Numerical modelling of atomization through an aperture plate in an active vibrating mesh nebuliser

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Low droplet size and high flow rate are critical factors in active vibrating mesh nebulisers to ensure effective drug delivery to the lower lungs. An active vibrating mesh nebuliser is composed of an aperture plate which vibrates mechanically due to piezoelectric effect. When the liquid comes into contact with the vibrating plate, aerosol droplets are forced through the orifice (aperture) of the plate [1].

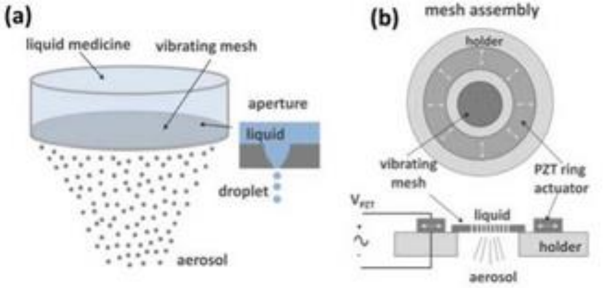


Figure 1. Vibrating Mesh Nebuliser Core [1]

Fluid and material properties, vibration parameters and mesh geometry influence the atomization rate, droplet size and distribution. A study on the effects of driving frequency and voltage on the performance of vibrating mesh nebulisers carried out by Moon et al. [2] indicated that a deviation in the drive frequency from the resonant frequency by 1% decreased the atomization rate by 11-30.1% (Figure 2) and increase in particle sizes by 1.6-7.7% (Figure 3).

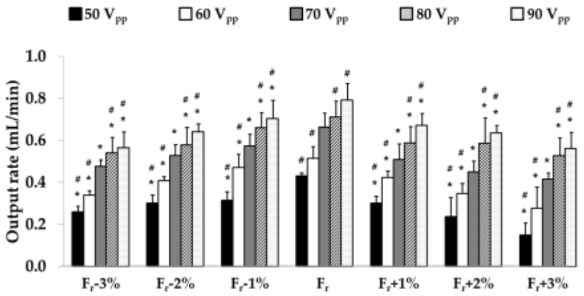


Figure 2. Output rate vs drive frequency and voltage [2]

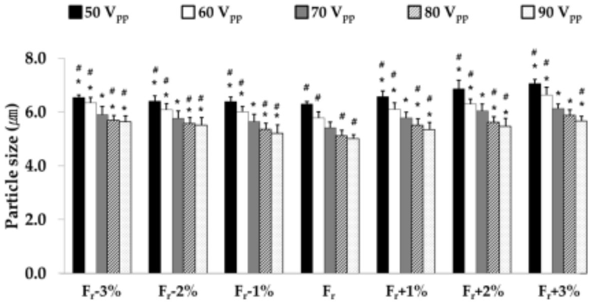


Figure 3. Particle Size vs drive frequency and voltage [2]

The findings also indicate that increasing peak to peak voltage (Vpp) increased the output rate and reduced particle size. However, this effect is decreased as the drive frequency deviated from the resonant frequency which indicates that for the purpose of reduction in power consumption, tuned operation to resonant frequency at lower voltage provides high outputs compared to operation at high voltage out of tune of resonant frequency.

Findings from Sharma et al. [3] also indicate that atomization rate increases as voltage increases. However, material type and fluid viscosity effect the atomization rate and droplet size as shown in Figure 4 with an increase in fluid viscosity reducing the atomization rate for both Stainless steel (a) and Silicon (b) based vibrating mesh atomizer (VMA).

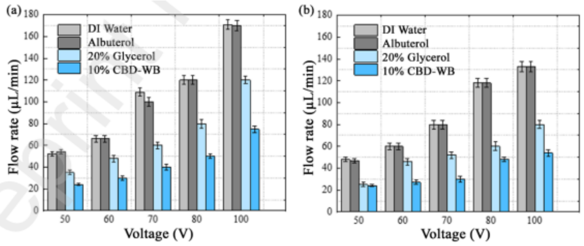


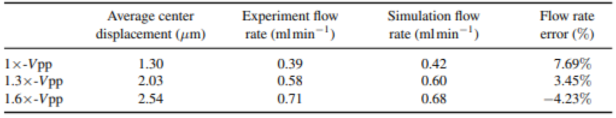
Figure 4. Flow rates at different voltages for (a) Stainless steel VMA and (b) Silicon based VMA [3]

These findings illustrate that material properties, fluid characteristics and optimal tuning of frequency and voltage must be considered to maximize the performance of active vibrating mesh nebulisers.

