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Investigation of Water Filtration Efficiency of Fabricated Nanofiber Membrane

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Access to clean water is a critical issue globally, affecting both developing and developed nations. The presence of contaminants in drinking water leads to significant health concerns, including waterborne diseases and hormonal imbalances caused by chemicals like estrogen. Conventional water filtering techniques have been in use for a long time, but they have drawbacks, including low flux and ease of clogging. Electrospun nanofibrous membranes (ENMs) and other recent developments in nanotechnology hold great promise for overcoming these constraints. This paper explores the development, application, and future potential of nanotechnology in water filtration systems, focusing on the key findings from recent research in the field.

Keywords: Electrospun, Nano Fibers, Polyester, Nylon, Reverse Osmosis, Spunbond, Meltblown, Nonwoven Fabric.

1. Introduction

Water filtration plays a vital role in ensuring access to clean drinking water. Traditional filtration methods—such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO)—have been widely used in water treatment systems. These methods rely on membranes that control pore size for filtering particles and impurities. Despite their success, conventional filtration systems face challenges related to low flux rates, fouling, and energy inefficiency. With growing water scarcity and increasing contamination from industrial pollutants, innovative filtration methods are required to meet the global demand for clean water.

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

2. Literature Review

2.1 Nanofibers

In the context of business, the word "nano" denotes a fibrous form with a diameter of less than one micron, or one thousand nanometres. A dramatic change in the governing physics occurs when one starts to work at the molecular level. The significance of gravity, for instance, diminishes dramatically while the strength of the formerly negligible Vander-Waals forces increases exponentially. The capacity to control the fundamental laws of physics, as well as the essential features and characteristics of materials, has been tremendously useful throughout history.

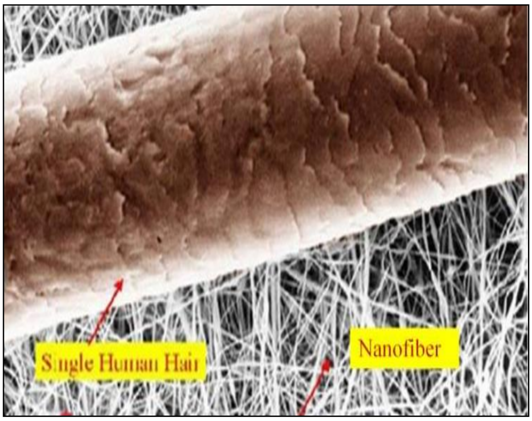
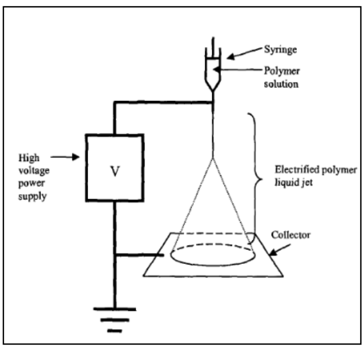


Fig 1 Nano Fiber as Compared to Human Hair[1]



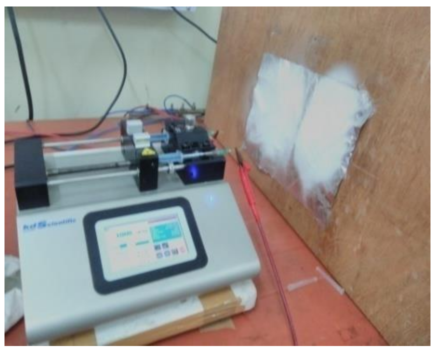


Fig 2 Basic Electrospinning [2] Fig 3. Manufacturing of Nylon-6 & Polyester Nanofiber

2.2 Filtration

Nanofibers have several potential applications, but one of the most apparent is in filters. A good filter will be able to provide a high flow rate while collecting and keeping the tiniest particles. Performance at a given pressure drop improves when using nanofibers because of their enhanced interception and inertial impaction efficiency and the slip flow that occurs at the fiber surface. Several of the world's leading filtration businesses are already using nanofibers in their air, liquid, and automobile filters for both commercial and consumer use.

2.3 Nanofiltration

The word "nanoscale" suggests that the pores are between 10 and 1 nanometre in size, and reverse osmosis can also filter in the ~1-0.1 nanometre range. Nanoscale filtration is the primary focus because contaminants in water may be more effectively adsorbed and separated at this size range. There have been many prior studies on evaluating nanofiber membrane filtration efficiency.

