DEVELOPMENT OF NONWOVEN FABRIC BASED FILTRATION SYSTEM FOR POTABLE WATER

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May 2021

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by

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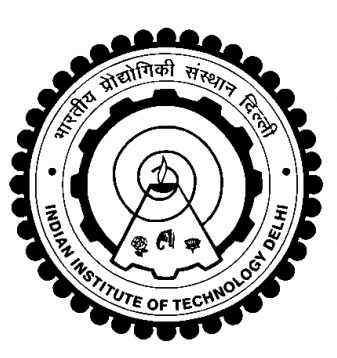
Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

May 2021

Dedicated to my nation

राष्ट्र देवो भवः

CERTIFICATE

This is to certify that the thesis titled **'Development of Nonwoven Fabric Based Filtration System for Potable Water'**, being submitted by **Mr. Rahul Rajkumar Gadkari**, to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of bonafide research work carried out by him. He has worked under my guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this Institute.

The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

The research work presented in the current thesis would have been impossible without the support of numerous individuals. I take this opportunity to recognise them and extend my genuine appreciation for assisting me craft this Ph.D thesis.

I take immense pleasure to express my deep sense of gratitude to my supervisors, ***Dr. S. Wazed Ali, Prof. Apurba Das*** *and* ***Prof. Ramasamy Alagirusamy*** *for their invaluable mentorship, and continuous encouragement and cooperation throughout this research work. Apart from technical inputs, they also bestowed upon me some precious lessons for life which shall guide me forever. I am also grateful to them for their faith in me, for providing opportunities to delegate several crucial responsibilities and for rendering constant support to pursue extracurricular activities - all of which helped me groom my personality. I am indebted for their contribution as supervisors and will always hold them in high regards.*

I would like to express my profound appreciation towards Prof. R. S. Rengasamy, Prof. Dipayan Das and Dr. Shaikh Z. Ahammad (Dept. of Biochemical Engineering and Biotechnology, IIT Delhi), who manifested their excellence in their suggestions that helped me improve my research work. I also wish to record my profound gratitude to Dr. Rajiv Srivastava, Dr. Bhanu Nandan, Prof. Mangala Joshi, Prof. Abhijit Majumdar, Prof B. S. Butola, Dr. Bipin Kumar and Dr. Javed Sheikh for kindly allowing me to use their technical facilities required for conducting my experiments. I am also grateful to the reviewers of my journal articles for their valuable feedback that helped to improve the quality of my research work.

Next, I express my sincere thanks to the Lab technicians of Dept. of Textile & Fibre Engineering, IIT Delhi. I extend special appreciation to Mr. Veerender, Mr. Kundu, Mr. Khattar, Mr. Rajkumar, Mr. Amarjeet, Mr. Suresh, Mr. Pratap Singh, Mr. Rohit and Mr. Vikas for their support in accessing the facilities in their respective laboratories. I would also like to thank the office staff, especially Mr. Sulabh, Mr. Rajkumar, Mr. Shreyansh, Mr. Deepak and Mr. Kishan. I also express my thanks to the staff of CRF, NRF, IRD, PG Section, Accounts Section and Zanskar Hostel of IIT Delhi. At this juncture, I also want to register a big thanks to the Ministry of Education (MoE), GoI, for providing me substantial fellowship for five years, relieving me of any financial burden and hence enabling me to calmly focus on my research. I also gratefully acknowledge the

financial support provided by the Department of Science and Technology (DST), GoI, through the project DST/TM/WTI/2K15/01G under the Water Technology Initiative (WTI).

Further, my heartfelt thanks to Mr. Nikhil, Dr. Avnish and Mr. Pradeep of Moonbow Living (Unit of Hindware Group) for allowing me to use their research facilities. I would also like to thank Mr. Vivek (Autotest Mechanisms Pvt. Ltd.) for helping me fabricate the pilot set-up of the two-stage water-purification system.

I express my deep sense of gratitude to Dr. Sanchi Arora for her 24×7 selfless support, valuable guidance and suggestions, and for constantly motivating me to stay focused. I am thankful to Dr. Vijay Goud for his valuable support, guidance and help. My heartiest gratitude to Pramod, Anilkumar, Dr. Shahadat, Anupam, Akshay Shukla, Viraj, Dr. Kiran, Mamta, Manali, Mayank, Sheetal, Ashutosh, Uddesh, Atul and Akshay Rathi for their valuable contributions in different forms. My heartfelt thanks to Ganesh Turerao, Dr. Ghanshaym, Swati, Dr. Nilay, Dr. Anuj, Pramod Shankar, Dr. Shilpi, Vivek and Utkarsh for always being by my side at times of need.

