Study On The Air Filtration Efficiency Of Fabricated Polyester And Nylon Nanofiber Membranes

Shailesh Anand B. Goswami

Lecturer, Textile Designing Department
Government Polytechnic for Girls, Surat , Gujarat , India.
Affiliated to Gujarat Technological University, Ahmedabad, Gujarat, India.

KEYWORDS

Electrospun
NanoFibers
Polyester
Nylon
Spunbond
Meltblown
NonWoven Fabric

Abstract: Value addition in textiles enhances properties and functionality, making them vital in diverse industries like filtration, medical, and transportation. Nanofibers, with diameters below 1 micron, are key to advanced filtration due to their high surface area, flexibility, and cost-efficiency. This study explores electrospun polyester and nylon nanofibrous membranes for air filtration. Polyester and nylon were chosen for their availability, mechanical strength, chemical resistance, and affordability. Using PP spunbond and meltblown nonwoven fabrics as base layers, various membrane combinations were developed and tested under controlled conditions. Filtration performance was assessed for air (PM 2.5, 1.0, and 10, HCHO, TVOC) The results demonstrated significant improvements in both air quality, showcasing the effectiveness of electrospun nanofiber membranes for filtration applications

Introduction

The main aim of the presented research work was to manufacture and evaluate the use of polyester and nylon nanofiber web for Air filtration. Different combinations of polyester and nylon nanofibers web were checked for improving air quality. The entire work done for this research is original. A customized instrument was designed for the testing of samples. The developed System is very cost-effective and can also be commercialized. It has a big potential to become a cost-effective system in indoor air quality and hospital operation theatre.

The advantages of nanofibers are increased surface area and new mechanical characteristics of nanoscale materials. There is a substantial improvement in the material's mechanical characteristics as the diameter of the fibers decreases. Similarly, nanofibers have a much larger surface area than fibers of a micron or higher size. All different applications are significantly affected by these elements. There are many different types of applications that are involved in nanofiber research. Improved filtration, enhanced moisture management, enhanced thermal properties, enhanced static charge management, enhanced tensile strength, enhanced breathability, enhanced application in smart textiles with reduced weight ratio, and enhanced protection against nanoparticles are among the more prominent applications[1].

Nanotechnology offers promising solutions in the field of air filtration, particularly through ENMs, which enhance air filtration by improving flux rates, reducing energy consumption, and enabling more effective removal of contaminants. This paper reviews recent developments in ENMs for air filtration and discusses their advantages over traditional methods of air filtration.

Nanofibers

The word "nano" is used to denote a fibrous form with a diameter of less than one micron, or 1,000 nanometers. When one starts to work at the molecular level, the physics behind it dramatically changes. Gravity, becomes remarkably less significant but the Vander-Waals forces, which were very less significant earlier, become very prominent. The capacity to control the fundamental laws of physics and the important features and characteristics of materials has been tremendously useful throughout history.

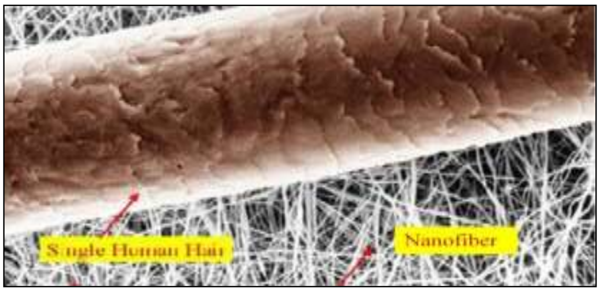


Fig 1 Nano Fiber as Compared to Human Hair [3]

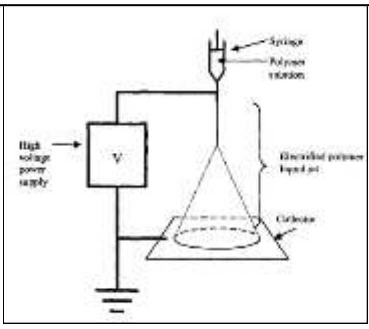


Fig 2 Basic Electrospinning[2]

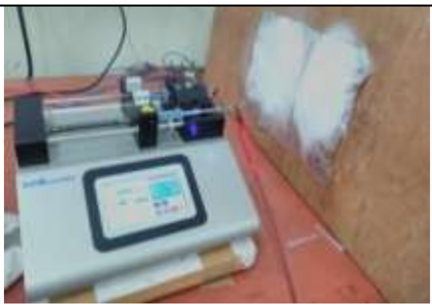


Fig 3 Manufacturing of Nylon-6 & Polyester Nanofiber

Filtration

One of the most apparent applications of nanofibers is in filters. A good filter will have a high flow rate and be able to capture and hold onto the tiniest particles without clogging. When using nanofibers, the enhanced interception, inertial impaction efficiency, and slip flow at the fiber surface lead to superior performance with a constant pressure drop. Many of the world's leading filtration businesses are already using nano fibers in theirAir filtration plant at industrial level as well as in domestic level.

The Technical University of Liberec issued a patent for the needleless electrospinning method in 2003. Industrial use of this technology inspired many researchers. They never thought that needleless electrospinning method could handle such a large output. It was not until 2004 that Elmarco Company helped try to commercialize the technology for making nanofibers.

Using a rotating roller, which was partially submerged in a polymeric solution, Jirsak devised a needleless electrospinning setup. The roller rotation caused the polymeric solution to come on the body of the roller. An enormous number of solution jets were produced from the roller surface upwards when a high voltage was given to the roller & collector. Elmarco Co. has marketed this configuration under the "NanospiderTM" brand name. As it spins, the spinneret covers its surface with a thin film of polymer solution. As a result of the rotation and disturbance, conical spikes cover the surface. Applying a high voltage causes the spikes to attract charges, which in turn increases the perturbance and causes the fluid to spin around them. This leads to the formation of Taylor cones. The edges of the roller launch of thin electro spinning jets, when the electric force is strong enough. Niu et al [4] have demonstrated this process Figure 2.29 depicts a conceptual diagram.

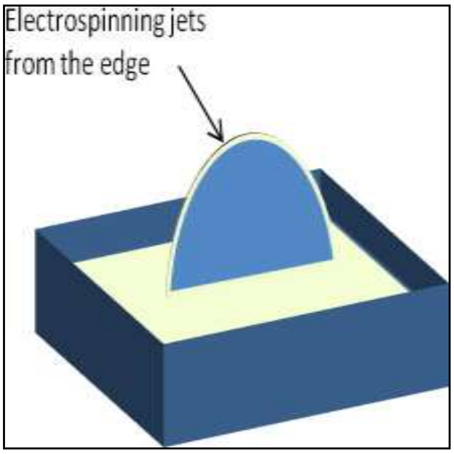


Fig 2.29 Needleless Electrospinning (Nanospider^{TM}) [4]

Nanofiltration

The primary application of nanofibers is the manufacturing of very efficient filters. The efficiency of the nanofibers relies on their ability to capture and retain the tiniest particles without obstructing the filter flow rate. According to filtration theory, the predominant mechanism in traditional HEPA filters is non-slip flow. Because the nanofibrous layer's smaller fiber size may disrupt the airflow, the slip flow mechanism becomes dominant when coated on the traditional filter. The standard filter medium performs depth filtration, whereas the nanofiber-coated conventional filter surfaces load dust particles. According to Sundararajan et al. [5], nanofibers aid in slip flow due to their superior inertial impaction and interference efficiency.

