Flash Atomization in a Model System Representing Pressurized Metered Dose Inhaler Sprays

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Introduction

The underlying cause of the atomization mechanism producing pressurized metered dose inhaler (pMDI) sprays is thought to be flash atomization. Flashing starts by forming nuclei that can develop into rapidly growing vapour bubbles which can disintegrate the liquid volume once they reach a sufficient size. Propellant evaporation impedes flash atomization due to evaporative cooling which leads to a decrease in propellant vapour pressure within the bubble. In the current study, the time scales involved in bubble growth and evaporative cooling are investigated theoretically and experimentally.

Theory

- A single HFA droplet with one spherical bubble at its center is considered. The behaviour of the droplet is determined by two competing parameters; bubble growth rate and droplet evaporation rate. The bubble growth rate controls the onset of flash atomization. Droplet evaporation rate controls the cooling rate of the droplet which eventually terminates flash atomization.
- Conservation equations for mass and energy were solved simultaneously to determine droplet diameter and droplet temperature as a function of time.
- Bubble radius is calculated as a function of time using Mikic's (1970) solution of the Rayleigh-Plesset equation.

Experiment

- A custom atomizer assembly comprising a high pressure liquid handling system as well as a temperature control circuit was used to produce cylindrical jets emerging from micro-orifices as an experimental model system.
- Orifice diameters used were: 5, 10, 15, 20, and 25 µm.
- The initial temperature of the jet was controlled in the range of 5 to 25 °C. The jet temperature was then increased gradually to the point when transition of the jet from a steady thin jet to a flashing unsteady expanded jet was visible .
- The liquids used were (a) HFA134a, (b) HFA134+20%w/w ethanol, and (c) HFA227ea

