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Towards generating sub-100 nm soot particles with the Argonaut miniature inverted soot generator

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SUMMARY

The Argonaut miniature inverted soot generator provides a low-cost method to generate soot particles in the laboratory. The burner performance has been characterized for ethylene [*Kazemimanesh et al., 2018*] and propane [*Moallemi et al., 2019*], where a simple two-flow setup is required. For these two fuels, the burner produces soot particles of 150 to 200 nm mobility diameter.

Here, with the goal of producing soot particles smaller than 100 nm, we have explored the influence of various combustion mixtures on particle size. Specifically, we explored the following parameters: five different fuels, air premixing, and oxygen enrichment of the combustion air.

The results presented below show that the Argonaut burner output is relatively robust to changes in fuel composition. Mobility diameters of about 100 nm were achieved for some mixtures, with the most experimentally convenient being premixed air. The emitted soot was highly mature under almost all conditions, as demonstrated by its MAC being in agreement with the Bond and Bergstrom (2006) value of 4.74 ± 0.76 m^2/g at 870nm (7.5 ± 1.2 m^2/g at 550 nm).

EXPERIMENTAL SETUP

The following setup was used to mix fuels (and in some cases premix air) before diluting and obtaining real-time MAC measurements at 870 nm.

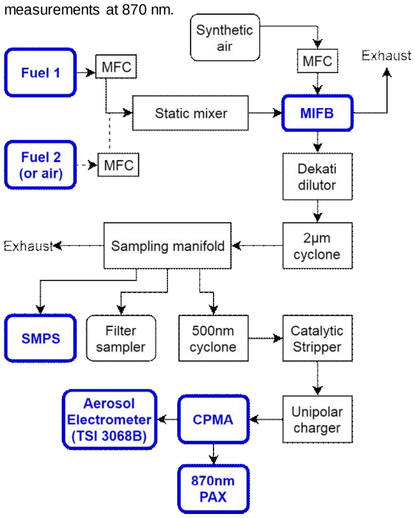

Figure 1. Experimental setup used to characterize the burner. The post-CPMA aerosol electrometer and PAX measurements provide the 870 nm **MAC** (Corbin et al., 2018). The SMPS provides mobility size distributions, from which the geometric mean diameter (**GMD**) was determined. The filter sampler was used to obtain EC/TC ratios, which were generally consistent with those reported by Moallemi et al. (2019).

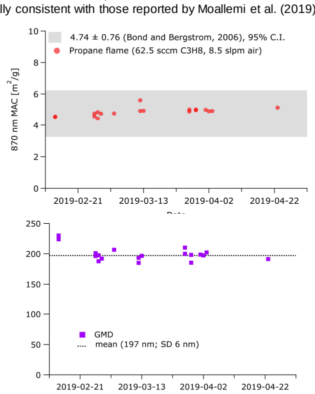

Figure 2. Repeatability of MAC (upper panel) and GMD (lower panel) measurements. All data are for a propane flame with 62.5 sccm fuel and 8.5 slpm synthetic air (21% O_2) flow. Shaded area in upper panel shows a literature value of MAC. Dashed line in lower panel shows mean GMD, calculated excluding the first day.

METHODS

Argonaut burner flame types

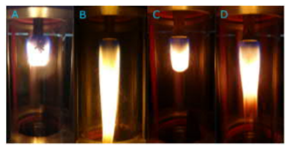

Figure 3. Examples of flame types achieved with the Argonaut burner.
A-asymmetric flame (buoyancy induced), B-asymmetric flame (flow force induced), C-closed-tip flame, D-open-tip flame. Adapted from *Moallemi et al. [2019].*

Determination of smallest-particle setpoints

The smallest particles produced by a given flame (i.e., given set of flow conditions) were defined as the conditions which produced a **minimal GMD with (1) a measurable particle size distribution and (2) a MAC close to 4.74 ± 0.76 (Bond and Bergstrom, 2006)**

This definition did not result in any ambiguity. The transition from open tip (sooting) to closed tip (non-sooting) flames occurred rapidly. All size distributions were lognormal except for the acetylene-containing exception shown in Figure 4.

Our real-time measurements of MAC and GMD (Figure 1) allowed us to rapidly investigate **all** non-flickering, open-tipped conditions (Figure 3D) for a given flame.

RESULTS

Table 1. Summary of the smallest-particle setpoints for each flame.