Enhanced performance at a fixed pressure drop is achieved when molecules pass through nanofibers without contacting their surfaces [6]. Therefore, compared to traditional filters made of knitted or woven fabric, filters made employing nanofibers in conjunction with nonwoven fabric have significant advantages. The filtering properties of these nanofiber filters are exceptional. Commercial air filters utilize nanofibers for the industrial and consumer sectors requirement.

A better understanding of how nanofibers compare to more conventional nonwoven filters in terms of filtering efficiency is the driving force behind this research. The pros and cons of nanotechnology concerning conventional nonwoven filters are also covered. There are many air contaminants and how they affect humans and the environment is also discussed. This study explores how to improve air quality using current equipment by measuring particle matter and volatile organic compounds. A low-cost air filter to meet the need for clean Air in hospitals and protective gear was the goal of this study's nanofiber production challenge. Similarly, inexpensive air filtration devices were developed to meet the fundamental filtering needs of those who could not afford more expensive alternatives.

Sudden death or adverse cardiovascular conditions, such as frequent visits to the emergency room or hospital for heart attacks and strokes, may result due to both long-term and short-term exposure to pollutants in the Air. Respiratory issues are another symptom of chronic exposure to these tiny particles. For example, asthma attack are associated with a host of respiratory symptoms, including wheezing, coughing, and shortness of breath, and they may even stunt a child's lung growth. Short exposures to thoracic particles may cause lung and heart diseases, which can cause premature mortality EPA2014)[7]

Because of its effective Brownian diffusion and intervention system, nanofibers can pick up any minute airborne nanoparticles. If the air stream temperature is increased and the fiber diameter is decreased, in that case, the filtration size of the Effective Neutralising Materials for nanoparticles may be improved, according to research on polymers by Maze et al. [8]. Wang et al. [9] investigated the efficacy of nanofiber filters in replacing conventional fiberglass filters for nanoparticle filtering. According to research, nanofiber filters outperformed their traditional fiberglass counterparts in particles bigger than 100 nm.

Literature Review

Facini et al. [10] identified nylon nanofibers as effective for nanoparticle filtration in defensive clothing, achieving over 50% retention of 200 nm particles and 80% retention of 20 nm particles.

Desai et al. [11] studied enhanced nanoparticle filtration efficiency to 99%. Scholten et al.[12] demonstrated that electrospun polyurethane fibers effectively absorbed and desorbed volatile organic compounds (VOCs), offering easy regeneration under ambient conditions. "Zhang et al [13] studied improved filtration performance by using multiple thin layers of PAN nanofiber mats." Podgorski et al. [14] developed polypropylene nanofibrous filters using melt-blown technology, achieving high filtration efficiency for aerosol particles with a moderate pressure drop. Graham et al. [15] studied the benefits of nanofibers in composite filter media, particularly for cellulose-based filters. Vitchuli et al. [16] achieved over 99.5% barrier efficiency against submicron-level threats using electrospun nylon six nanofibers on nylon/cotton fabric while maintaining air permeability. Ramakrishnan et al. [17] developed functionalized PVC nanofibers with β-cyclodextrin and IBA for the decontamination of nerve agents, making them suitable for lightweight protective clothing. Zhang et al. [18] developed PAN nanofibrous membranes with amidoxime groups and silver nanoparticles, demonstrating dual antimicrobial and filtration properties. Sundarrajan et al. [19] explored the use of ENMs for VOC removal, filtration, protective clothing, and antimicrobial applications. “Leung et al. [20] studied the effect of face velocity, packing density, and thickness on the filtration efficiency and pressure drop of nanofiber-coated filters”. Wang et al. [21] compared nanofiber filters with conventional fiberglass filters, showing superior performance for particles larger than 100 nm.

Summary

ENMs offer significant advancements in filtration, antimicrobial activity, protective clothing, and environmental decontamination. Contributions from various researchers demonstrate their versatility and effectiveness.

Research Gap and Motivation

By studying the above summary of the literature review, there was a need to check the filtration efficiency of Air by fabricating the composite membrane, having different nanofiber layers, especially commercially available polymer chips, i.e., polyester and nylon fiber. Different blends of both nanofibers were also required to check them for filtration efficiency. Nanofiber deposition on different types of nonwoven fabric has also been given weightage infiltration. There was a requirement to study the filtration efficiency of polyester and nylon nanofibers with a polypropylene nonwoven fabric base made by spun bond and melt-blown technology. A comparative study of those blends of nanofiber webs was also required to know the change in filtration efficiency. This motivated me to do work in this area. After lots of brainstorming, it was decided to go on this topic, and a work plan was made for this project. Still, there is big scope that can take this research into a new avenue

The research work reported in this thesis was to explore different products and applications, which are as follows:-

- To produce polyester nanofiber
- To produce nylon nanofiber
- To check air quality after passing polluted Air through polyester nanofibers membrane on nonwoven fabric
- To check air quality after passing polluted Air through nylon nanofibers membrane on nonwoven fabric
- To find the best combination of polyester and nylon nanofiber membranes for air and water filtration.
- To design and develop value-added low-cost applications using the nanofibers webs developed during this research work

Mechanism of air filtration

Air Filtration mechanism: - In filtration, the main purpose is to remove the unwanted particulate matter from the surrounding atmosphere. The most predominant mechanisms contributing to particle collection are interception, inertial impaction, and diffusion.A thin layer of semi-permeable material separates substances when a driving force is applied across the membrane.

When a particle in the airflow around a fiber comes within a radius of one particle from the fiber, this is called interception. The greater the particle's radius, the more efficiently it may be captured via interception compared to smaller particles.

A particle experiences inertial impaction when it moves towards and collides with the fiber instead of bending to follow the streamlines around it. The effectiveness of impaction collection grows as the square of the particle diameter increases.

The uneven jittering of an airborne particle generated by continual bombardment by air molecules is known as Brownian motion, and it is this motion that causes particles to collect by diffusion. As a particle passes through the Air around a fiber, this jittering may sometimes impact it. Diffusion captures more particles as their sizes drop because Brownian motion becomes more significant as particle diameters decrease.

An air purifier is a device that removes airborne allergens and microorganisms by capturing them in an air filter. The most common air purifier uses a network of blowers and filters to remove airborne particles.

Planning of the different samples (Membrane)

We had three variables for checking filtration efficiency

1. Number of layer to form membrane,(i.e – Two / Three / Four / Five / Six / Seven)
2. Type of nanofiber web (i.e. Nylon / Polyester)
3. Base: The type of nonwoven fabric used to collect the nanofiber web (i.e., PP spun Bond/ PP Melt Blown).

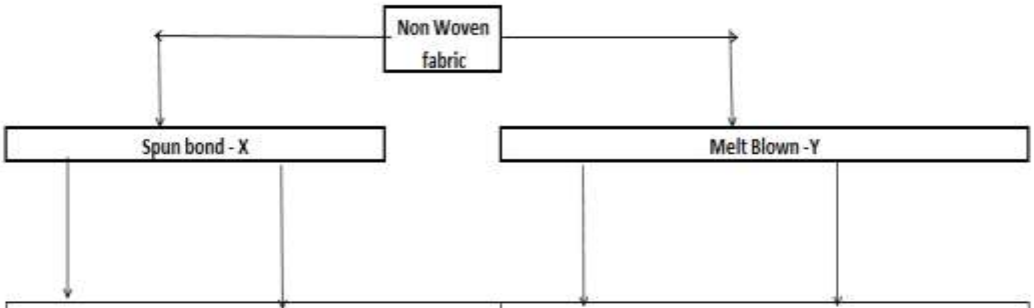
Sample preparation was quite costly, so we selected the Box—Behnken design because it offers few testing numbers. To take advantage of making fewer samples, we preferred to go with the Box—Behnken design over the CCC and CCI designs.

