CONSULTANCY TESTING REPORT

Part 1 – the Airshield

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Executive summary

Respiratory infections could be transmitted through the airdroplets. Droplets equal to 10 µm or less may travel for long distances and suspend in the air for an extended period of time. Therefore, one of the ways to limit the spread of infections including COVID-19 is to decrease the level of such droplets. This report is focused on testing the Airshield system using aerosol and particulate OPC-N3. Both concentration of particular matter and abundance of particles were determined with and without the Airshield using aerosol alone, surgical mask and visor, respectively. Moreover, an acrylic clear screen was placed instead of the nozzles. Its performance to reduce particular matter was compared to the Airshield. The measurements were performed in two positions: from one side after the Airshield nozzle and towards the Airshield. The results obtained from aside of the Airshield showed than it provided an effective barrier against small particles equal to or less than 10 µm and reduce the concentration of such particles by up to 96%. Moreover, the measurements from the side of the Airshield showed that the protective materials such as a surgical mask and a visor were found to reduce the abundance of particles in a range from 0.4 to 35 µm by around 80%, respectively, compared to the Airshield that reduced these particles by 99%. This means that such protective materials let particles pass through, whereas the Airshield reduced the abundance of particles that passed through a mask and a visor by up to 88% and up to 75%, respectively.

Furthermore, the results obtained from the front of the Airshield confirmed that it can reduce the abundance of particles sizing from 0.4 µm to 35 µm by 99%, whilst a mask and a visor reduced those particles by 80% and 66%, respectively. Moreover, it has been observed from the results obtained from the front of the Airshield that the concentration of particles equal to or less than 10 µm passed through a mask and a visor was reduced by up to 92% and up to 98%, respectively. In addition, a clear acrylic screen reduced the abundance of particles by 51% and 31% from aside and infront measurements, respectively. The concentration of particles equal to or less than 10 µm was reduced by 45% using the acrylic screen.

1. Introduction

Transmission of respiratory diseases is likely to occur through aerosol particles during human cough or sneezing. Aerosol particles containing viruses and bacteria could travel for a distance of 2 or more metres. It has been previously reported that air droplets larger than ~50 µm are likely to be affected by the gravity and fall on to surfaces, whereas intermediate (10-50 µm) and small (less than 10 µm) droplets could travel for a long distance and remain in the air for an extended time [1]. This means that a development of a protective barrier such as the Airshield could help to limit transmission of infections and overcome limitations associated with human social interactions.

Moreover, it has been observed elsewhere that a cough aerosol, which was obtained by a number of patients with influenza, contained particles in a range from 0.1 to 30 µm with a mean diameter of 7-8.5 µm [1], [2]. It has been discovered elsewhere that particles larger than 0.5 µm could affect pulmonary and tracheobronchial regions of the lungs [2]. Otherwise, particles smaller than 0.5 µm could enter the lower airways during nose breathing. In order to test an Airshield provided, an aerosol spray containing droplets with the diameter in a range of 0.1-40 µm was chosen.

Airborne droplets might carry pathogenic microorganisms such as bacteria and viruses. However, the spread of pathogens could be reduced by their exposure to antimicrobial agents. High-efficiency particulate air (HEPA) filters can provide support in reducing concentration of pathogens. For instance, filters may block around 99.97% of particles over 0.1 µm in diameter [3]. The fibres of HEPA filters are randomly orientated. That means that the air flow is not straight, but has turns and twists. This allows particles to be trapped inside a filter. Moreover, such filters can be provided with enhanced antiviral technology. For example, ultraviolet light type A, B and C (UVA, UVB and UVC) can express antimicrobial activity. UVC and UVB lights were found to be absorbed by RNA or DNA molecules [4]. This can lead to a damage of RNA protein cross-linking, affect energy transfer between proteins and subsequently result in a site-specific damage to RNA [4]. UVC was reported to provide the strongest antimicrobial activity among other types of UV radiation. It has been observed that *far*-UV light can be used as a germicidal approach for killing microorganisms [5]. For instance, it has been detected that *far*-UVC light (222 nm) is able to inactivate airborne influenza virus [5]. Based on the evidence provided above, both UVC lamps and HEPA filter incorporated in the Airshield could lead to antimicrobial activity and limit the distribution of pathogens present in air droplets.

2. Experimental methods

The concertation of particles in the aerosol was measured using OPC-N3 particulate (particle analyser, Alphasense; Fig.1) continuously from 1 to 23 seconds.

Like conventional optical particle counters, the OPC-N3 measures the light scattered by individual particles carried in a sample air stream through a laser beam. These measurements are used to determine the particle size (related to the intensity of light scattered via a calibration based on Mie scattering theory) and particle number concentration. Particle mass loadings- PM1, PM2.5 and PM10, are then calculated from the particle size spectra and concentration data, assuming a particle density and refractive index (RI). Default settings are: density 1.65 g/ml, RI 1.5+i0. Respiratory profiles are included in the PM calculations. It is also possible to select PM4.25 instead of one of the other PM values.

The OPC-N3 contains 10 weighting index sets, each comprising a weighting value for each of the 16 size bins. Index Set 0 can be adjusted by the end user; the other 9 are factory set (See later for more information).

The OPC-N3 classifies each particle size, at rates up to ~10,000 particles per second, recording the particle size to one of 24 “bins” covering the size range from 0.35 to 40 µm. The OPC-N3 will detect ~100% of particles at 0.35 um and ~50% at 0.3 um. OPC-N3s have measured PM10 values of 10 000 µg/m3. To carry this out the OPC automatically switches between a high gain and low gain mode and combines the data, note this means that the histogram sampling period is half of the repeat interval. The additional range is designed to enable pollen and other bio-particles to be measured; the collection efficiency

8 of large mineral dust particles is likely to be lower due to rapid sentimentation in the environment.

The resulting particle size histograms can be evaluated with user-defined sampling times from 1 to 30 second duration. This histogram data is transmitted via an SPI interface to a host computer.

The OPC-N3 is designed to minimise particle deposition within the unit and thus allow for prolonged unattended operation in dusty environments.

Consistent with most commercial Optical Particle Counters (OPCs), all particles, regardless of shape are assumed to be spherical and are therefore assigned a ‘spherical equivalent size’. This size is related to the measurement of light scattered by the particle as defined by Mie theory, an exact theory to predict scattering by spheres of known size and refractive index (RI). The OPC-N3 is calibrated using Polystyrene Spherical Latex Particles (PSLs) of a known diameter and known RI. Correction factors can be applied for errors resulting from particles of different density or refractive index.

Figure 1. OPC-N3 particulate is used to measure particles.

The velocity of such spray was found to be 0.001-1.2 gram/second[6]. There were two setups of the particulate to measure particle concentrations. The dispersed particles were firstly detected from one side of the Airshield, whereas the second setup represented measuring particles towards the particulate. In both ways, the sensor was placed on a table approximately 1.15 m above ground and 0.4 m away from the Airshield. The Airshield is illustrated in Figs. 2-3, whereas the arrangements of the experiments are shown in Figs. 4 and 6. The approximate visibility of the laser in both positions are shown in Figs. 5 and 7. The baseline (Airshield off) and Airshield On measurements were carried out in tandem with the same time period between each measurement across all experiments.

Figure 2. A photograph of the Airshield.

Figure 3. A photograph of the top of the Airshield.

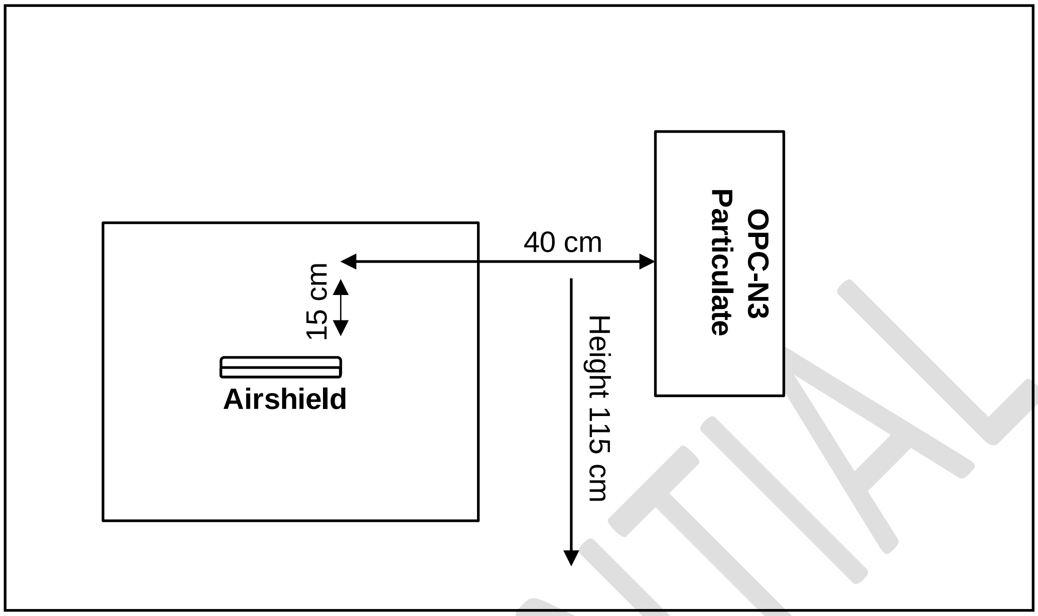

Figure 4. A diagram showing the side position of the particulate to the Airshield.

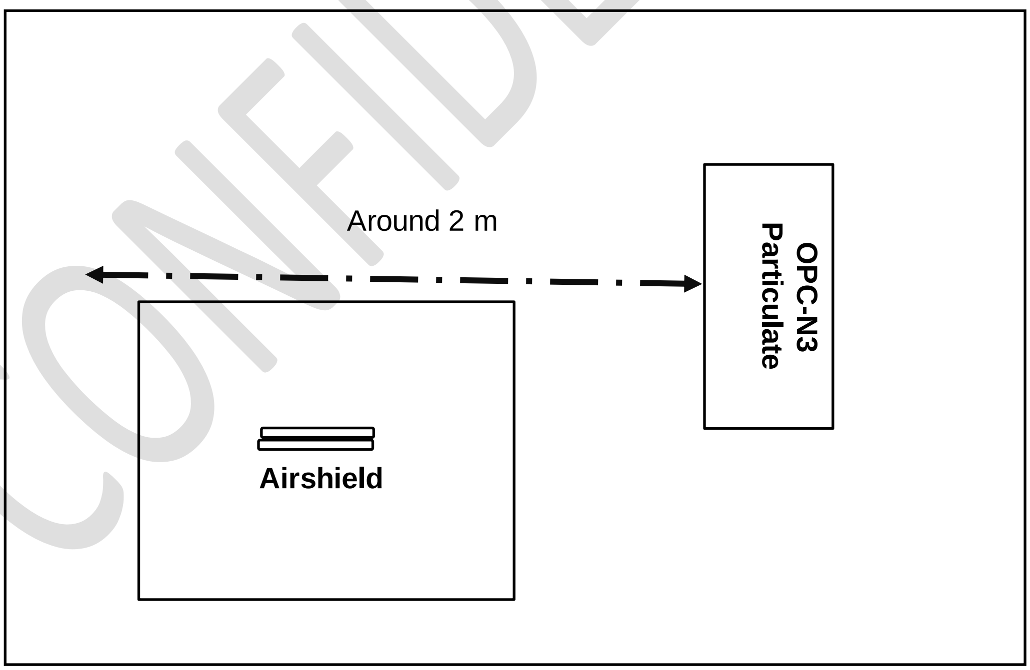

Figure 5. A schematic diagram showing the visibility of the laser from the side position. The laser measures particles that could reach the second side of the Airshield.

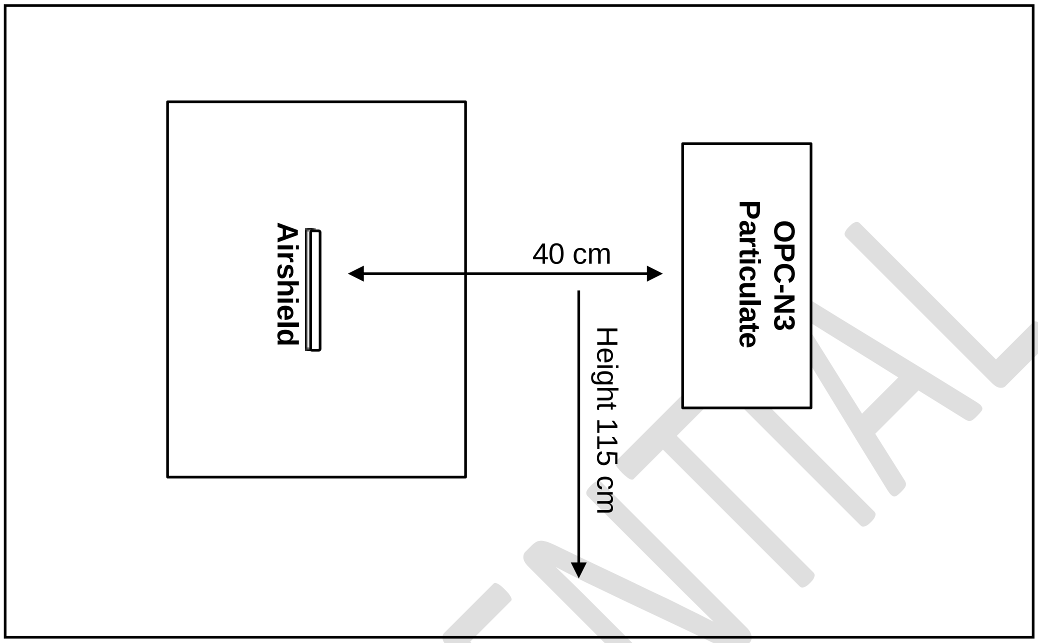

Figure 6. A diagram showing the position of the particulate toward the Airshield.

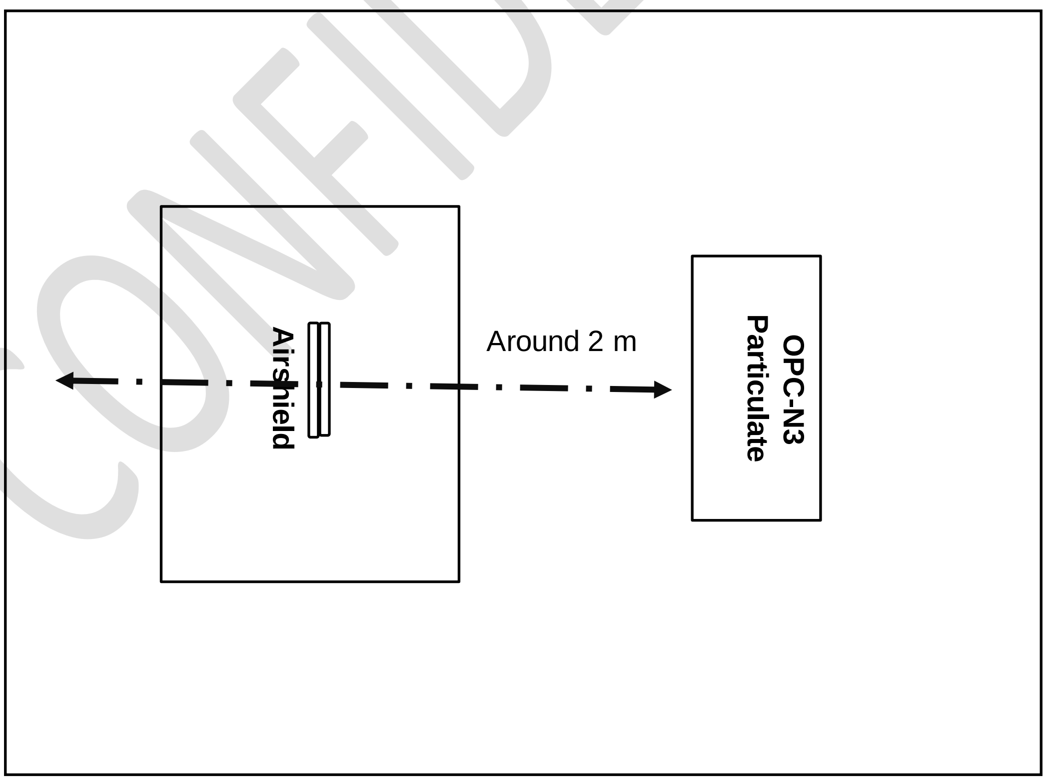

Figure 7. A schematic diagram showing the visibility of the laser toward the Airshield position. The laser measures particles present on both sides of the Airshield.

