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Application of Nanotechnology in a Novel Air Purifier for Remediation of Airborne Pathogen and to Prevent the Spread of COVID-19

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Abstract

The spread of COVID-19 occurs via airborne transmission. With a constant and variable spread of COVID-19, indoor air-quality has become a major concern all over the world. People who are infected with COVID can release particles and droplets of respiratory fluids that contain the SARS CoV-2 virus into the air when they exhale (e.g., quiet breathing, speaking, singing, exercise, coughing, sneezing). Once infectious droplets are exhaled, they move outward from the person (the source) into the surrounding environment; these droplets carry the virus and transmit infection. Indoors, the very fine droplets and particles will continue to spread through the air in the room or space and can accumulate. Harmful pathogenic organisms like fungi, bacteria and viruses, as the one responsible for causing contagious diseases like the ongoing pandemic of COVID-19 can also be successfully destroyed and neutralized. We have developed and studied the efficiency of the AFL Mini

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Sanifier II® in a simulated environment of a fiberglass chamber using various types of meters to assess the suspended particulate matter (PM) in the ambient air. We also report the development of a novel face mask that was assessed for safety measures and further improvement by the researchers in the West Texas A&M University. The mask is user friendly and portable, equipped with a small internal fan that supplies a continuous air to the user preventing the suffocating effect caused by the other masks. The novel mini air purifier is equipped with the advanced nanotechnology that cleans and sanitizes both the air and surfaces and subsequently has been shown to reduce common allergy, asthma and hay fever related symptoms. This mask and the mini air purifier function in an advanced way to combat all forms of airborne pathogens including the bacteria, viruses, mold spores and harmful Volatile Organic Compounds (VOC) present in the air.

Keywords: Air Quality, Particulate Matter 2.5 (PM2.5), air purifier, advanced mask

Introduction

The aerosolized solid, liquid, or mix-phased particles in the air are commonly referred to as *Particulate Matter* or *PM* and usually note the average particle size due to subsequent health impacts. The body has various barriers to prevent the entry of foreign particles, but the finer the particle the easier they are able to enter the body and travel to deeper tissues in the lungs. This is also true for the ultramicroscopic size of SARS CoV-2 that facilitates entry into the human body via respiratory droplets from infected individuals. These particles and droplets can travel throughout the room and accumulate in a space, suspended for variable time periods (EPA, 2016).

Ambient air quality in the Texas Panhandle affects everyone, especially the young, elderly, and those who are ill. It has been reported that the air in the Texas Panhandle has a unique mixture of pollutants that can negatively influence human health. Some of these things can occur naturally from sources such as pollen and mold spores, or from anthropogenic sources including automobile exhaust, oil and gas operations, and agricultural activities and feedlots. Many of these substances are from local sources but can also be transported from other distant locations. This is due to the specialized geographical terrain with unique meteorological air patterns. Examples of particulate matter that seasonally travels to this area includes the particulates emitted from wildfires in the western United States including states such as California. It is important to have a grasp on common air pollutants in the area to provide a record of seasonal fluctuations and trends, and provide the public with knowledge of options to empower individuals with

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steps they can take to improve air quality, thereby improving their health (Howard, 2022).

A healthy individual breathes in just over 2,000 gallons of air-enough to fill up a normal-sized swimming pool (American Lung Association, 2017). According to the WHO (2018), in addition to outdoor air pollution, indoor smoke from household air pollution is a serious health risk for some 2.6 billion people who cook and heat their homes with biomass fuels and coal. According to WHO, (2018) 3.8 million premature deaths were attributable to indoor air pollution. Among these 3.8 million deaths: 27% are due to pneumonia, 18% from stroke, 27% from ischemic heart disease, 20% from chronic obstructive pulmonary disease (COPD), 8% from lung cancer (FIRS, 2019). Others studies also show that kids are more vulnerable to the detrimental effects of pollution. Every day around 93% (1.8 billion) of the world's children under the age of 15 years breathe air that is so polluted, puts their health and development at serious risk (Banerjee, 2018).