Sundarrajan et al. [3] investigated nanofiltration as a potential option to treat water with low salt content. Research has shown that desalination might benefit from NF's increased flow, decreased operating pressure, and energy savings. A thin-film composite structure consisting of electrospun nanofibrous membranes (ENMs) has been used in NF applications for the mid-layer. Compared to traditional membranes, the permeate flows that were attained were much more significant.

Crittenden et al. [4] addressed the goal of treating municipal water. In addition to identifying the most common causes of water pollution, they established a connection between water quality and public health. Purification of potable water was one of the topics covered. Additionally, a comparison was made between membrane filtration and rapid granular filtering.

The production of FO membranes was covered by Huang et al. [5]. In order to achieve high-performance FO, new composite membranes were created using electrospun polyethersulfone (PES) nanofiber substrates and multilayered PA produced by cyclic interfacial polymerization (IP). Electrospun substrate shape, thickness, and fiber diameter are significantly affected by the PES concentration, as well as the ideal concentration, according to the findings. With each IP cycle, the mechanical strength, surface hydrophilicity, and thickness of the membrane all rose. Commercial thin film composite membranes can't hold a candle to optimized FO membranes with two PA layers when it comes to water flow and membrane selectivity.

Nanofibrous membranes made of carbon were created by Faccini et al. [6]. Thermotreatment and electrospinning of a polyacrylonitrile (PAN) precursor solution allowed for the production of free-standing carbon nanofiber (CNF) mats with varying fiber diameters. Bendable and mechanically robust, the produced membranes could endure vacuum or pressure filtration. Experimental filtering findings showed that the manufactured membranes could effectively remove Au, Ag, and TiO2 nanoparticles with a diameter ranging from 10 to 100 nm from water solutions at a very high flux.

Mokhena et al. [7] reviewed recent advances in electrospinning technology for generating biopolymers, their blends, and functionalization utilizing metal oxides. In the field of water filtration, the use of electrospun nanofibrous membranes was addressed. Not only that, but these materials were the subject of substantial study to ensure the success of electrospinning to bio-based polymer nanofibers, hybrids, and derivatives of these materials.

The needleless melt electrospinning process was used by Li et al. [8] to create orientated polypropylene fibers. They next investigated how the arrangement of orientated fiber membranes affected the filtering efficiency. Additionally, they measured the effect of electrical field intensity on fiber diameter and the distance between the nozzle and electrode. They found that when the cylinder speed increased, the fiber diameter shrank noticeably

(Collector). Electrospun-orientated membranes have significantly reduced mean pore sizes compared to electrospun-random membranes. The findings demonstrated that orientated electrospun membranes were more effective than the native membrane in rejecting the 0.5 μm particles while maintaining the same permeate flow.

The functions, manufacturing processes, and purification mechanisms of several hydrophobic and hydrophilic electrospun polymeric water purification membranes have been investigated and described by Suja et al. [9]. There has been a thorough classification and explanation of electrospun polymeric membranes used for filtering and adsorption. Additionally, methods for improving membrane characteristics via the use of thin film nanocomposite membranes, surface modification, blending with polymers, and inorganic nanofillers are covered. Researchers looked at the necessary alterations for hydrophilic and hydrophobic polymers so they might be used in water treatment systems. Its potential uses and benefits in water treatment have been investigated using before and after treatment methods. Additionally, they said that the production of industrial-scale electrospun water filtration membranes that are both reusable and recyclable is necessary in the long run.

Nanomaterials have recently made great strides in water treatment, with developments in filtration membranes, large surface area adsorbents, and efficient photocatalysts calling for regulatory clearance to ensure their efficacy and safety Liang et al., [10]. This chapter provides a foundational overview of relevant ideas and concepts in the following areas: adsorption, advanced oxidation processes, particularly photocatalytic degradation, reverse osmosis, and pressure-driven membrane filtration and its rejection mechanisms for filtering.

By using a composite membrane, Ma et al. [11] were able to achieve a flow that was double that of commercial microfiltration membranes. Electrospun nanofibrous scaffolds were filled with tiny cellulose/chitin nanofibers with a diameter of around 5 nm, allowing them to create a membrane. In addition, they investigated a three-layer TFNC membrane for UF application; this membrane would include a PET nonwoven mat on the bottom, an electrospun PAN nanofiber scaffold in the center, and a barrier made of cellulose regenerated from an ionic liquid solution. They found that the rejection ratio was about the same between the three-layered TNFC membrane and the commercial PAN10 UF membrane, but the penetration flux against oily bilge water was ten times greater.

