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Study of Modern Air Purification and Sterilization Techniques

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ABSTRACT

Very few studies are available on workable air pollution treatment, especially for airborne microbiota on human health. The present study has attempted to summarize the commonly known forms of air pollution, airborne viral, bacterial, and fungal attack, their possible effects on human health, and possible treatment. A testing rig is also designed and developed for air purification. Earlier, air purifiers were used to deliver clean air by treating particulate matters (PM) only, but due to the pandemic situation, i.e., COVID-19, air purifier units are expected to treat potentially harmful microbiota as well. In the present study, HEPA (High-Efficiency Particulate Air) filter is studied in combination with conventional mechanical filters. It is observed to be very efficient in trapping and neutralizing viruses and bacteria when used with sterilization techniques. This article also highlights the critical aspects required to be examined for the installation of air purification unit.

1. INTRODUCTION

It is a human right to breathe pure air naturally. The human immune system is majorly attacked by micro and nano airborne allergens and pollutants prompting fatigue, muscle aches, headaches, a runny nose, etc. and may lead to an acute health issue. It is quite obvious that we spend nearly 30 to 40% of our lives in the bedroom and indoor conditions. Therefore, clean air is essentially required for humans because our immune system tries to rebuild itself when we sleep or nap. It is well known that nanoparticles (common pollution and harmful gas contents) matter much as far as human health is concerned. Viruses are found in typical sizes of the order of 0.0025µm (or of the order of rainwater drop divided by 1000×1000), and bacteria are of the order of 2.5 µm (or of the order of rainwater drop divided by 1000). COVID-19 is an irresistible infection triggered by means of the coronavirus, SARS-CoV-2, [a respirational pathogen particles of the order of diameter < 5-10 μm and also referred to as respirational droplets] [1]. Corona pandemic has taken a hefty toll worldwide in the year 2020 and 2021, with huge numbers of reported deaths. A former natural study showed that the 2003-SARS pandemic affected many Hong Kong, China and Canada regions. It revealed a clear relationship between ambient air pollution and SARS-related deaths. Recently, the same has been confirmed for the COVID-19 virus, too, by the studies conducted at Harvard University and Italy. Also, it was discovered that northern Italy, one of the most polluted areas in Europe, suffered more massive COVID-19 related mortality, wherein high air pollution loading could also make it worse.

COVID-19 virus mainly transmits through liquid droplets, and suspended particles in the air may also contain viruses. Infected humans generate these droplets and airborne virus-containing particles, majorly through coughing and sneezing. Viruses and bacteria can transmit to uninfected individuals by direct inhalation or by fouling on nearby surfaces. Literature shows that SARS-CoV-2 can survive in air droplets for several hours, and in some particular cases, it may survive up to three days [2, 3]. A communicable virus could be spotted on copper surfaces for as long as up to four hours, over cardboard for up to 24 hours, and on stainless steel (SS) and plastic for at least 72 hours [1, 3]. Suppose any viruses and bacteria, e.g., SARS-CoV-2, may possibly move in the air (apart from liquid droplets). In that case, an air current may carry it for a long distance, especially in living and indoor conditions where air currents recirculate repeatedly.

The currently available data reveal that viral/bacterial pathogens are usually too light and short-lived in the ambient air to affect healthy people potentially but could be life-threatening to unhealthy humans or humans with pre-existing diseases. Airborne spores of fungi may intensify allergies and asthma [4]. Also, the information accessible on viruses, including phages, are very sparse, the information available on viruses, including phages, is very sparse, and future studies and product developments, must be focused on known and novel viruses, e.g. COVID 19. Nowadays, product and technological developments dealing with solutions to commonly known forms of air pollution, including airborne viruses and bacteria, have become essential and a high priority need. By noticing the alarming situation due to the worsening effect of commonly known air pollution with airborne viruses and bacteria attacks, industries are continuously trying to develop many innovative solutions in the form of products to provide workable solutions.

Approximately 6,000 different categories of viruses exist. However, practically 1,500 types of viruses may give rise to infections leading to serious illnesses, as reported by the International Committee on Taxonomy of Viruses (ICTV).

Humans affected with the acute influenza virus can harbour approximately 10^9 virus particles per millilitre in the bloodstream and discharge roughly 10,000 viruses in the form of aerosol by sneezing or coughing. In a closed environment, the influenza virus can reach a concentration of about 2.6×10^5 particles per cubic meter of air [5]. Recently revealed coronavirus causes coronavirus disease COVID-19. The existence of this new virus was unfamiliar before the epidemic activated in Wuhan, China, in November or December 2019. COVID-19 is now a global pandemic that affected many countries, including India. The human immune system is attacked by airborne allergens, viruses and pollutants, prompting fatigue, muscle aches, headaches, fever, runny nose, etc., which may lead to an acute health issues. An air purifier may be used for the treatment of airborne viruses. A combination of filtration and sterilization techniques may be used to treat viruses, particularly COVID-19. It is important to know that Asthma, COPD (Chronic Obstructive Pulmonary Disease), Leukemia, Pneumonia, Lung Cancer, birth defects Autism, immune system defects, Deterioration of Lung Function, and Circulatory Diseases followed by premature deaths are due to air pollution [6, 7].

