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COMPUTATIONAL MODEL OF A DROPLET GENERATOR USING THE VOF METHOD

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INTRODUCTION

Aerogen Vibronic® is a droplet generation technology for pulmonary drug delivery. At the core of the device is a palladium plate, approximately 5 mm in diameter, perforated with approximately 1,000 orifices of ~ 4 µm diameter. The plate vibrates at a frequency of 128 kHz and amplitude of 2.5 µm transverse to the plate. Liquid stored on one side of the plate is pumped through the orifices, producing fine droplets which can reach the deepest areas of the lung [1]. For deep lung penetration, droplet size range of 1-5 µm is required [2]

The objective of this work is to simulate, using a Computational Fluid Dynamics (CFD) model, the droplet formation mechanism at one orifice of the Aerogen nebulizer. The mechanism of droplet formation will be discussed and compared with theoretical and experimental results.

METHOD

The CFD software ANSYS-FLUENT has been used to solve the Navier-Stokes equations (mass conservation and momentum) for the two-phase air-liquid flow using the Volume of Fluid (VOF) method. An axisymmetric computational model was generated for one orifice with a mesh of 200,000 quadrangular cells. The liquid drug is modelled as water and surface tension effects are included. The numerical scheme is second-order implicit in space.

The fluid is modelled in the reference frame of the plate by applying a sinusoidal body force corresponding to the acceleration of the plate. Defining $y=A\sin(\omega t)$ as the plate displacement, the acceleration is $\ddot{y}= -A\omega^2\sin(\omega t)$, where A and ω are the amplitude and frequency of the vibrating plate respectively.

RESULTS

The breakup of a liquid jet issued from an Aerogen orifice is presented in Figure 1 for six cycles (0-46.8 µs). Droplet generation is associated with the reduction in the cross-sectional area of a primary ligament (a) ejected from the nozzle (Figure 1). The narrowest section of the ligament is known as the 'neck' and its evolution is driven by static pressure and surface tension. The mass from a neck is transferred to the first droplet detached (b). It can be observed that the first droplet is formed at the end of the first cycle (7.8 µs). The droplet generation downstream the nozzle is also caused by other factors, such as the interaction between surface tension and aerodynamic forces.

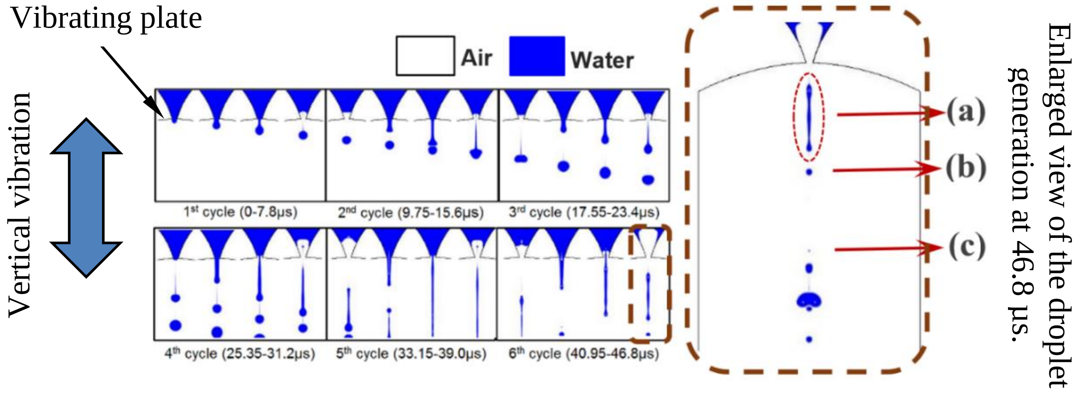

Figure 1 Volume fraction for droplet formation during the first six cycles (0-46.8 μs)

DISCUSSION

According to classical experiments for steady liquid jets, the breakup of a jet can be categorized within four different breakup regimes [3]. Each regime is localized in the Ohnesorge diagram [4], as a function of Ohnesorge ($Oh=\mu/(\rho d\sigma)^{1/2}$) and Reynolds ($Re=\rho Ud/\mu$) numbers.

The present simulation shows that, under the operating conditions described above, average jet velocity is approximately 150 ms^{-1}. These results predict Re=600 and Oh=0.0583, which lies in the first wind-induced breakup regime, where the surface tension effect is increased due to the relative velocity between the jet and the ambient gas, accelerating the breakup process. The shape and length observed in the resulting ligament detached from the nozzle (a), the detachment of a primary droplet similar in diameter to the orifice (b), and secondary breakup due to aerodynamic forces on the primary droplet (c), are also characteristics predicted in this breakup regime. These properties are in agreement with previous theoretical [5] and experimental [6] works.

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