Due to the cost, the number of samples planned was limited, and one sample was used a maximum of 2-3 times for any type of testing due to the destructive nature of the test.

Proposed System

Thus, a cost and quality-effective device has been intended to be developed during this research work. The proposed work decided that the first nanofiber of polyester and nylon fiber should be made. After that, a fabricated membrane was made with the help of different samples in different proportions so that we could check them for air filtration efficiency. To stop the slippage of layers while preparing the membrane, a nonwoven fabric with a nanofiber layer was bonded with the help of a heat-sealing machine. The sealing was not done in the center part as heat sealing could melt the nanofiber and the supporting base nonwoven fabric, which might be inherent in its properties and our purpose.

Proposed System for making fabricated membrane for Air Filtration Efficiency



Polyester nanofiber web -A		Nylon nanofiber web -B	
Sample No	Fabrication of membrane	No of Layers	Proportion of Nano Fiber (Polyester + Nylon)
1	X	1	-Nil-
2	X + A*X + X	3	100 % Polyester
3	X + B*X + X	3	100 % Nylon
4	X + A*X + B*X +X	4	50 % Nylon + 50 % Polyester
5	X + A*Y + X	3	100 % Polyester
6	X + B*Y + X	3	100 % Nylon
7	X + 2(A*Y) + B*Y + X	5	70 % Polyester + 30 % Nylon
8	X + 2(B*X) + A*X +X	5	70 % Nylon + 30 % Polyester
9	X + 2(A*X) +2(B*X) + X	6	50 % Polyester + 50 % Nylon
10	X + B*Y + B*X + X + A*Y + A*X + X	7	50 % Polyester + 50 % Nylon

Fig: 3.1 the arrangement of polyester and nylon nanofiber webs is taken on two types of nonwoven fabric to fabricate Filtr filtration membranes.

Development of Polyester and Nylon Nano Fiber

Initially, a study was carried out on nanofibers and the technologies behind producing them. Based on an in-depth literature review, we were able to develop our own distinguished and conceptual thoughts.

By studying all these things, it was decided to make Polyester and Nylon-6 Nanofiberweb. The production of nanofiber and its properties are highly dependent on many external factors. After searching a lot, finally, The Ahmedabad Textile Industry's Research Association (ATIRA), Ahmedabad, Gujarat was contacted to make the sample. ATIRA had a pilot plant for needleless electrospinning. So, all nanofiber webs were made over there and brought into the shape of samples that could be tested in different combinations for various properties.

Testing Procedure to check the Nanofiber diameter and Atomic Structure

The nanofibre diameters depend on the types of polymer used and the manufacturing method. All polymer nanofibers are remarkable in their large surface area-to-volume ratio, high porosity, considerable mechanical strength, and functionalization stability**.** Any fiber having a diameter size smaller than 1 µm can be considered as Nanofibers

Scanning electron microscope images

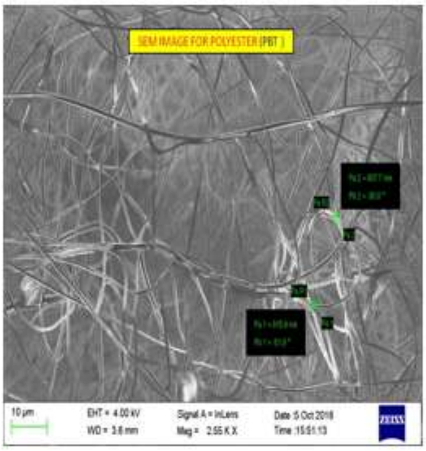


Fig 3.3 SEM Image PET Nanofiber

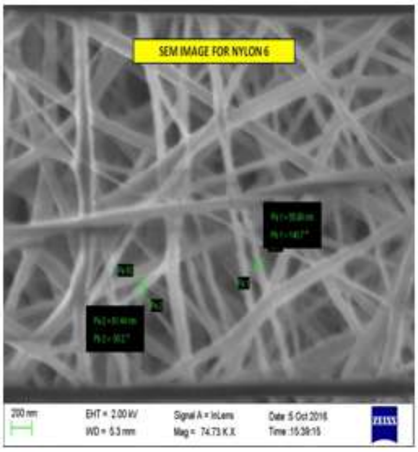


Fig 3.4 SEM Image Nylon6 Nanofiber

Both pictures show that the manufactured nanofibers' diameter is more than 10^{-6} meters. The picture concludes that the fiber web produced is in nanofiber categories.

Fourier Transform Infrared Spectroscopy

Unknown materials (such as films, solids, powders, or liquids) may be identified and characterized using Fourier transform infrared (FTIR) analysis. This test verifies that polyester and nylon nanofibers have the same atomic structure as their original fiber counterparts.

Following are the results of FTIR for Polyester and Nylon fibers:-

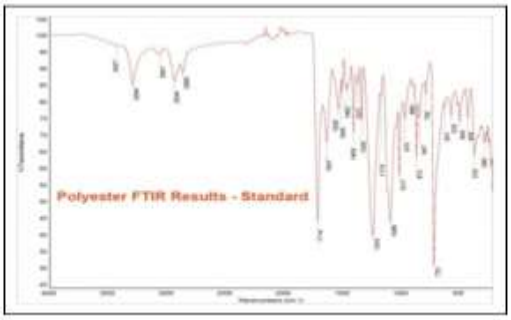


Fig 3.5 Standard FTIR Image PET fiber

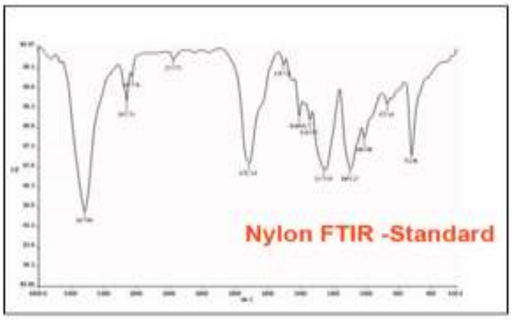


Fig 3.6 Standard Nylon-6 Image fiber

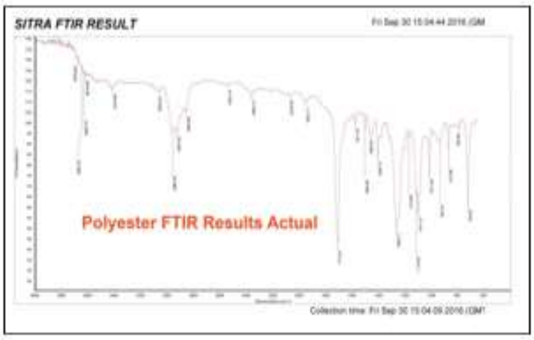


Fig 3.7 Actual FTIR Image PET Nanofiber

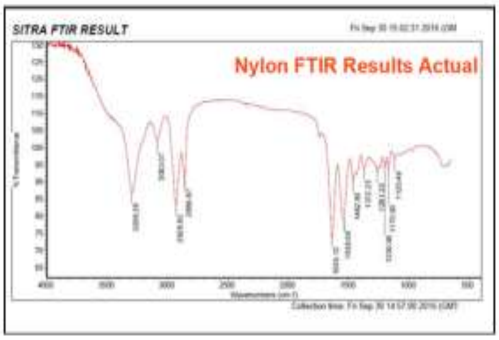


Fig 3.8 Actual FTIR Image Nylon-6 Nanofiber

From all of the images, manufactured nanofibers have almost the same atomic structure what polyester and nylon fiber is having. This means that while making polyester and nylon nanofibers, , their properties remain intact.