Preparation of various nanofibers with various secondary nanostructures was reviewed by Feng et al. [12]. Researchers looked at the potential of hollow nanofibers for desalinising salty water and removing volatile organic compounds (VOCs) from gases. Among the membranes that were examined were one made of polyvinylidene fluoride (PVDF) and another of polytetrafluoroethylene (PTFE) with a nonwoven backing. High porosity, an interconnected open pore structure, and a membrane thickness that can be adjusted were all claimed by the researchers working on electrospun nanofiber membranes (ENMs). On top of that, membrane distillation (MD) works well with them due to their very hydrophobic surfaces. Before water is treated with ultrafiltration or reverse osmosis, ENMs may be used as a prefilter. The findings demonstrated that under identical operating circumstances, the PTFE microfiltration membranes generated a much larger flux during distillation than the PVDF membranes.

To determine the ideal thickness of a self-sustained electrospun polyurethane nanofiber membrane to optimize flux rate and minimize heat losses, Jiriceket al. [13] produced membranes of several thicknesses and tested them on a direct-contact membrane distillation machine. We tested salt retention and flux in very salty environments. By bringing new materials with revolutionary capabilities, nanotechnology might provide current methods for desalinating waste streams. The most efficient membranes have the thinnest profiles.

Nanofiltration, reverse osmosis, and forward osmosis are only a few of the aqueous media-based separation techniques investigated by Lau et al. [14] using polyamide (PA) in thin film nanocomposite (TFN) membranes. They claimed that by adding the correct quantity of nanofiller to a thin selective PA layer of a composite membrane, TFN membranes could be made with better separation properties than the standard TFC membrane. They illuminated new avenues for addressing the difficulties inherent in TFN membrane production.

The use of nanotechnology in the treatment of water and wastewater is rapidly expanding worldwide. Due to their exceptional characteristics and the fact that they are converging with existing treatment methods, there are tremendous opportunities to transform water and wastewater treatment. Quet al., [15].

An antimicrobial covering for a fibrous medium or a self-supporting membrane made of electrospun nanofibers is an intriguing possibility. Compared to traditional melt-blown microfibers, nanofibers provide a much greater surface-to-volume ratio, allowing for more effective particle separation (Boteset et al., [16]).

The capacity of electrospun polysulfone nanofiber membranes to extract microparticles from solutions was examined. Because of their large surface area and high porosity, nanofibrous membranes are excellent prefilters for high-flux applications. The membrane could safely remove more than 99 percent of particles with sizes of 10, 8, and 7 microns, and it had a bubble point of 4.6 μm. In reference to Gopalet al. [17]

Traditional Water Filtration Membranes Conventional water filtration membranes consist of a selective layer supported by a thick, highly absorbent, non-selective substrate. These membranes are designed to separate suspended solids from liquids based on pore size and material characteristics. However, they are often limited by low flux rates and susceptibility to fouling, which reduces their efficiency and increases maintenance costs. Despite these limitations, traditional filtration systems have been used for decades in municipal water treatment.

The most commonly used traditional membranes include MF, UF, NF, and RO. While compelling in filtering contaminants, these methods can need help with emerging pollutants such as nanoparticles, viruses, and pharmaceuticals, which are difficult to remove due to their small size.

3. Methodology

- Testing Procedure for checking Water filtration efficiency by ORP and TDS meter
- Measurement of Oxidation-reduction potential (ORP) in water

3.1 ORP Measurement

The redox potential (ORP) of a solution is a measure of its electron-releasing and -accepting capabilities. Millivolts (mV) is the unit of measurement. An oxidising solution is one with a positive ORP value, whereas a reducing solution is one with a negative ORP value. The oxidising power increases as the ORP value rises, and falls as the ORP value falls.

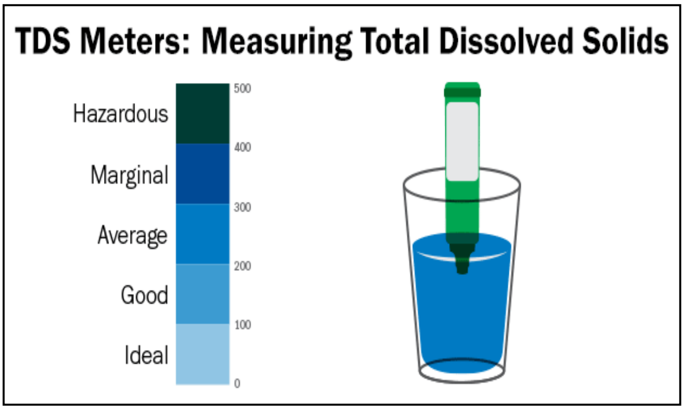


Fig 4 TDS amount for Ideal to Hazardous Level for Drinking Water [18]