Air Purifiers are used to provide clean air by arresting pollutants that are potentially harmful to human health and it may be as small as PM0.1. Earlier air purifiers were used to deliver clean air only, but now those may also be used to treat bacteria, viruses and VOCs (Volatile Organic Compounds). In recent times, it has been seen that air purifiers can eliminate viruses and bacteria using a combination of Filtration and Sterilization Techniques [8-10]. A HEPA (High-Efficiency Particulate Air, 99.97% efficient on particles with size $\leq$ 0.3 microns) filter can trap viruses when used with some sterilization method, and they are surprisingly good in doing so. This article aims to explore various ways in which different viruses and bacteria can be treated and the key aspects to look at while purchasing a filter. Cleaning the air and making it free from viruses and bacteria involves several challenges, must be studied in more significant detail, and needs proper research. Such studies will have to pass through an evolution phase, and then only a strong theory or technology will come into general practice. Studies show that using a mask, use of air purifiers, and regularly following an effective social distancing protocol wherever the chances of spread are strong may substantially decrease the spread of highly contagious viruses such as the coronavirus (COVID-19). Also, the rate of spread of other types of viruses and bacteria may also be stopped, which are expected to commute through droplet and air current transmission [11].

The possibility of aerosol propagation of the viruses and bacteria can be treated using some combination of air purification techniques. Therefore, there are some open questions, which are not much researched, must be answered by researchers and scientists, i.e., how do the different types of air purifiers work, especially in the treatment of viruses and bacteria? What are the effective air purification technologies, which are capable of killing the COVID-19 virus? Coronavirus is a family of viruses that may be a key reason for illness in animals or humans. Particularly in humans, numerous coronaviruses are identified to cause respiratory infections. Recently discovered coronavirus causes a disease named COVID-19. The main objective of this article is to give an idea of how an air purifier may be used to treat viruses?, and a combination of filters and sterilization techniques to treat viruses, particularly COVID-19. Due to the pandemic situation that arose in 2019, COVID -19 virus gained much magnetism among the researchers and industries working on air purification technologies. Most air purifiers that are currently in use can be categorized into two basic groups: Filtration and Sterilization. If your target is to purify the air from particulate matter, then only filtration technology may work, and as the target shifts towards treating harmful gases, viruses and bacteria, then filtration and sterilization both must be needed for an effective easing.

The main objective of an air purifier design must be focused on the enhancement of the quality of indoor air by eliminating microscopic PM, which is present in the surrounding, e.g. smoke, dust, pollen and pet dander. Current anti-viral/bacterial air purifiers use filters combined with sanitization/sterilization techniques and are constructed/intended to destroy viruses, mold or fungal microorganisms and bacteria, that must be found all around easily. These effects take place in the surroundings obviously. However, such an environment may lead to falling you down by certain sickness, in a situation where you are exposed to voluminous concentrations of them. Some general combination can be considered to avoid these harmful situations with air purification and sterlizarion techniques (indoor or outdoor) [11].

Particularly in the winter season, the cold air is denser and moves slower than the warm air. Therefore, cold air can trap more pollutants, including viruses and bacteria. Air pollution in wintertime stays in a confined or sometimes in open space for a considerably longer duration. Therefore is inhaled in at an elevated flow rate compared to the summer time and is expected to increase the respiratory problems further and accentuate the Corona effect. In India, the impending stubble burning, burning of crackers, emissions from factories, and even burning fossil fuels create air pollution, which contributes to smog formation. Till the point, we are not getting a permanent solution against pollution and COVID-19, we need to take precautions because it is better than the cure. The government of various countries with the World Health Organization (WHO) have also taken many steps to reduce pollution. One of those is implementing BS-VI norms in the automobile segment. Other regulations are applied to industries, so that these should generate less pollution in terms of PM2.5 particles, nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons (HC). In the combination with some sterilization techniques, HEPA filtration was found to be superior in providing clean air by eliminating viruses and bacteria. However, one should not get confused that it can be used as a replacement for good hygiene, such as washing hands and cleaning hard surfaces. With increasing air pollution contents and viruses and bacteria attacks, air purifiers with sterilization technology can be a promising future for human health, hygiene and certain medical treatments as well. This article aims to explore various ways in which different viruses and bacteria can be treated and what are the key aspects to look at while purchasing a filter.

Many countries are sincerely taking air pollution issues and changing away from fossil fuels. Hence, they are trying o shift to the electric vehicles (EVs) through the hybrid vehicle concept and applying various norms to cover up the air pollution and focus on clean air or zero-emission. But one must take care of optimum energy utilization and use more energy-efficient devices. Nowadays, product and technological developments dealing with solutions to commonly known air pollution forms, including airborne viruses and bacteria, have become essential and a high priority

need. By noticing the alarming situation due to the worsening effect of commonly known air pollution with airborne viruses and bacteria attacks. Researchers are continuously trying to develop many innovative solutions in the form of products to provide workable and sustainable solutions.