Testing Procedure for checking Air filtration efficiency by Air Quality Detector

Particle Size Distribution Measurement by the Laser Diffraction/Scattering Method

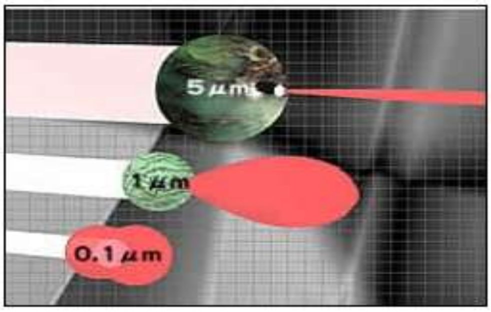


Fig 3.9 Laser light falling on different size of particle [92]

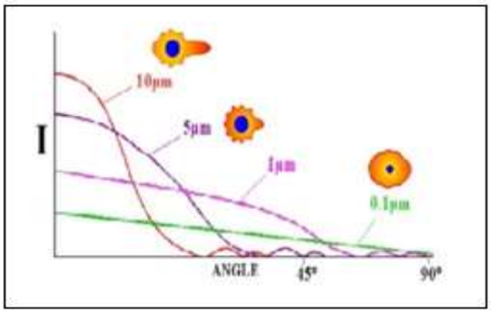


Fig 3.10 Scattering Pattern of Laser Light on angle dependence [93]

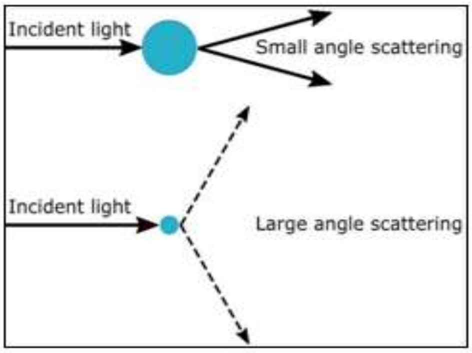


Fig 3.11 Principal of Light scattering on different size particle [94]

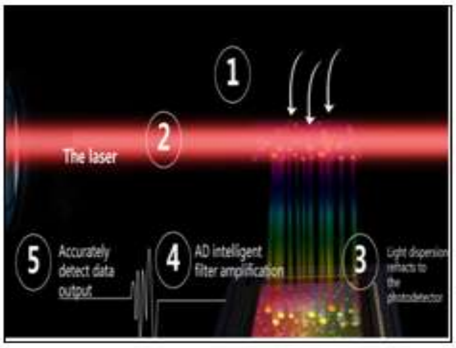


Fig 3.12 Steps showing, how particles are measured in the air. [95]

Standards for the Measurement of Airborne Particle Size (ASTM D4464-15). This approach involves irradiating a sample of particles with a laser and then analyzing the resulting pattern of diffracted and scattered light to ascertain the sample's size distribution. When a laser beam is focused on a particle, it causes the particle to release light in all directions (forward, backward, up, and down). We term "diffracted/scattered light" this kind of light. A distinct spatial pattern is generated for the intensity of diffracted or scattered light in the direction of the light's emission. A "light intensity distribution pattern" describes this. This light intensity distribution pattern is known to change form depending on the size of the particles. In this case, the forward direction (the direction of motion of the laser beam) is where the diffracted or scattered light from the particles concentrates. The light scattered or diffracted in several directions is much dimmer than light traveling straight ahead. As the size of the particles is measured, the forward direction of the diffracted or scattered light becomes more apparent. The light intensity that is diffracted or scattered from particles that are one µm in size is distributed in this pattern.

As the size of the particles decreases, the pattern of the diffracted or scattered light shifts somewhat to the periphery, away from the forward direction, following the path of the laser beam. The light intensity of diffracted or scattered light emitted by particles on a scale of 0.1 µm is distributed in this manner. As the size of the particles decreases, the strength of the light reflected from the sides (against the direction of the laser beams journey) and back (up and down) increases. A "cocoon" or "gourd" shape describes the light pattern as it extends in every direction.

In the actual measurement of particle size distribution, the target was not a single particle but a community of particles. The light intensity distribution pattern released by a particle group, composed of several particles of varying sizes, results from the diffracted or scattered light by each particle.

By observing and analyzing this light intensity distribution pattern, we may determine the particle size distribution or the relative abundance of different particle sizes. The aforementioned is the basic reasoning for calculating particle size distributions using the laser diffraction/dispersion method. Ultimately, the key idea was that changes in the pattern corresponding to particle size, rather than light intensity, were used to determine particle size.

The technique for counting particulate particles is shown in Figures 3.9 to 3.12. Laser beams illuminate particles of varying sizes. Only particles that exist or are suspended in the Air are considered in the calculations. The pattern of laser light scattering as it hits particles of varying sizes. Light is scattered at a lesser angle by larger particles and a larger angle by smaller ones. Particles enter the path of the laser beam, which is then dispersed at various angles before falling on the photodetector. Data is shown on the screen once the processor converts the signal from analog to digital (AD) from the photodetector.

Phatic laser light scattering may determine particle sizes are as small as a few millimeters or as large as tens of nanometres. Laser light scattering allows one to measure the size of particles by analyzing their angular intensity distribution. The "Fraunhofer theory" for relatively big particles and the "Mie theory" for both big and tiny particles are the physical theories that back up this computation.

When the diameter of a particle is less than the wavelength of the laser light that is used to illuminate it, we say that the particle is tiny. The typical range of wavelengths used by Laser Particle Sizers is 500 to 700 nm. The area of 0.5-1 μm is where the Fraunhofer and Mie limit transition. Just to be clear, the Mie and Fraunhofer limitations might be affected by factors other than particle size, such as sample material and application.

Measurement of Formaldehyde in Air

Continuous Measurement of Formaldehyde in Air: Standard Test Method (EPA-METHOD-8520)

Electrochemical sensors use the concept of galvanic cell reactions to detect formaldehyde. This method's output signal is quite linear concerning the concentration of formaldehyde. Cooperating with multi-layer filtering technology, it has a higher anti-interference ability to non-formaldehyde molecules and a more precise capacity to catch formaldehyde molecules. An electrolyte-soluble metal anode and an electrolyte-insoluble metal cathode are submerged in the electrolyte according to the measuring principle. Electrons are transferred to the cathode from the anode when it dissolves. When electrons are released from the anode, the oxygen penetrating the thin membrane layer in the cathode takes them in. You may use a meter to detect the oxygen concentration permeating the membrane layer, and this electron's flow (current) is directly proportional to that concentration. This kind of sensor does not need any power source since the response happens independently.

When detected, a gas interacts with certain places on the sensor's surface physically or chemically. On occasion, the alterations are more profound, impacting the sensing material's electrical structure and the bulk phase. When gas molecules react with certain spots on a sensing surface, they often cause a significant disruption to the solid's electronic structure, which may then be translated into electrical qualities that can be measured.

The receptor is the layer of detecting material that directly touches the gas. Changes in electrical charge, polarisability, electrical potential, mass (as measured by the resonant frequency), and optical characteristics are among the observable changes brought about by the gas-receptor interaction.

3.9.3 The Standard Test Method for Determination of Gaseous Organic Compounds (ASTM D6420-18) is used to measure volatile organic compounds (VOCs) in Air.

In most cases, MOS sensors are used to monitor TVOC continuously. Not all MOS sensors are created equal, and sensors within this category offer readings of varied quality. However, we will get into the same technology employed below. Heating a surface layer of metal oxide particles causes MOS (metal oxide semiconductors) to conduct electricity. Kaiterra's products use a very thin layer of metal-oxide nanoparticles. The warm-up time after turning on a Kaiterra device is due to the film being heated to roughly 300'C.