In the recent years with the spread of the COVID-19 pandemic, it became a necessity that the scientific world comes forward with an objective of developing more equipment for air purification with novel technology to combat airborne pathogens, aeroallergens and viruses. The average human breathes 11,000 liters of air daily. It is essential each liter of air is free of pollutants such as PMs, CO, NOx, SOx and O_3. This is especially important for higher risk populations and athletes that breathe more than 20,000 liters of air per day. Air quality is an important factor for overall health. Photocatalytic oxidation (PCO) is a very powerful air purification technology and has the ability to destroy particles as small as 0.001 microns (nanometer) such as carbon based impurities in air like bad odor, volatile organic compounds (VOC), allergens like household dust mites and their droppings, mold, pollen and fungal spores.

At our Aerobiology Lab at the West Texas A&M University, we have acquired various equipment to sample the air including mobile handheld air monitors like the *Light House Handheld Particle Counter* (Fig.1) that sample specific locations at points in time, and stationary sampling units such as the Burkard Volumetric Spore Trap. We have focused on different sources of particulate matters and tested various air purifying units to evaluate the effectiveness of improving indoor air quality.

Particulate matter often abbreviated as PM is everything in the air that is not a gas. Particulate Matter is a mixture of solid and liquid particles suspended in air composed of different sizes, shapes and chemical substances. They are subsequently divided into different categories depending on the aerodynamic diameter of the particles (Table 1). The *particle pollution* influences the capability of the PM to penetrate deeply in the lung. Particle pollution refers to a mix of tiny solid and liquid particles that are in the air we

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breathe. Many of the particles are so small as to be invisible, but when levels are high, the air becomes opaque. Nothing about particle pollution is simple. In fact, it is so dangerous that it can shorten one's life. (American Lung Association, 2017).

Primary and secondary PM present in the atmosphere can be transported over long distances and their removal may occur via rainfall, gravitational sedimentation or coagulation with other particles. PM is usually made up of both anthropogenic and natural sources. While primary forms are directly emitted from sources like agricultural and industrial processes, vehicles, construction sites and forest fires, secondary forms are derived from complex chemical reactions of substances suspended in the atmosphere.

Table 1. Particulate Matter (PM) Basic. (EPA, 2016)

Table 1: Characteristics and Sources of Various PM Fractions		
PM fraction	Characteristics	Sources
PM 10 (*Inhalable PM*)	diameter ≤ 10 µm	Outdoor Sources like Vehicular traffic, Organic matter and Fossil fuel combustion and Power stations/industry
PM (10-2.5) (*Coarse particles*)	diameter ranging from 2.5 to 10 µm able to penetrate into the upper respiratory tract	Outdoor Sources like Marine aerosol, Soil erosion, Volcanic eruptions
PM2.5 (*Fine PM*)	diameter ≤ 2.5 µm able to penetrate into the tracheobronchial tract	Outdoor Sources like Windblown dust from roadways, agriculture and construction, Bushfires/dust storms
PM 0.1 (*Ultrafine PM*)	diameter ≤ 0.1 µm able to penetrate into alveolar region	Indoor Sources like Wood stoves, Organic matter and fossil fuel combustion, Tobacco Smoke

Particulate Matters (PM) adversely affect health due to its ability to bypass bodily defenses and reach deeper into the tissues of the lung. The human respiratory airway is particularly susceptible to the integration of toxins into the body. Inhalation of aero-toxins may lead to a quick dispersion of that toxin to the other parts of the body via the bloodstream. This is due to the highly vascularized alveoli and soft tissues of the lungs that easily absorb molecules from various substances, leading them to travel to different organs of the human body. Typical physiological defenses like nose hairs, secreted mucus, and cilia in the respiratory tract trap larger particles. Additionally there is a ninety-degree bend in the airway to deposit and expel foreign substances out of the body (Howard, 2022). Particulate matters of sizes ranging from 0.1 to 10 micron have been particularly in focus in recent years. Our objective was to develop and assess equipment and PPE (Personal Protection Equipment, like advanced masks) that will protect individuals from COVID-19. A collaboration between industry and academia is mutually beneficial. In order