Theoretical Results

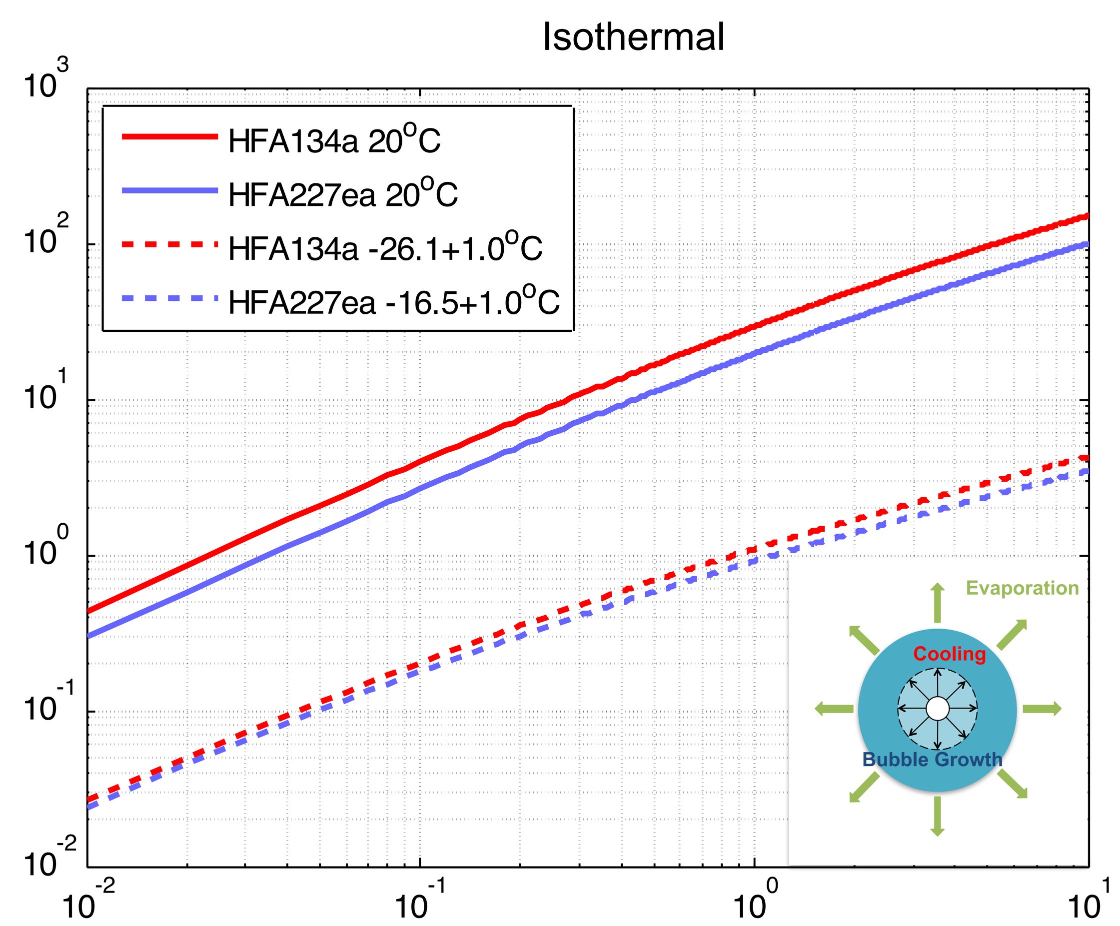

Figure 1: Bubble diameter vs. time for bubbles in HFA134a and HFA227ea at different temperatures.

