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JAMES DYSON FOUNDATION UNDERGRADUATE BURSARY – PROJECT SUMMARY

Development of a miniature water CPC

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Background

Aerosols are suspensions of particles (either liquid or solid) in a gas. The particles forming aerosols range in size from $1\,\mathrm{nm}$ *to about* $100\,\mu\mathrm{m}$ *(Fig. 1), and there is a growing concern about the effect that the smaller particles (below* $1\,\mu\mathrm{m}$*) can have on our health. These particles come from natural sources as well as from human activities, including combustion, abrasion of brakes and tyres, dust, and pathogens such as viruses. A range of instruments is used to monitor the number concentration of aerosols. In particular, condensation particle counters (or CPCs) have been developed for particles smaller than* $0.3\,\mu\mathrm{m}$*. Various CPCs are available commercially, but their size, complexity, and cost still make widespread control of air quality difficult to achieve. This project investigated the possibility of developing a compact condensation particle counter by miniaturising the established technology for water-based CPCs.*

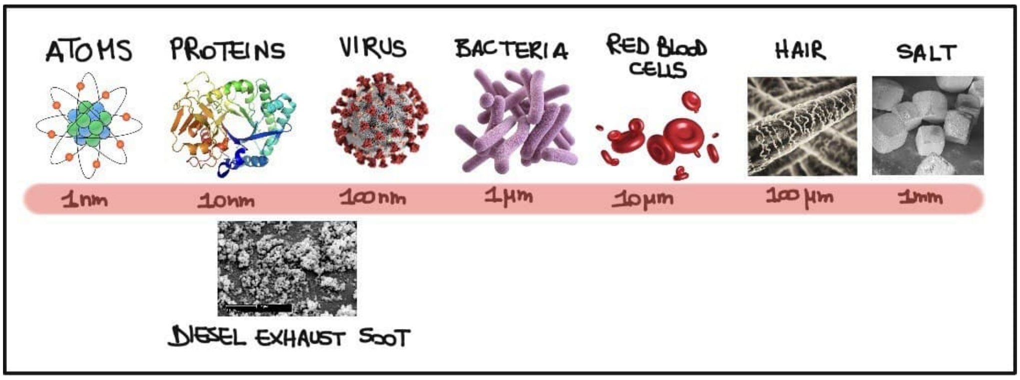

Figure 1: Typical dimensions of different particles.

Methodology

The development of this new instrument was carried out in three phases:

- We investigated the fundamental (thermodynamic) limitations placed by the physics of the problem;
- We developed prototypes based on the above limits, while also taking into account practical constraints such as manufacturing;
- We started to validate the concept through initial lab testing.

Fundamental analysis

The fundamental analysis was based on simulations in COMSOL Multiphysics and semi-analytical methods reported in the literature. Through this analysis, we identified suitable operating conditions for a miniature device meeting the required specifications in terms of supersaturation, particle penetration, and particle growth.

We identified the minimum tube diameter and flow rate for the miniature water CPC, as well as the temperature difference required to achieve the desired supersaturation.

Device development

To account for the impact of real-life constraints which had been omitted from the fundamental analysis, such as manufacturing tolerances and compatibility with other functional parts, we had to use an iterative design approach (Fig. 2).

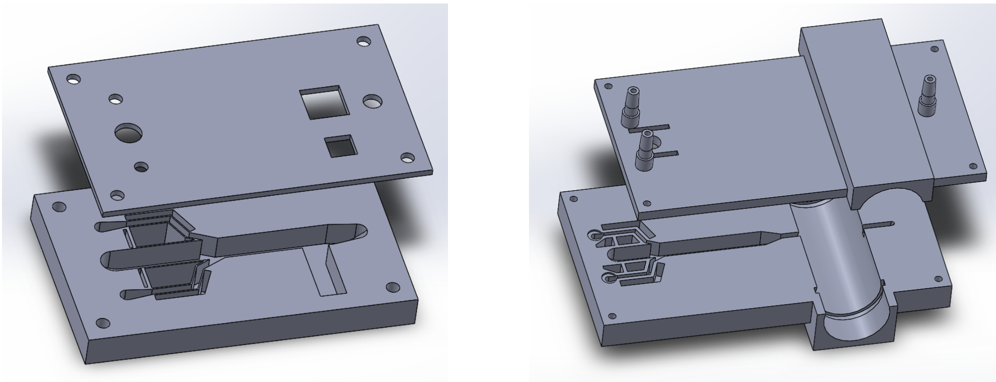

Figure 2: Evolution of the miniature CPC design from its first iteration (left) to the most recent manufactured version (right).

The most challenging aspect of the practical design was the identification of a suitable material and manufacturing process. The type of material and the minimum thickness that could be manufactured strongly influenced the heat transfer allowed through the walls of the device, accounting for most of the power required to maintain the required temperature difference within the CPC.