It is well known that the respiratory system is the leading cause of illness or health impact due to the worsening condition of air pollution and the spread of viruses and bacteria. Therefore, such scenarios must be avoided by living in a healthy environment. For clean water, RO water purifiers have taken care of that, like that for clean air; we need to use technologies that must help us create a healthy environment. Until we are not getting a stable solution for clean air, we should take essential majors or adopt an alternative option to live a safe life. One must be less exposed to places or environments where the pollution is observed to be worst and if required, should obey all the precautionary measures declared by the government or authority. One may use some workable practices with proper knowledge or expert suggestions, e.g., indoor House plants, air purifiers, mask and Smog Towers etc. We cannot rely upon only one of those as each of them has its limitations, such as,

(a) Indoor plant: There are many indoor plant-like, Barberton daisy, English Ivy, spider plant, money plant, broad lady palm , and many more, which can absorb toxic gases. Still, they can purify PM2.5 particles and require care, proper sunlight and room temperature to function optimally.

(b) Air Purification Devices: It is a well-known fact that the limitations in one-way result in an improvement and give birth to the next capable/workable option. To capture PM2.5 particles, dust mold, saliva or dander, even toxic gases, the use of an air purifier is indispensable nowadays. In an air purifier, the most vital part is the types of filter media used in combination with effective sterilization technology. Therefore, to choose an air purifier, we should know and read carefully about the construction, various sterilization technologies used, efficiency, DHC (dust holding capacity) and CADR (clean air delivery rate). One must be confident enough with the element and its technology which is going to be used for good indoor air quality. It is all about the robust frame/structure (necessary to avoid any leakage), efficient filter media (must be of high quality), and the product must come through smart manufacturing facilities and the element's easier availability.

One should check the air purifier's effectiveness by looking at the PM2.5 level before and after 30 minutes of its running. Major Indian cities like Delhi NCR, Lucknow, Kanpur and Agra observed the peak PM level approximately equal to 800 to 1000 during the Diwali festival. Therefore breathing in such an environment is challenging. Such data can be seen on *www.aqi.in*. Therefore, if your air purifier can get a level of less than 100 within 30 minutes in an indoor condition, you can say it is effective. It is also vital to select an air purifier based on the room size, especially the area and volume need to be cleaned. Currently, most of the available air purifiers have limitations as they cannot kill viruses and bacteria. For that, we need special media and a combination of different sterilization technologies (UV-C light, thermodynamic sterilization etc.) which can capture and neutralize those microbes. Recently, some of the air purifiers claimed to have very good effectiveness using some antiviral filter media to kill bacteria and viruses with an efficiency of deactivating viruses and bacteria above 99.999%, which is very high. The media used in such purifiers are H14 Grade [12]. Again, a noisy air purifier is also a pain to the ears of the occupants. The allowable noise levels for different CADR capacities are tabulated below [9]. Table 1 shows the admissible noise level for air purifiers.

Table 1. Allowable noise in air purifiers

CADR (m^3/h)	Allowable noise level (db)
<150	50-55
150-300	55-60
300-450	60-65
>450	65-70

Plants and air purifier may take care of indoor clean air solution, but what about outdoor? So, we need a mask and other categories for air purification techniques such as Smog towers for outdoor. The currently available masks are not that effective as they can't protect us from pollution or any viruses because most of the masks are having significantly less efficiency and sealability issues. These are also not as per WHO standards. Mask should contain three layers, where the middle layer should be of 10 microns, and it should have an efficiency level above 95% at 0.3 microns, or you can say N95 masks but without the valve. Suppose you are going to use the mask with a one-way valve. In that case, you are protecting yourself, but simultaneously infecting another person because it allows droplets to go out of the mask, forming a nozzle type flow and makes the surroundings vulnerable. Wearing a mask only will never provide complete protection. For the reason that most of you have seen that area near the nose is never sealed properly even most of the mask use hard metal for sealing but still some gap remains there. These gaps let contaminated air go in/out very easily (because the air passes easily where there is no restriction). Sometimes, it also makes uncomfortable situations for persons wearing goggles or eyeglasses. Therefore, it is better to use a nasal mask to protect you from pollution and viruses. It is well understood that more than 70% of the air we are inhaling is through the nose (which we can extend up to 100% under most controlled conditions). Therefore, we should make sure that we breathe it from the nose only for safe and protective breathing. Nasal Filter technology should also be capable of deactivating viruses and bacteria and retaining small dust particles.

While driving cars during summer, most of us recirculate the inner air to avoid cooling loss, but most of us are directed to get the air from outside in winter. It is very harmful because of the accumulation of dust particles and gases such as PM2.5 particles, nitrogen oxides, carbon monoxide, and hydrocarbons generated due to fossil fuel burning. Therefore, to avoid these pollutants getting in your car, you need to use N95 cabin filters and car air purifiers and always keep your window glasses closed. Though we have covered pollution sources and remedies for indoor, outdoor, and personal/passenger vehicles, however at a public places such as malls, schools/universities campuses, housing societies, hospitals, and open and crowded marketplace, we need advanced technology to provide clean air in these particular places. It is well said that safeguarding is always healthier than going for medical treatment. Until we get a permanent solution for air pollution, which is sufficiently stable, efficient and cost effective, we should take essential care, or adopt alternative options for being safe and getting less exposed to pollution.