I take this opportunity to also acknowledge my fellow lab mates Dr. Ramamoorty, Dr. Krishnasamy, Dr. Mahadev, Satyaranjan, Ganesh Jogur, Dr. Rupayan, Dr. Gnanauthayan, Shivendra and Ashraf for their readiness to help me both in my professional as well as personal life. Apart from the lab mates, I am grateful to Dr. Vikas, Sanjay Kumar, Chandrajeet, Prasun, Indrajeet, Nagender, Zunjarrao, Hardeep, Avinash, Ankur, Mayuri, Ankita, Pratibha, Jayashree, Hema, Manisha, Rupali, Ranjana, Priyal and Priyanka for being joyful friends. I deeply appreciate their appropriate help and shall always treasure the cordiality shown by them.

The last round of thanks goes to the most important people at my personal front:

- *Foremost, my parents, who provided me unremitting inspiration and patience to face the challenges encountered during my Ph.D; and also for giving me complete liberty in all aspects of life and for trusting my decisions.*
- *My brothers Pankaj and Dr. Nilesh for being my pillars of support.*
- *My beloved friend and mentor Mr. Shrikant Bedkyale for his love, care and support.*
- *Dr. Unnat Pandit, Mrs. Ushma, Daivam and Rocky; Mr. Ashok Arora and Mrs. Archna Arora for their selfless love and care, and for being my family away from home.*

- *My beloved friends Abhijit, Nitish, Samrat, Sushant and Sushil for their passionate encouragement and relentless support.*
- *All my maternal uncles and their families for their motivation and care.*

I humbly extend my thanks to all those who directly or indirectly contributed to the completion of this research work. Last but most important, I thank Almighty God for enclosing me with such wonderful people in all walks of my life who made me accomplish this endeavour in a pleasantly fruitful manner.

RAHUL GADKARI

ABSTRACT

Water is necessary for the survival of all living beings. However, the toxic impurities in drinking water generate various health risks, making it extremely important to protect the water from being contaminated. More than half of the world population lives in rural areas with most of them deprived of adequate access to clean water. Moreover, because of extreme poverty and limited electricity, they are unable to afford advanced filtration modalities such as reverse osmosis, electro-deionisation, ultraviolet disinfection, ion exchange and distillation. Considering their need, this research work is motivated towards the design and development of a simple and sustainable water purification system from a nonwoven fabric and bioactive nanomaterials.

In the first part of this research, an attempt was made to explore the capillary action of a needle-punched nonwoven as a new water filtration technique for the removal of solid impurities and turbidity from raw water. The effect of fibre shape factor, needle-punch density and depth of needle penetration of a polyester nonwoven on its filtration performance was investigated in order to optimise them for obtaining desired water filtration rate and better turbidity removal efficiency. Moreover, in order to avoid germination of nonwoven during actual use, silver nanoparticle incorporated polyester nanocomposite fibres (P/Ag-NFs) were used. Besides, surface modification of nonwoven was also carried out to further enhance its antibacterial efficacy.

The second part of this research reports the development of an antibacterial nonwoven for the removal of bacterial contamination from water. Chitosan, a natural bioactive material, was chosen to functionalise the nonwoven. A unique eco-friendly method for the synthesis of chitosan nanoparticles (CSN) was developed in which chitosan and cinnamaldehyde were chemically cross-linked. The detailed material characterisations and antibacterial activity assessment of CSN were carried out very systematically. The synthesised CSN were applied over polyester needle-punched nonwoven using layer-by-layer (L-B-L) self-assembly coating technique. The L-B-L coated nonwoven exhibited excellent antibacterial activity and heavy metal ions adsorption behaviour. Overall, L-B-L coting technique was established as a promising method to imbue desired functionalities in the nonwoven filtration media without causing any considerable deterioration to its permeability and other physical properties.

An attempt was also made to apply nanofibrous coating of chitosan over polyester needle-punched nonwoven. Chitosan/poly(lactic acid) (CS/PLA) nanofibres was incorporated with silver nanowires (AgNWs) via electrospinning technique. The CS/PLA/AgNW composite nanofibrous membrane, thus developed, showed excellent antibacterial properties and heavy metal ions adsorption capacity. The AgNWs were found to be suitably integrated within nanofibrous structure which resulted in less amount of silver leach from the membrane, hence making this antibacterial membrane safe to be used for water filtration applications. Lastly, the CS/PLA/AgNW composite nanofibrous membrane was coated over needle-punched nonwoven for subsequent use in the development of an antibacterial filter cartridge.