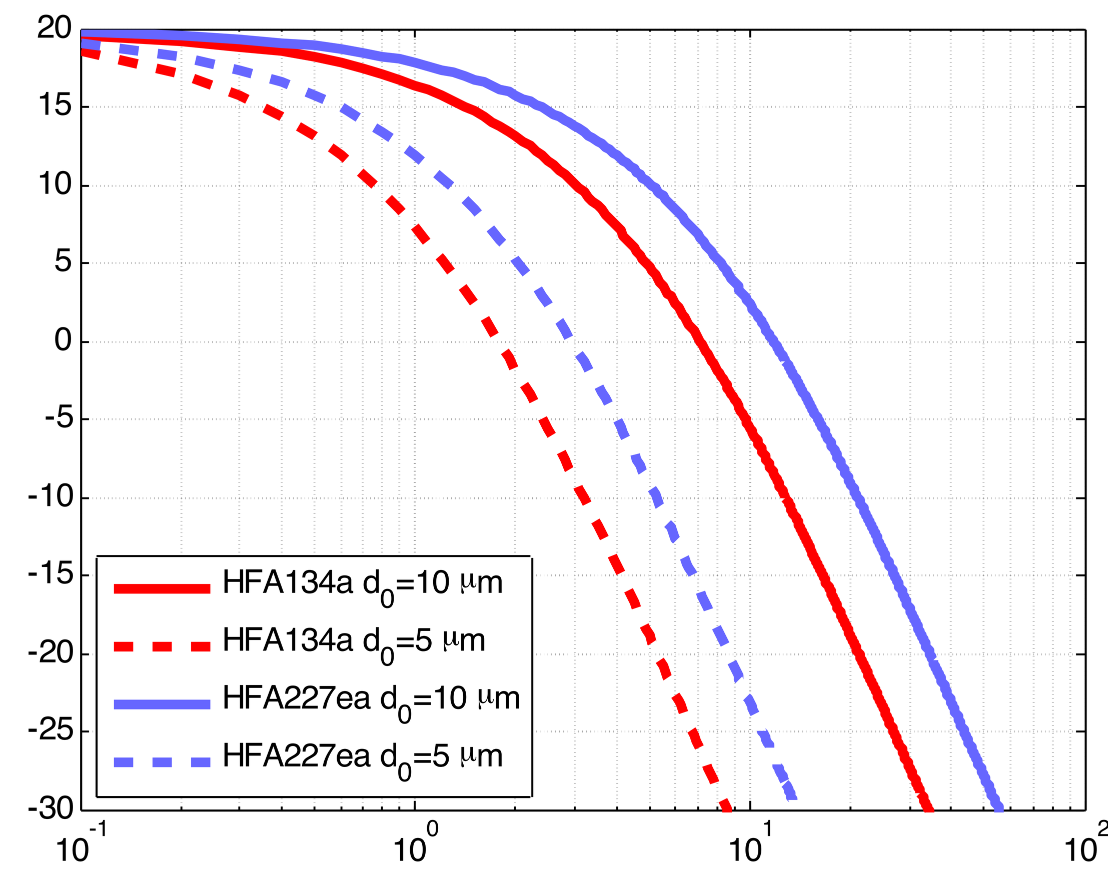

Figure 2: Droplet temperature as a function of time for HFA134a and HFA227ea droplets with different initial diameters

Experimental Results

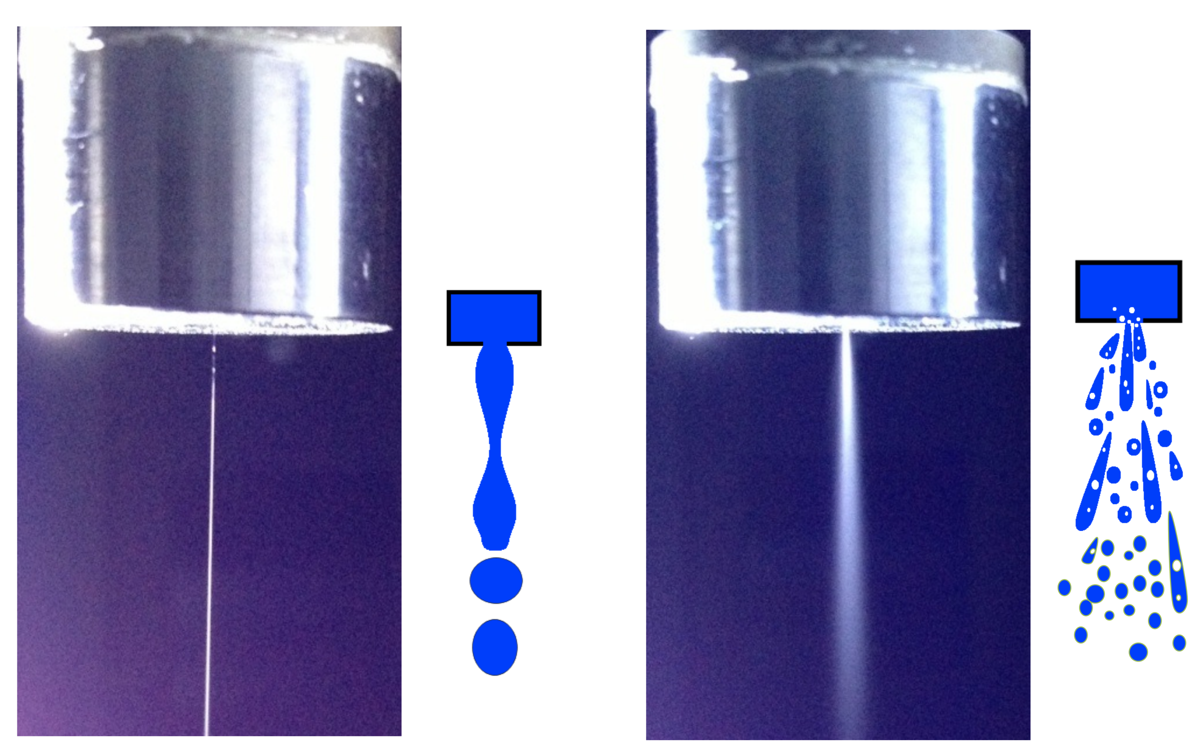

Figure 3: Images of HFA jets:
(a) jet below flashing temperature, characterized as being thin and steady