Date	Fuel Mixture	Mixture Flow Rate (ccpm)	Air Flow Rate (slpm)	GMD (nm)	MAC (m^2/g)
2019-03-12	Propane	62.5	8.5	185	4.9 ± 0.1
2019-02-14	Propane ; Air	62.5 ; 20	7.5	104	5.0 ± 1.2
2019-02-26	Propane ; Acetylene	15 ; 60.45	8.5	168[a]	2.1 ± 0.2
2019-02-28	Propane ; +O_2[b]	62.5	8.5 ; 0.5	154	6.2 ± 0.4
2019-03-04	Propane ; Acetylene +O_2[b]	62.5	7.5 ; 0.6	160	5.8 ± 0.8
2019-03-12	Propane ; DME	55 ; 7.6	8.5	95	5.0 ± 0.5
2019-03-19	Acetylene ; DME	30 ; 51.38	8.5	110	6.2 ±0.6
2019-04-03	Ethylene	81.13	8.5	128	4.5 ± 0.3
2019-04-03	Propane ; Ethylene	0 ; 81.13	8.5	128	4.5 ± 0.3
2019-04-05	Ethylene ; DME	81.13 ; 0	8.5	139	5.5 ± 0.6
2019-04-23	Propane ; Methane	60 ; 50	8.5	153	4.4 ± 0.1
2019-04-23	Methane ; DME[c]	n.s.	n.s.	n.s.	n.s.
2019-04-24	Ethylene ; Methane	56.7 ; 61.5	8.5	110[d]	4.3 ± 0.5

[a]This flame was bimodal, as shown in Figure 4.
[b]Oxygen-enriched flame, according to the second value shown under "Air flow".
[c]All stable flames were closed-tip and therefore non-sooting (n.s.).
[d]Preliminary results suggest poor repeatability for this test point ($d_{mobility}$ ranging from 100 to 120 nm on a single day).

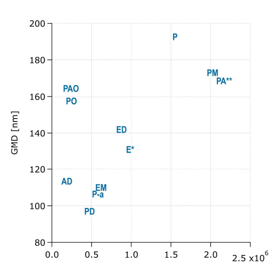

Figure 4. Relationship between GMD and number concentration for each flame in Table 1. Symbols code the flame composition:
A = acetylene
D = dimethyl ether
E = etyhelene
M = methane
O = Oxygen-enriched air.
P = propane
-a = Premixed fuel-air flame.
** = Bimodal, see Figure 4.
*Preliminary results suggest poor repeatability for this test point. *cf.* Table 1.
"O" flames show evidence of enhanced soot burn-off.

RESULTS (CONT'D)

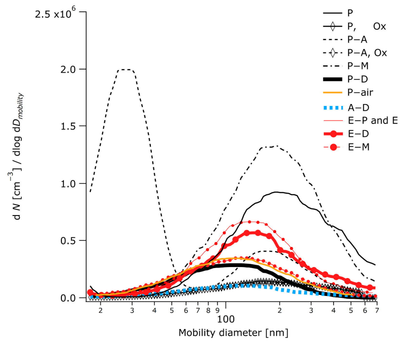

Figure 5. Mobility size distributions for the flames summarized in Table 1. Symbols are as defined in Figure 4.

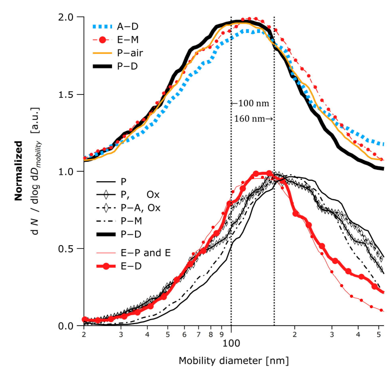

Figure 5. ***Normalized*** **mobility size distributions for the flames summarized in Table 1.** Data are arbitrarily translated on the ordinate to illustrate that the flames can be divided into roughly two groups: 100 nm or 160 nm flames.

CONCLUSIONS AND FUTURE WORK

The MAC of MISG soot was remarkably stable for different flames and flow rates, indicating that soot particles were mature (highly graphitic) in all cases.

We found that premixed propane–air flames, as well as fuel mixtures of propane-DME and ethylene-methane, were able to produce soot particles of 100 nm mobility diameter, down from 150-200 nm for the simple propane flame. The most convenient mixture is premixed propane–air, since it does not require additional gases compared to regular burner operation. These smaller particles are closer to the size of diesel-exhaust soot particles.

Future work will measure the repeatability of the smallest-particle setpoints. Modifications to the experimental setup will also be explored, with the goal of reducing particle sizes down to 50 nm, the typical size of aviation-turbine soot particles.

References

Kazemimanesh, M., A. Moallemi, K. Thomson, G. Smallwood, P. Lobo, and J. S. Olfert. *A novel miniature inverted-flame burner for the generation of soot nanoparticles*. Aerosol Sci. Technol. 53, 184-195, 2019.

Moallemi, A., M. Kazemimanesh, J. C. Corbin, K. Thomson, G. Smallwood, J. S. Olfert, P. Lobo. *Characterization of black carbon particles generated by a propane-fueled miniature inverted soot generator.* J. Aerosol Sci., in press, 2019.

Acknowledgements

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