To summarise, one can notice that the air purifiers use different filters to produce clean air. These air filters can be divided into four categories i.e. prefilter, medium filter, high-efficiency particulate air (HEPA) filter and ultra-low

particulate air (ULPA) filter. The ULPA is used for a particle diameter of 0.12-0.17 μm having filter efficiency over 99.999% [13]. Similarly, HEPA removes over 99.97% of particulate matter, bacteria, and smog with a size over 0.3 μm. HEPA filters [14] are one of the most commonly used and easily available air filters used in homes, theatres, hospitals, ventilators, vehicles, and air conditioning units. Everyone knows very well that every little particulate matter, especially the tiny stuff in the air, hurts your health when you breathe. The primary health concern is particulate matter, including particles of all sizes and causing airborne movement (bacteria, viruses, dust mites, animal dander, chemical vapours, and harmful gasses). Enhancement of the performance studies of indoor air purifiers has extensively been studied and reviewed by various researchers [9, 15-19]. Also, some computational and experimental studies related to air quality and performance assessment of air purifiers can be referred in the literature [20-24].

1.1 Different techniques to be used for filtration and sterilization

As we have seen that apart from conventional air pollution agents such as PM of various sizes, one needs all to be serious about airborne viruses, bacteria, VOCs and harmful gases. Following are the ways following which one can tackle both the problems [9-11, 25, 26].

1.1.1 Antimicrobial-filters or antimicrobial technology

This technology kills microorganisms or limits the evolution of microorganisms. Therefore, it is called a sterilization methodology and can effectively be used in air purifiers. This antimicrobial technology can be used in an air purifier for indoor or industrial use. This technology needs further research and analysis to be used in air purifiers.

1.1.2 Ultraviolet germicidal irradiation (UVGI)

This is not a filter; it purely comes under the sterilization category. UVGI can be used to sterilize the air and disinfect various surfaces. UVGI kills certain cells using UV type C light by damaging their DNA. UV light is electromagnetic energy comprising of different wavelengths (smaller than visible light spectrum but longer than x-rays). A typical wavelength in the range of 10 - 400 *nm* has been classified into three sub-bands: UV-A, B, and C. Importantly, the UV-C (which comprises wavelengths smaller than 280 *nm*) has been observed to have germicidal properties. Efficient UV-C treatment with a shorter wavelength can better treat viruses and bacteria, but the time duration of exposure must be researched. This is also an active field of investigation that needs to be done to treat COVID-19.

1.1.3 Negative Ionizer based purifiers

An air ionizer, often named a negative ion generator, make use of electrically charged air molecules having high voltage. It is well known that a negative ions or Anions have one or more extra electrons, resulting a negative charged particle. Whereas Cations are positive ions, leading to a situation where it is missing one or more electrons, causing a positively charged particle. Due to negative ions the airborne pollutants fall to the ground or deposited to a collector surface and later can effectively be removed. They can even kill bacteria and viruses [27].

1.1.4 Thermodynamic sterilization (TS)

Air heating up to 200°C results in killing 99.9% of bacteriological agents, e.g., bacteria, viruses, mold and fungus spores by incineration. This technology or process is technically and medically safe but needs specialized attention owing to high heat energy content.

Literature or blogs [28, 29] available on air purification technologies can be referred to before the purchase of air purifiers. These blogs/articles will give you an idea about the pros and cons associated with air purifiers. They will help in the selection of the best air purifiers as per individual or organizational needs.

1.1.5 Plasma air

It is valuable to note that Plasma Air is a highly efficient and proven technology to treat pollutants. It is observed to be suitable for the treatment of the particulate matter, viruses, mold spores, bacteria, odours, and VOCs. Other sub-technologies are available, such as photocatalytic oxidation PCO and plasma air electrostatic air filter (ES.)

2. CAUSES OF AIR POLLUTION, DEFINITION AND IMPORTANT GUIDELINES (WWW.AQI.IN)

- The quality of air is commonly explained by the absorption of particulate matters usually termed as PM [30-32] [varying in sizes from 10 μm (PM10) to 0.1 μm (PM0.1)] and also the gaseous toxins, namely, Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), and Ozone (O_3).
- The World Health Organization (WHO) currently suggests 10 and 20 $\mu g/m^3$ per year for PM2.5 and PM10, respectively.
- The upper threshold for SO_2, O_3, and NO_2 are 20, 100 and 40 $\mu g/m^3$, respectively. It is very important to note that roughly 92% of the world's total population reside where the WHO standards are not touched.
- Significant air pollution or Smog emitters come from industries, power plants (run on fossil fuels), portable sources (cars, diesel diesel electric generators, agricultural equipments and other vehicles), agriculture, wildfires, and numerous others natural processes occurring in various ecosystems.
- In the US, stationary sources contribute mainly to the emissions of SO_2, PM2.5, and PM10; whilst the portable sources are counted as the key producers of nitrogen oxides (NO_x) as per EPA, the USA.
- The PM10 comprises particles majorly generated by burning wood or biomass and diesel fuel combustion.
- The PM2.5 emissions are coming in to the picture directly from combustion processes and the exhaust of vehicles.
- Additionally, the gases such as Ammonia (NH_3), Nitrogen Oxides (NO_x), Sulfur Oxides (SO_x), may also develop the PM2.5, termed as fine secondary dust, arises from the gas-to-particle conversion activity. In many parts of the world, agriculture is also a prominent supplier of PM2.5 fine secondary dust.