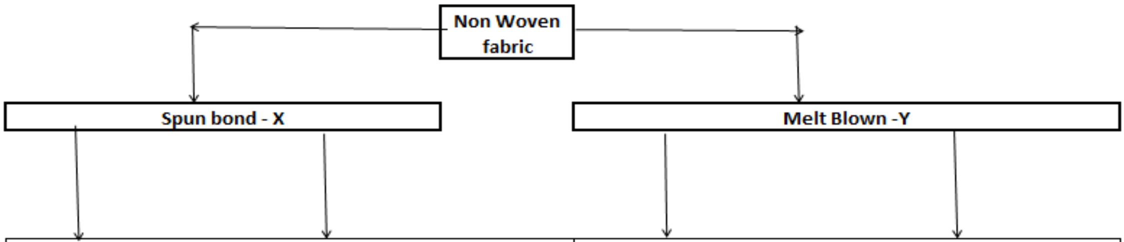
3.1.1 TDS Measurement

TDS is a measure of the combined dissolved substances, both organic and inorganic, in water. This is typically measured in parts per million (ppm). TDS concentration provides an indication of the water's overall purity, with lower values indicating cleaner water. The TDS of a solution can be measured using either gravimetric analysis or conductivity.

Fig 5 ORP Meter for checking the oxidation capacity of filtered water

Fig 6 TDS, PH and Temp Meter for checking hardness and acidity of water

Proposed System for making fabricated membrane for Water 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+ B*Y +X	4	50 % Nylon + 50 % Polyester

Fig 7 Arrangement of Polyester and Nylon nanofiber web taken on 2 types of nonwoven fabric for fabrication of Filtration membrane for water.

3.1.2 Fabrication of Nanofiber Membranes

This research focused on the use of polyester and nylon nanofibers for water filtration membranes. Five samples were prepared using varying layers of polypropylene (PP) spunbond fabric combined with either polyester or nylon nanofibers. These samples were:

1. Single layer of PP spunbond fabric
2. One layer of polyester nanofibers sandwiched between two PP layers
3. One layer of nylon nanofibers sandwiched between two PP layers
4. Polyester and nylon nanofibers combined in alternating layers between PP
5. Polyester and nylon nanofibers combined with a PP meltblown fabric layer

For Checking the Water filtration capability of nano fibres , below were the details of sample made in various combination :-

Total 05 samples were made

1 Single Layer PP Spunbond Fabric

2 1 Layer PP Spunbond Fabric + 1 Layer Polyester Nanofibers web on PP Spunbond Fabric + 1 Layer PP Spunbond Fabric

3 1 Layer PP Spunbond Fabric + 1 Layer Nylon Nanofibers web on PP Spunbond Fabric+ 1 Layer PP Spunbond Fabric

4 1 Layer PP Spunbond Fabric + 1 Layer Polyester Nanofibers web on PP Spunbond Fabric + 1 Layer Nylon Nanofibers web on PP Spunbond Fabric + 1 Layer PP Spunbond Fabric

5 1 Layer PP Spunbond Fabric + 1 Layer Polyester Nanofibers web on PP Meltblown Fabric + 1 Layer Nylon Nanofibers Web on PP Meltblown Fabric + 1 Layer PP Spunbond Fabric

Base Fabric Poly Propylene Spun Bond = X

Base Fabric Poly Propylene Melt Blown = Y

Polyester Nanofibers Web = A

Nylon Nanofibers Web = B

GSM of Poly Propylene Spunbond Non-Woven Fabric = 30 GSM

GSM of Poly Propylene Meltblown Non-Woven Fabric = 15 GSM

Table 1 Sample detail with their combination in terms of no. of layer as well nanofiber % for water filtration

Sr. No	Combination	Total Layer	Nano Fiber % (Polyester + Nylon)
Sample 1	X	1 Layer	-Nil-
Sample 2	X + A*X + X	3 Layer	100 % Polyester
Sample 3	X + B*X + X	3 Layer	100 % Nylon
Sample 4	X + A*X + B*X + X	4 Layer	50 % Nylon + 50 % Polyester
Sample 5	X + A*Y +B*Y+ X	4 Layer	50 % Nylon + 50 % Polyester