An effect of the Airshield was compared to an acrylic screen. The screen was 70 cm in length and 60 cm in height. The screen was placed on the top of the Airshield instead of the nozzles (Fig. 8). Both concentration and abundance of particles was measured in two positions as shown in Figs. 4 and 6. The Airshield was off.

Figure 8. A photograph of the screen (70 cm length x 60 cm height). The screen was placed on the top of the Airshield. The laser measures particles present on both sides of the Airshield. The Airshield was off during the experiments.

The testing room was aerated and the particle size distribution in the room air (background) was controlled before and after series of aerosol measurements. The aerosol particle counts were separated into 23 size bins with optical diameters from 0.4 to 37 μm. The total volume of the aerosol particles in each size bin was estimated by assuming that the particles were spherical and that the physical diameter was approximately equal to the optical diameter. Particular matter (PM) represents an aerodynamic diameter of 1 μm or less (PM_1), 2.5 μm or less ($PM_{2.5}$), 10 μm or less (PM_{10}). Both concentration and abundance of particles (mean particle count per second) were compared in two conditions: Airshield OFF and Airshield ON.

There was an additional experiment involving either a surgical face mask or a visor. The aerosol was sprayed 2 cm away from the surface of either surgical mask or visor. Subsequently, the concentration of particles was analysed as described above.

3. Results

As was described previously, the analysis of air droplets was perfomed either from aside or infront of the Airshield. Additional tests involving an acrylic clear screen was pefomed by disassembling the nozzles and placing the screen in the middle of the Airshield as shown in Fig. 8.

3.1. Airshield with the top and nozzles

The analysis of air droplets was perfomed either from aside or in front of the Airshield as described in Section 2.

3.1.1. Side determination of particles with nozzles

3.1.1.1. Aerosol

The side determination of particles was performed as shown in Figs. 4-5. Fig. 9 shows the abundance of particles (mean particle count per second) with and without the

Airshield. There were small amount of particles around 5 µm. However, the Airshield is able to eliminate 99% of the particles.

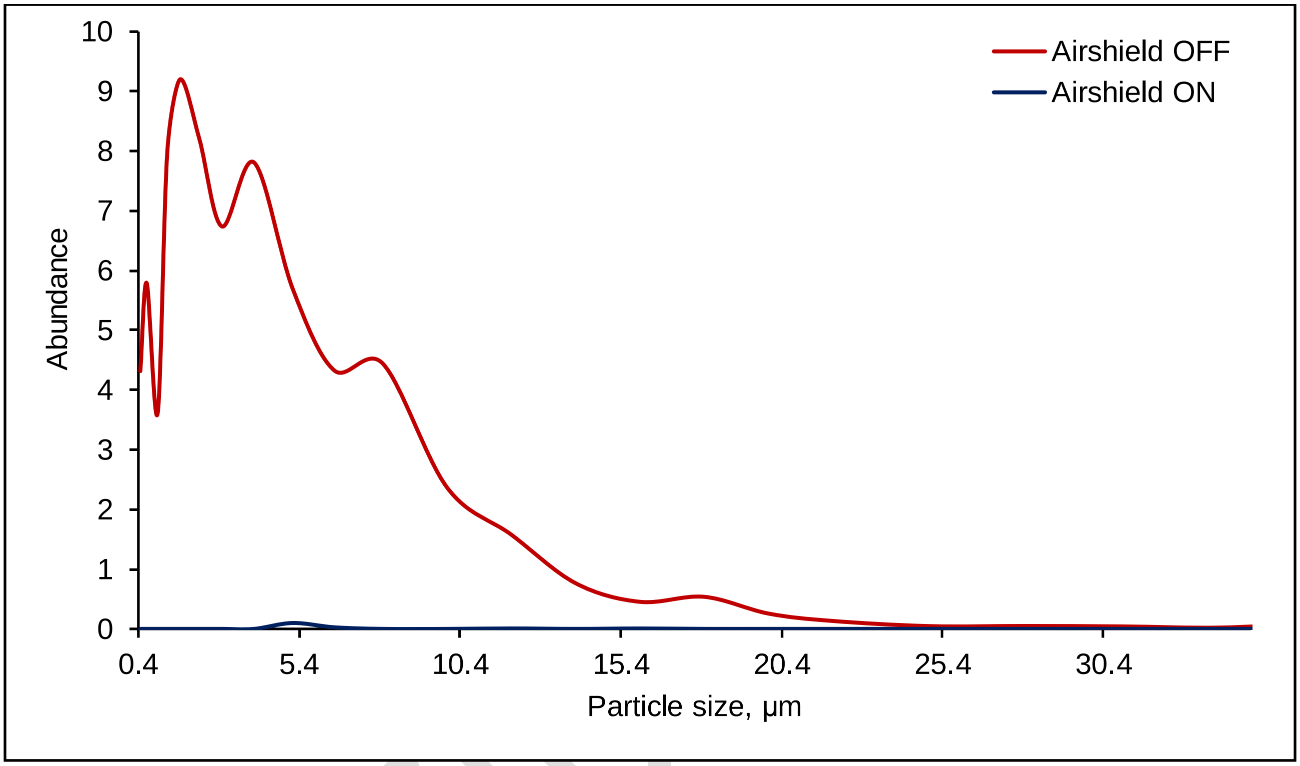

Figure 9. The abundance of particles in a range of 0.4-35 µm with and without Airshield. Data shown represent the mean of three independent experiments.

Figs. 10-12 show the concentration of PM_1-PM_{10} within first 23 seconds of the aerosol dispersion. As seen from Fig. 10, the concentration of PM_1 did not exceed 1.37 ug/m^3 using the Airshield, whereas the concentration of particles without the Airshield reached 23.8 ug/m^3. This mean that the airshield decreased the concentration of PM_1 to 94%. Regarding $PM_{2.5}$ particular matter, the Airshield was able to decrease the concentration of particles from around 546 ug/m^3 to 6.3 ug/m^3 which corresponds to 98% percent particle reduction (Fig. 11). Furthermore, as shown in Fig. 12, it was detected that the concentration of particles 10 µm in diameter was the highest and reached over 4000 ug/m^3. However, the Airshield reduced such a concentration to 153 ug/m^3 that is over 96% particle reduction. As shown in Figs. 10-12, the concentration of particulate matter was much lower with the Airshield. Moreover, the concentration of PM_{10}, which represents all particles equal to or lower than 10 µm, was dramatically reduced by the Airshield.

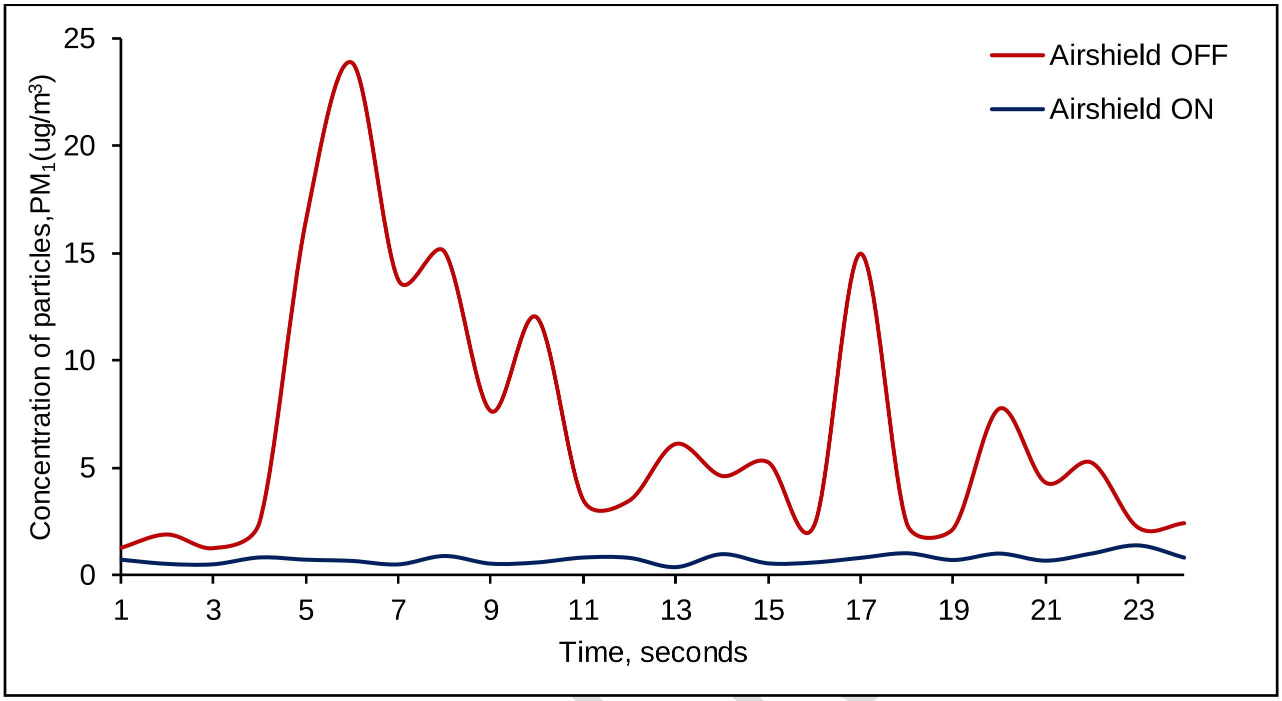

Figure 10. The concentration of PM_1 (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

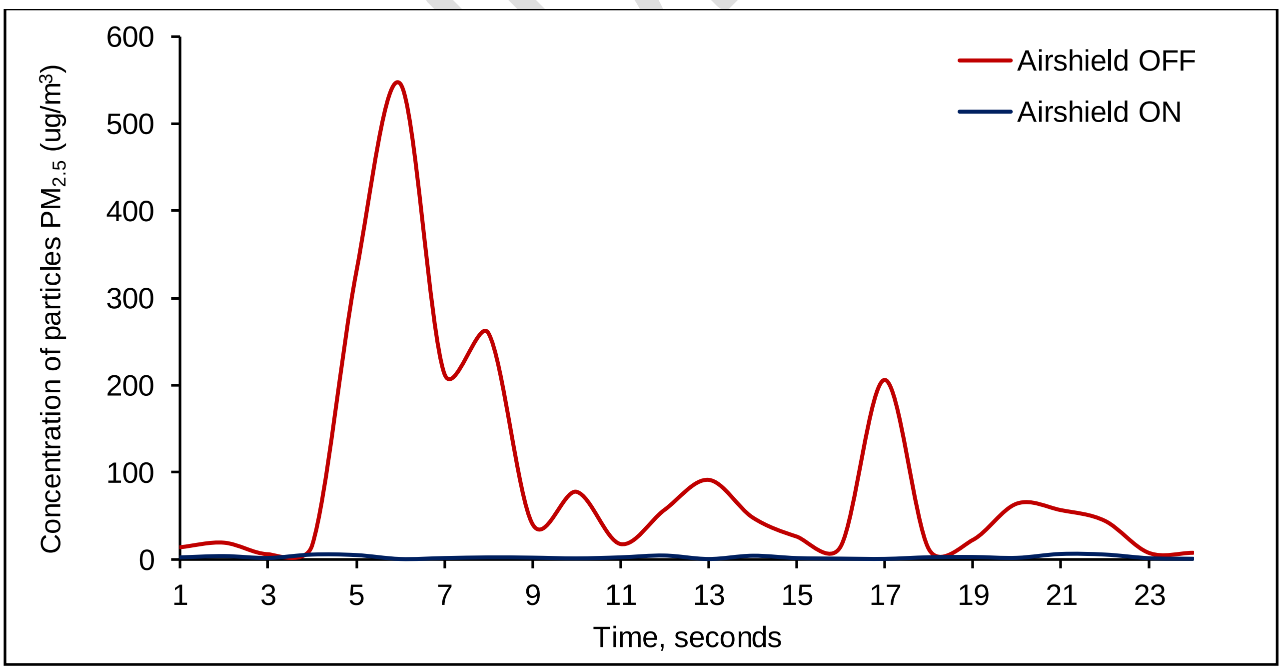

Figure 11. The concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

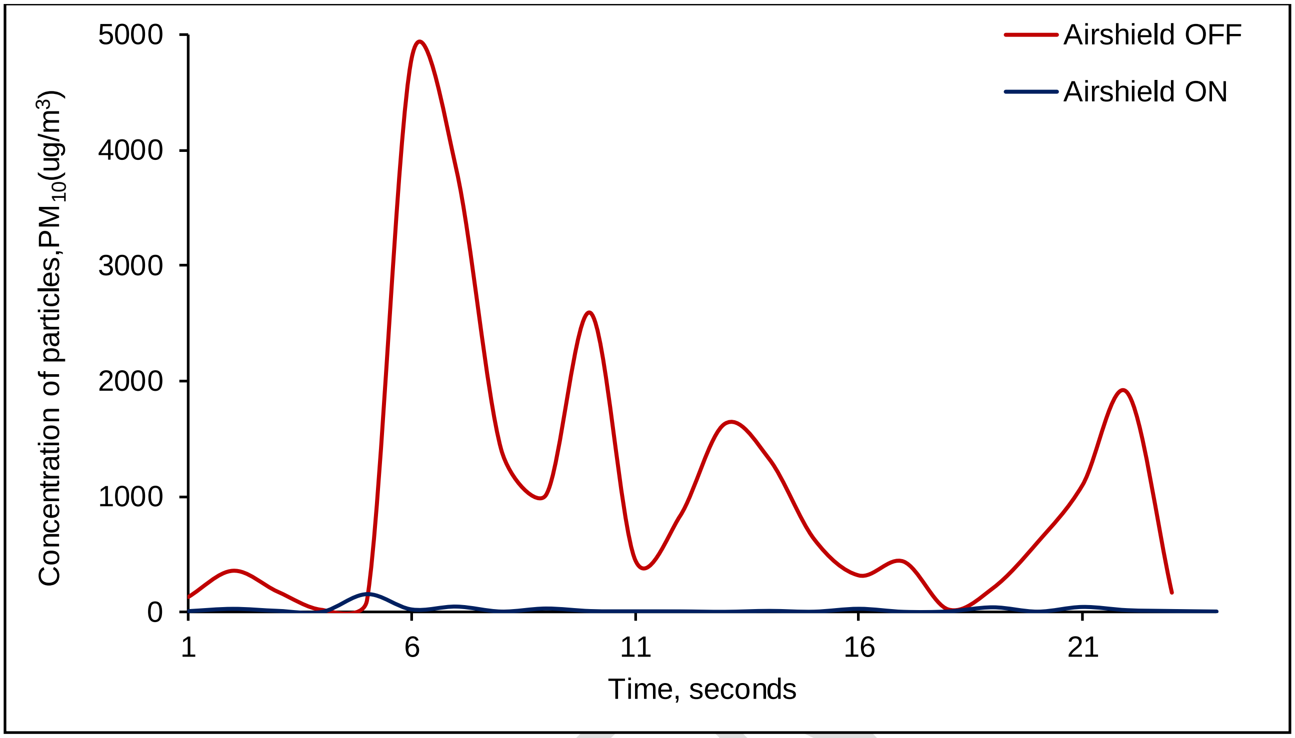

Figure 12. The concentration of PM_{10} (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

In order to test the effectiveness of the Airshield in the prevention of distribution of droplets, either a surgical facial mask or visor was applied as a barrier between the aerosol and the environment.