As the process progresses, the surface will adsorb oxygen molecules, reacting with the gas of interest. This process changes the electrical resistance of the metal-oxide layer by releasing electrons from the surface oxygen. Specifically, the sensor is trying to measure the electrical resistance of this metal oxide layer. To get our TVOC reading, we need to take this resistance reading in real-time and output it.

As the concentration of the target gases changes, so does the resistance across the sensor's surface. The specific amount to which the resistance will change—a ratio indicating a relationship—may vary depending on the specific gas in the environment. A good example of a related but not identical interaction is that between formaldehyde and ethanol. Instead of being sensitive to only one kind of volatile organic compound, the sensor will pick up on a broad range of them.

Fig 3.13 Air Quality Detector Front View

Fig 3.14 Air Quality Detector LHS View

Fig 3.15 Air Quality Detector RHS View

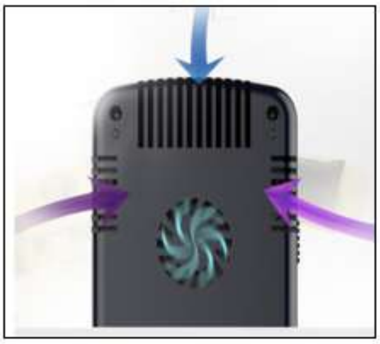


Fig 3.16 Air Quality Detector Back View [96]

Fig 3.17 Air Quality Detector inside View [96]

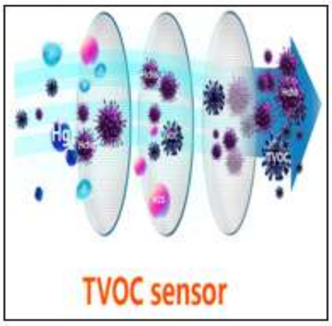


Fig 3.18 Air Quality Detector TVOC sensor [96]

Fig 3.42 Solution Making

Fig 3.43 Solvent (TFA)

Fig 3.44 Solution Box Housing

Fig 3.45 Needle less wired roller for continuous production

Fig 3.46 Fixing the fabric on Take up Roller

Fig 3.47 Let off Roller of Elmarco Pilot Plant

Details and photos of fabrication of different membrane

Fig 3.48 Sample Preparation

Fig 3.49 Controlled Environment

Fig 3.50 Sample: 01

Fig 3.51 Sample : 02

Fig 3.52 Sample: 03

Fig 3.53 Sample: 04

Fig 3.54 Sample: 05

Fig 3.55 Sample: 06

Fig 3.56 Sample: 07

Fig 3.57 Sample: 08

Fig - 3.58 Sample: 09

Fig: - 3.59 Sample: 10

Figure number 3.51 shows a composite membrane, which was made of three layers of nonwoven fabric. In this composite membrane, the first layer was made of polypropylene spun bond fabric, the second layer had polyester nanofiber web on polypropylene spun bond nonwoven fabric, and the third layer had the same structure as the first.

Figure number 3.52 shows the composite membrane structure, which has three layers. The first layer was made of polypropylene spun bond nonwoven fabric, the inner layer was made of nylon nanofiber web on polypropylene spun bond nonwoven fabric, and the outermost layer was the same as the first. In short, this fabricated membrane is a 100% nylon nanofiber web.

Figure number 3.53 shows the composite membrane having four layers in it. The first layer was made of polypropylene spunbond nonwoven fabric. The second layer contained a polyester nanofiber web on polypropylene spun-bond fabric. The third layer had a nylon nanofiber web on polypropylene spunbond nonwoven fabric; the outermost layer was the same as the first. In short, this fabricated membrane had 50-50 % polyester and nylon nanofiber web.

Figure 3.54 shows sample number 5, a composite membrane made of three layers. The composite membrane had the same structure as sample number 2. Instead of polypropylene spun bond nonwoven fabric, melt-blown polypropylene nonwoven fabric was used in the middle layer. The polyester nanofiber web accumulated on the middle layer of the PP melt-blown nonwoven fabric. In short, this membrane is a polyester nanofiber web on PP meltblomelt blown fabric.

Figure number 3.55 shows the sample number 6. In this sample, the composite membrane was made of three layers and had the same structure as sample number 5. Instead of polyester nanofiber web, nylon nanofiber web was accumulated on polypropylene melt-blown nonwoven fabric in the middle layer. In short, this membrane had 100% nylon nanofiber web on PP melt-blown nonwoven fabric.

Figure number 3.56 shows the sample number 7. This membrane was fabricated by clubbing five layers of nonwoven fabric. The first layer was made of polypropylene nonwoven spun-bond fabric. The second and third layers had the same structure and were made by collecting the polyester nanofiber wave on PP melt-blown nonwoven fabric. The fourth layer was my collection of nylon nanofiber webs from polypropylene melt-blown nonwoven fabric. The last layer had the same structure as the first layer. In short, this fabricated membrane will have 70 % polyester nanofiber web and 30 % nylon nanofiber web on melt-blown nonwoven fabric.

Figure 3.57 shows sample number 8, a composite membrane made of 5 layers. It had the same configuration as sample number 7. The only change was that nylon nanofiber wave was used instead of polyester nanofiber web. The first layer was comprised of polypropylene spunbond nonwoven fabric. The second and third layers comprised a nylon nanofiber web on polypropylene spunbond nonwoven fabric. The fourth layer consisted of a polyester nanofiber web on polypropylene spun-bond fabric, and the outermost layer was the same as the first layer. In short, this fabricated membrane had 70 % nylon nanofiber and 30 % polyester nanofibers.

Figure number 3.58 shows the sample number 9. This sample was a composite membrane with six layers in it. The first layer was the polypropylene spunbond nonwoven fabric. The second and third players comprise polyester nanofiber on polypropylene spunbond nonwoven fabric. The fourth and fifth layers consisted of nylon nanofiber on polypropylene spun bond nonwoven fabric, and the last layer had the same structure as the first. In short, this fabricated membrane has six layers containing 50% polyester and 50% nylon nanofiber. The only difference that came was that the thickness of the membrane increased.

Figure 3.59 shows the details of sample number 10. This sample was made by combining seven layers of nonwoven fabric. In this fabricated membrane, the first layer is polypropylene spunbond nonwoven fabric. The second layer comprised a nylon nanofiber web on polypropylene nonwoven melt-blown fabric. The third layer comprises a Nylon nanofiber web on polypropylene nonwoven spun-bond fabric. The fourth layer was the same as the first layer. The fifth layer comprises a polyester nanofiber web on polypropylene melt-blown nonwoven fabric. The sixth layer comprised the polyester nanofiber web on polypropylene spunbond nonwoven fabric. The last and outermost layers had the same structure as the first layer. In brief, this membrane has seven layers and consists of 50% polyester nanofiber and 50% nylon nanofiber.

Fig 3.60 Weight of Spunbond Fabric

Fig 3.61 Weight of Melt blown Fabric

Figures 3.60 and 3.61 show the picture taken to check the GSM of spun bond and melt-blown fabric. So, to find the weight of both spunbond and melt-blown fabric, they were cut into 1-meter lengths and 1-meter widths. The weight was measured on a weighing balance. The reading confirmed that spun-bond fabric and melt-blown fabric had a GSM of 30 and 15, respectively. The weight of the fabric was used to study the effect of GSM of the nonwoven fabric on filtration efficiency.

Nanofiber web thickness is expressed as grams per square meter or coating percentage. In our case, the basis weight was the nanofiber web coating between 0.3 and 0.4 grams per square meter.