To report daily air quality the AQI index is being used [33]. The AQI is measured on a scale of 0 to 500. The higher level of air pollution relates the higher AQI level; therefore, these situations imposes serious attention on wellbeing interest. To consider it more understanding, an AQI value less than 50 denotes good air quality, but an AQI score on top of 300

symbolizes unsafe breathable air condition. While the AQI score less than 100 are normally believed to be reasonable for breathing condition. When AQI score is above 100, the air quality is considered unfit for sensitive groups of individuals, then for all, as AQI values go higher. The AQI is calculated considering major pollutants - PM (Coarse: PM10, Fine: PM2.5), CO, O_3, NO_2, SO_2, NH_3, and Pb. Following are the effects and considerations of AQI levels.

Good AQI Score (0-50): Considered good.

Satisfactory AQI Score (51-100): Considered moderate and may possibly lead to minor breathing irritation to weak people having weak lungs.

Moderately polluted AQI Score (101-200): Considered poor and may cause breathing irritation to individuals with lung disorders such as asthma. Children and older adults must follow precautions in such scores [34].

Poor AQI Score (201-300): Considered unhealthy, the situation may cause discomfort to the individual with a poor heart condition and having heath disease patients.

Very Poor (301-400): Considered acute and may cause respirational sickness to individuals on continued exposure. Such a scenario will be dangerous to people with lung and heart diseases and considered a poor AQI score.

Severe (401-500): Considered hazardous and may cause respirational influence even on average healthy individuals. It could leave a terrible health impact on individuals with lung/heart disease. Such impact on health could be experienced even in the course of light physical movements.

2.1 Life expectancy in India and worldwide

- Worldwide, as per WHO, about 3.3 million people suffer premature death due to outdoor air pollution per year. Also, about 3.8 million fatalities occur due to domestic air pollution, majorly in the growing countries.
- Of these people, approximately 27-30% fatalities occur from pneumonia, 8-10% from lung cancer, 20-22% from COPD, and more than 45% from circulatory diseases.
- The life expectancy in the western countries is estimated to be reduced by 8.3 months on average due to continuous contact with PM2.5.
- The impact of air pollution on life expectancy worldwide is anticipated to be greater than double and more severe, leaving a collective effect on soil, water, and occupational pollution.
- Annually, 9 million untimely deaths are estimated owing to the air pollution (indoor and outdoor), which exceeds the numbers assessed for smoking (around 7 million) and other key infectious diseases (about 3 million).
- In India, the air pollution gives a serious well-being worry because, in the list of highly air polluted towns/cities/municipalities internationally, 21 out of 30 cities listed from India in 2019 (WHO).
- A study reported based on the data compiled in the year 2016, at least 140 million Indians breathe in the air where it is ten times or even more dangerous compared to the safety maximum set by WHO. In 2017, a study carried out by the Global Burden of Disease Study revealed that 76.8% of individuals in India are inhaling higher ambient PM over 40 $\mu g/m^3$ (considerably higher than the national and the WHO limit).
- In 2015, the Government of India and IIT Kanpur introduced the National AQI index. India aimed at 20% - 30% reduction in PM2.5 and PM10 concentrations by 2024 under the National Clean Air Programme. The base year of comparison will be 2017 to observe the reduction.
- The Global Burden of Disease (2010-2013) reported the fifth-largest killer in India is due to outdoor air pollution or smog. The air pollution-related infections took about 620,000 souls ahead of time in 2010.
- One of the highest numbers of COPD patients observed in India and China has the highest number of deaths due to COPD.

3. SOME CLEAN AIR SOLUTION TECHNOLOGY DEVELOPMENTS TO IMPROVE AIR QUALITY INDEX

- Presently, many companies produce the best quality air purifiers and are observed to clean the air effectively.
- Recently, some Clean Air Towers have been installed to provide clean air to school/colleges/universities campuses, shopping malls, housing societies, crowded sports stadiums, and other marketplaces.
- Most of the towers were designed to clean an area covering 200-300 meters distance radially and provide restful breathing to approximately 300-500 people in a populated area (considering that a person may need nearly 10000-20000 litres of clean air to breathe). The present objective in designing clean air towers is to ensure that each litre of air is free of pollutants such as PMs, NOx, SOx, CO, and O_3. Athletes may breathe more than 15,000-20,000 litres of air daily. Such breathing scenarios can cause pollutants to reach deeper regions inside their lungs.

3.1 Definitions of viruses, bacteria and allergens [35]

- **Pathogens and allergens** are the cause of severe health issues. Pathogens can spread through air ventilation inside a building.
- **Viruses** are infectious fragments that reproduce inside the cells of living hosts. Viruses measure only 0.02-0.3 μm but are distributed in larger liquid droplets or dust particles. Viruses cause diseases like influenza and Covid-19.
- **Bacteria** are living cells and typically 1-10 μm in dimension.
- **Allergens** are protein molecules which are only a few nm in dimension and come from different biological origins, such as plants or animal hair. They cause-specific and severe reactions in the human immune system like hay fever or asthma.

Figure 1 shows the comparison of sizes of different pollutants, viruses, bacteria etc.