Thin walls and a material with a low thermal conductivity were preferable, such that our final decision was to 3D print nylon prototypes. The power required to operate the manufactured prototypes at the design operating point was estimated using COMSOL simulations.

To operate the device, additional parts were procured: the temperature of the flows was controlled using thermoelectric (TE) coolers; a HEPA filter was used to obtain particle-free air for the sheath flow; humidification of the flow was achieved through a wick located in the warmest section of the channel. The optical detector was also integrated downstream, and connections to the pump and flow distribution system were designed for the top plate.

Experimental testing

Finally, we carried out initial tests on the manufactured prototypes, obtaining the temperature profiles across the device and checking the correct functioning of the flow system (Fig. 3).

The images taken with an infrared camera were used to understand how the TE coolers affected the temperature distribution within the prototypes. Exposing the cold side of the TE coolers directly to the sample channel significantly improved the cooling of the sample and

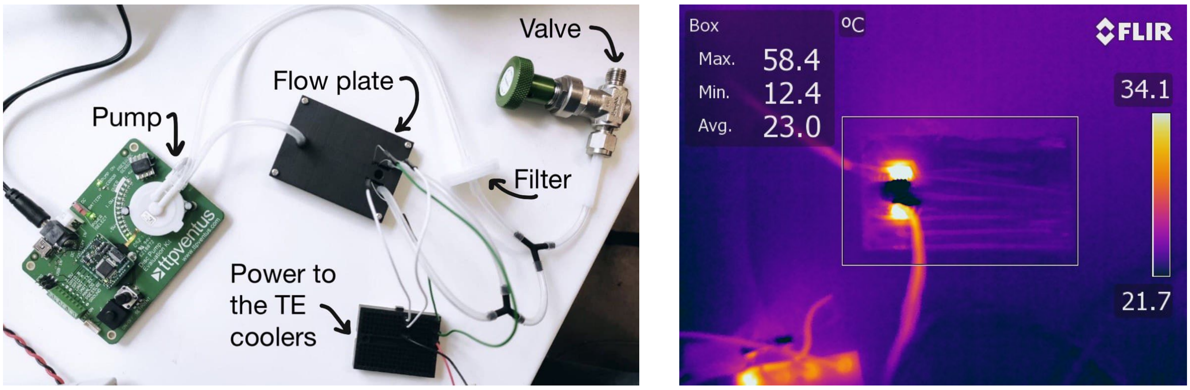

Figure 3: Experimental testing set-up (left) and IR image showing the temperature across the device (right).

reduced heat transfer between the cold and hot sides. However, the net heat flux generated by the TE coolers caused the device to gradually heat up, such that further iterations of the device should investigate alternatives to dissipate some of the excess heat by redistributing it around the device.

Conclusion and future work

This project investigated a solution which would help improve the monitoring of air quality, showing that it is possible to miniaturise the current technology for water CPCs (Fig. 4). The initial testing was promising, and further work is being carried out to adjust the presented design in light of experimental results.

More advanced testing, such as measuring the outlet relative humidity and using aerosols of known concentration and size distribution to confirm successful particle growth, will be necessary to fully evaluate the potential of the proposed miniature water CPC.

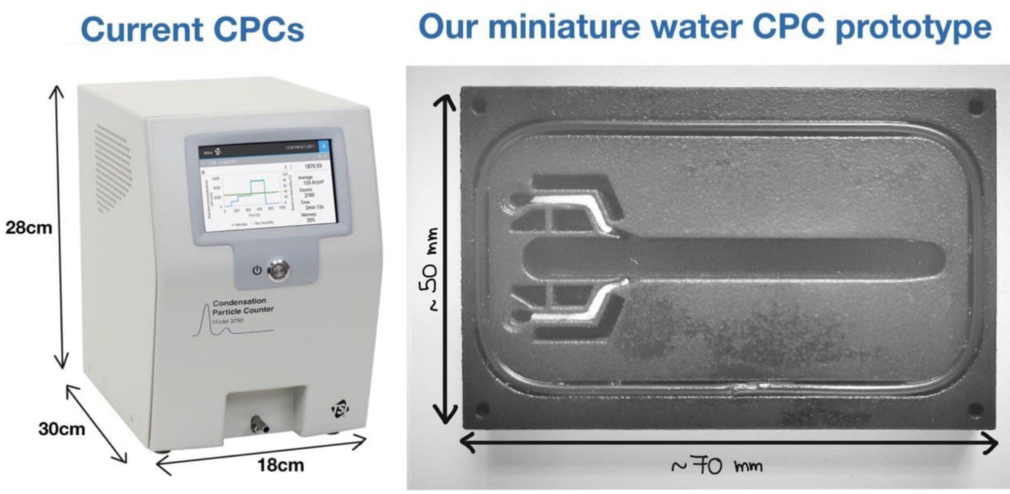

Figure 4: Comparison of an existing commercialised CPC with the miniature version under development.