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to foster this environment, we have been working on the development and assessment of the devices that use Photo Catalytic Oxidation Nanotechnology to combat airborne pathogens and different forms of impurities and pollutants present in the indoor air. Nanotechnology promises significant improvements of advanced materials and manufacturing techniques, which are critical for the future competitiveness of national industries (Miyazaki & Islam, 2007). New world trade and economies are based on the application of innovative technology, developing novel products that are in great demand. We are in need of a more advanced air purifier that works on airborne pathogens and improves the air quality with a greater extent than existing air purifiers in the market. The collaborative research team has come forward with a novel nanotechnology to develop unique air purifiers to combat aeroallergens, PM 2.5 to PM 10, bacterial and fungal spores, and viruses. The target is to improve the air quality for remediation or alleviate respiratory ailments.

Some studies show a significant correlation between air pollution and increasing heart rate and blood pressure (Langrish et al., 2019). Wearing a facemask could therefore potentially help maintain healthy rates of blood pressure and heart rates in susceptible people due to reduction of environmental pollution exposure.

Bleakley et al. (2021) show that many people are reluctant to wear face masks due to the following reasons:

1. They feel psychological effects of feeling suffocated and cannot breathe properly, 2. In many cases, there is leakage on the sides of the mask, reducing effectiveness, 3. Wearing a mask improperly would fail to prevent the entry of pathogen, especially the tiny particulate matters and viruses, 4. Many people experience re-inhalation of CO_2 upon wearing a facemask that may lead to an increase in blood pressure and toxemia.

There are reports finding that the wearer can develop physiological stress from the long-term wearing of the N95 masks. Healthcare providers may develop headaches following the use of the N95 facemask. Shorter duration of facemask use may reduce the frequency and severity of these headaches (Lim et al., 2006; Bolashikov et al., 2009). Wearing a mask may be harmful to some people with heart or lung disease because it can make the lungs work harder to breathe. Some masks like the N95 give exhaled moisture breathing resistance if wore for more than four hours (Roberge et al., 2010). We proposed to develop a user friendly mask that would allow the user completely filtered air preventing the suffocation.

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Materials and method: Lighthouse Handheld 3016 IAQ

Fig. 1. Lighthouse Handheld Monitor used for assessing the indoor air quality.

This equipment measures the PM concentration of varying sizes (Fig. 1). The number “3016” indicates a 0.3 µm minimum channel size at 0.1 CFM with up to 6 channels. The instrument uses a laser-diode light source and collection optics for particle detection. Particles scatter light from the laser diode. The collection optics collect and focus the light on to a photo diode that converts the bursts of light into electrical pulses. The pulse height is a measure of particle size. Pulses are counted and their amplitude is measured for particle sizing. Results are displayed as particle counts in the specified size channel. We have tested the efficiency of the novel facemask and the mini air purifier in a custom-built fiberglass chamber. To test the efficiency of the novel facemask, we have divided the chamber into two sub-chambers: C1 and C2. We have placed the novel facemask at the junction in a custom-built hole to which the mask would fit properly. We used rubber tubing, silicone grease and tape to seal the sides of the mask with the fiberglass partition (Fig. 6D).

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Dust, Fan and Fiberglass chamber and assessing the mask

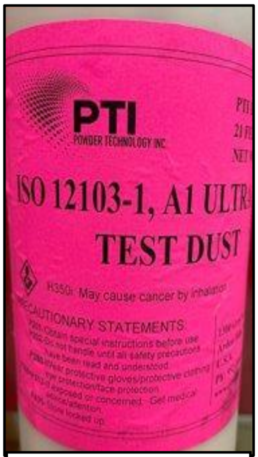

Fig. 2. Showing the Ultrafine Test Dust.

We have obtained the ISO 12103-1 ultrafine dust particle (Fig. 2.) with an average size of 2.75 micron from PTI Powder Tech., Minnesota. We used this powder as a source of PM 2.5 and to create a PM 2.5 rich environment in the fiberglass chamber. We then have used a fan to circulate air in the chamber to uniformly spread the PM towards saturation (Fig.3). In this experiment, we used this dust to evaluate any reduction of the particle concentration.