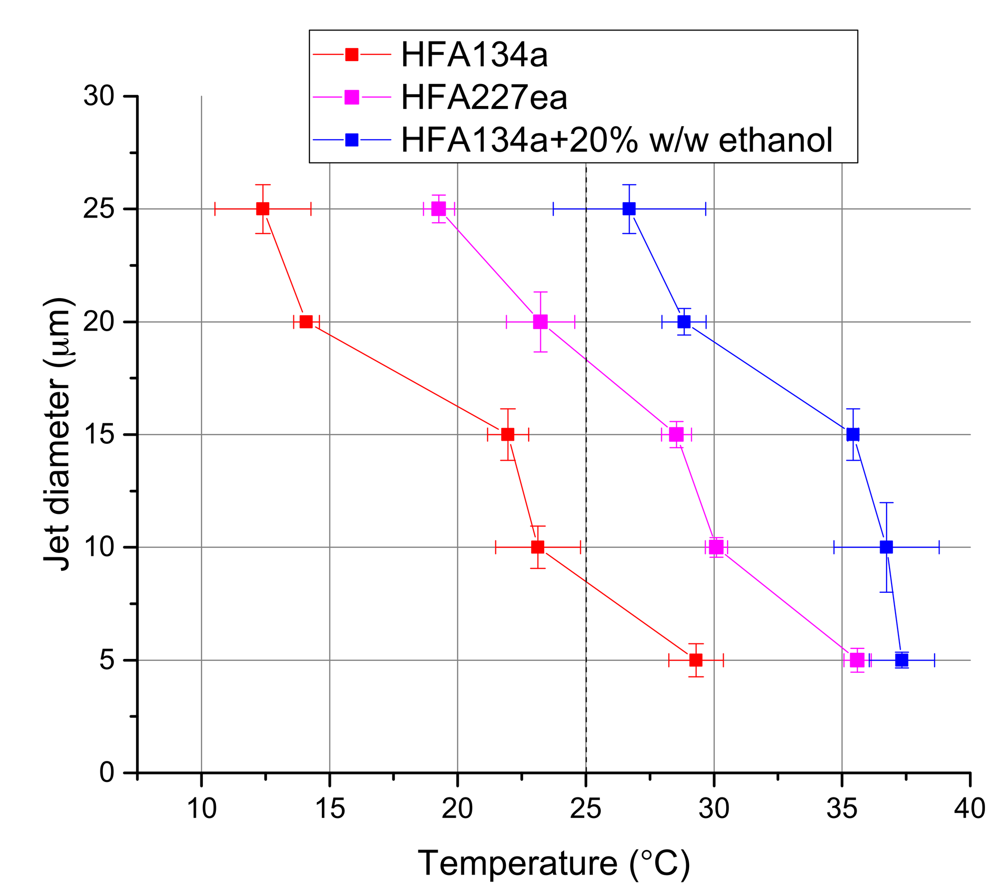

Figure 4: Transition temperature of HFA and HFA-ethanol jets from non-flashing to flashing. Vertical error bars represent the deviation of the orifice diameters from their nominal ones.

Conclusion

In the current study, the time scales involved in flash atomization as the main mechanism to produce a wide variety of droplet sizes in metered dose inhalers is studied theoretically and experimentally.

- It is observed that propellant selection affects onset of flash atomization in propellant jets. HFA134a jets tend to flash at lower temperatures compared to HFA227ea jets. Addition of ethanol postpones flash atomization.
- Evaporative cooling in propellant droplets is both affected by the choice of mixture and droplet size. It is observed theoretically that HFA134a droplets cool down faster than HFA227ea droplets. At smaller droplet sizes evaporative cooling is accentuated, and it is believed to be due to higher surface to volume ratio of smaller droplets, and lower heat capacity of smaller droplets compared to large ones.
- The current results show that for each formulation at ambient temperature, there exists a characteristic jet (droplet) diameter below which breakup into smaller duplets due to flash atomization does not occur.
- The current results may be useful in efforts aimed at finding new propellants and formulations to produce finer MDI sprays for more effective pulmonary drug delivery.

References

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- Brennen CE: *Cavitation and Bubble Dynamics.* New York: Oxford University Press; 1995.
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