3.1.1.2. Surgical Mask

Figs. 13 illustrates the effect of both surgical face mask and the Airshield on the abundance of particles sizing from 0.4 to 30 µm. As seen from Fig. 13, the surgical facial mask could allow particles larger than 1 µm to pass through, whereas the Airshield was an effective barrier and could prevent further distribution of particles. The Airshield reduced abundance of all particles by 88%.

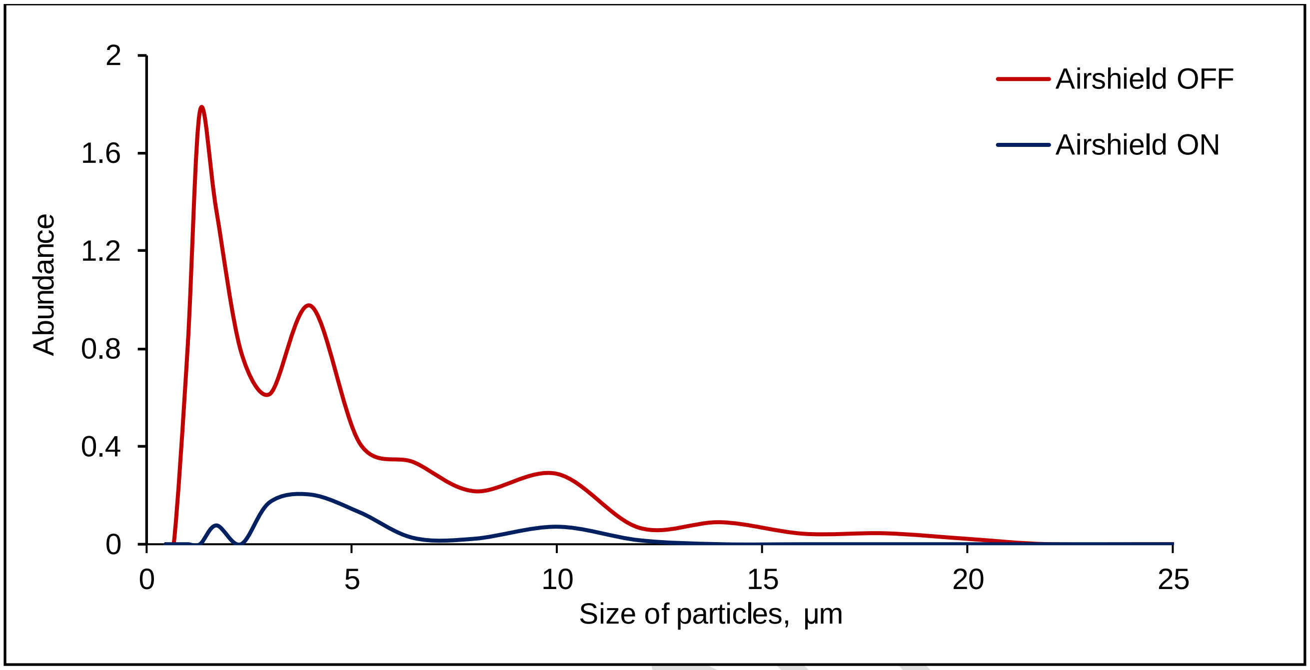

Figure 13. The effect of the Airshield on the abundance of particles passed through a surgical face mask. Data shown represent the mean of two independent experiments.

Figs. 14-16 show the concentration of PM_1-PM_{10} within first 23 seconds of the aerosol dispersion into the surgical mask. As seen in Fig. 14, the concentration of PM_1 without the Airshield was almost double within first 11 seconds. A similar pattern was observed with the concentration of $PM_{2.5}$ as shown in Fig. 15. Regarding the concentration of PM_{10}, the Airshield was able to provide an effective barrier and decrease the concentration of particles from 49.6 ug/m^3 to 6.6 ug/m^3 within first 16 seconds and to 20.6 ug/m^3 within 23 seconds, respectively, that corresponds to 59% reduction of particles (Fig. 16).

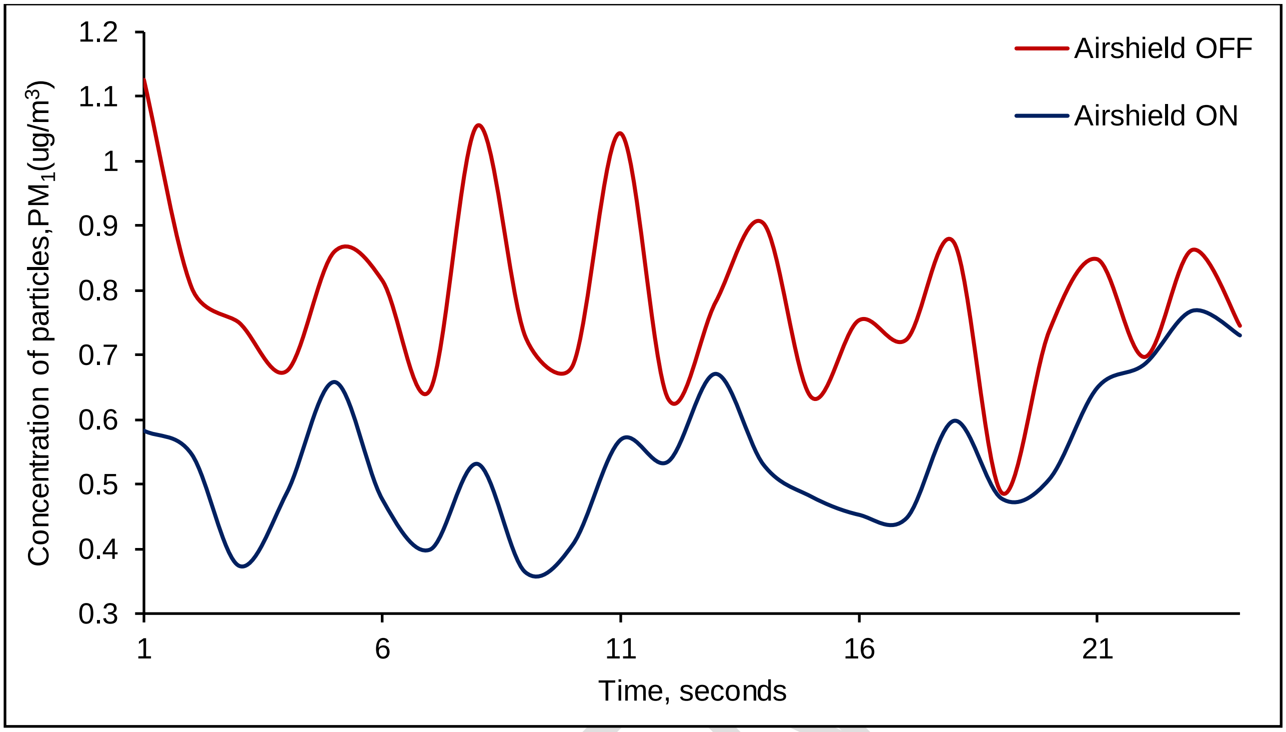

Figure 14. The concentration of PM_1 (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

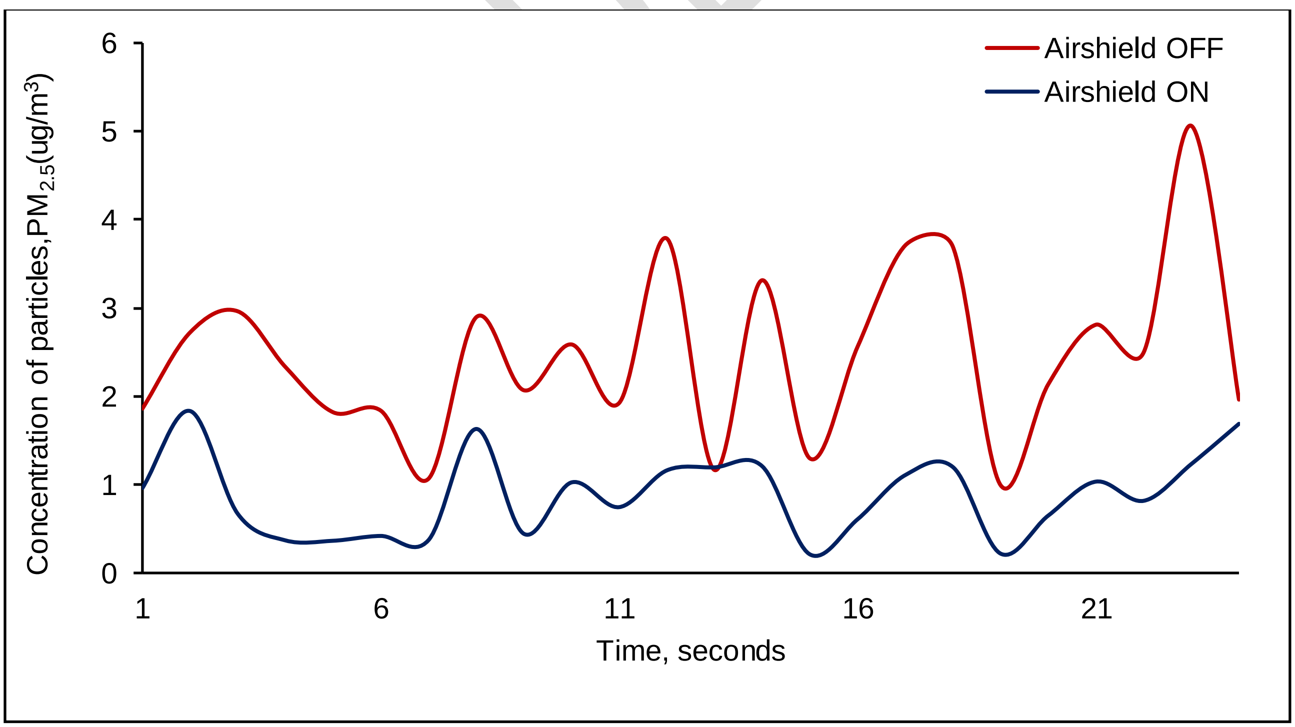

Figure 15. The concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

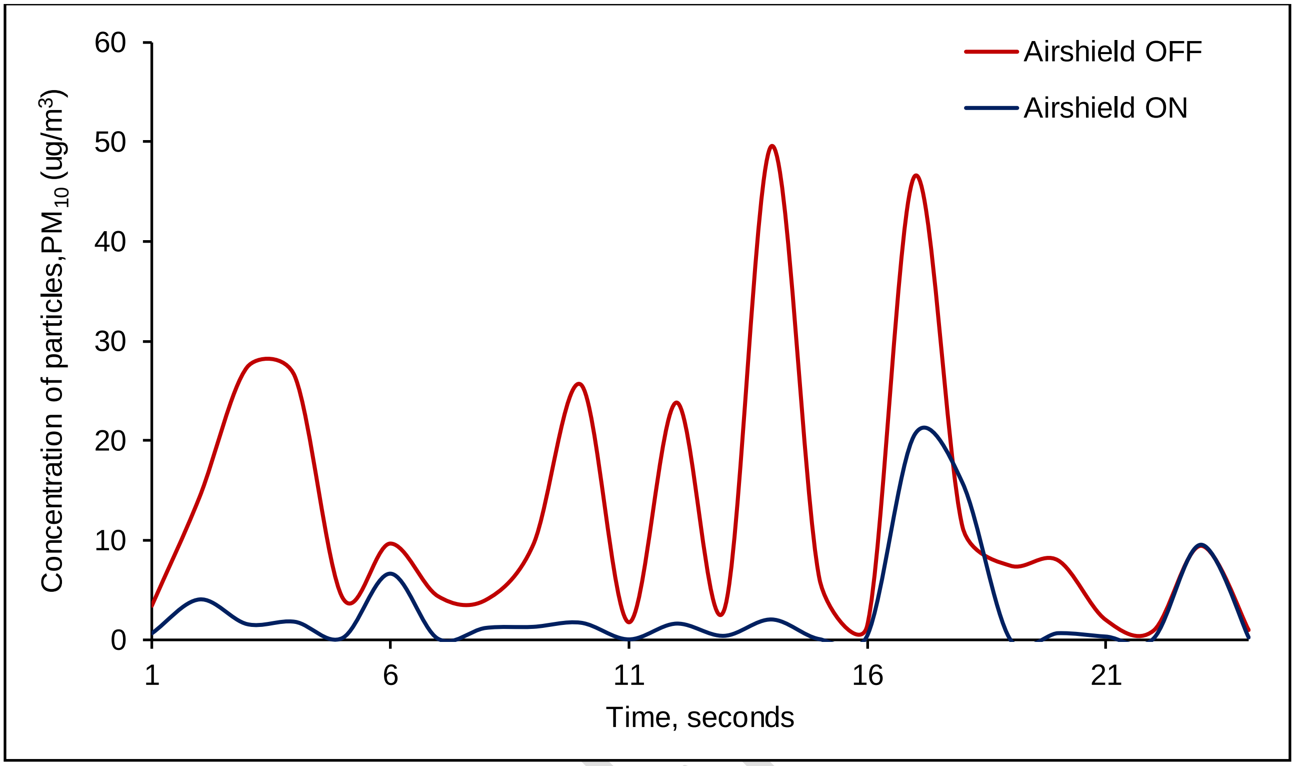

Figure 16. The concentration of PM_{10} (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

3.1.1.3. Visor

Similarly to the mask, the aerosol was sprayed to a visor. Both abundance and concentration of partular matter was subsequently analysed. It was observed that a visor can also passed small size particles (less than 2 µm). Moreover, the presence of larger size particles (15-20 µm) was also detected (Fig. 17). However, the Airshield is able to effectively reduce the abundance of small particles as well as completely eliminate larger airdroplets. The Airshield reduced abundance of 75% of all particles.

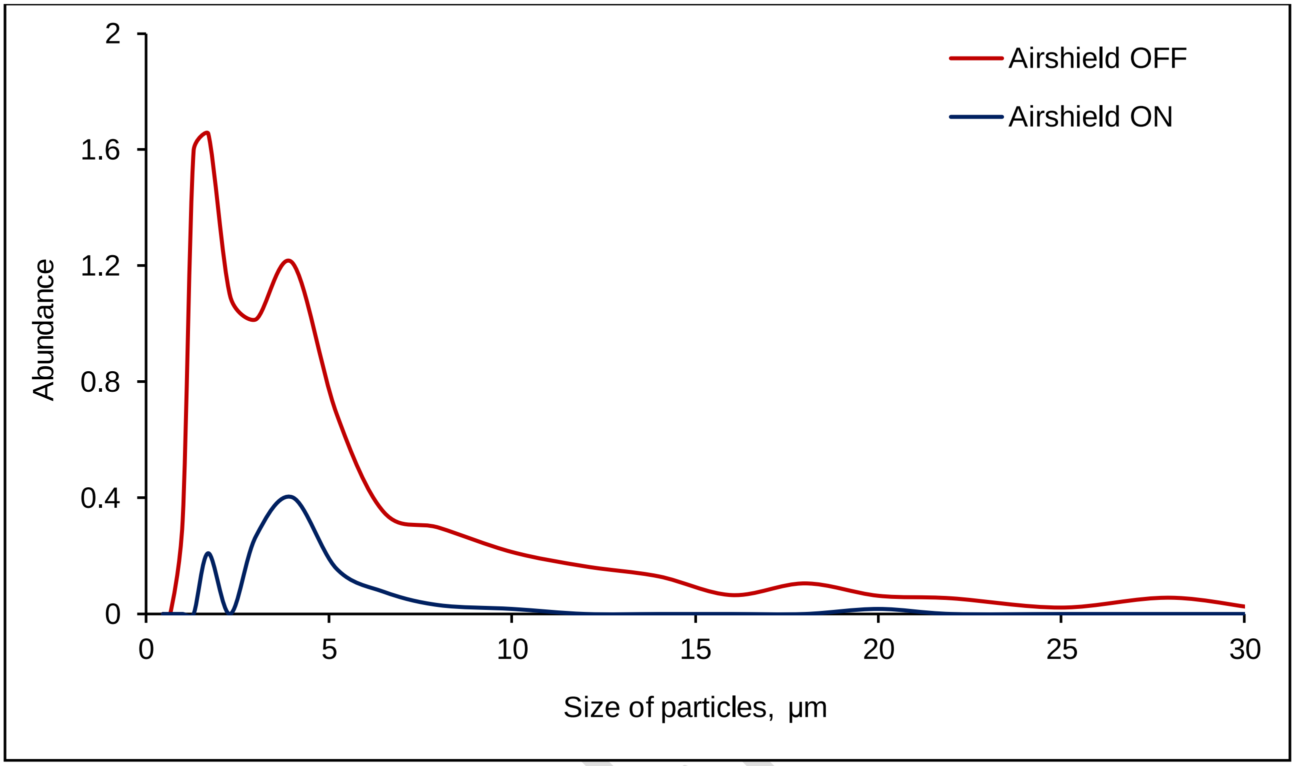

Figure 17. The effect of the Airshield on the abundance of particles passed through a visor.