Instrument Developed for Testing the Air Filtration efficiency

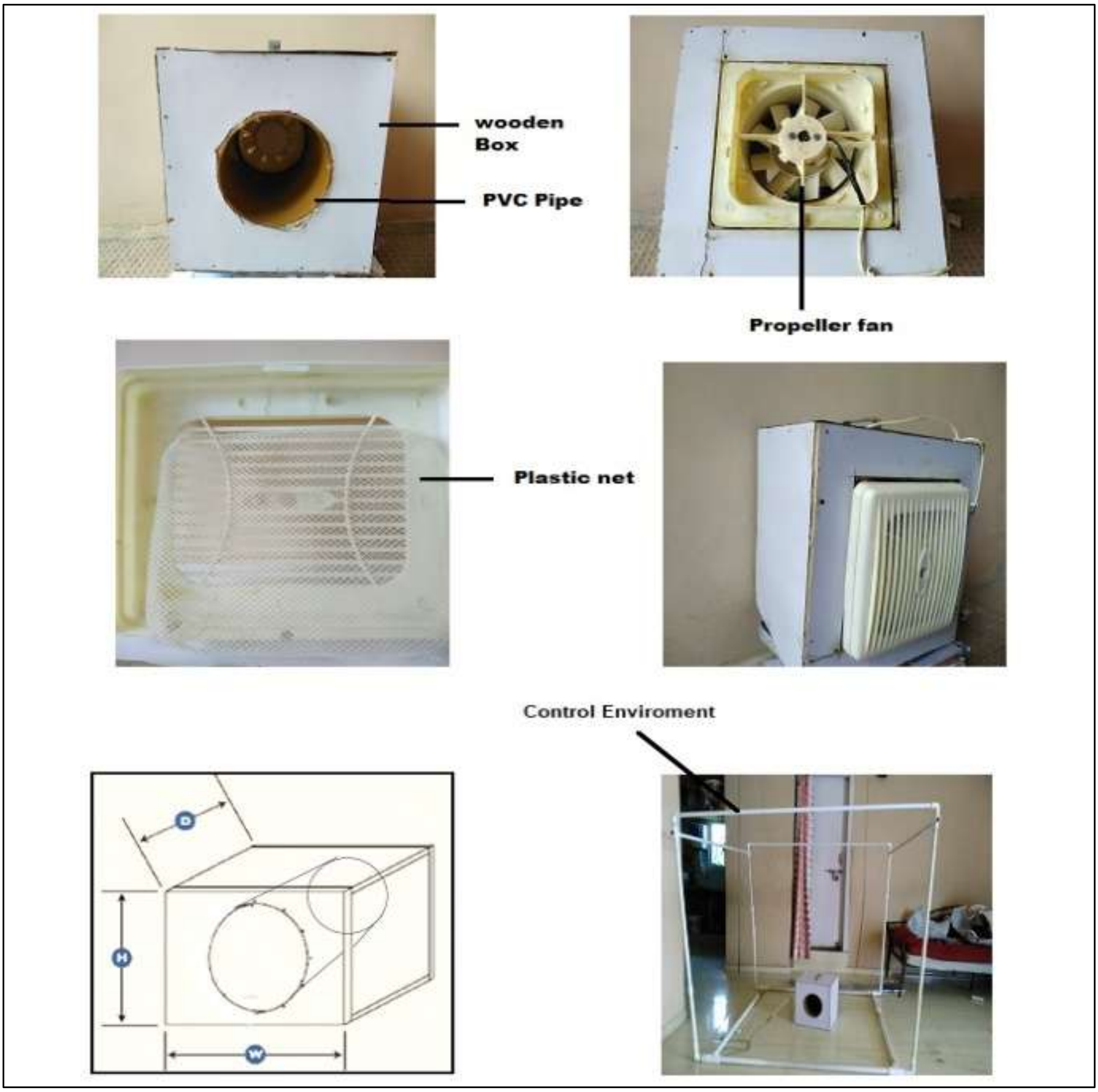


Fig: - 3.62 Instrument Developed for testing of Air Filtration efficiency

An air purifier device was made to check the filtration efficiency of the prepared composite membranes. Figure 3.62 shows the gradual development stages of the instrument used to check the air filtration efficiency of different composite membranes. A wooden box with a length, width, and height of 11, 12, and 12 inches was prepared. After that high speed, a 6-inch propeller fan with nine blades was fixed in the wooden box.

Creation of a Controlled Environment for Air Filtration

Fig 3.63 Controlled Environment

Fig 3.64 Ready Samples

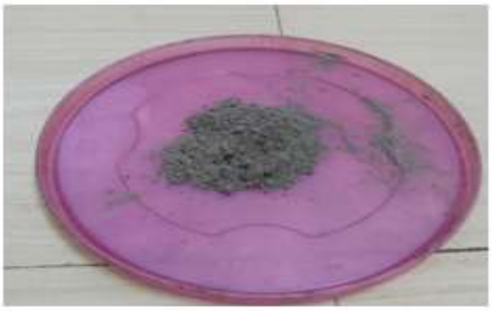


Fig 3.65 Air Pollutant

Fig 3.66 Hot Air Blower

Fig 3.67 Front Door for Clamper

Fig 3.68 Clamper

An air quality detector with laser light scattering technology was used to check the different particulate sizes in the control environment. One by one, all prepared membranes were mounted on the air purifier. The control environment was polluted with the help of cement and a hot air blower. The air quality detector reading was taken in 2 conditions, one before turning on the air purifier instrument and another after turning on the air purifier instrument. The reading was taken for the particles that existed in the controlled environment. With one sample membrane, three readings were taken, and their average was taken to check the relationship between air quality and prepared membranes**.**

Figure 3.63 shows the controlled environment made with the help of PVC pipe and a transparent thick polyethylene sheet. Figures 3.64 to 3.68 show the photos of the different ready membranes equipped with the air purifier.

The environment was polluted with cement particles and with a hot air blower. Both of them were used jointly to create a polluted environment. There was a front door and clamper in the air purifier device. With that help, all membranes were mounted individually and tested for air filtration efficiency.

The Air Quality Detector screen photo for reading was taken randomly by clamping the different samples on the Room Air Purifier to show the details of the results.

Fig 3.69 With Out Filter in fresh Air

Fig 3.70 with Out Filter in Polluted Environment

Fig 3.71 AQI with Sample: 01

Fig 3.72 AQI with Sample: 02

Fig 3.73 AQI with Sample: 03

Fig 3.74 AQI with Sample: 04

At first, the Air in the control environment was polluted with small cement particles. After that, air quality measurements of the controlled environment were taken with the help of an air quality detector. The next step was clamping the different fabricated filtration membranes on the room air purifier. The device was placed inside a controlled environment. Room Air Purifier, having prepared membrane as a filter, was turned on for 5 minutes. During this time, pollutants in the Air were sucked off on the filter membrane and filtered fresh Air remained in the control environment. At last, air quality measurements of the controlled environment were taken with the help of an air quality detector. Three readings were taken with one fabricated membrane to ensure the consistency of the results.

Figure 3.69 shows the reading of the air quality detector in a controlled environment, where there were no pollutants or turbulence in the Air. The air quality index was 36. Particulate matter of size 2.5 microns was 92, 1.0 was 69, and 10 microns was 103. This reading was high compared to Fresh Air because the reading was taken in a tightly packed environment.

Figure number 3.70 shows the reading taken in a manually polluted environment. The filter membrane was removed from the room air purifier, and after that, the air quality detector readings were taken. Particulate matter of size 2.5 micron was 264, 1.0 was 200, and 10 was 295. The reading was very high because the controlled environment was destroyed by polluting it with the help of cement particles and a hot air blower.