Instrument developed for testing the Water Filtration efficiency

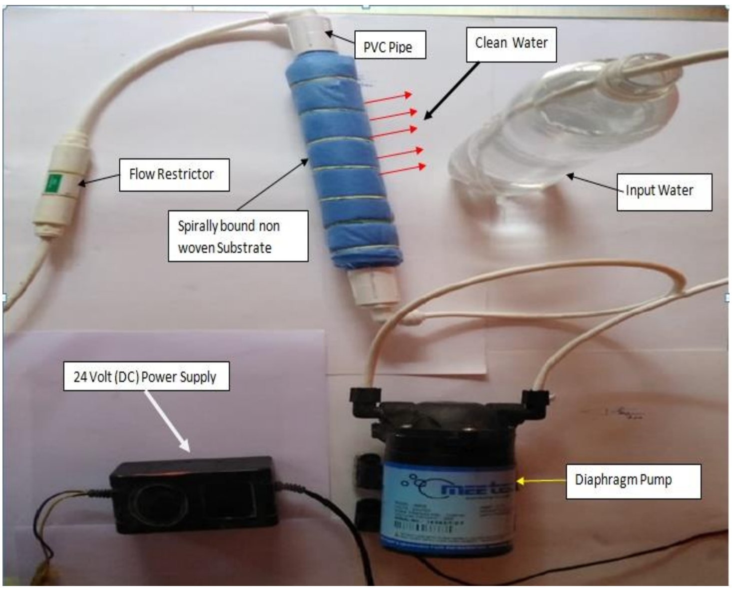


Fig 8 Instrument for testing the water filtration efficiency with spiral bound nonwoven fabric

In this type of instrument it was tried to bind the prepared membrane on PVC pipe spirally.

The PVC pipe was having holes on the periphery. This was done by considering that more surface area would be available for the polluted water. By doing so, there were many layers available, through which polluted water was passed forcibly and Filtered water was checked for the PPM and ORP reduction with the available instruments .