The design and development of active vibrating mesh nebulisers rely heavily on experimentation methods and prototyping which can develop significant costs overtime and waste of materials. The use of computational numerical modelling in the design process can provide a predictive framework before prototyping to reduce material waste and cost.

There have been limited studies on numerical modelling of active vibrating mesh nebulisers, specifically the analysis of fluid behaviour during atomization.

Previous work form Chen et al. [4] designed, developed and validated a multiple-orifice Volume of fluid (VOF) model on a Palladium aperture plate with a comparison of simulation flow and experimental flow shown in Figure 5. The resulting flow rates from simulation compared to flow rates obtained from experimental methods with minimal percentage of error. By increasing the Vpp, it was also observed that the average center displacement increased and that in turn increased the flow rate. These findings correlate very well with work observed in the literature [2] [3].



	Average center displacement (μm)	Experiment flow rate (ml min^{-1})	Simulation flow rate (ml min^{-1})	Flow rate error (%)
1×-*V*pp	1.30	0.39	0.42	7.69%
1.3×-*V*pp	2.03	0.58	0.60	3.45%
1.6×-*V*pp	2.54	0.71	0.68	−4.23%

Figure 5 Experimental flow rate vs simulation flow rate [4]

However, the behaviour of alternative and cost-effective aperture geometries is largely unexplored.

This study will implement the VOF Model approach to simulate droplet formation and break up through an alternative cost-effective material such as stainless steel with the aim to predict droplet size and distribution and flow rate and validate the model with experimental methods.

Prior to implementation of an alternative suitable material, a transient laminar air-water multiphase VOF Model for a single orifice with existing material was developed with previously validated inputs and boundary conditions using Ansys. A fluid domain was set up closer to the orifice for finer mesh application as shown in Figure 6. A time step of $\Delta t=10^{-8}$ over 300 time steps to capture droplet break up. Local refinement was applied to the fluid domain with element size of 1.5×10^{-6} m and growth rate of 1.2. Plate oscillation was implemented with a user-defined function which assigned sinusoidal displacement:

Equation 1 Sinusoidal function for plate oscillation

$$D = A \times \sin(\omega t)$$

Where D is displacement, A is amplitude, ω is angular velocity, t is time. The UDF represented maximum displacement of 1.3μm at 100 peak-to-peak voltage (Vpp).

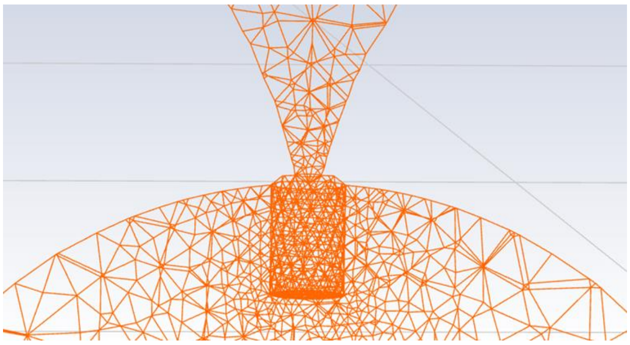


Figure 6 Fluid Domain and mesh set up

Figure 7 illustrates fluid flow through the orifice. A plane was created at the exit to capture the flow rate. The flow rate was calculated to be 2.847×10^{-8} m^3/s. A single orifice model of a stainless-steel plate is in progress with different Vpp values implemented. Future work will involve a multiple orifice model and flow rates validated through experimental methods.

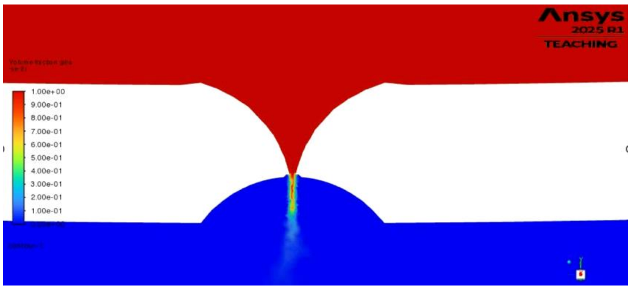


Figure 7 Simulation of single-orifice VOF Model

Following the stainless steel VOF model, a mechanical model of the aperture plate will be coupled with the VOF model.

This work will provide data which enables exploration of fluid and material properties effect on droplet formation and break up. The computational fluid dynamics data sets can be utilised to train future AI models to predict fluid flow, droplet break up and size. This work provides a foundation for AI driven modelling which aims to reduce processing time and cost of computational resources.

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