The fiberglass chamber has three airtight lids, two on the top and one on the side to maintain the equipment. It has a volume of 12.45ft^3. In this custom-made Fiberglass chamber, a slot was made to fit the mask and sealed to make the sub-chambers airtight. We placed Petri plates in 24-hour increments on both the C1 and C2 sides and counted the microbial colonies formed while keeping the mask running. The exposed Petri plates were sealed and incubated in an incubator at 37^{o}C for 48 hours. Once the visible colonies emerged we placed the Petri plates on a colony counter and counted the number of colonies emerged in each set. The number of microbial colonies in the Petri plates on side C1 (No filtered air) were compared with the C2 (Filtered air passed through the mask) (Fig. 5 B, D, 6E) Petri plates. Every 24-hour interval showed variable counts of the microbial colonies (Fig. 6D, F) with lower colony counts in the C2 side.

In the next part of the experiment we compared the PM 2.5 count in both of the chambers, C1 and C2, after 24, 48, 72, 96, and 120 hours. We have calculated the natural rate of decay of the PM represented by the ISO 12103-1 Ultrafine Dust Particle by placing a meter, the *LightHouse Handheld*

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Particle Counter, in the chambers after aerosol saturation in 24-hour periods. Using fans, we spread the PM2.5 in the chamber (C1) uniformly and waited for 72 hours to develop an equilibrium in the suspended aerosol. All chamber doors and the slot where the mask was fitted were sealed airtight using silicone grease. We have recorded the number of PM2.5 floating inside the chambers C1 and C2 by using the mobile handheld air monitor to sample the airborne particles (Fig. 5D). We have recorded the particle concentrations in the divided chamber at various intervals to determine the percentage of the particles prevented entering into the other chamber when the mask was placed in the chamber junction.

Mini Filter-less Germicidal Air Purifier

Fig. 3. Mini Filter-less Germicidal Air Purifier.

The novel mini air-purifier (Mini Sanifier) cleans and sanitizes both the air and surfaces. It can reduce common allergies, asthma, and hay fever related symptoms. It can eliminate allergens such as household dust, dust mites, pollen, bacteria (including MRSA), viruses, PM2.5, bathroom odors, pet dander, pet smells, cooking smells and cigarette smoke. It produces low doses of human friendly negative ions that have been shown to improve alertness, concentration levels, mood and sleep. Controlled low doses of negative ions are sometimes referred to as the "vitamins of the air" due to observed positive effects (Mindell, 2016).

We have tested the mini air purifier on its efficiency to reduce the concentration of particulate matters, pollen and mold spores present in indoor air. Using the ISO 12103-1 Ultrafine Dust we have calculated the rate of natural decay of the PM and compared that with the rate when using the Mini Filter-less Germicidal Air Purifier. We weighed the particulate matter on a chemical balance and placed it on a Petri plate in the fiberglass sub-chamber marked as C1. We used a fan to spread the particulate matters in that sub-chamber uniformly. We have recorded the rate of the decay of the PM2.5 and compared that to when the Mini air purifier was on. The decay rate for both the sets were recorded at 24h, 48h, 72h and 120h time intervals.

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The main aim of this study was to test the efficacy of the Mini air purifier in decaying the suspended artificially generated PM2.5. For all sets of experiments, we used a fiberglass chamber of volume $12.45ft^3$ to assess the Mini air purifier in terms of reduction of PM2.5. The chamber was first cleaned using Clorox wipes and was dried for 24 hours. About 2 grams of dust was spread from the top lid of the chamber to create a high concentration PM2.5 environment. In all of the experiments, temperature was maintained between 22^oC-25^oC and humidity between 20%-30%. Experiments were done in five replicates. For all the PM2.5 decaying experimental data was recorded until the PM2.5 concentration reached $30\mu g/m^3$, as $35\mu g/m^3$ is the acceptable range by EPA.