In order to analyse the effect of time on the concentration of particles passed through the visor, concentrations of PM_1-PM_{10} was monitored for 23 seconds with the results presented in Figs. 18-20. According to Fig. 18, the highest concentration of PM_1 of 5 ug/m^3 occurred within 23 seconds without the Airshield. The Airshield significantly reduced the particle concentrations to 2.3 ug/m^3 and below. Furthermore, the overall concentration of particles less or equal to 10 µm reduced from 67 ug/m^3 to 14.5 ug/m^3 by the Airshield that is corresponed to over 78% reduction.

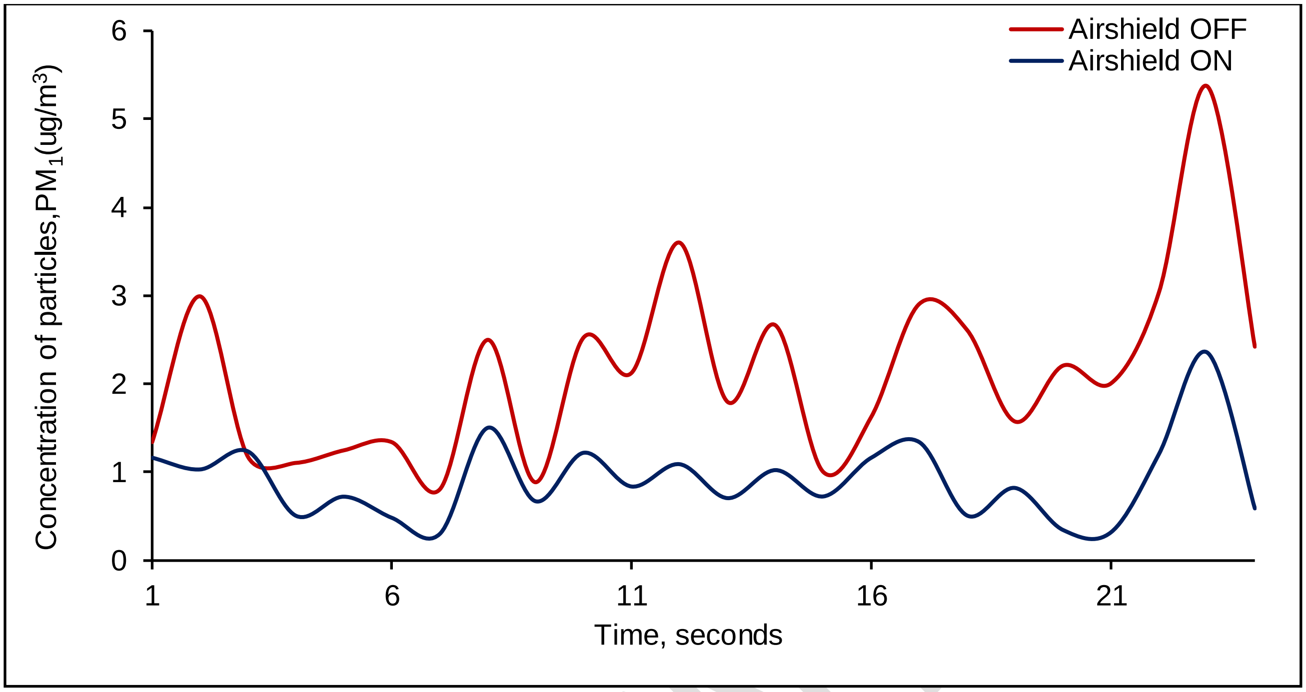

Figure 18. The effect of the Airshield on the concentration of PM_1 (ug/m^3) passed through a visor within first 23 seconds with and without the Airshield.

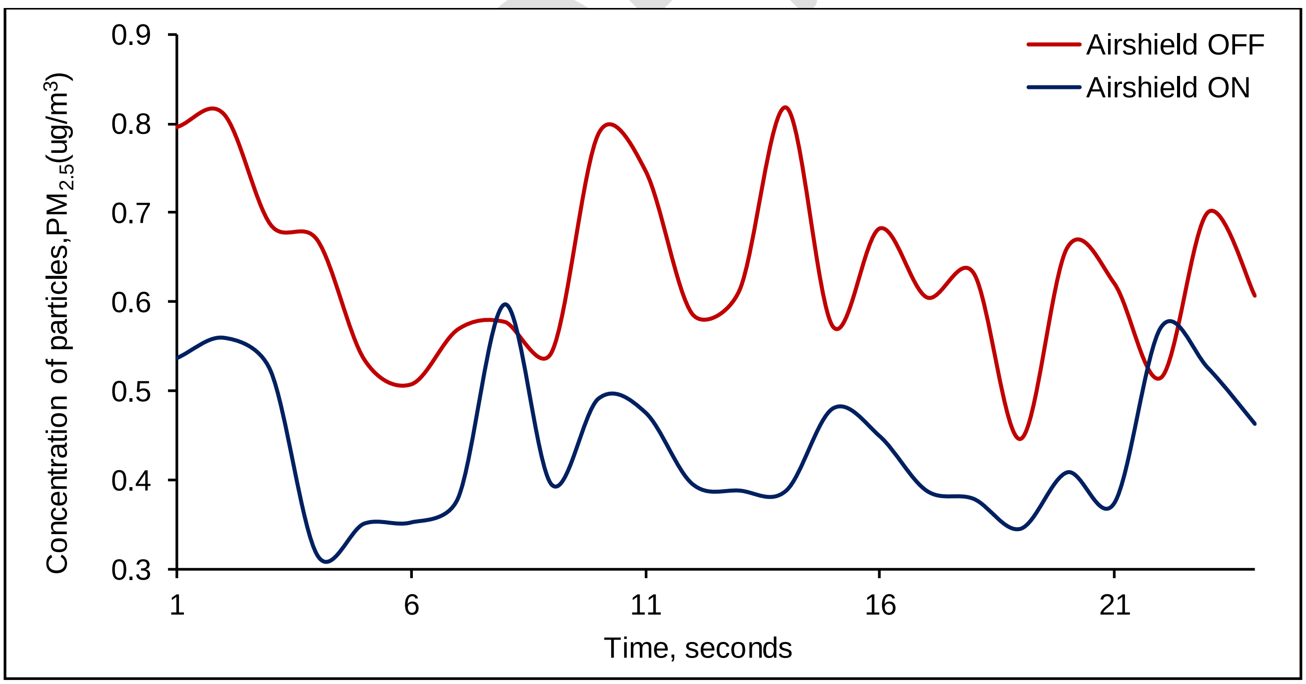

Figure 19. The effect of the Airshield on the concentration of $PM_{2.5}$ (ug/m^3) passed through a visor within first 23 seconds with and without the Airshield.

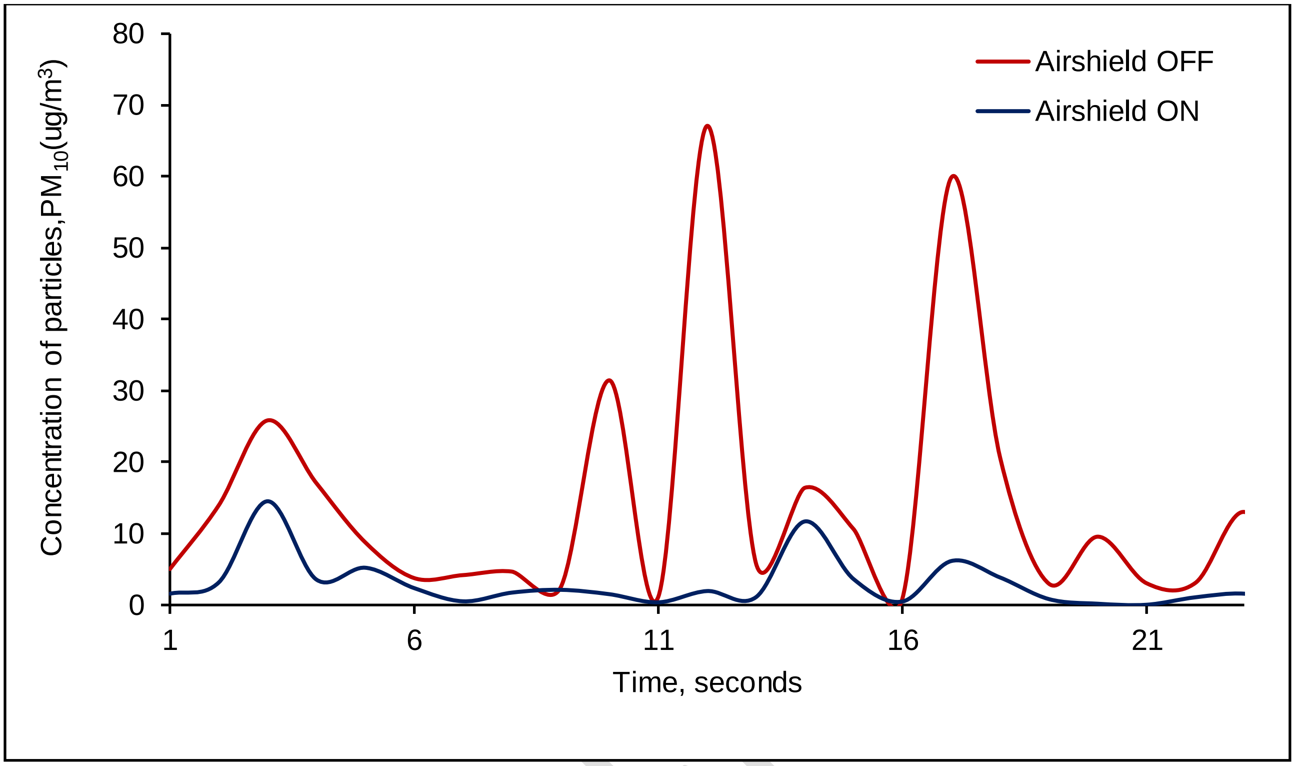

Figure 20. The effect of the Airshield on the concentration of PM_{10} (ug/m^3) passed through a visor within first 23 seconds with and without the Airshield.

3.1.1.4. Acrylic screen

The effect of the Airshield was compared to a clear acrylic screen that was placed on the top of the Airshield instead of the nozzles while the Airshield was off. Fig. 21 shows the abundance of particles in a range from 0.4 µm to 30 µm. As seen from Fig. 21, the screen could reduce the abundance of particles that passed through by around 50%.

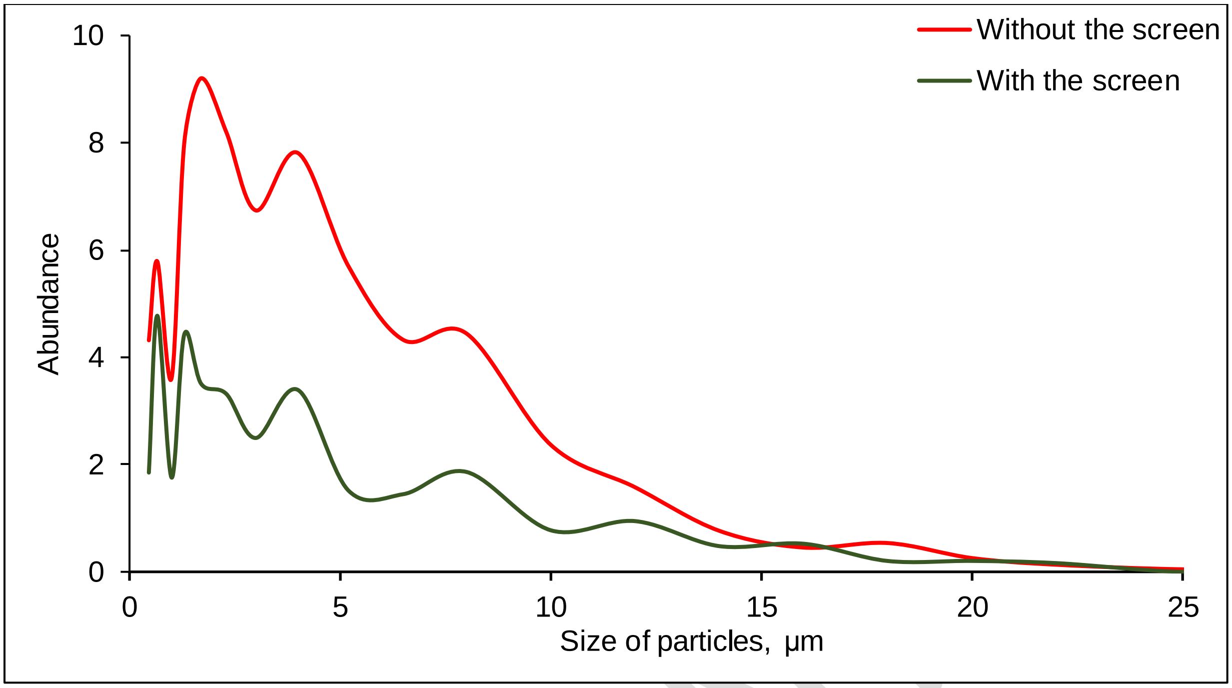

Figure 21. The effect of the acrylic screen on the abundance of particles.

In order to analyse the effect of time on the concentration of particles passed through the acrylic screen, concentrations of PM_1-PM_{10} was monitored for 23 seconds with the results presented in Figs. 22-24. According to Fig. 22, the highest concentration of PM_1 of 4.14 ug/m^3 occurred within first 7 seconds without the screen. The acrylic screen reduced the particle concentrations to 1.4 ug/m^3 and below that corresponds to 66% particle reduction. Furthermore, the overall concentration of particles less or equal to 10 µm reduced from 216 ug/m^3 to 119 ug/m^3 by the screen that is equal to 45% reduction.

