



Investigating rules of design to optimise pMDI plume properties

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Drug Delivery
to the Lungs (DDL),
Edinburgh, UK 2022

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Introduction

Consensus on the optimal design for a pressurised metered-dose inhaler (pMDI) has not been achieved. It has been shown that across a range of commercially available devices performance is impacted by both the formulation and the product's design [1], [2].

This study attempts to establish design rules by experimentally characterising the impact of two key parameters: sump height (controlling the nozzle internal volume), and orifice internal diameter on the plume's structure and the resultant particle size distribution.

Method

Guided by literature and devices available in the market the nozzle geometries investigated in this study are outlined Figure 1 and Table 1 [3], [4].

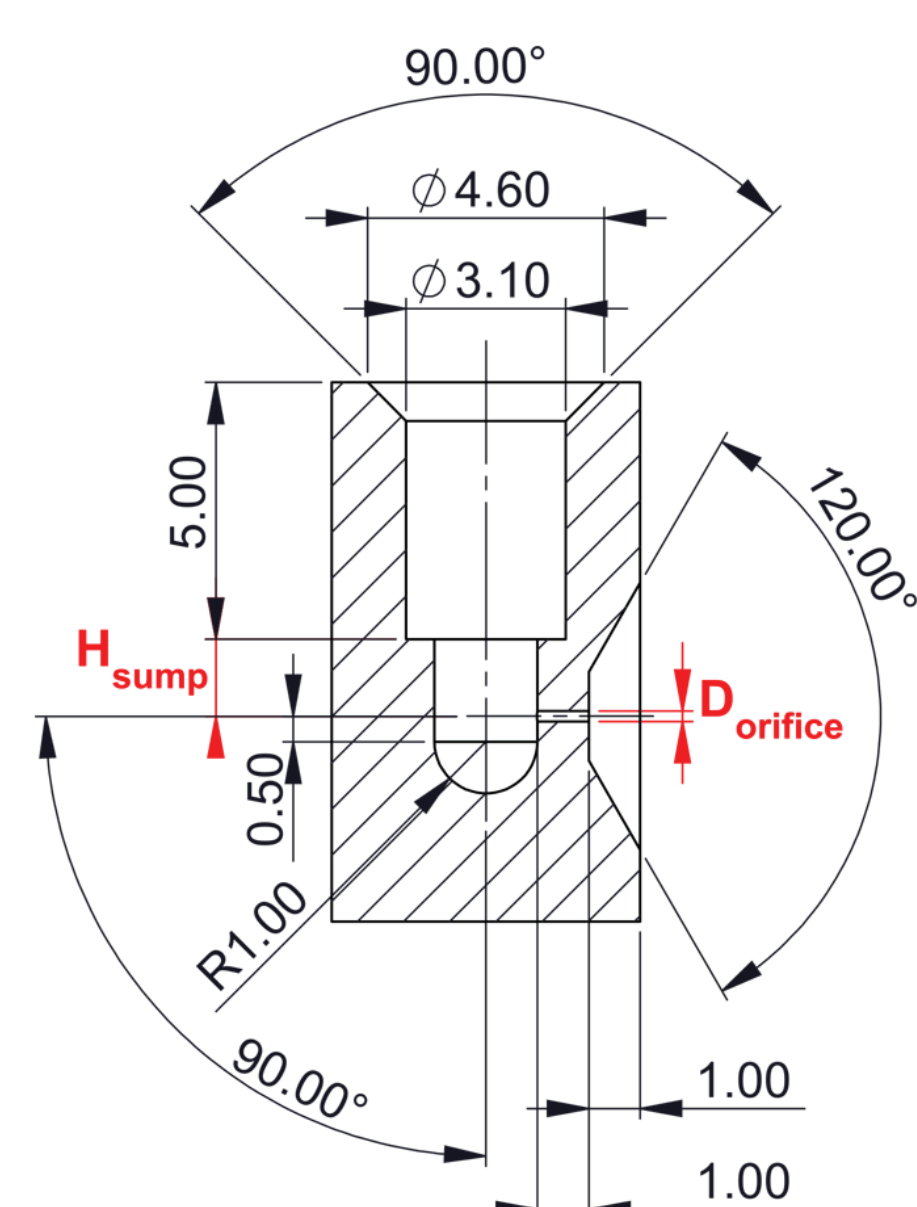


Figure 1 - Schematic showing the nozzle geometry and the varied dimensions.

