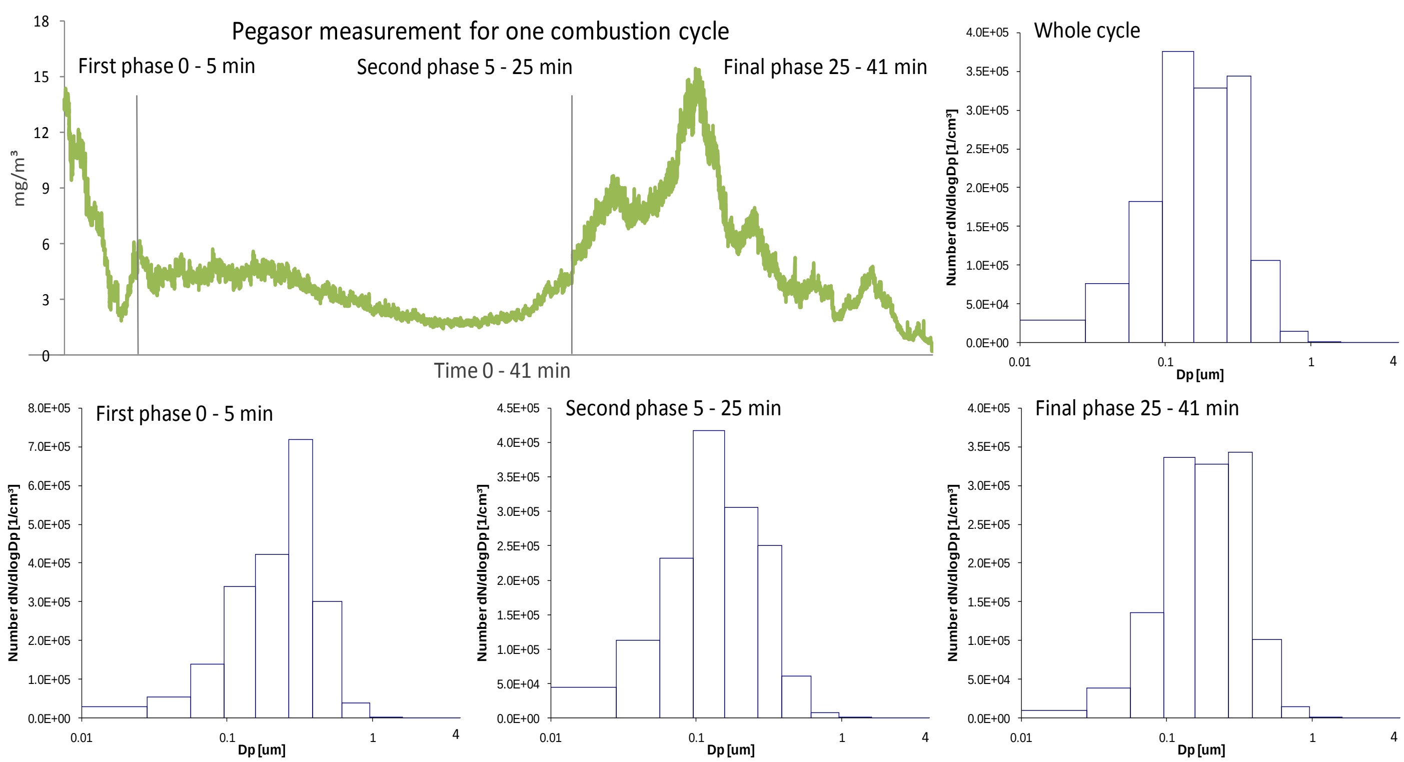

Figure 4 Pegasor M-sensor and ELPI measurements for Cycle 5