The last part of this research reports the design and development of two-stage water purification system using nonwoven filter media developed in first and second parts of this research. In the first stage of filtration, raw water passing through gutters laid with polyester needle-punched nonwoven got rid of solid impurities and turbidity. Further, the bacterial contaminations and heavy metal ions got removed in the second stage of filtration through the antibacterial cartridge developed from polyester needle-punched nonwoven coated with CS/PLA/AgNW composite nanofibrous membrane. The unique water purification device, thus designed, involves low level of mechanisation, low complexity, ease of use and can be easily maintained by unskilled people. It can also serve as a sustainable technology for delivering safe potable water that can function without electrical power.

सार

सभी जीवों के अस्तित्व के लिए पानी आवश्यक है। हालांकि, पीने के पानी में जहरीली अशुद्धियां विभिन्न स्वास्थ्य जोखिम पैदा करती हैं, जिससे पानी को दूषित होने से बचाना बेहद जरूरी है। विश्व की आधी से अधिक आबादी ग्रामीण क्षेत्रों में रहती है, जिनमें से अधिकांश स्वच्छ पानी की पर्याप्त पहुंच से वंचित हैं। इसके अलावा, अत्यधिक गरीबी और सीमित बिजली के कारण, वे रिवर्स ऑस्मोसिस, इलेक्ट्रो-डिओनिज़ेशन, अल्ट्रावॉयलेट डिसइन्फेक्शन, आयन एक्सचेंज और डिस्टलेशन जैसे उन्नत निस्पंदन मोडलिटी को वहन करने में असमर्थ हैं। उनकी आवश्यकता को ध्यान में रखते हुए, यह शोध कार्य एक नॉनओवन कपड़े और बायोएक्टिव नैनोमैटिरियल्स से एक सरल और टिकाऊ जल शोधन प्रणाली के डिजाइन और विकास के लिए प्रेरित किया जाता है।

इस शोध के पहले भाग में, अशुद्ध पानी से घन अशुद्धियों और मैलापन को हटाने के लिए एक नई जल निस्पंदन तकनीक के रूप में नीडल-पंच नॉनवॉवन की कैपिलरी एक्शन का पता लगाने का प्रयास किया गया है। फाइबर शेप फैक्टर, नीडल-पंच डेंसिटी और डेप्थ ऑफ नीडल पेनिट्रेशन का पॉलिएस्टर नॉनवॉवन की निस्पंदन प्रदर्शन के ऊपर प्रभाव जाँचा गया ताकि वांछित जल निस्पंदन दर और बेहतर मैलापन हटाने दक्षता प्राप्त करने के लिए उन्हें अनुकूलित किया जा सके। इसके अलावा, वास्तविक उपयोग के दौरान नॉनवॉवन को अंकुरण से बचने के लिए, सिल्वर ननोपार्टिकल्स शामिल पॉलिएस्टर नैनोकॉम्पोसिट फाइबर (P/Ag-NFs) का उपयोग किया गया। इसके अलावा, जीवाणुरोधी प्रभावकारिता को और बढ़ाने के लिए नॉनवॉवन का सतह परिवर्तन भी किया गया।

इस शोध का दूसरा हिस्सा पानी से जीवाणु के संदूषण को हटाने के लिए जीवाणुरोधी नॉनवॉवन के विकास की रिपोर्ट करता है। चिटोसन, एक प्राकृतिक जैवसक्रिय पदार्थ, जिसे नॉनवॉवन को फंक्शनलाइस करने के लिए चुना गया। चिटोसन नैनोपार्टिकल्स (CSN) के संश्लेषण के लिए एक अनोखी पर्यावरण के अनुकूल विधि विकसित की गई जिसमें चिटोसन और सिनैनामलडिहाइड रासायनिक रूप से क्रॉस-लिंक्ड किये गए। CSN की विस्तृत सामग्री लक्षण और जीवाणुरोधी गतिविधि का मूल्यांकन बहुत व्यवस्थित रूप से किया गया। संश्लेषित CSN को लेयर-बाय-लेयर (L-B-L) सेल्फ-असेंबली कोटिंग तकनीक का उपयोग करके पॉलिएस्टर नीडल-पंच नॉनवॉवन पर लागू किया गया। L-B-L कोटेड नॉनवॉवन ने उत्कृष्ट जीवाणुरोधी गतिविधि और भारी धातु आयनों सोखना व्यवहार का प्रदर्शन किया। कुल मिलाकर, L-B-L कॉटिंग तकनीक को नॉनवॉवन निस्पंदन मीडिया में वांछित कार्यक्षमताओं को लागू