Nozzle ID	D _{orifice} [mm]	H _{sump} [mm]	V _{sump} [μL]
1	0.29	0.54	5.2
2	0.28	9.29	35.1
3*	0.22	1.53	8.4
4	0.48	1.55	8.4
5	0.29	1.53	8.4
6	0.49	10.05	35.1
7*	0.22	0.51	5.2
8	0.39	1.53	8.4
9	0.29	5.06	19.4

*Nozzles 3 and 7 appeared to be misshapen after analysis on the X-rays and were discarded.

Table 1 - Geometric definition of each nozzle.

Analysis was conducted with canisters containing HFA 134a only (Vitalograph). All sprays were formed in static air with no co-flow at ambient temperature (21°C).

The resultant plume structures and particle size distributions were investigated via high-speed imaging and light scattering particle size analyses (a Spraytec instrument - Malvern), respectively. The 50th percentile particle diameter (Dv50), was used to quantify a plumes representative particle size.

Image processing was developed to analyse the captured high-speed videos [5]. Aimed at tracking the downwards motion of the canister and identifying the plume edge position over time, the processing was used to quantify the following metric [6], [7]:

- Cone angle:** Difference in angles of the line of best linear fit of the upper and lower plume boundaries, Figure 2 a).
- Expansion coefficient, k:** Characterising the expansion of the plume; $L = \sqrt{kt}$ [7]. Where L is the position of the front of the plume along the axis of the orifice. It's increase over time, $L(t)$ is shown in Figure 2 a).
- Optical duration:** Duration for which the plume is continuously connected to the nozzle front; indicative of total dose event time.
- Delay:** Time between actuation start and the first frame where the plume appears. With actuation start defined by a trigger level of 0.5mm of movement from the canister's resting position, Figure 2 b).