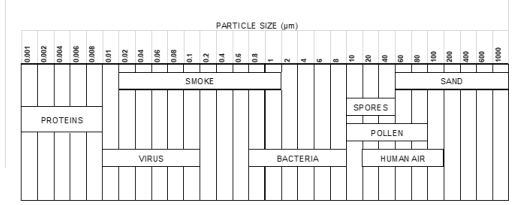

Figure 1. Sizes of viruses, bacteria and allergens

3.2 What is an air purifier?

Air pollution is a distinctive term used for the presence of physical, chemical, and biological agents that alter air's natural characteristics. An air purifier is a machine that eliminates or sterilizes the presence of the above-discussed contaminants from the indoor air or outside environment leading to an improved indoor/outdoor air quality. Air purifiers are beneficial to asthmatics and allergy sufferers and reduce or eliminate passive smoking. Air purifiers are also being used in many industries (and are subject to an open area of research) to remove impurities from the air for wellbeing concerns or before processing conditions. Initially, a patent was granted in 1830 to Charles Anthony Deane for an apparatus, which comprised a copper helmet with an accompanying flexible collar and clothing to deliver clean air. The very first HEPA filter was allegedly marketed in the year of 1963 in Germany by Manfred and Klaus Hammes.

3.3 What causes air pollution, indoor/outdoor? [36-38]?

- Air pollution is triggered by liquid and solid particles that are floating in the air and certain gases.
- These gases and particles are emitted from the waste produced by vehicular exhaust, factories, pollen, dust, mold spores, volcanoes, and wildfires.

3.4 Types of sources

There are four main types of outdoor air pollution sources [39-41]:

Portable supplies - such as vehicles, traffic and trains.

Motionless sources - Many industries**,** i.e., oil refineries, leather, distillery, power plants based on fossil fuels and many other industrial facilities.

Region-specific elements include municipalities, farming areas, and related industrial setups.

Ecological elements - such as volcanoes and wildfires, etc.

3.4.1 Basic reasons of indoor air problems

- Fuel-burning due to ignition appliances.
- Tobacco products and due to pets.
- Construction supplies and furnishings.
- Chemically manufactured goods for household cleaning, maintenance and personal care.
- Humidification devices in office and home.
- Excess of moisture, microorganism and smoke during cooking.

3.4.2 Exhaustive sources of indoor pollution

- Excess Humidity
- Personal hygiene products like hair sprays, deodorants etc.
- Kitchen Smoke
- Cigarette Smoke
- Vehicle smoke from indoor car parking
- Biological pollutants like fungus from carpet, bedsheets, etc.
- Dust mites
- Fine dust particles from outdoor pollution.
- Dust from unclean AC filters
- Allergic aerosol
- Insect sprays and repellents - Organic and VOC
- Pesticide residue
- Pet hair & pet dander
- Inhalation of contaminated air leads to Serious Health Hazards [42, 43] (Table 2).

Table 2. Short- and long-term effects

Short Term	Long Term
Headache	Damage to vital organs
Bronchitis	Cardiovascular Disease
Asthma	Respiratory Failure
Fatigue	Skin Disease
Eye Irritation	Cancer
Shortness of Breath	Birth Defects
Allergies	Impaired brain function

Researchers are expected to search for answers to the following questions till a workable solution is met (Table 3). A solution to Inhalation of contaminated air? Solutions to air pollution: how to improve air quality?

Table 3. Required and essential measures

Required or Desired	Essential or Alternate
The most important air pollution resolution is to avoid fossil fuels following a replacement with unconventional clean energy sources like solar, wind and geothermal. Clean energy is essential by adopting accountable habits and utilizing more economical devices. Green and healthy building Eco-friendly transportation	For home or office, which is predisposed to significant air pollution, an air purifier can improve air quality by removing harmful particles suspended in the air. It can also rejuvenate good living conditions by sterilising the air's microorganisms. Use Air Purifiers SMOG or Clean Air Towers Mask

4. WHY DO WE NEED AN AIR PURIFIER? AND WHAT ARE THE BENEFITS OF AN AIR PURIFIER?

- It is a myth that the worst air pollution is limited to the outdoors.
- An indoor environment also creates hazardous pollutants, which even affect more than that for an outdoor because we spend most of the time indoors.
- The heating and cooking particles in a kitchen, tobacco smoking, carbon monoxide, lead in paint and even the marker pens used by your children are the major indoor pollutants. Plus, the minute we step out of our homes, we have to deal with hazardous outdoor air.
- In recent times, it has been seen that most air purifiers can eliminate viruses and bacteria. A HEPA filter can trap viruses when used with some sterilization method, and they are surprisingly good in doing so.
- Therefore, an air purifier is a must for your home, workspace, and car.

An air purifier can provide safeguards to humans from the following [44-46].

- The air pollutants lead to poor air quality. Such a scenario leads to various disorders such as dizziness, asthma, headaches, coughing & sneezing, shortness or difficulty in breathing, fatigue, and allergies.
- Along with respiratory ailments, poor air quality can cause serious health issues for you and your family in

the long term. An air purifier is the safest way to keep you and your loved ones happy and healthy.