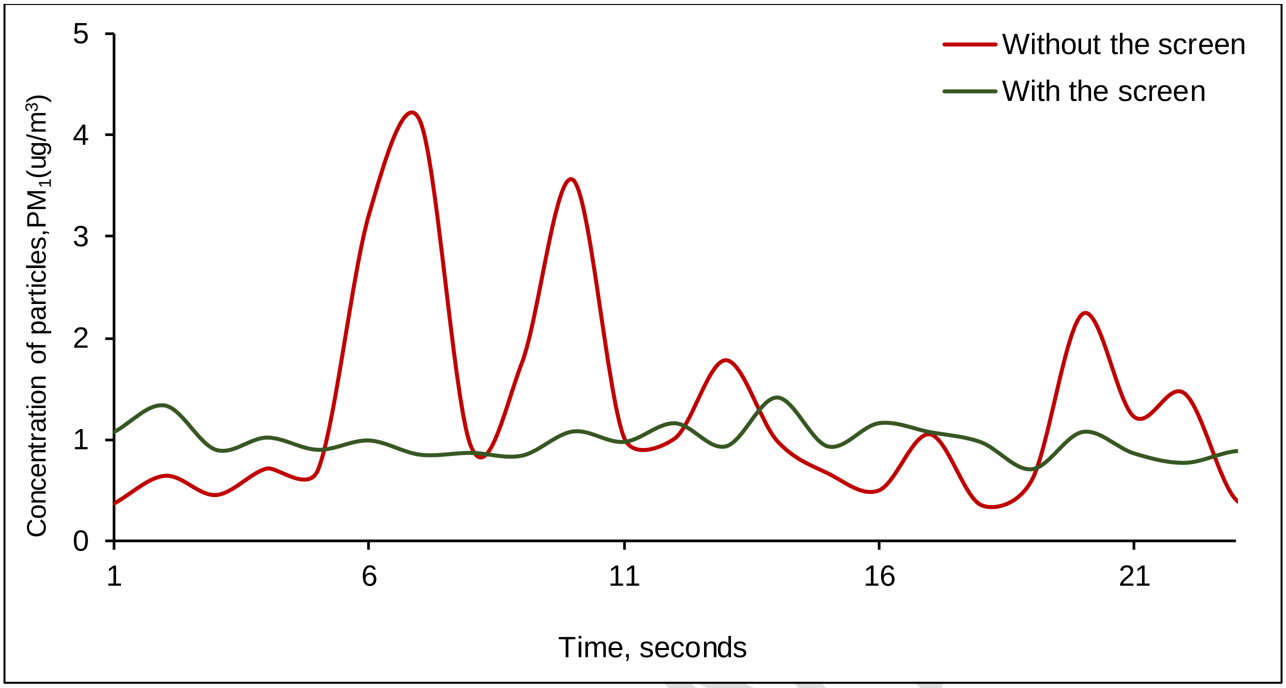

Figure 22. The effect of the acrylic screen on the concentration of PM_1 (ug/m^3) within first 23 seconds.

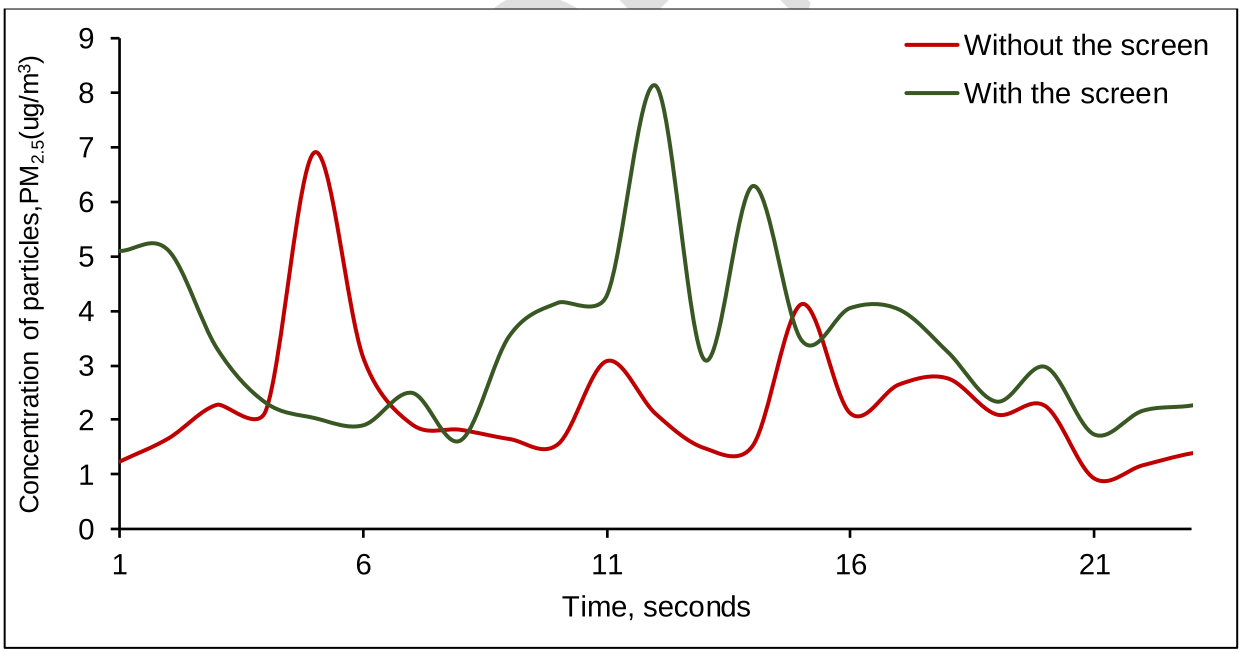

Figure 23. The effect of the acrylic screen on the concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds.

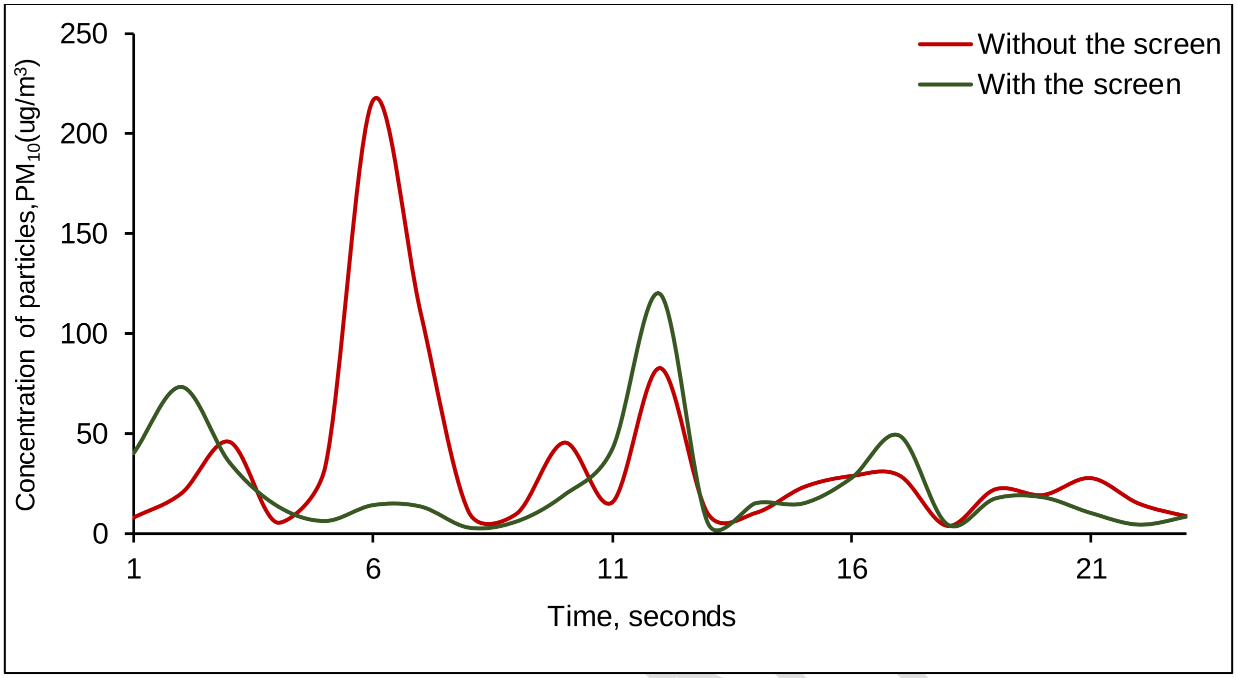

Figure 24. The effect of the acrylic screen on the concentration of PM_{10} (ug/m^3) within first 23 seconds.

3.1.2. Measurement of particles towards the laser beam

Another method for particle analysis was perfomed by placing the laser beam infront of either the Airshield or the screen as shown in Figs. 6, 7 and 8.

3.1.3. Aerosol

The effect of the Airshield on concentrations of particles in aerosol was also measured by placing the particulate in the front of the Airshield as illustrated in Figs. 6-7. Figs. 25-28 show the abundance and concentration of particles in the aerosol with and without the Airshield. According to the results presented in Fig. 25, the Airshield reduced the concentration of particles dramatically by over 99%. Furthermore, the Airshield eliminated particles smaller than 1.17 µm and larger than 10 µm. The Airshield successfully cleared up 76% of particles lager than 10 µm.

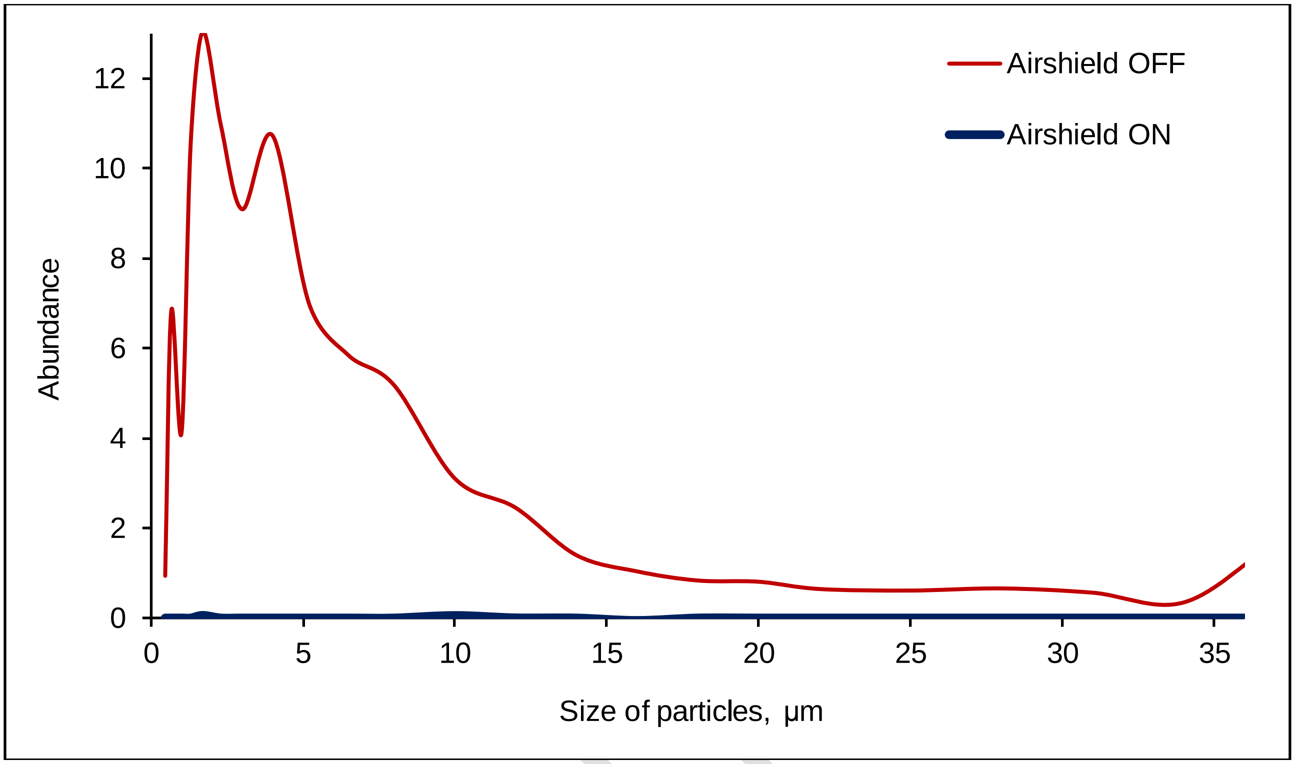

Figure 25. The abundance of particles in a range of 0.4-35 µm with and without Airshield. Data shown represent the mean of three independent experiments.

Regarding the concentrations of PM_1-PM_{10} within first 23 seconds, the front side analysis showed a reduction in concentrations of PM_1, $PM_{2.5}$ and PM_{10} (Figs. 26-28). Noticeably, the concentration of particles less or equal to 10 µm detected from the front was much lower compared to previously reported data (Figs. 11 and 28). This might be due to a position of laser beam that was not able to catch particles that either settled down or distributed above the laser. The maximum concentration of PM_{10} did not exceed 3.27 ug/m^3, whereas the concentration of PM_{10} without the Airshield reached 13.7 ug/m^3.

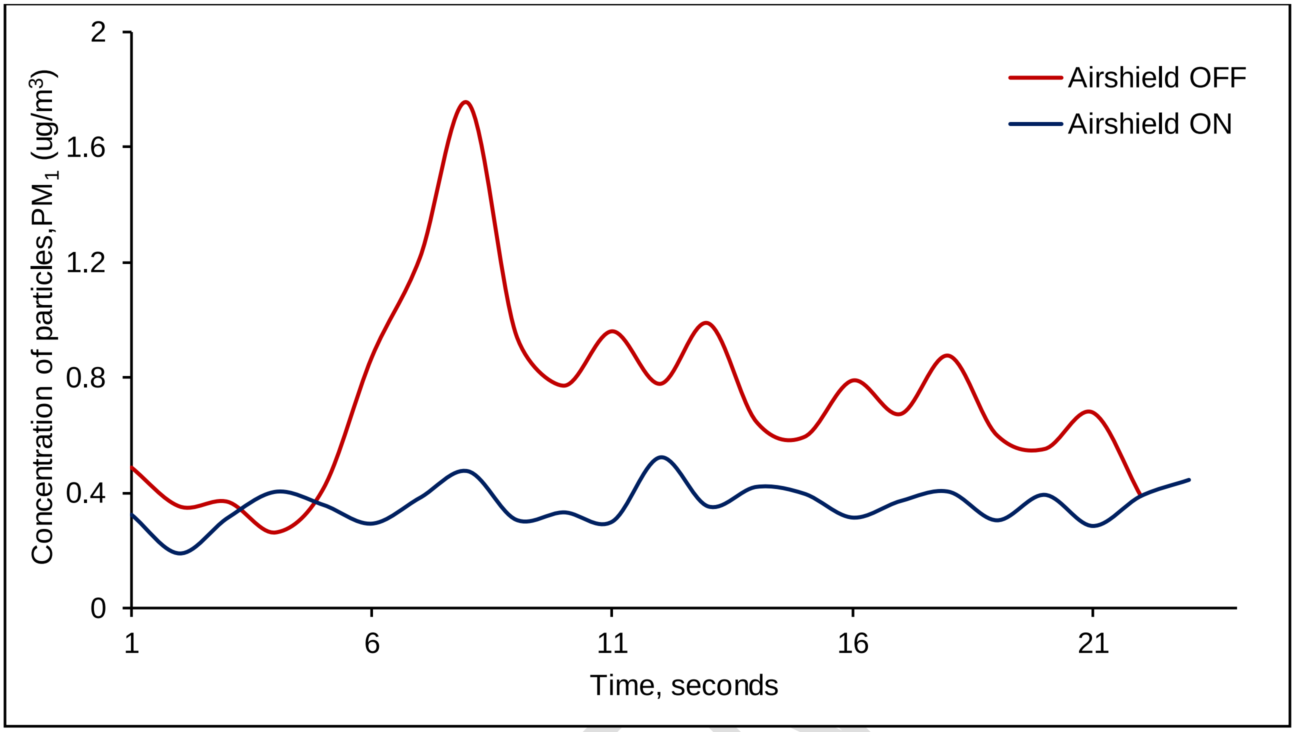

Figure 26. The concentration of PM_1 (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