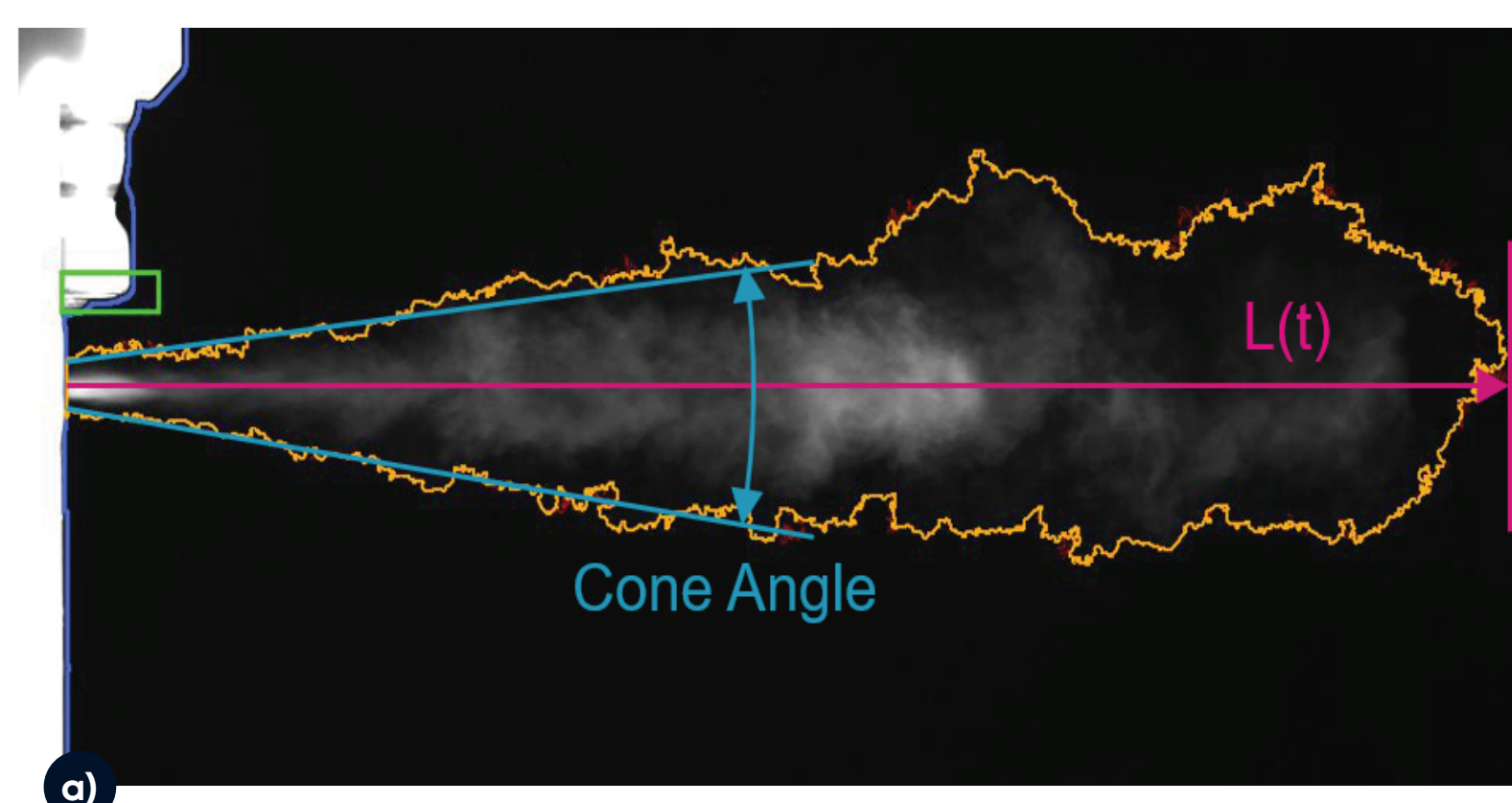
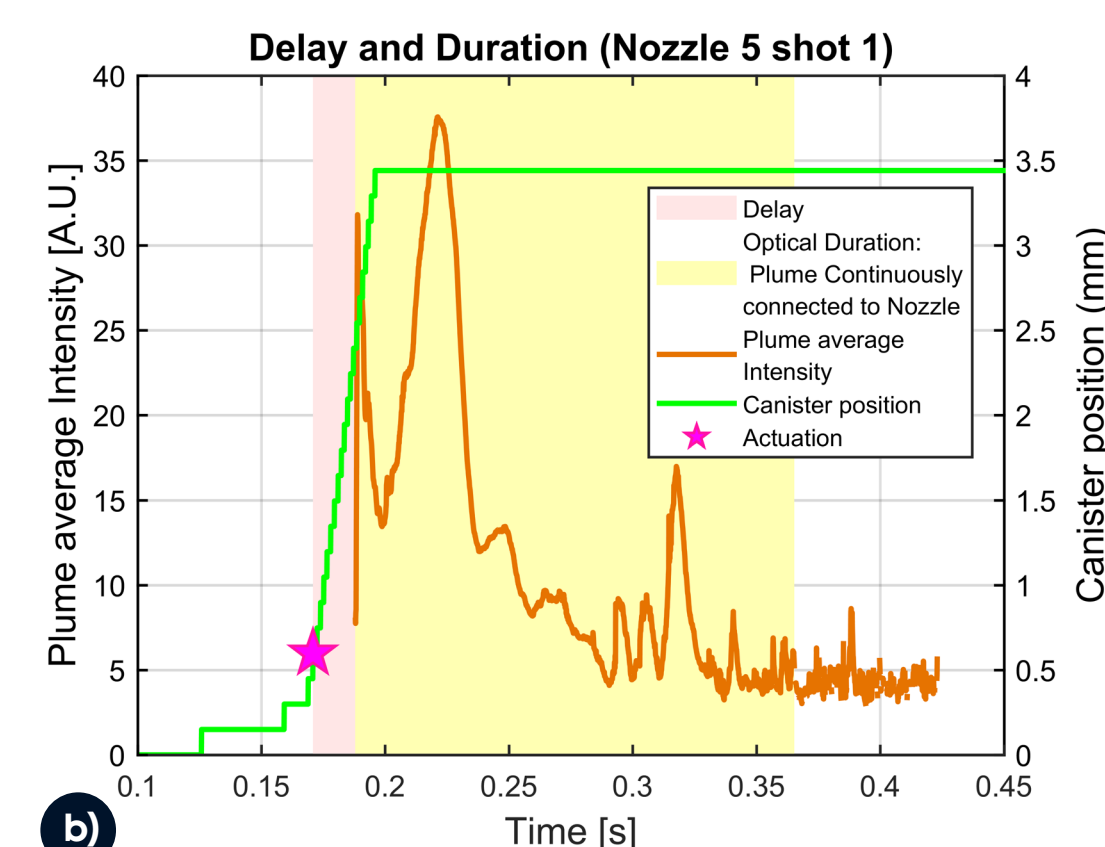