करने के लिए एक आशाजनक विधि के रूप में स्थापित किया गया, जिससे इसकी पारगम्यता और अन्य भौतिक गुणों में कोई गिरावट नहीं हुई।

पॉलिएस्टर नीडल-पंच नॉनवॉवन के ऊपर चिटोसन के नैनोफाइबर कोटिंग को लागू करने का भी प्रयास किया गया। चिटोसन/ पाली (लैक्टिक एसिड) (CS/PLA) नैनोफाइबर्स को इलेक्ट्रोसपिनिंग तकनीक के माध्यम से सिल्वर नैनोवायरस (AgNWs) के साथ शामिल किया गया। इस प्रकार विकसित CS/PLA/AgNW समग्र नैनोफाइबर झिल्ली, उत्कृष्ट जीवाणुरोधी गुण और भारी धातु आयनों सोखना क्षमता को दर्शाता है। AgNWs को नैनोफाइब्रस संरचना के भीतर उपयुक्त रूप से एकीकृत पाया गया, जिसके परिणामस्वरूप झिल्ली से सिल्वर की कम मात्रा बाहर जा पाई, इसलिए इस जीवाणुरोधी झिल्ली को जल निस्पंदन अनुप्रयोगों के लिए उपयोग किया जाना सुरक्षित है। अंत में, CS/PLA/AgNW समग्र नैनोफाइबर झिल्ली को नीडल-पंच नॉनवॉवन पर लेपित किया गया, बाद में इसको एक जीवाणुरोधी फिल्टर कारतूस के विकास में उपयोग किया गया।

इस शोध के अंतिम भाग में इस शोध के पहले और दूसरे भाग में विकसित किए गए नॉनवॉवन निस्पंदन मीडिया का उपयोग करके दो-चरण जल शोधन प्रणाली के डिजाइन और विकास की रिपोर्ट है। निस्पंदन के पहले चरण में, पॉलिएस्टर नीडल-पंच नॉनवॉवन के साथ रखी गटर से गुजरने वाले अशुद्ध पानी को घन अशुद्धियों और मैलापन से छुटकारा मिला। इसके अलावा, बैक्टीरियल संदूषण और भारी धातु आयनों को CS/PLA/AgNW कम्पोजिट नैनोफाइबर झिल्ली के साथ लेपित पॉलिएस्टर नीडल-पंच नॉनवॉवन से विकसित जीवाणुरोधी कारतूस के माध्यम से निस्पंदन के दूसरे चरण में हटा दिया गया। इस प्रकार डिजाइन किए गए अद्वितीय जल शोधन उपकरण में निम्न स्तर का मशीनीकरण, कम जटिलता, उपयोग में आसानी और अकुशल लोगों द्वारा आसानी से बनाए रखा जा सकता है। यह सुरक्षित पीने योग्य पानी पहुंचाने के लिए एक स्थायी तकनीक के रूप में भी काम कर सकता है जो विद्युत शक्ति के बिना कार्य कर सकता है।

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ABBREVIATION AND SYMBOLS

g m^{-2}	Gram per meter square
cm^{-2}	Centimeter square
mm	millimeter
ft	foot
NTU	Nephelometric Turbidity Units
L h^{-1} ft^{-2}	Liter per hour per foot square
%	percentage
µm	micrometer
S.D	Standard deviation
nm	nanometer
g cm^{-2}	Gram per centimetre square
g L^{-1}	Gram per liter
°C	degree Celsius
in	inches
h	hour
min	minute
mbar	millibar
°	degree
s	second
cm	centimeter
psi	Pound-force per square inch
CFU	Colony-forming units
µL	microlitre
SE	Standard error
ppm	Parts per million
MW	Molecular weight
Da	Dalton
w/v	Weight / volume
v/v	Volume / volume
mL	millilitre
rpm	revolutions per minute

kV	kilovolt
mA	milliampere
MHz	megahertz
kHz	kilohertz
ms	milliseconds
θ	theta
W	Watt
cN tex^{-1}	Centinewton per Tex
AATCC	American Association of Textile Chemists and Colorists
ASTM	American Society for Testing and Materials
WHO	World Health Organization
S. aureus	*Staphylococcus aureus*
E. coli	*Escherichia coli*