4.1 Future of air purification

Future of air purification must focus on treating airborne allergens and pollutants. Air purifiers are highly recommended for indoor spaces, especially in bedrooms and offices where we spend significant time during our daily routine. Also, while we sleep, our immune system rebuilds itself. Asthma is very prominent in childhood, especially in children under five years. Air purifiers are highly recommended in such cases because prolonged exposure to an allergic environment can trigger such diseases and cause severe and frequent asthma attacks. Air purification systems are proven to prevent asthma and allergies.

4.2 Technical specification to be taken care while designing air purifiers

Parameters such as AQI, PM1, PM2.5, PM10, CO, CO_2, O_3, HCHO, TVOC, Noise, Light, Temperature & Humidity should be taken care of while designing an air purifier.

- Required PM Accuracy and PM Range: 0-600 µg/m^3 +/- 10%, 150 µg/m^3 onwards +/- 15%
- CO Score range: 1-200 PPM (resolution 1 PPM)
- CO2 Score range: 0-2000 PPM (resolution 1 PPM)
- HCHO Score range: 0-2 PPM (resolution 0.001 PPM)
- TVOC Score range: 0-20 PPM (resolution 0.01 PPM)
- O3 Score range: 0-10 PPM (resolution 0.01 PPM)
- Noise Score range: Upto < 80 db
- Temperature measurements: -30℃ to 60℃ (resolution 0.1℃)
- Humidity Range: 0%-99%
- Different filtration and sterilization requirements (Table 4).

Table 4. Summary of air filtration and Sterilization techniques [9]

Filtration and Sterilization Technology	Filtration	Sterilization	Effective Particle Diameter	Efficiency	Effectiveness Against Viruses, Bacteria and VOCs	Pressure Drop
HEPA	YES	NO	> 0.3 µm	> 99.99%	No	Yes
ULPA	YES	NO	0.12-0.17 µm	> 9.999%	May Be	YES
Glass Fiber	YES	NO	2-10 µm	99.00%	No	Yes
Nano Fiber	YES	NO	< 0.3 µm	> 99.99%	Yes	Yes
Fibrous Filter Media Medium Fiber	YES	NO	> 0.3 µm	60-90%	No	Yes
HEPA, Carbon Filter	YES	NO	> 0.3 µm	> 99.99%	YES, VOCs	Yes
UV - C	NO	YES		99.99%	YES	Negligible
Negative Ionization	NO	YES	< 0.1 mm	80%-99%	Yes	Negligible
Plasma Air	NO	YES	< 0.1 mm	99%	Yes	Negligible
Bio Filter	YES	YES	< 0.1 mm	90%-99%	Yes	Yes
PCO	NO	YES		80-99%	Yes	Negligible
Electrostatic Plate	NO	YES	< 0.1 mm	80%-99%	No	Negligible
Thermodynamic Sterilization	NO	YES		99.99%	Yes	Negligible
Antimicrobial-filters	YES	YES	> 0.3 µm	80-99.99%	Yes	Yes

5. DESIGN AND FABRICATION OF TEST RIG FOR CAR AIR PURIFICATION

While designing an air purifier, one must take care of the purification capacity, power input & consumption, etc. Therefore, the basic changes should be focused on: body size, air exhaust area, body shape, air inlet area, filter size, power input slots, air blower size, ionizer size and other arrangements for sterilization of air.

5.1 Key-points while designing

- Identify the location where the purifier needs to be placed, e.g., living room, office area, car etc.
- The size of the body must be in accordance with the space available and must be optimized.
- The Filtration area must be sufficient to purify the air as per the volume that needs to be cleaned.
- The blower size compatible with the size of the body must be capable enough to provide sufficient airflow.
- The base or the standing edge must have sufficient area or support to protect the purifier from jerks while moving or installing.
- All the elements inside the body must be fastened properly.
- The power supply wire must be long enough to reach the socket available and should have a proper matching port.

5.2 Proto developments

We developed prototypes [P1, P2, P3 and P4, listed in Figure 2-6] based on different designs.

- The blower is well suited to our shape and size and has different outer diameters.
- The filter media used for the purifier was HEPA in the combination of the prefilter and activated carbon.
- For Proto 1 (P1), the number of pleats was 23, the height of the filter was 58 mm, and the pleat depth was 14 mm; thus, the total filtration area was 0.037 m².

- The material used for the prototype outer body was Stainless steel and plastic.
- The power input was provided by a DC pin with the supply of 12 V and 2.5 AMP.
- The filter was side sealed using a carton of 3 layers using adhesive.
- The inlet air area in the first prototype was 0.042 m², the outlet area was 0.0038 m².

Figure 2. First prototype (P1)

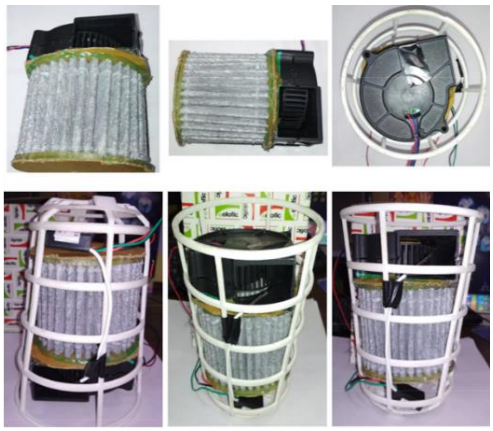

Figure 3. Second prototype (P2)

Figure 4. Third prototype (P3)

Figure 5. Fourth prototype (P4)

Figure 6. Final proto and filter elements

5.3 Final design

A filtration efficiency test was carried out on the media used, using the test conditions of 100 cm^2, face velocity of 5.3 cm/sec, dust mass concentration of 200 mg/m^3, and the total volume flow rate was 32 litres/min.