Figure 2 - a) Typical frame from a post-processed plume video.

b) Canister motion vs Plume average intensity over time, allowing the measurement of the delay at which the plume appears and the duration over which it is continuously connected to the orifice.



Results

Data from high-speed video processing and particle size measurement was analysed for each nozzle and is presented in Figure 3.

Computation of correlation coefficients suggests that, across the range of parameters investigated, most metrics are significantly impacted by orifice diameter; only plume delay is dominated by the sump's height. Data suggests that plume delay increases with sump volume (0.44). However, it also anti-correlates with the orifice diameter (-0.43).

Expansion coefficient shows a positive correlation with orifice diameter (0.68). As the orifice diameter is the dominant resistance in the system, a reduction in diameter increases the resistance to flow, resulting in a slower plume expansion and a longer plume duration: optical duration shows a strong negative correlation with orifice diameter (-0.96). Coupling this with the observed delay suggests that the mid-actuation pressure in the sump is unaffected by sump volume (within the range investigated). As the volume dispensed per actuation is constant, a lower sump pressure would result in an extended plume duration, which is not observed.

Dv50 shows a positive correlation with nozzle diameter (0.98). Particle size increases from 4.87 to 9.92 μm for an orifice diameter of 0.29 and 0.48 mm respectively. A positive correlation between cone angle and orifice diameter is also observed (0.91). Furthermore, particle size also correlates with cone angle 0.84).