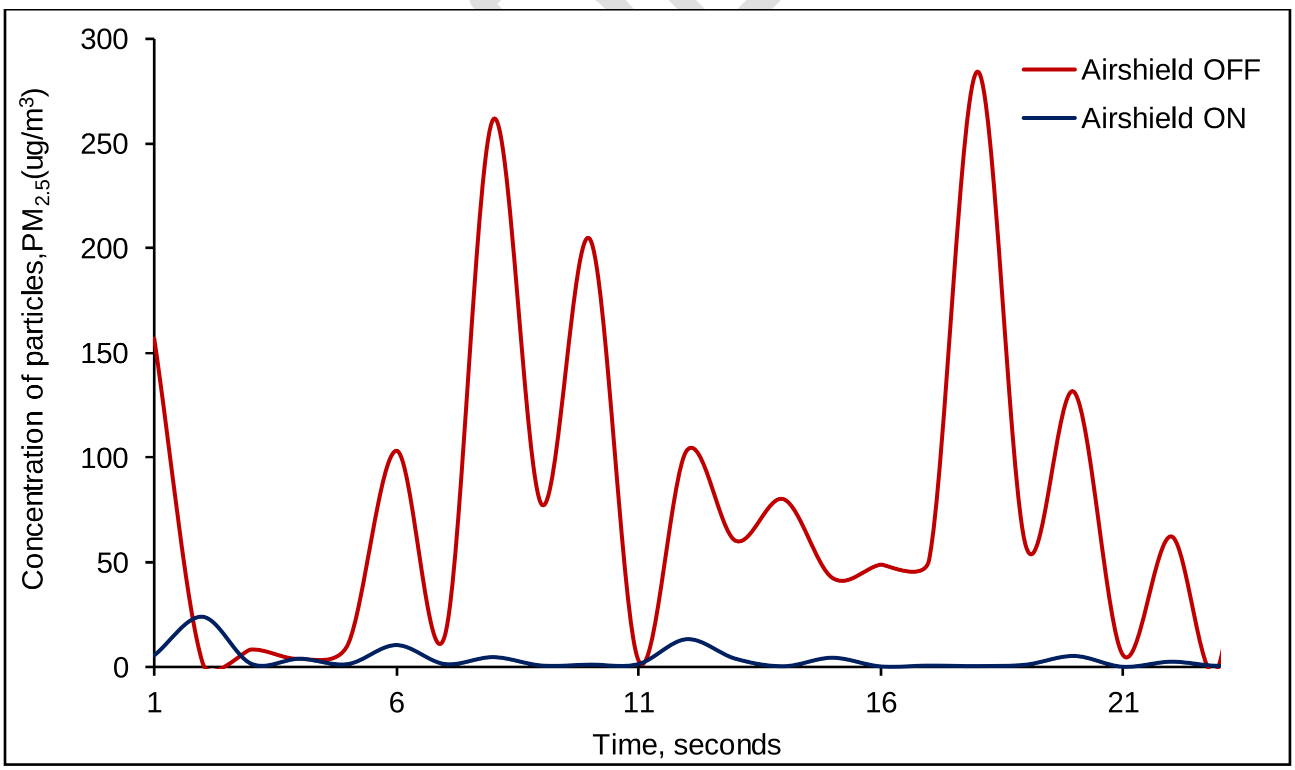

Figure 27. The concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

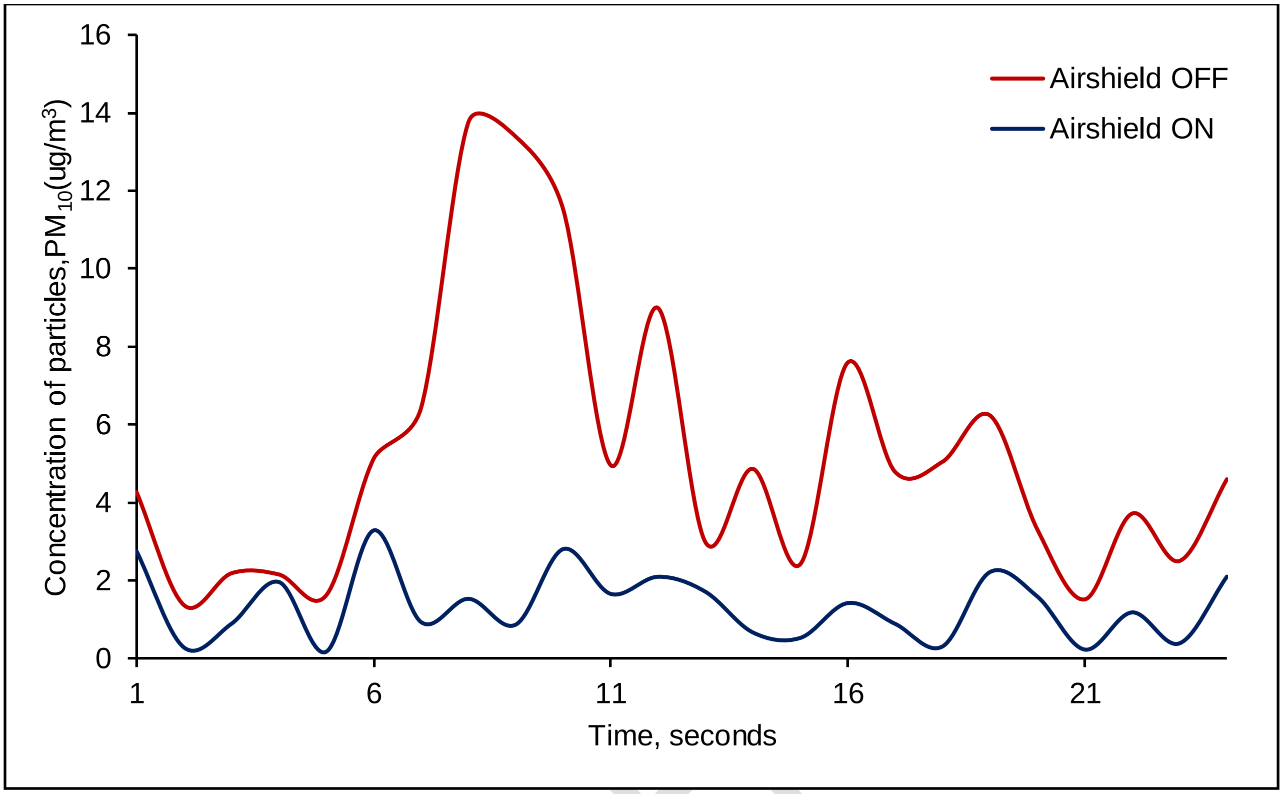

Figure 28. The concentration of PM_{10} (ug/m^3) within first 23 seconds with and without the Airshield. Data shown represent the mean of two independent experiments.

3.1.3.1. Surgical Mask

The abundance of particles passed through a surgical mask with and without the Airshield was measured. Figs. 29 illustrates the effect of both the surgical face mask and the Airshield on the abundance of particles sizing from 0.4 to 30 µm. As seen in Fig. 29, the surgical facial mask could let particles smaller than 1 µm pass through, whereas the Airshield was an effective barrier and could prevent the distribution of 92% of particles.

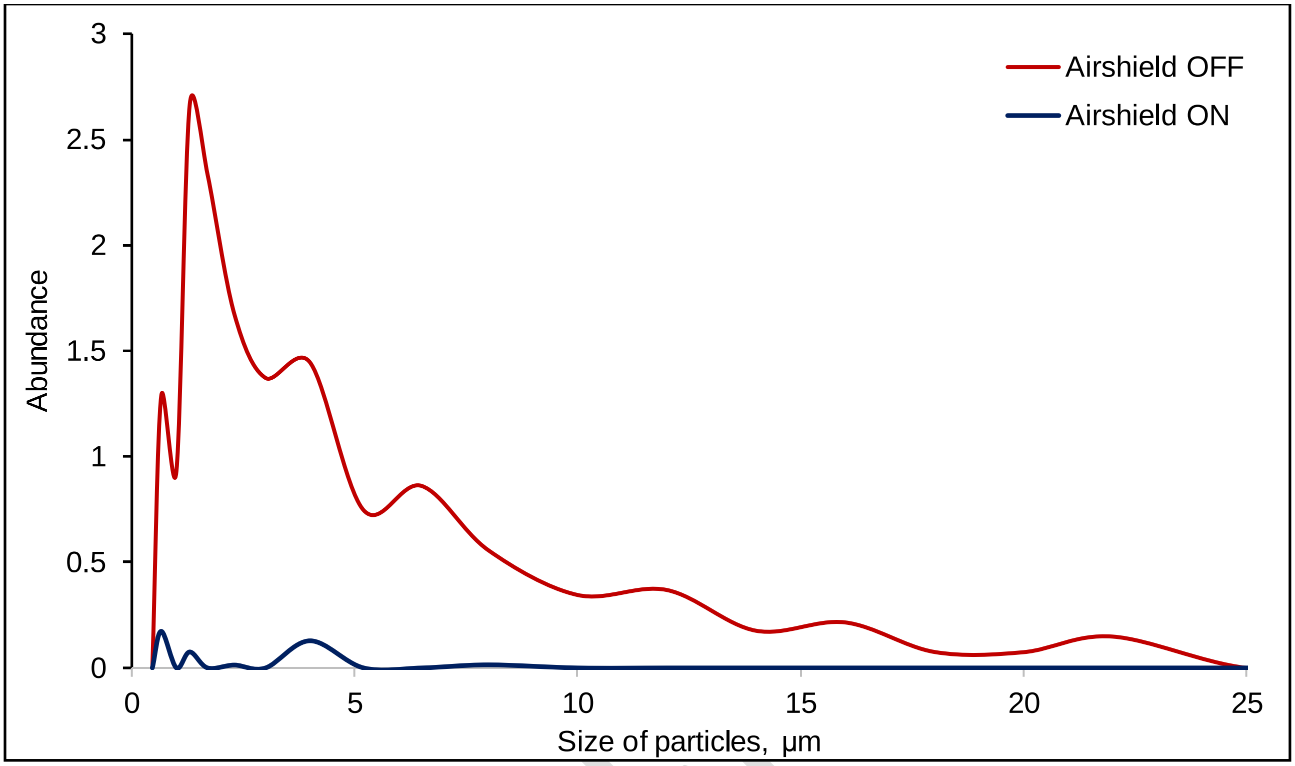

Figure 29. The effect of the Airshield on the abundance of particles passed through a surgical face mask.

According to Fig. 30, there was a slight reduction of concentration of particles with the Airshield. Figs. 30-32 show a more dramatic reduction of both $PM_{2.5}$ and PM_{10} with the Airshield. As shown in Fig. 32, the concentration of PM_{10} reduced by 94% from 124 ug/m^3 to 7.4 ug/m^3 within first 3 seconds.

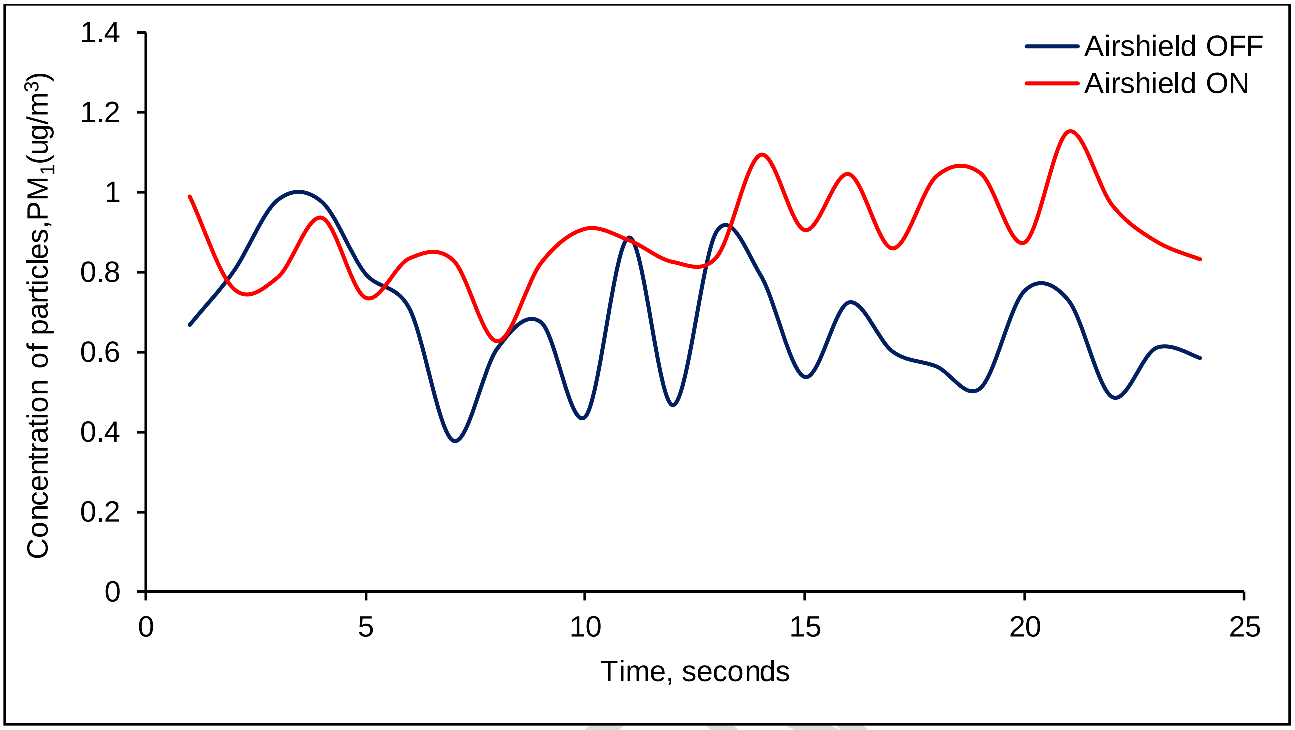

Figure 30. The concentration of PM_1 (ug/m^3) within first 23 seconds with and without the Airshield.

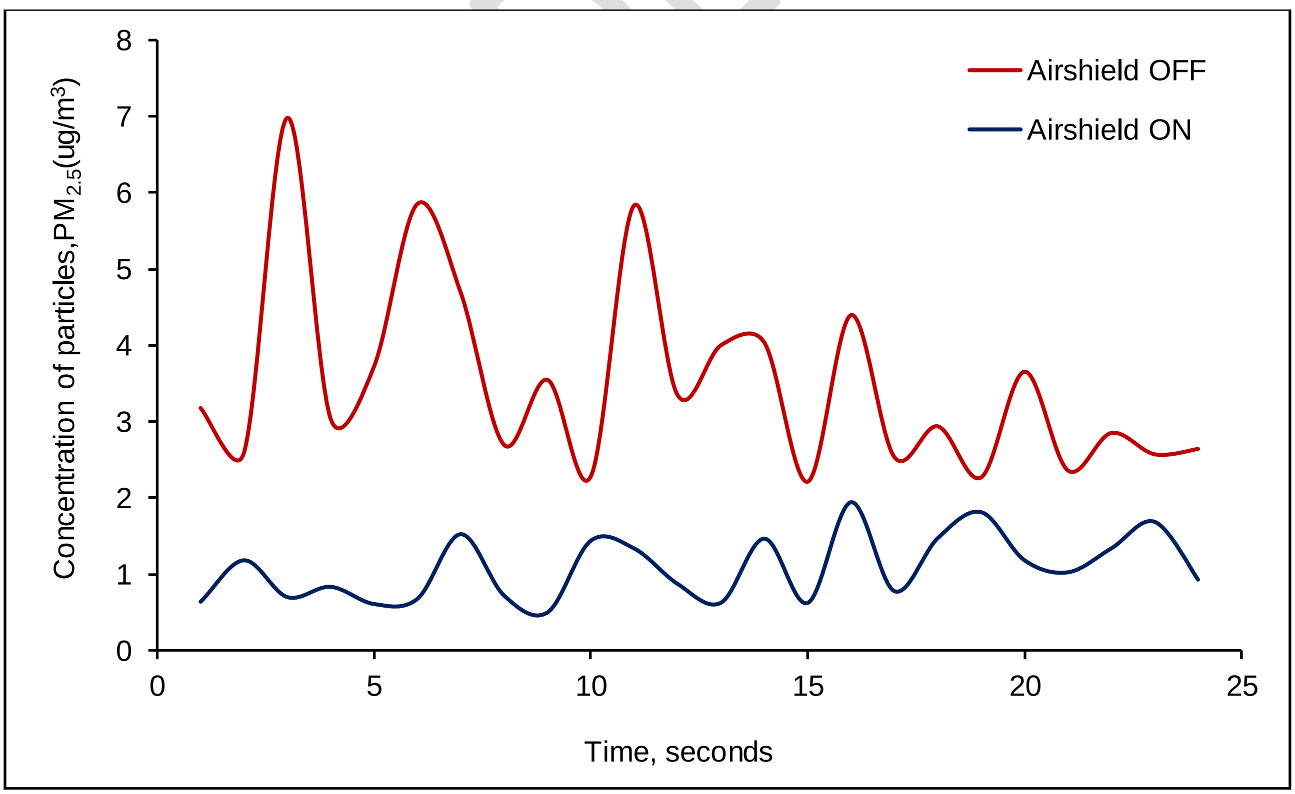

Figure 31. The concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds with and without the Airshield.