Comparison of PM 2.5 decaying rate with and without using air purifier under no air circulation

For the first set of experiments no fan was used, this was done to create a still air environment inside the chamber. Firstly, the Lighthouse handheld meter was placed in the chamber. It was set at 30 minute-intervals to record the change in PM2.5 concentration. For the control, no air purifier units were on inside the chamber. Then, the dust was spread from the top lid of the chamber. The data recorded reflected the natural decay rate of PM2.5, which was considered the control. This experiment was repeated twice with the Mini air-purifier and the average PM2.5 decay rate for the experimental replicates with no air circulation then compared with the control. We have used another air purifier named IonicAir unit that follows the same nanotechnology to determine the efficiency of the Mini air-purifier.

Analyzing the decay rate of high concentration PM2.5 using the air purifiers and control

To test the working capacity of air purifier in decaying high concentration PM2.5, firstly a Lighthouse handheld was placed in the chamber. It was set at 30 minute-intervals to record the change in PM2.5 concentration. A fan was also placed inside for the continuous airflow in the chamber. For control, no air purifier units were run inside the chamber. Both the equipment were turned on, and then 2g dust was spread from the top lid of the chamber. Within one minute, the chamber concentration reached 2000 $\mu g/m^3$.

This concentration was ideal to record high concentration decay. The data recorded gave the natural decay rate of PM2.5, which was considered as the control. This experiment was repeated with IonicAir and then Mini air-purifier using the same PM2.5 concentration range of $2000\mu g/m^3$ to $2140\mu g/m^{3.}$ Time taken for PM2.5 decaying by the air purifier was recorded and compared with the control.

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Comparing the PM2.5 decaying rate of air purifiers and with the control

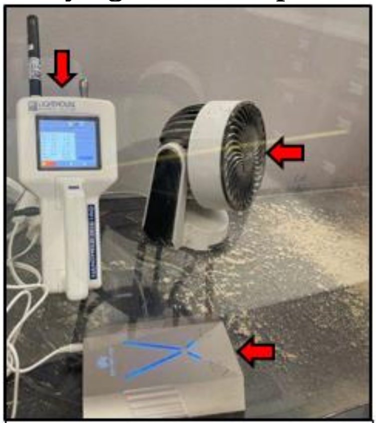

Fig. 4. Lighthouse handheld was placed (Pointing with arrow) in the chamber. A fan was used to circulate air in the chamber. The sidewise arrow points the Mini Air purifier.

To test the working capacity of the air purifiers' influence on the decay rate for PM2.5 concentration, firstly a Lighthouse handheld meter was placed in the chamber. It was set at 30 minute-intervals to record the change in PM2.5 concentration. A fan was also placed inside for the continuous airflow in the chamber. For the control, no air purifier units were on inside the chamber. For the experimental set, both equipment were turned on and then 1g of dust was spread from the top lid of the chamber. We began collecting our data once the PM2.5 concentration reached between 92 $\mu g/m^3$-105 $\mu g/m^3$. This experiment was repeated with the IonicAir unit and the Mini air-purifier using the same PM2.5 concentration range of 92 $\mu g/m^3$-105 $\mu g/m^3$. The times for the PM2.5 rates of decay were recorded and compared with the control taken by both of the air purifiers. For further analysis and comparison of the data obtained from the controlled exposure, we used Petri plates to compare microbial colony count when exposed to the indoor air, with (experimental) and without the air purifying units (control).