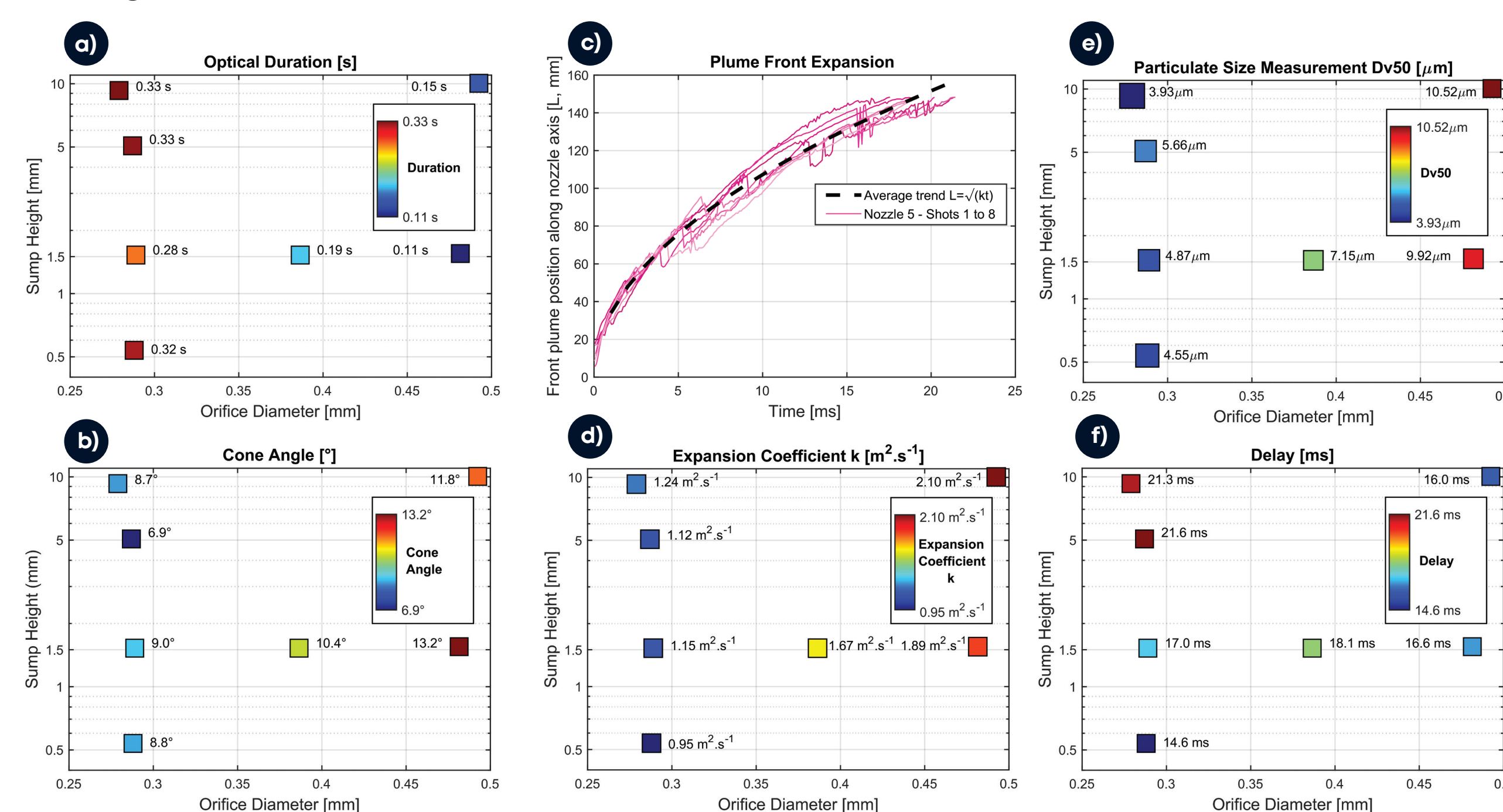


Figure 3 - a-b) The delay between actuation and the first appearance of the plume depends essentially on the sump height. However, the plume duration depends essentially on the orifice diameter. c-d) At the start of the flow, the plume front progresses as the \sqrt{kt} . The expansion coefficient k increases essentially with the nozzle diameter. e-f) The average particle size increases with the diameter and so does the plume cone angle.

Conclusion

The experimental approach outlined here has proven to be tools in the quantification of pMDI plume structures. Application of these techniques to a parameterised nozzle geometry allows investigation of the interplay between sump height and orifice diameter on several metrics by the computation of correlation coefficients.

The developed method illustrates how pMDI nozzle designs could be optimised by such an empirical approach. Further investigations could be pursued with formulations containing Active Pharmaceutical Ingredients (APIs) to optimise actuators and improve performance in terms of drug delivery.

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