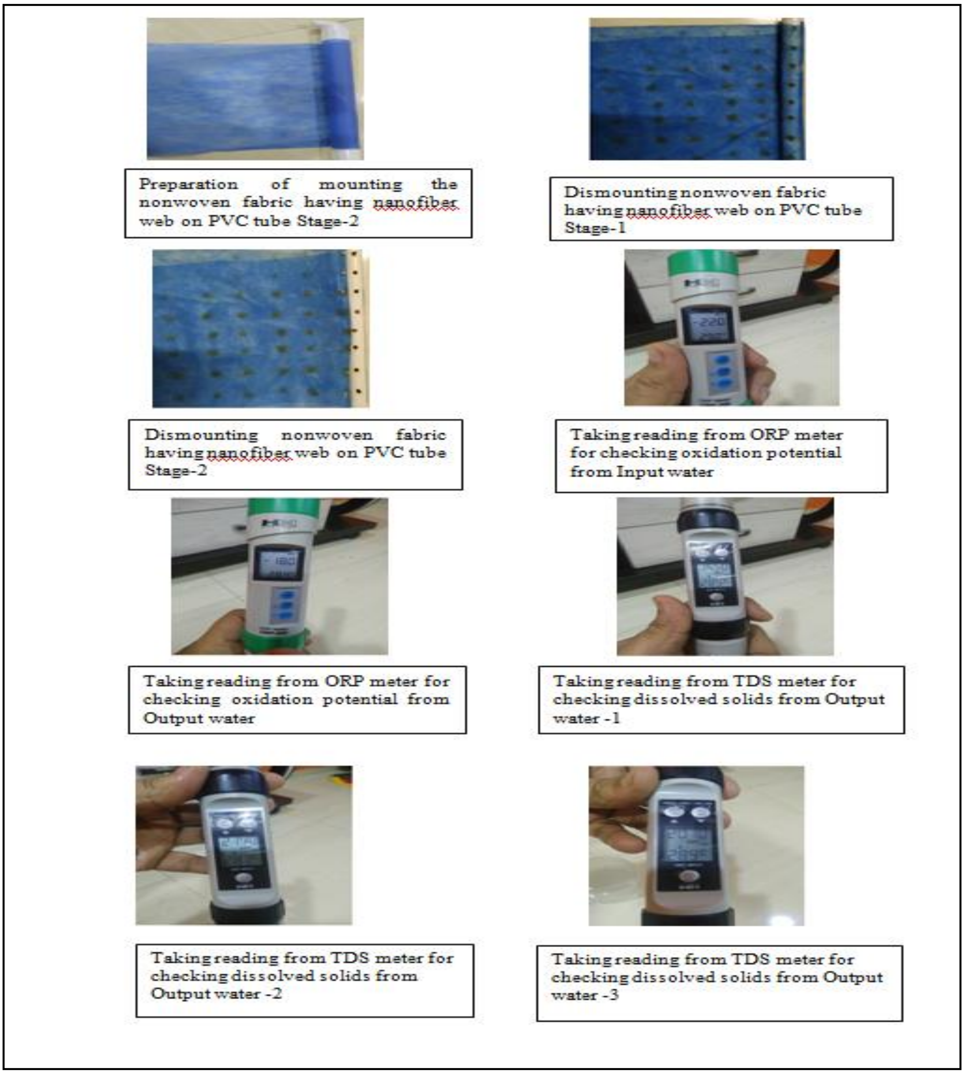


Fig 9 Procedure followed for taking the different readings

4. Results of Water Filtration

The Results were taken at room temperature (26°C - 27°C) and humidity of (41% to 44%)

Table 2 Results of different sample for water quality with reference to PPM ,PH, ORP

Sr. No	PPM	PH	ORP	PPM	PH	ORP	PPM	PH	ORP
	Feed Water			Output water			Rejected Water		
Without Filter	3590*	11.2	-231						
Sample :- 1	3590	11.2	-231	2590	11.1	-220	3210	11.2	-205
	3590	11.2	-231	2480	11.1	-228	3220	11.2	-208
Avg.- S-1	3590	11.2	-231	2535	11.1	-224	3215	11.2	-207
Sample :- 2	3520	11	-241	1910	10.9	-199	2960	11.2	-185
	3520	11	-241	1904	10.9	-195	2985	11.2	-183
Avg.- S-2	3520	11	-241	1907	10.9	-197	2973	11.2	-184
Sample :- 3	3510	11	-241	1850	10.7	-182	2990	11.2	-181
	3510	11	-241	1810	10.7	-186	3010	11.2	-180
Avg.- S-3	3510	11	-241	1830	10.7	-184	3000	11.2	-181
Sample :- 4	3520	11.1	-231	1440	10.5	-170	3425	11.2	-184
	3520	11.1	-231	1385	10.5	-172	3315	11.2	-185
Avg.- S-4	3520	11.1	-231	1413	10.5	-171	3370	11.2	-185
Sample :- 5	3528	11	-240	960	10.1	-168	3550	11.2	-180
	3528	11	-240	875	10.1	-167	3465	11.2	-182
Avg.- S-5	3528	11	-240	918	10.1	-168	3508	11.2	-181

* High PPM water was created manually, by adding $CaCO_3$ in the water. and after that water filtration efficiency of filtration membrane was checked.

4.1 Percentage shift in the value of water quality with reference to polluted water

Table 3 Improvement in water quality with reference to PPM ,PH, ORP by using different membranes

Sr. No	PPM	PH	ORP	PPM	PH	ORP	PPM	PH	ORP	% Gain in PPM	% Gain in PH	% Gain in ORP
	Feed Water			Output water			Rejected Water					
WO Filter	3590*	11.2	-231									
S- 1	3590	11.2	-231	2535	11	-224	3215	11	-207	29.4%	0.9%	3.0%
S- 2	3520	11	-241	1907	11	-197	2973	11	-184	45.8%	0.9%	18.3%
S- 3	3510	11	-241	1830	11	-184	3000	11	-181	47.9%	2.7%	23.7%
S- 4	3520	11.1	-231	1413	11	-171	3370	11	-185	59.9%	5.4%	26.0%
S- 5	3528	11	-240	918	10	-168	3508	11	-181	74.0%	8.2%	30.2%

5. Conclusions

In this research work, polyester and nylon nanofibers were produced by dissolving commercially available chips in their respective solvents. The nanofiber web was taken on both PP spunbond nonwoven fabric as well as PP meltblown nonwoven fabric also. After taking the sample, different combination was made and their performance was checked for water filtration efficiency. All the testing was done in a controlled environment. For testing we polluted the system with the help of pollutant water was polluted with the help of fine crushed powder of calcium carbonate. After that, by using the fabricated membrane, the efficiency of all the samples were checked for polluted water. We can conclude the whole research as per the below-mentioned points

In the water filtration area sample no- 5, shows good results. This combination reduces the TDS and ORP level from the incoming water, by 60 % and makes it drinkable. The developed system can provide normal drinking water for poor people, who cannot afford a costly reverse osmosis system.

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