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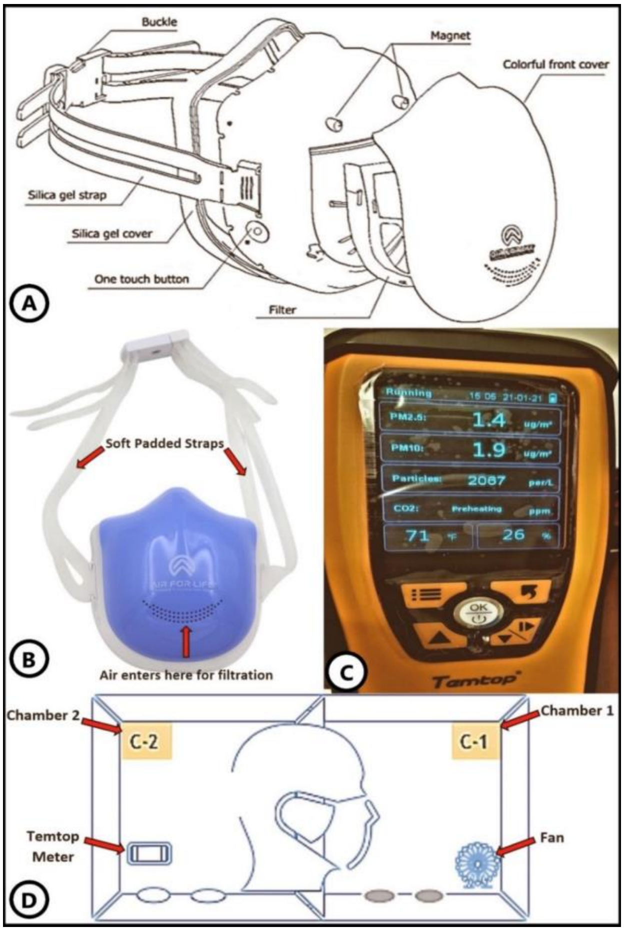

Fig. 5. A. Components and design of the novel face mask, **B**. Air inlet and soft padded straps of the facemask, **C**. Temtop Air Quality Meter, **D**. Organization inside the fiberglass chamber. D shows the diagram of the fiberglass chamber that was divided into sub chambers C1 and C2 for testing the efficiency of the mask. On the C1 side, the fan and the Petri plates were kept to assess the composition of the air on the C1 before using the mask. On the C2 side, the Petri plates and the *Temtop monitor* were placed to assess the air after it passed through the mask.

Figures 5A to D show the design of the novel facemask including the one-touch button to control the operation, the front cover, the magnets to attach the front cover, and the four filters, all attached together. The back of the mask is padded with a silica gel cover. The silica gel strap provides a comfort fitting of the mask to the users face. Figure 5B is showing the whole mask with the soft padded straps. From the front of the mask, the air flows inside through a series of holes. Then, the air passes through the 4-

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staged filtration system in the mask. The air is filtered before entering into the users nostrils.

Fig. 5C showing the *Temtop air quality monitor* that provides the reading of the concentrations of the PM2.5, PM10, particles and CO_2 in the ambient air. This multi-functional air quality monitor has an easy calibration module and it also records the ambient temperature.

Figures 6A-F showing the steps followed during the experimentation to assess the air quality on using that mini air purifier and the novel mask. Fig. 6A showing the investigator recording the reading and collecting data from the Lighthouse Handheld 3016 IAQ air quality monitor placed in the researchers analyzing the data collected from the experiment. Figure 6C showing the mini air purifier and 6E showing the novel mask.