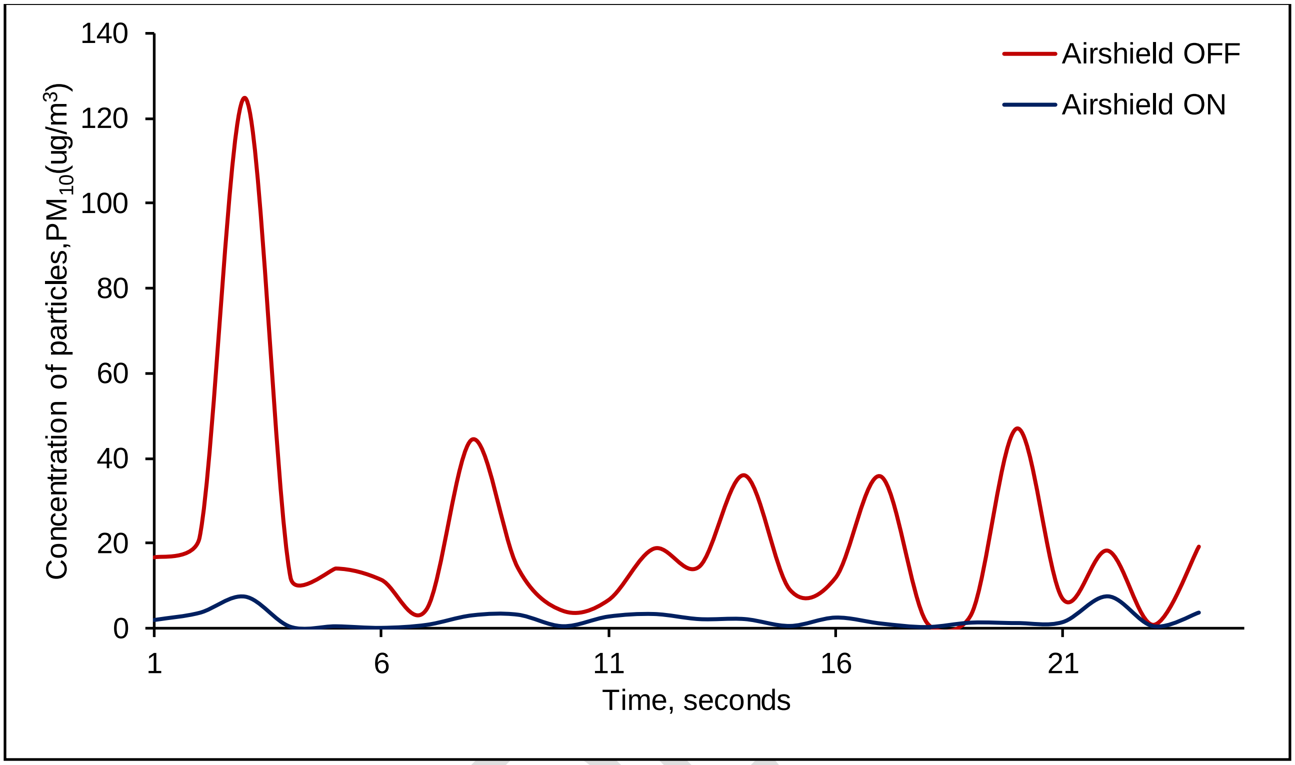

Figure 32. The concentration of PM_{10} (ug/m^3) within first 23 seconds with and without the Airshield.

3.1.3.2. Visor

Both the abundance and concentration of particulate matter passed through the visor was also measured by placing the laser beam towards the aerosol. As seen in Fig. 33, the Airshield decreased the abundance of 98% of particles larger than 10 µm.

Figs. 34-36 show the concentration of PM_1 - PM_{10} with and without the Airshield. The Airshield was effective in the prevention of distribution of $PM_{2.5}$ and PM_{10} after the exposure. As shown in Fig. 36, without the Airshield, an increase in concentration could reach a maximum of 194 ug/m^3 after 20 seconds, whereases the Airshield reduced this number to 13 ug/m^3 after 8 seconds. The Airshield reduced PM_{10} particles by 93%.

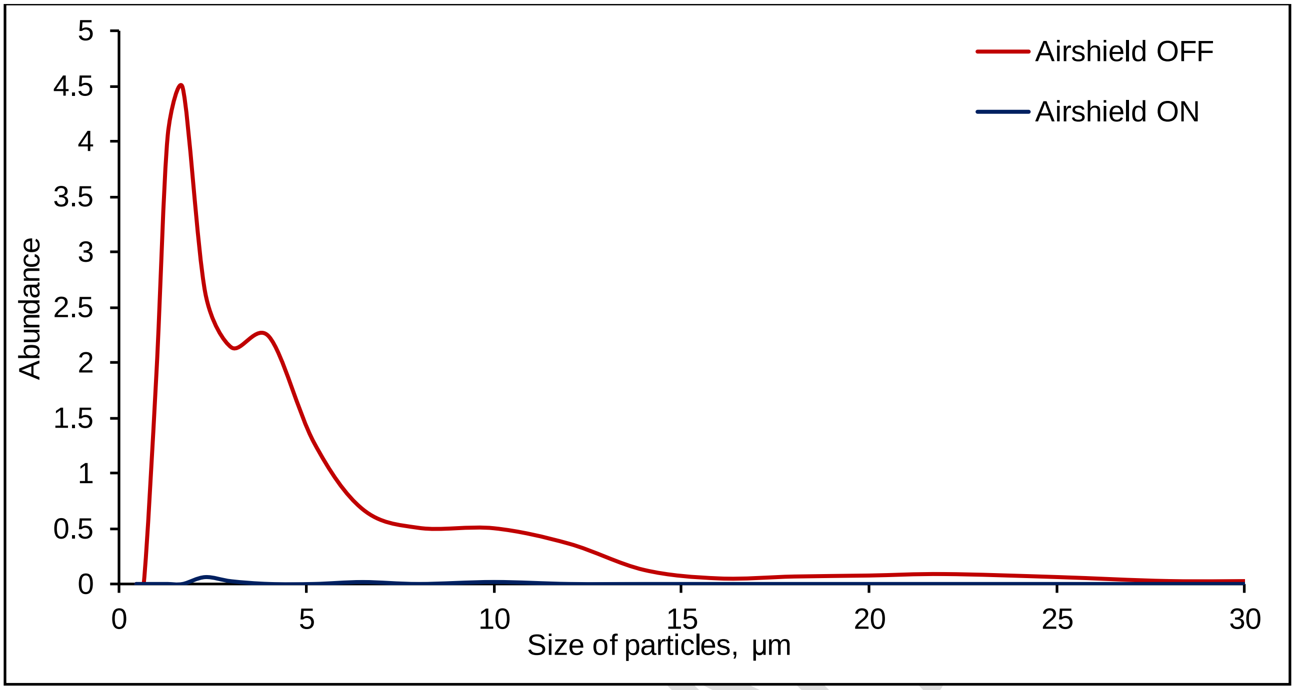

Figure 33. The effect of the Airshield on the abundance of particles passed through a visor.

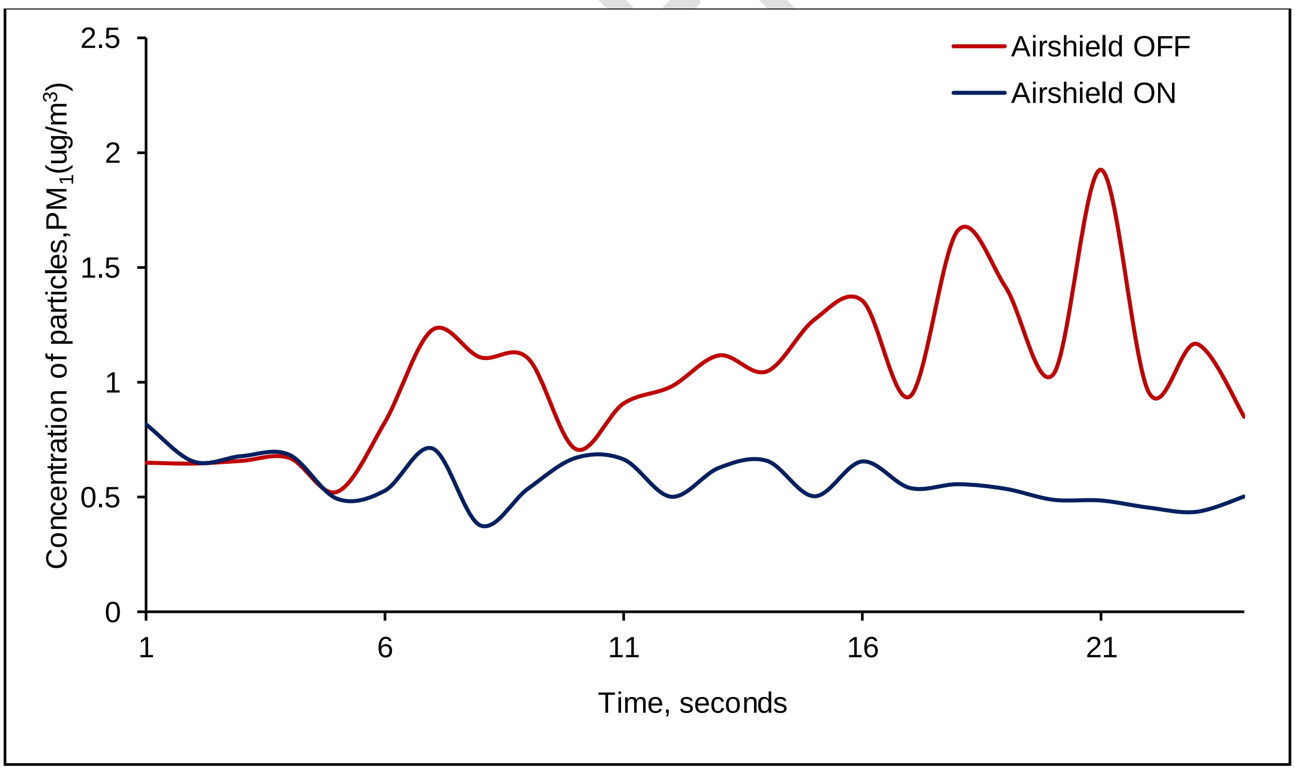

Figure 34. The concentration of PM_1 (ug/m^3) within first 23 seconds with and without the Airshield.

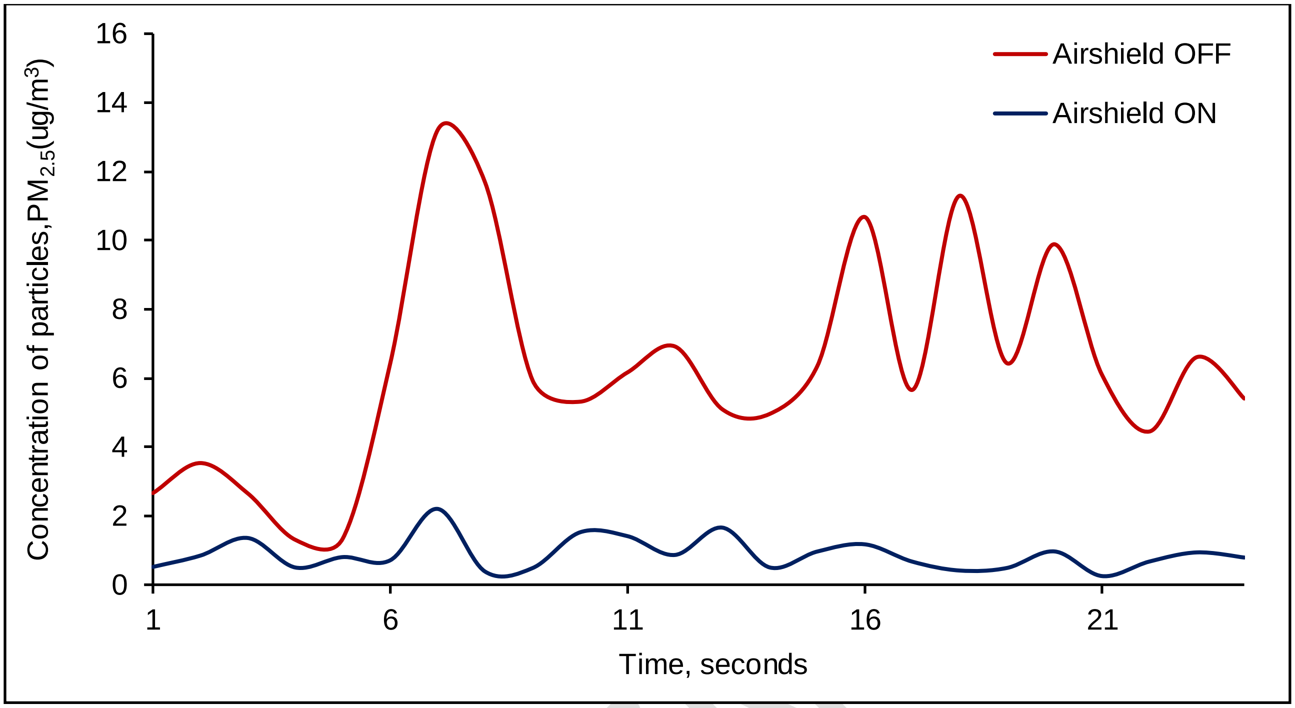

Figure 35. The concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds with and without the Airshield.