Figure 3.71 shows the reading of the air quality detector with sample number 1. In this situation, sample number 1 was equipped with a room air purifier, and reading was taken with the help of an air quality detector. Particulate matter of size 2.5 microns was reduced to 82, 1.0 to 62, and 10 microns to 91. The reading was reduced because single-layer polypropylene spun bond nonwoven fabric was used as a filter membrane.

Figure number 3.72 shows the reading of the air quality detector with sample number -2. This reading reduced particulate matter of size 2.5 microns to 78, 1.0 to 59, and 10 microns to 87. The value was reduced because the three-layered membrane with a Polyester nanofiber web on polypropylene spun bond nonwoven fabric was used.

Figure number 3.73 shows the reading of the air quality detector with sample number 3. In reading, particulate matter of 2.5 microns was reduced to 72, 1.0 to 54, and 10 microns to 80. The reading was reduced little because the three-layer membrane with a nylon nanofiber web on polypropylene spun bond nonwoven fabric was used.

Figure number 3.74 shows the reading of the air quality detector with sample number- 4. This reading reduced particulate matter of size 2.5 microns to 64, 1.0 to 48, and 10 microns to 71. Sample number 4 was made of four layers, of which two layers had polyester nanofiber web, and the other 2 had nylon nanofiber web on polypropylene spun bond nonwoven fabric. For this reason, we can see an improvement in the air quality readings.

Figure number 3.75 shows the reading of the air quality detector with sample number 5. This reading reduced particulate matter of size 2.5 microns to 58, 1.0 to 45, and 10 microns to 66. Sample number 5 was made of three layers, out of which the middle layer had a polyester nanofiber web on melt-blown nonwoven fabric. Meltblown nonwoven fabric shows higher filtration efficiency than spun-bond nonwoven fabric due to the random orientation of fibers. For this reason, we can see an improvement in the air quality readings.

Figure number 3.76 shows the reading of the air quality detector with sample number- 6. This reading reduced particulate matter of size 2.5 microns to 52, 1.0 to 39, and 10 microns to 48. Sample number 6 comprised three layers; the middle layer had a nylon nanofiber web on melt-blown nonwoven fabric. The high cohesion of nylon nanofiber web with melt-blown nonwoven fabric resulted in higher filtration efficiency than sample number 5.

Figure number 3.77 shows the reading of the air quality detector with sample number -7. This reading reduced particulate matter of size 2.5 microns to 14, 1.0 to 10, and 10 microns to 15. Sample number 7 consisted of 5 layers, in which the inner two layers had polyester nanofiber web on PP melt blown nonwoven fabric, and the third layer had nylon nanofiber web on PP melt blown nonwoven fabric. So, a total of 3 layers had nanofiber web on PP melt blown nonwoven fabric, and because of this reason, we got the best and optimum filtration efficiency out of all samples.Figure number 3.78 shows the reading of the air quality detector with sample number- 8. In reading, particulate matter of 2.5 microns was reduced to 44, 1.0 to 33, and 10 to 49. Sample number 8 again had 5 5-layer structure. However, the middle two layers had nylon nanofiber web on PP spunbond nonwoven fabric, and the third layer had polyester nanofiber web on PP spunbond nonwoven fabric. So, 3 layers had nanofiber web on PP spunbond nonwoven fabric. However, this membrane did not show the same filtration efficiency as sample number 7. This is because melt-blown nonwoven fabric had higher filtration efficiency than spun-bond nonwoven fabric due to random fiber orientation in melt-blown fabric.

Figure number 3.79 shows the reading of the air quality detector with sample number- 9. This reading reduced particulate matter of size 2.5 microns to 39, 1.0 to 29, and 10 microns to 43. Sample number 9 had 6 6-layer structure in which two layers had nylon nanofiber web on PP spunbond nonwoven fabric, and the rest of the 2 layers had polyester nanofiber web on PP spunbond nonwoven fabric. So, 4 layers had nanofiber web on PP spunbond nonwoven fabric. The air quality readings did not improve much due to the base fabric, which is made of spun-bond nonwoven fabric.

Figure number 3.80 shows the reading of the air quality detector with sample number -10. This reading reduced particulate matter of size 2.5 microns to 20, 1.0 to 15, and 10 microns to 22. Sample number 10 was having an arrangements of 7-layered, and one layer had a nylon nanofiberweb on PP melt-blown nonwoven fabric.

The second layer is a nylon nanofiber web on PP spun-bond fabric. The third layer was a simple PP spunbond nonwoven fabric. The fourth layer is a polyester nanofiber web on PP melt-blown nonwoven fabric. The fifth layer is a polyester nanofiber web on PP spunbond nonwoven fabric. So, there are four layers, two of which have nanofiber web on PP melt blown nonwoven fabric, and two layers have nanofiber web on PP spunbond nonwoven fabric. We got better results for this membrane due to its increased thickness due to the seven layers and the meltblown fabric membrane. However, with this type of configuration, it was difficult to fabricate it, and the cost also increased due to the more no layers having nanofiber web.

Except for sample 1, all the samples had the two outermost layers of PP spunbond nonwoven fabric to reinforce the membrane. In sample no 10, one extra layer of PP spunbond nonwoven fabric was used in the middle to support all layers.

The filtration membrane can be used at one time once it is equipped with the room air purifier. The reason is that the nanofiber web is laid over the nonwoven base fabric and is not adhered to. The clogging of the filtration membrane depends on the use of the room air purifier and the working atmosphere. However, if we wash the membrane, there is a high chance that the prepared membrane can be damaged and may not work as effectively as it did before washing.

Generally, a room's filter should be changed every two weeks, but it can be changed earlier if the environment is dustier or polluted.

Results and Discussion
All the measurements were taken with the help of an air quality detector instrument. One sample was tested 3 times to reduce the possibility of error. The average value of all samples is taken for the null hypothesis. For taking another reading, the Controlled Environment, Air purifier instrument and Air Quality detector instrument were cleaned with the help of a soft cotton fabric and blower (Dry Air and Wet Air).

Results of Air Purification

All readings are taken at room temperature (26ºG 27ºC) and humidity of (41% to 44 %)

Sr. No	AQI	Level	HCHO	TVOC	PM - 2.5	PM – 1.0	PM – 10
Sample-1	32	Poor	0	0	82	62	91
Sample-2	31	Poor	0	0	78	59	87
Sample-3	28	Normal	0	0	72	54	80
Sample-4	25	Normal	0	0	64	48	71
Sample-5	23	Normal	0	0	58	44.5	65
Sample-6	20	Normal	0	0	52	39	57.5
Sample-7	5	Fresh	0	0	14	10	15
Sample-8	17	Normal	0	0	44	33	49
Sample-9	15	Normal	0	0	39	29	43
Sample-10	8	Fresh	0	0	21	15	23

Table 4.1 Results of different sample for Air Quality with reference to PM – 2.5, 1.0, 10