We have observed a 99.424% retention rate for particle size ranges between 0.198 to 40.706 µm. Therefore, the filter media used to have the capability to filter PM 2.5 with an efficiency of 99.99% and can effectively be used for indoor air purification (Figure 7).

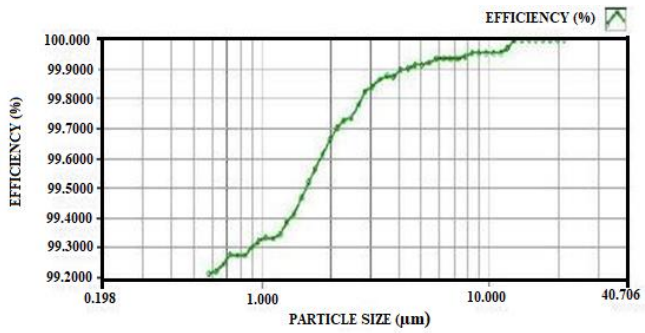

Figure 7. Filteration efficiency vs particle size

5.4 Testing of prototypes developed for car/vehicle purification

- For testing, a car cabin was used.
- The Temperature range was between 20º to 30°C.
- The airflow rate was kept constant.
- The Particulate Matter level was raised artificially.
- The PM 2.5 value was monitored with the help of a digital meter.
- The value of PM 2.5 was raised up to 900 particles per cubic feet of volume.
- The time period was kept being 30 minutes.
- The supply provided to the purifiers was 12 V and 5 AMP.
- Various products were tested in the same condition.

6. RESULTS AND DISCUSSION

From the test results (Table 5), it can be seen that the different prototypes have different readings. Therefore, it can be concluded that the different design with additional filtration and sterilization medium gives different results. The filtration area, sealability, filter medium, sterilization techniques and orientation play a key role. Thus, it is concluded that the CADR, noise level, different filtration setup and sterilization strategies must be focused on while purchasing an air purifier. Different target cleaning areas, e.g., hospitals, malls, shops, tool room, living rooms, offices and sports stadiums, needs a new design with further sterilization and filtration setups. Our next target is to design purification devices for industrial, outdoor and specific medical use. The present study is carried out using different methods to test the functionality of prototypes. Researchers or users should assess their particular application and environmental conditions when conducting research or using it directly. Transmission of pathogens, including viruses can be prevented using safety precautions. One can not solely rely on the products alone to prevent its spread. Treatment of cabin air pollution, including PM, viruses, bacteria and VOCs, is very important, and such products may extensively be used in buses, trucks, cars, railways and aircraft, etc. Using a proper design (as per clean air requirement) by incorporating different filtration and sterilization techniques such as UV-C, plasma air, thermodynamic sterilization etc., one can treat PM, viruses (COVID-19), bacteria and most important VOCs in vehicles. The present outcome also recommends that using such technologies in vehicle cabins, where public transport is concerned, will be very effective. Following are the future proposed design and some of the currently developed filter elements by the current R&D team (Figure 8-10).

Figure 8. Future proposed design

Figure 9. Carbon-impregnated media polyurethane sealed

Figure 10. New cabin media polyurethane sealed

Table 5. Car air purifiers test results for PM 2.5

S.No.	Proto Name	Filter Media	PM 2.5 Level#	
			Initial	Final
1	First Proto (P1)	HEPA in the combination of the prefilter and activated carbon	900	590
2	Second Proto (P2)	HEPA in the combination of the prefilter and activated carbon	900	500
3	Third Proto (P3)	HEPA in the combination of the prefilter and activated carbon	900	220
4	Fourth Proto (P4)	HEPA in the combination of the prefilter and activated carbon	900	190
5	Final Proto	HEPA in the combination of the prefilter, activated carbon and Ionizer	900	40

7. CONCLUSIONS

A substantial threat to human health is related to air pollution and affects life expectancy. Experiencing air pollution by humans in the form of particulate matter (PM), harmful gases and airborne viruses and bacteria give birth to many life-threatening diseases. Air pollution prevention is highly needed and must be avoided either through a

sustainable solution or using air purification technologies. Using an air purifier with different filtration and sterilization techniques can rejuvenate you through clean air. Therefore, it can prevent you from some life-threatening diseases.

Further, It can also be concluded from our design and tests that setups using different filtration and sterilization techniques can be used for better and optimum results. Different sterilization techniques can be used in combination with filtration techniques to achieve different filtration needs, such as treatment of PM, viruses and bacteria, etc. Some appropriate combination of mechanical purification and sterilization-based purifiers must be used in vehicle cabins, especially where public transport is concerned. Further, the need of the hour suggests that the future of purifications must be focused on specific medical use and outdoor air purification. Therefore, it is an open area of research to produce air purification technologies for different medical use and treatments.

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