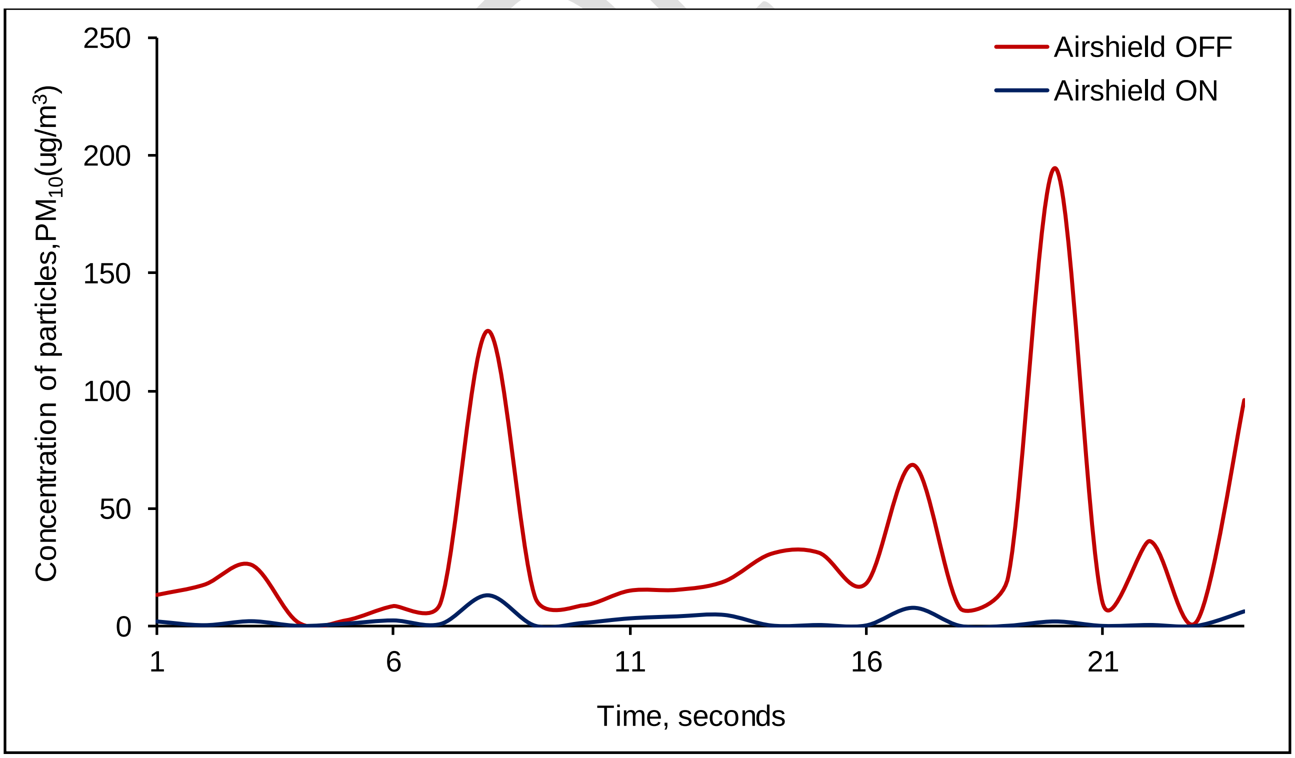

Figure 36. The concentration of PM_{10} (ug/m^3) within first 23 seconds with and without the Airshield.

3.1.3.3. Acrylic screen

Both the abundance and concentration of particulate matter passed through the acrylic screen was also measured by placing the laser beam towards the aerosol. As seen in Fig. 37, the screen decreased the abundance of 31% of particles.

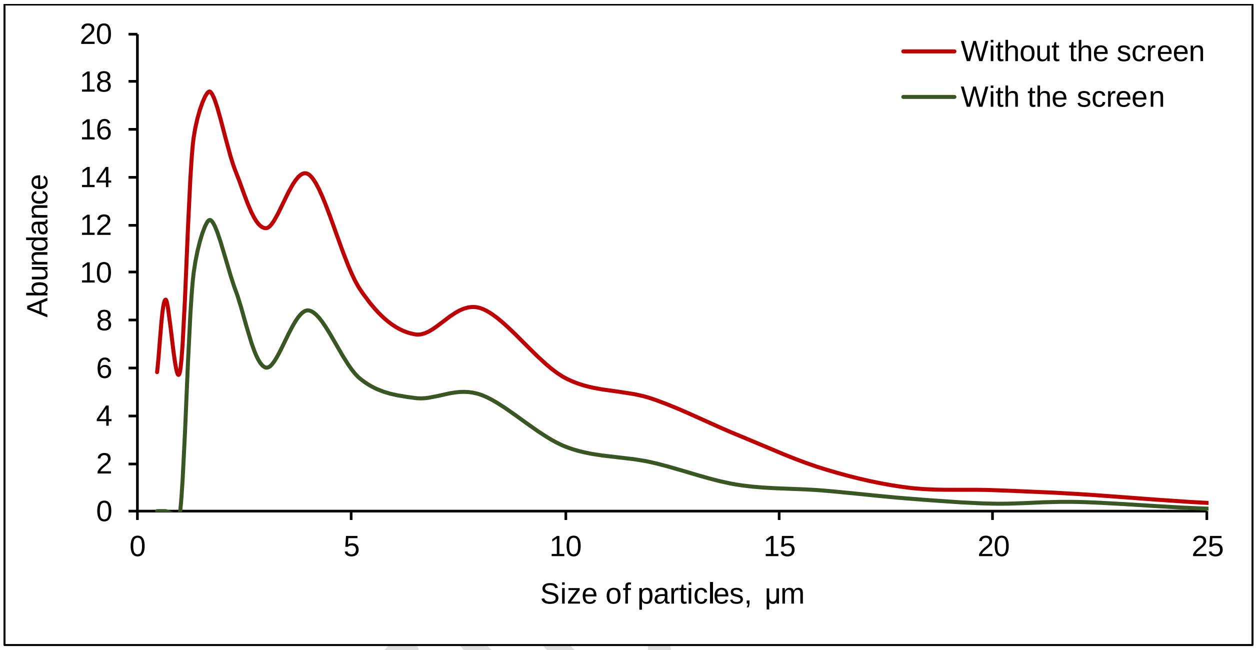

Figure 37. The effect of the screen on the abundance of particles.

Figs. 38-40 show the concentration of PM_1 - PM_{10} with and without the screen. The screen was not highly effective in the prevention of distribution of $PM_{2.5}$ and PM_{10} after the exposure. This might be due to particles being settled down on a surface of the screen, whereas they were suspended in air after the explosure without the screen.

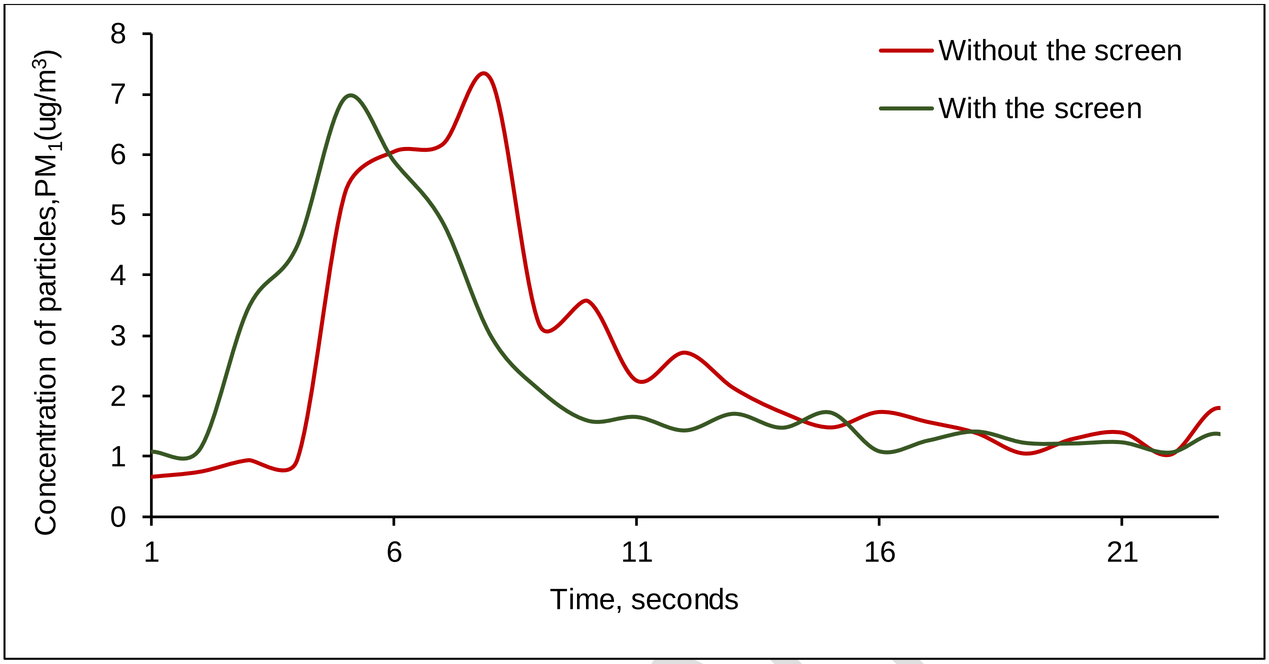

Figure 38. The concentration of PM_1 (ug/m^3) within first 23 seconds using the acrylic screen.

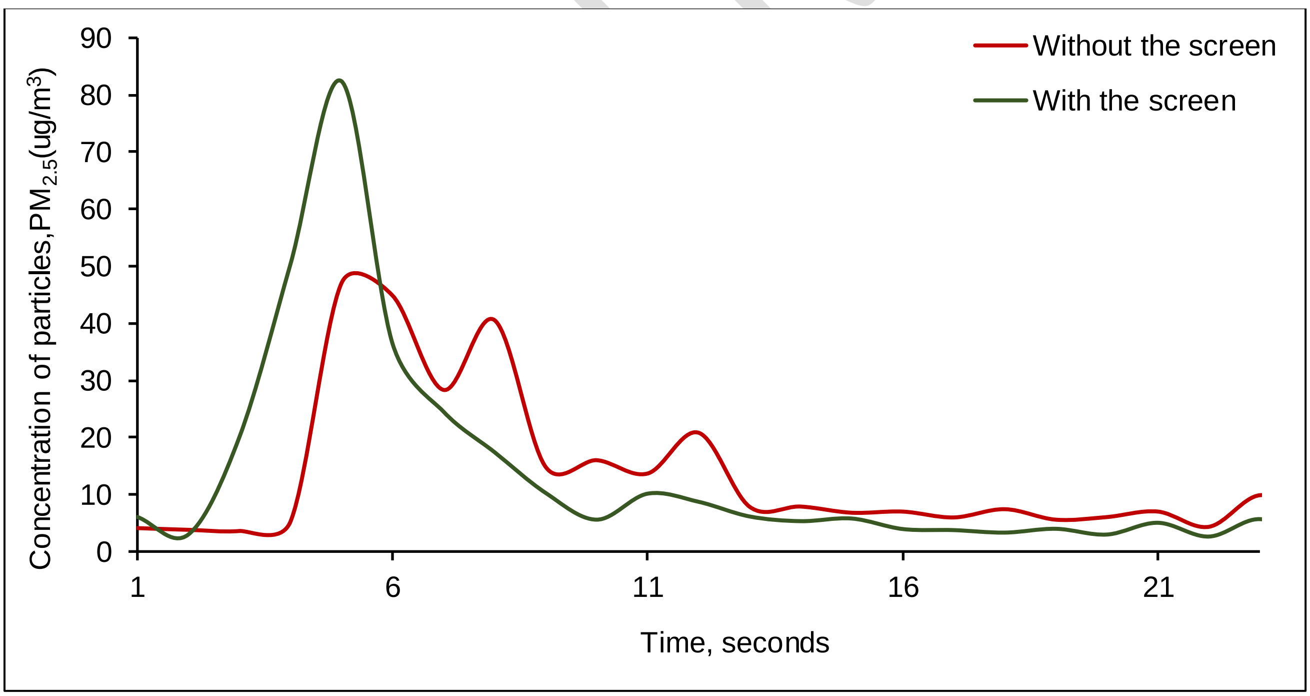

Figure 39. The concentration of $PM_{2.5}$ (ug/m^3) within first 23 seconds using the acrylic screen.

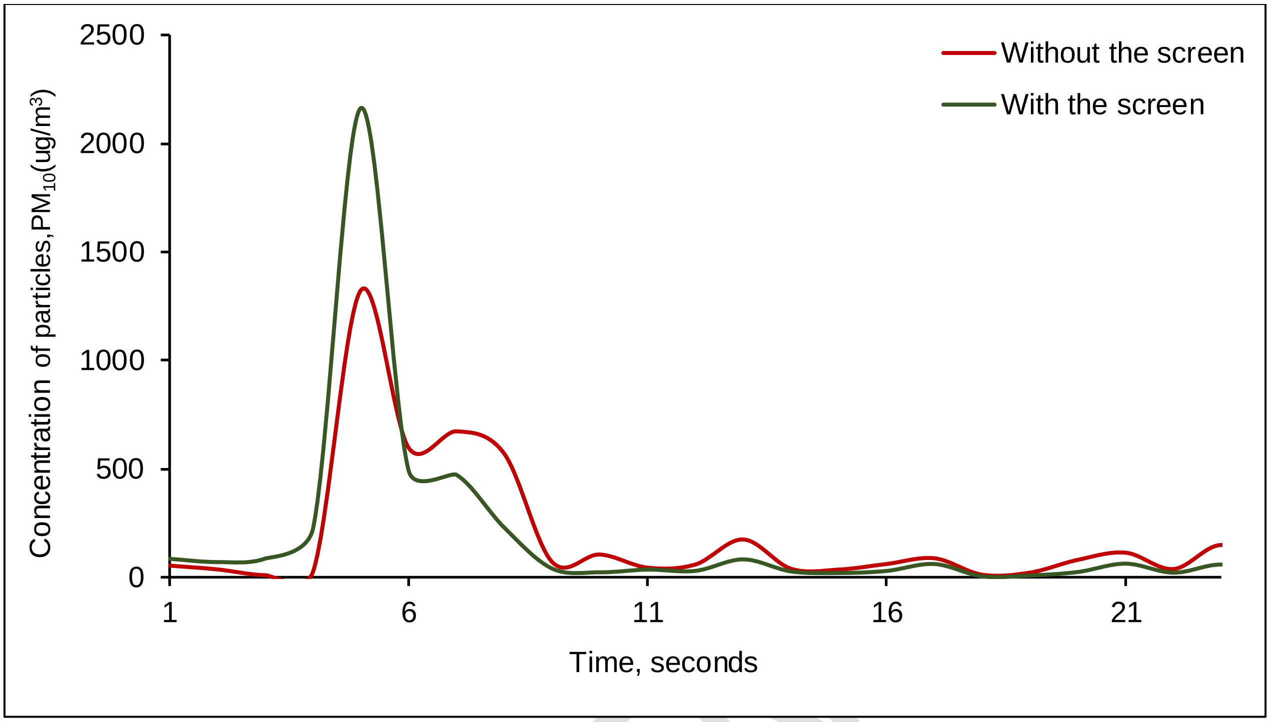

Figure 40. The concentration of PM_{10} (ug/m^3) within first 23 second using the acrylic screen.

4. Conclusion

The effectiveness of the Airshield was analysed by measuring concentration of particular matter and abundance of particles with and without the Airshield using aerosol, surgical mask and visor, respectively.

Each Figure and thereby experiment should be considered independent, and the difference as opposed to the absolute particle concentrations should be assessed. Indeed, by nature the background particle concentration will vary according to time, temperature and room size however by considering the difference between background and intervention for each experiment we are able to assess the individual effects of the instruments on a case-by-case basis as opposed to assuming the same baseline

The effect of the Airshield was compared to an acrylic clear screen that was placed instead of the nozzles. The measurements were performed in two positions: from one side after the Airshield nozzle and towards the Arshield. The results obtained from aside of the Airshield showed than it provided an effective barrier against small particles equal to or less than 10 µm and reduce the concetration of such particles by up to 96%. The protective materials such as mask and a visor let particles pass through, whereas the Airshield reduced the abundance of those particles by up to 88% and up to 75%, respectively. Furthermore, the results obtained from the front of the Airshield confirmed that it can reduce the abundance of particles sizing from 0.4 µm to 35 µm by 99%, whilst a mask and a visor reduced those particles by 80% and 66%, respectively. In addition, a clear acrylic screen reduced the abundance of particles by up to 51%. All repeats of experiments combined to the plots shown with repeats offering data within 3 standard deviations of the mean. The concentration of particles equal to or less than 10 µm was reduced by 45% using the acrylic screen.

5. References

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