Percentage Shift in the value of air quality with concern to different sample

Sr. No	AQI	Level	HCHO	TVOC	PM - 2.5	PM - 1.0	PM - 10	% Gain in AQI	% Gain in HCHO	% Gain in TVOC	% Gain in PM - 2.5	% Gain in PM - 1.0	% Gain in PM -10
WF*	36	P	0.08	0.37	92	69	103	*Normal Environment					
WOF**	100	D	0.089	0.37	264	200	295	*Polluted Environment					
S-1	32	P	0	0	82	62	91	68%	100%	100%	69%	69%	69%
S-2	31	P	0	0	78	59	87	69%	100%	100%	70%	71%	71%
S-3	28	N	0	0	72	54	80	72%	100%	100%	73%	73%	73%
S-4	25	N	0	0	64	48	71	75%	100%	100%	76%	76%	76%
S-5	23	N	0	0	58	45	65	77%	100%	100%	78%	78%	78%
S-6	20	N	0	0	52	39	58	80%	100%	100%	80%	81%	80%
S-7	5	F	0	0	14	10	15	95%	100%	100%	95%	95%	95%
S-8	17	N	0	0	44	33	49	83%	100%	100%	83%	84%	83%
S-9	15	N	0	0	39	29	43	85%	100%	100%	85%	86%	85%
S-10	8	F	0	0	21	15	23	92%	100%	100%	92%	93%	92%

Table 4.9 % Improvement inAir quality with reference to AQI, PM -2.5, PM - 1.0, PM-10

Conclusions

This research work produced polyester and nylon nanofiber by dissolving commercially available chips in their respective solvents. The nanofiber web was taken on PP spunbond nonwoven fabric and PP melt-blown nonwoven fabric. After taking the sample, different Combinations were made, and their performance was checked for Air and water filtration efficiency. All the testing was done in a controlled environment. For testing, we polluted the system with the help of pollutants, i.e., Air was polluted with the help of cement particles, and water was polluted with the help of calcium carbonate. After that, the samples' efficiency was checked for Air and water using the fabricated membrane. We can conclude the whole research as per the points mentioned below.

- Both polyester and Nylon nanofiber webs produced during the research show very good filtration properties. However, considering the cost factor, nylon is recommended for further development in filtration.
- Specifically, sample no - 7 showed excellent results if we consider the indoor air filtration field. This Combination reduced Air's PM 2.5 and PM 1.0 levels Air to 95 %.
- A combination of sample -7 can be used in respiratory masks, preventing us from polluting the Air and dangerous viruses like influenza, flu, Corona, anthrax, etc.
- A combination of sample -7 can be used to clean our indoor Air with the help of an air purifier developed during the research work.

Objective Achieved

- Successfully made polyester and nylon nanofiber from Polyester and Nylon chips, widely used commercially and easily available at phenomenal rates.
- Successfully implemented the nanofibers in Air and water filtration under the concept of value addition in textiles.

Successfully designed and developed an instrument that can clean the Air within 2-3 minutes, depending upon the area of the room. The device's manufacturing cost is quite low, and it can further be reduced if it is produced in bulk.

References

[1] JK Patra and S Gouda, Application of nanotechnology in textile engineering: An overview, Journal of Engineering and Technology Research (2013)
[2] Seeram R, Schematic diagram of the electrospinning process, An Introduction to Electrospinning and Nanofibers-World Scientific (2005)
[3] S. Bharat , Nanofibers In Pharmaceuticals-A Review - Scientific Figure on Research Gate , https://www.researchgate.net/figure/Figure1-Comparison-between-human-hair-and-nanofiber-web-3_fig1_329829241 (2012)
[4] Niu – 2012, Schematic representation of needleless electrospinning Rotating disk for initiating electrospinning jet at its edges, http://electrospintech.com/images/txt-disk _dispenser_electrospin.jpg
[5]. Sundarrajan, S., Tan, K. L., Lim, S. H., and Ramakrishna, S. (2014). Electro spunnanofibers for air filtration applications. ProcediaEng, 75,159-163.
[6]. Ahn, Y. C., Park, S. K., Kim, G. T., Hwang, Y. J., Lee,C. G., Shin, H. S., and Lee, J. K. (2006). Development of high efficiency nanofilters made of nanofibers. Current Applied Physics, 6(6), 1030-1035.
[7]. Air Sensor Guide Book, EPA, United States. EPA 600/R-14/159, June (2014), www.epa.gov/ord
[8] Maze, B., Tafreshi, H. V., Wang, Q., and Pourdeyhimi,B. (2007). A simulation of unsteady-state filtration via nanofiber media at reduced operating pressures. Journal of aerosol science, 38(5), 550-571.
[9]. Wang, J., Kim, S. C., andPui, D. Y. (2008). Investigation of the figure of merit for filters with a single nanofiber layer on a substrate. Journal of Aerosol Science, 39(4), 323-334.
[10] Faccini, M., Vaquero, C., Amantia, D., (2012). Development of Protective Clothing against Nanoparticle Based on Electrospun Nanofibers, Journal of Nanomaterials, ArticleNo.–18,1-9.
[10]. Desai, K., Kit, K., Li, J., and Zivanovic, S. (2008). Morphological and surface properties of electrospun chitosan nanofibers. Biomacromolecules, 9(3), 1000-1006.
[11] Vitchuli, N., Shi, Q., Nowak, J., McCord, M.,Bourham, M., and Zhang, X. (2010). Electrospun ultrathin nylon fibers for protective applications. Journal of Applied Polymer Science, 116(4), 2181-2187.
[12] Scholten, E., Bromberg, L., Rutledge, G.C., Hatton, T.A., 2011. Electrospun Polyurethane Fibers for Absorption of Volatile Organic Compounds from Air, ACS Applied Materials Interfaces, 3, p 3902.
[13] Zhang, Qi., James, W, H., Park, Wu C –Yu., Sigmund, W., Marijnissen, J. C. M., 2010. Improvement in Nanofiber Filtration by Multiple Thin Layers of Nanofiber Mats. Journal of Aerosol Science; 41, p230.
[14] Podgorski, A., Bałazy, A., Grado, L., 2006. Application of Nanofibers to Improve the Filtration Efficiency of the Most Penetrating Aerosol Particles in Fibrous Filters, Chemical Engineering Sciences 61, p 6804
[15] Graham, K., Ouyang, M., Raether, T., Grafe, T., McDonald, B., Knauf, P., Polymeric Nanofibers in Air Filtration Applications, presented at the Fifteenth Annual Technical Conference and Expo of the American Filtration and Separations Society, Galveston, Texas, April 9-12, 2002.
[16] Wang, J., Kim, S. C., Pui, D. Y.H., 2008. Investigation of the Figure of Merit for Filters with a Single Nanofiber Layer on a Substrate, Aerosol Science 39, p 323.
[17] Ramakrishnan, R., Sundarrajan, S., Yingjun, L., Barhate R. S., Lala N. L., Ramakrishna S., 2006. Functionalized Polymer Nanofibre Membranes for Protection from Chemical Warfare Stimulants, Nanotechnology 17, p2947.
[18] Sundarrajan, S., Ramakrishna, S., 2007. Fabrication of Nanocomposite Membranes from Nanofibers and Nanoparticles for Protection Against Chemical Warfare Stimulants, Journal of Materials Science 42, p8400.
[19] Vitchuli, N., Shi, Q., Nowak, J., McCord, M., Bourham, M., Zhang, X., 2010. Electrospun Ultrathin Nylon Fibers for Protective Applications, Journal of Applied Polymer Science 116, p2181.
[20] Neeta L. Lala., Ramaseshan, R., Bojun, Li., Sundarrajan, S., Barhate, R.S., Ying-jun, L., Ramakrishna, S., 2007. Fabrication of Nanofibers with Antimicrobial Functionality used as Filters - Protection Against Bacterial Contaminants, Biotechnology and Bioengineering 97, p 1357.
[21] Zhang, L., Luo, J., Menkhaus, T.J., Varadaraju, H., Sun, Y., Fong, H., 2011. Antimicrobial Nano-fibrous Membranes Developed from Electrospun Polyacrylonitrile Nanofibers, Journal of Membrane Science, 369, p 499.