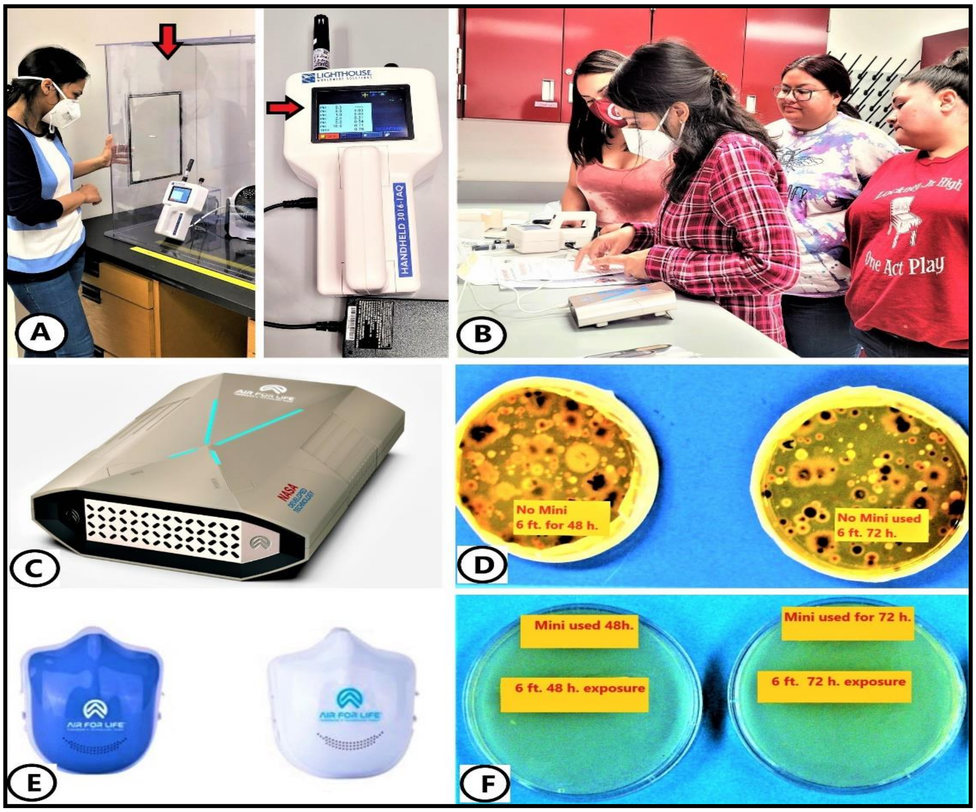

Fig. 6. A-F Showing the experimental steps to assess the indoor air quality.
A. Sampling the air using the air monitor, the *LightHouse Handheld Particle Counter*.
B. Analyzing the data collected for the indoor air. **C**. Mini air purifier. **D & F**. Petri

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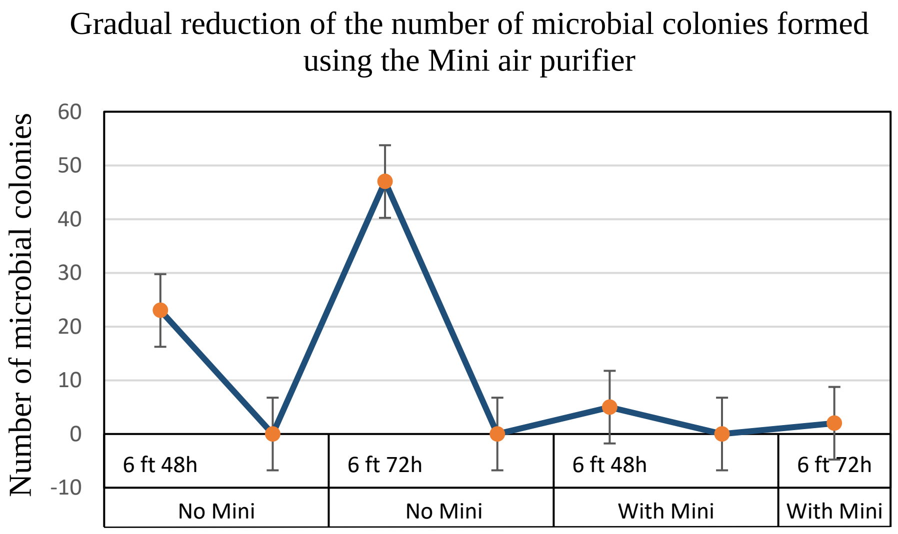
Results and Discussion

We have collected the data using the air quality monitors and from the colony counts from the exposed Petri plates (Figs. 6A-F). The data from the Petri plates were collected after the 24h, 48h and 72h of exposures (Figs. 6D, F). The rate of infection varied with the distance and the period of exposures (Graph 1).

Temtop M2000C CO_2 Air Quality Monitor Detects CO2 PM2.5 PM10 and Temperature and humidity. This multi-functional air quality monitor has an easy calibration module. It can detect the counts for PM2.5, PM10, other particles, CO_2 and it records the ambient temperature. Using this multi-functional air quality monitor we have collected the data on particulate matters from the ambient air on simulated running of the experiments within the fiberglass chamber (Fig. 5D).



