Modelling Infectious Aerosols

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Introduction

- Bio-aerosols such as the droplets people expel via coughing and sneezing have been long understood as an important mode of transmission of infectious diseases.
- Transmission via infectious droplets can be split into two categories; droplet transmission, larger droplets (>5µm) that fall to the ground quickly and airborne transmission, smaller droplets (5µm<) evaporate quickly travelling large distances[3].
- Airborne infection is a concern for people with Cystic Fibrosis (CF). This project focusses on two pathogens affecting those with CF: *P. aeruginosa and M. abscessus.*
- It is hypothesised that microorganisms and drug treatments can affect the potential for the microorganism to be released in aerosol as well as the size of the aerosol formed and hence the risk of transmission.
- Using three different approaches to gain an enhanced understanding of this transmission process will aid in helping tackle infection control especially in respiratory wards.

Optimising Experiments

To model infectious aerosols experimentally a previous experiment has been adapted[1]. *P. aeruginosa* was nebulised down a pipe and sampled using a 6 stage Anderson sampler. Figure 1 shows the schematic of the rig design.

HEPA filter
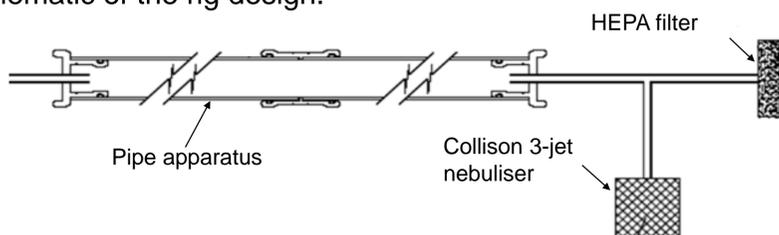
Pipe apparatus

Collison 3-jet nebuliser

Figure 1. Schematic of rig design from previous research[1]

A CFD study is being conducted to optimise the geometry of the experimental rig design. Simulations have been ran using FLUENT to analyse the inlet and shape of the rig. The table below states the parameters used.

Boundary conditions	Nebuliser inlet: Velocity inlet at 0.65ms^{-1} HEPA filter inlet: Pressure inlet Pipe: No slip walls Outlet: Velocity inlet at -3.03ms^{-1}
Turbulence model	Coarse mesh: Standard k-ε with standard wall functions Fine mesh: Transition kkl-ω

Several inlet designs were modelled. Figure 2 shows the difference between two inlet designs, with figure 2a) being the original inlet. Recirculation is reduced when modelling the pipe within a pipe inlet and this geometry is used for the optimised rig design.
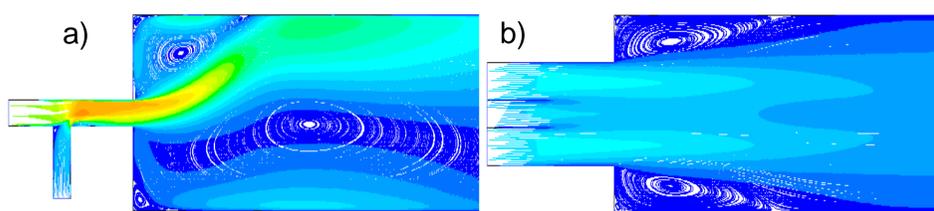
a)   b)

Figure 2. Comparison of inlets a)T junction b) Pipe within a pipe

Square and circular pipe geometries were modelled. It was found that there is no significant difference in the flow for these geometries. A square pipe is chosen for the rig design as this is the optimal geometry for use with the particle sizing apparatus. Figure 3 shows a cut plane of the optimised geometry.
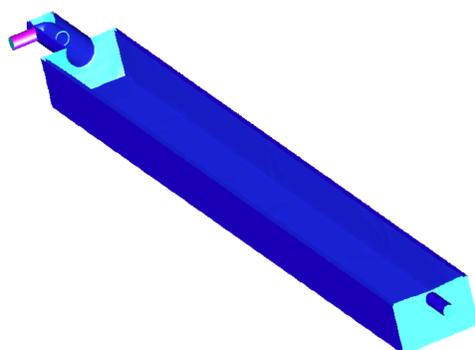
Figure 3. Geometry of optimised rig

Bio-aerosol Decay

- Knowing the decay rate can improve the CFD model of the experiment.
- Bio-aerosol concentration follows a first order decay process

$$\frac{dC}{dt} = -kC \ \Rightarrow C = C_0 e^{-kt} \ (1)$$

- k is a decay rate, k is a sum of the decay due to deposition and survival.
- Decay rate due to deposition can depend on several factors such as: particle size, electrostatics and surfaces.
- Decay rate due to survival depends on: temperature, humidity and species.
- Figure 4. shows the concentration of *P. aeruginosa* over time. Using this data figure 5 plots time against the log of the concentration, the gradient of the line of best fit is k.
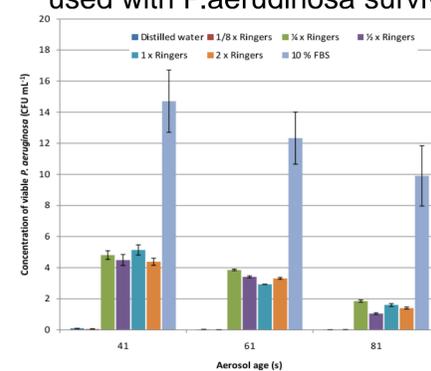- Figure 5 shoes that decay rate also depends on the base fluid used with P.aeruginosa surviving best in 10% FBS.

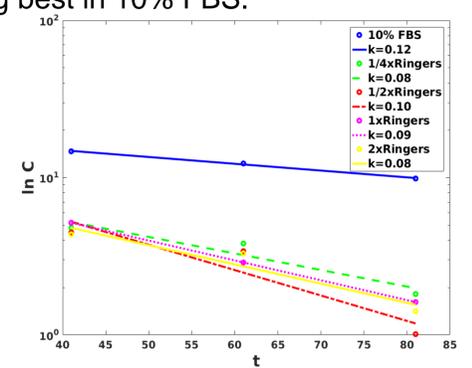Figure 4. Concentration of *P. aeruginosa* sampled from aerosols[1]

Figure 5. Decay rates of *P. aeruginosa*

Future Work

CFD approach
- Model evaporating droplets down the optimised rig geometry.
- Using the CFD results find the decay rate k due to deposition.
- Find the particle residence time using the CFD model and see how this changes with the rig design.

Experimental approach
- The effects on rheology and evaporation by the pathogens will be explored experimentally.
- Viscoelasticity influences particles within an aerosol[2].
- Varying base fluids will be used to represent CF mucus before and after medication.

Numerical approach
- An evaporating water droplet will be modelled using MATLAB.
- Adaptations will be made to include a pathogen at the centre.

References

1. Clifton, I. J., Fletcher, L. A., Beggs, C. B., Denton, M., & Peckham, D. G. (2008). A laminar flow model of aerosol survival of epidemic and non-epidemic strains of Pseudomonas aeruginosa isolated from people with cystic fibrosis. *BMC microbiology, 8*(1), 105.
2. Hasan, M. A., Lange, C. F., & King, M. L. (2010). Effect of artificial mucus properties on the characteristics of airborne bioaerosol droplets generated during simulated coughing. *Journal of Non-Newtonian Fluid Mechanics, 165*(21), 1431-1441.
3. World Health Organization. (2007). Infection prevention and control of epidemic-and pandemic-prone acute respiratory diseases in health care: WHO interim guidelines.