Numerical Study on the Effect of Vacuum Flow Rate on Mask Efficiency with Exhalo™ Device

Kira Haller[1], Rym Mehri[1], Edgar Matida[1], Frank Fiorenza[2]

[1]Department of Mechanical & Aerospace Engineering, Carleton University, Ottawa, ON, Canada,

[2]Product Development, McArthur Medical Sales Inc., Rockton, ON, Canada and Respiratory Therapy Department, University of Ottawa Heart Institute, Ottawa, ON, Canada

INTRODUCTION

Patients requiring oxygen therapy use oxygen masks which vent respiratory droplets. The EXHALO™ device has been developed to be used in conjunction with an oxygen mask. A connected vacuum line provides suction to collect exhaled aerosols. Figure 1 shows the set-up of an oxygen mask (left) and the mask with the Exhalo™ device (right).

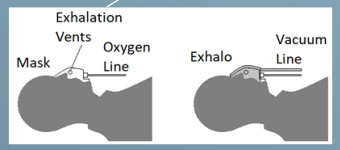

Figure 1. Mask and EXHALO™ device with mask connected to vacuum line.

Aerosols are classified by size:

- Small particles (5-10 µm): short-range trajectories
- Particles <5 µm can reach the lungs.
- Large droplets (>20 µm): remain airborne and travel longer distances.

The SARS-CoV-2 virus is ~60-140 nm in diameter and is shown to be transmitted through droplets.

METHODS

Geometry:

- Oxygen mask and EXHALO™ meshed using ICEM CFD using a tetrahedral (unstructured) mesh
- Geometry and mesh depicted in Figure 2
- Half the domain was used to reduce computational time of the simulation

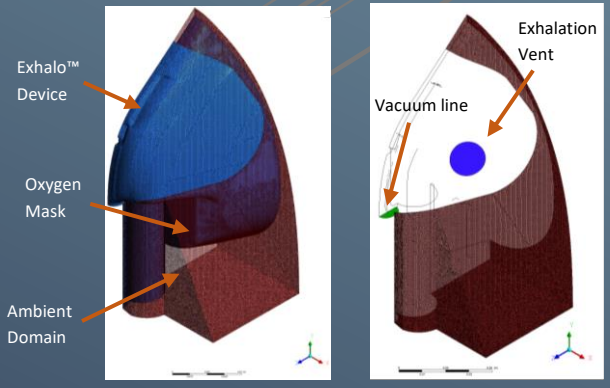

Figure 2. Left: Geometry of oxygen mask and EXHALO™, Right: View of oxygen mask (located under EXHALO™ device)

Grid Convergence:

- Compared results using meshes with 1, 2 and 3 million elements
- Suction flowrate used: 100 L/min

Methods:

- Solver: ANSYS CFX Version 20.2
- Suction flowrates tested: 0, 10, 50 and 100 L/min
- SST turbulence model with isothermal flow at 36°C
- For the EXHALO™ device and mask: no slip, smooth wall boundary conditions were used
- Inlet boundary conditions mimicked a breathing rate of 11 L/min
- 1000 particles of 2.5 µm in diameter were released

RESULTS

Grid Convergence:

Table 1. Results of grid convergence study

Number of elements	Particles on mask (%)	Particles removed (%)	Particles released (%)
1 million	13.0	85.2	1.8
2 million	5.9	92.9	1.2
3 million	5.3	93.9	0.8

- Figure 3 shows the particle trajectories and velocities of the simulated particles in the computational domain.
- Results were obtained from the mesh 3 million elements at a vacuum flowrate of 100 L/min.

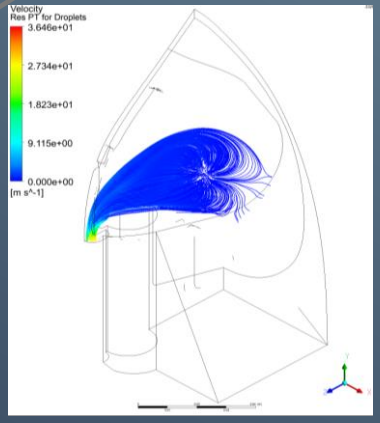

Figure 3. Particle trajectories with velocities.

- From the grid convergence analysis, the computational domain of 3 million elements was chosen.
- The results as the percentage of particles deposited onto the mask, removed by the vacuum or released into the room are shown in Figure 4.
- Increasing the vacuum flowrate was shown to increase the number of particles removed by the vacuum suction line, decreased the number of particles deposited on the mask and decreases the number of particles being vented to the ambient air.

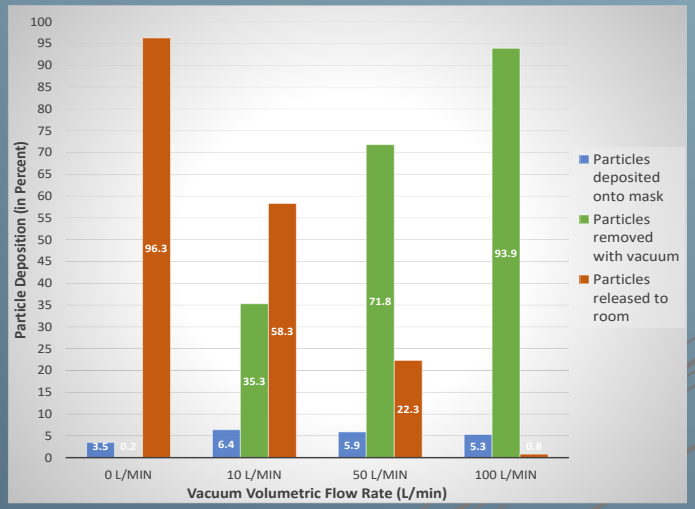

Figure 4. Percent of particle deposition within the mask, EXHALO™ device and surroundings for suction flowrates of 10, 50 and 100 L/min

For a vacuum flow rate of 100 L/min, 99.2% of the particles were contained using the EXHALO™ device in conjunction with the oxygen therapy mask.

CONCLUSION

Particle-mass dispersion is reduced in this simulated model with the addition of the EXHALO™ device, and further reduced by increasing the flowrate of the vacuum suction line. The EXHALO™ device could provide support in combatting the ongoing COVID-19 pandemic by mitigating the release of aerosols produced by patients receiving oxygen therapy or other aerosol-generating medical procedures.