Graph 1. Showing the reduction of the bacterial colonies formed on the Petri plates using the air purifier at different intervals.

Graph 1 is showing the comparative account between the two sets of Petri plates exposed to air with and without using the mini air purifier. The graph clearly shows a decline in the formation of the microbial colonies on using the mini air purifier. The Petri plates were placed 6 feet apart, equidistant from the air purifier and were exposed to the air on running the air purifier for 24, 48 and 72 hours to test for any reduction in the air borne microbes.

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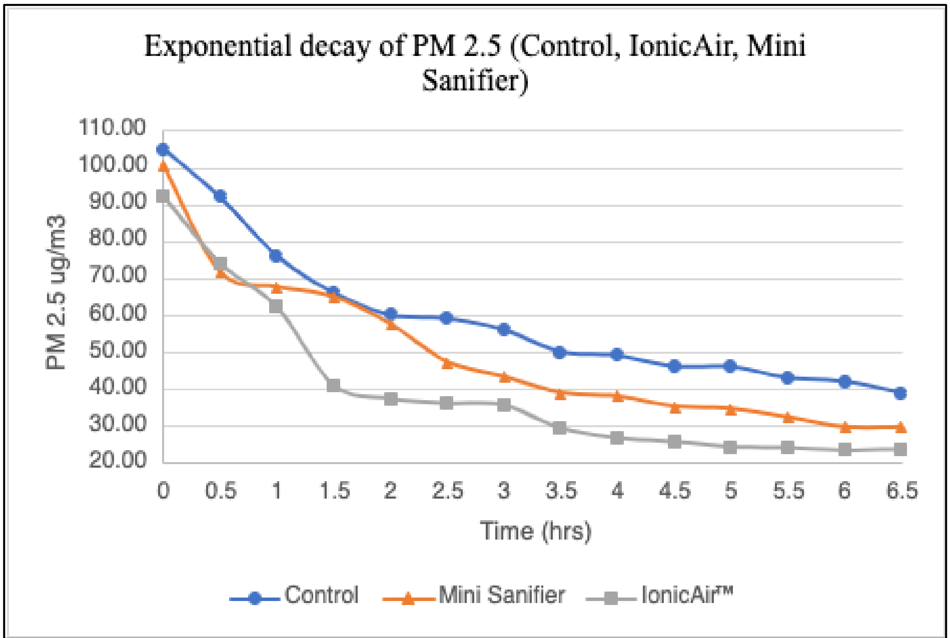
Graph 2 shows the comparison of the PM2.5 decay rate for the control (no air purifier was used) and experimental set in which two air purifiers, the mini and the IonicAir units were are used. The graph shows a faster reduction of the PM2.5 on using the two air purifiers (Goyal, 2022). The overall collected data exhibit the efficiency of the air purifier in reducing the airborne microbes with the advanced nanotechnology applied. It is very clear from the graph that the air purifiers were able to clean the air more efficiently by reducing the PM 2.5 with a gradual, faster decay. On running the air purifiers for 6.5 hours, the PM2.5 count was reduced from 100 to a range of 22 to 30 per cubic meter. From the results, we can conclude the use of the air purifier technology shows an effective reduction of particulates in the indoor air. Usage of these air purifiers will reduce the symptoms of allergy, asthma, and other respiratory ailments due to reduction of irritants and aeroallergen concentration (Ghosh et. al, 2021).



Graph 2. Comparison of PM 2.5 decay for control and when using IonicAir and Mini air-purifier units as a function of time.

The facemask is an effective way to protect the wearer from the particulate exposure and provide filtered, clean air to the wearer. From the data that we collected from the fiberglass simulation experiment, it can be concluded that the newly devised mask is very efficient in protecting an individual from all kinds of airborne pathogens and PM2.5. This mask can

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provide an internal air supply within the mask and maximum comfort with its ergonomic design and improved filtration technology (Ghosh et. al, 2020). The advanced technology used in that mask can provide maximum comfort to the user with its soft gel-filled straps, continuous supply of the internal air that is filtered with 4-staged filtration system ensuring the protection from all kinds of pathogens and particulate matters.

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