Review Article

Nano Fibrous Materials for Capturing Air Pollutants in the Ambient Air - A Review

Padmavathi Papolu[1]*, Ashok Bhogi[1], Dharmikantha[2], Rahitya[2], Keshav[2] and Lakshmikanth[2]

[1]Department of Humanities and Sciences, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India; [2]Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India

Abstract

A number of air pollutants released from vehicles and Industries contaminate ambient air and causes air pollution which is the major threat to the globe at present. This results in damage to environment and public health. A serious research is in demand to mitigate air pollution by removing the air pollutants accumulated in the ambient air. This paper reviews about the different types Nano membranes used to filter pollutants from air. Fibrous filters are found to be the most economical and efficient devices to capture air pollutants. Pore size and fiber material properties play a major role in filtering air pollutants. Electrospinning technology is found to be the most versatile technique to prepare electrospun nanofibers used for filtration of air pollutants.

Keywords: Air pollutants, Nanofibers, porosity, filters, Electro spun nanofibers

***Correspondence**
Author: Padmavathi Papolu
Email id: padmavathi_p@vnrvjiet.in

Introduction

Environmental pollution has become the major concern in the world today threating the future with its consequences. Among all types of environmental pollutions air pollution is considered as the major pollution as it leads to respiratory diseases and results in death even. Generally, the size of the particulate matter that enters into human breath for air are in the range of 0.01-100μm and smaller the size deeper it penetrates into lungs and causes choking and unconsciousness and finally death. The main sources of air pollution since long time are vehicular exhaust and Industrial pollution. Apart from public the transport vehicles, personal vehicles contribute more to the total air pollution. Various greenhouse gases namely CO_2, CH_4, NO, and other gases like chlorofluorocarbon (CFCs) are liberated from the vehicles leading to pollution in air. These exhaust gases form a blanket over the atmospheric layer and reflects back the sun light. This increases the global temperature and leads to global warming. Along with vehicular pollution another major source of air pollution is Industrialization. With advancement of industrialization and urbanization air pollution is increasing and the polluted air is leading to millions of deaths every year. Ambient air quality can be improved by reducing the particulate matter accumulating in the air by filtration. One of the major globally concern at present is climate change and demanding for new strategies and techniques to mitigate global warming. Reducing the accumulation of all the greenhouse gases in the atmosphere will decrease environmental pollution.CO_2 is considered as one of the major greenhouse gas responsible for global warming. Hence a new technology for the direct capture of CO_2 from the ambient air is in demand and provides an useful tool for carbon management [1] Electrospinning technology and electrospun nanofibers are drawing attention both academically and industrially as they possess novel applications mostly in the fiber and textile industry [2]. Fibers with diameter less than 1 micron are called as nanofibers and possess novel properties due to them with their large surface area and porosity.

Material and Methods

High performance air filtration modes are used to filter air pollutants. A number of materials are in use to filter particulate matter from the atmosphere [3].

Adsorbing materials like activated carbon and fiberglass are generally used in the air filtration process because of their potential advantages. Activated carbon removes hazardous chemicals by adsorption process and high efficiency particulate air (HEPA) filters particulate matter from the ambient air. Advancement of nanotechnology benefited healthcare, energy and environment and showed solutions to deal with the problems in that sector [4-6].

As per the Inter-governmental Panel discussions over Climate Change, CO_2 emissions should be mitigated to 30–85% by 2050 for stabilizing atmospheric CO_2 in the range of 350 and 440 ppm by volume [7]. Based on all the studies to reduce greenhouse gases concentration in the ambient air membrane technology has come into rescue to filter off the pollutants from the ambient air. Nanomaterials and polymers play a major role in the manufacture of membranes.

Nanomaterials play a major role in the mitigation of environmental pollution. Nanofibers are found to be significant and nanostructured materials that are used in various fields like healthcare catalysis, electronics, protective Textiles, energy, and biotechnology and environment. Electrospinning is one of the methodologies to make nanofibers. Electro spun nanofibers consists of dense porous structure and large surface area to volume ratio and high permeability [8].

Polysulfide material with its special properties, like chemical inertness, compressive strength, thermal stability and mechanical strength are being used in the fabrication of membranes [9, 10].

Changing the dimensions of basic components of filtration process and filters will increase the efficiency of removal of even gaseous harmful substances [11, 12]. It is also found that with decrease of fiber filter thickness a rapid increase in the pressure loss will occurs during the flow of contaminated air through the membranes [13, 14]. This problem is solved by designing the membranes to capture the pollutants from air by enlarging the fibrous component exposed area and folding it in the form of folders [15]. Lackner et al. in 1999 reported first the concept of capturing CO_2 to reduce climate change [16].

Following the concept of green chemistry, use of toxic and harmful organic solvents are avoided in manufacturing membranes and are fabricated by electrospinning process using a non-toxic solvent [17].

This paper reviews about the various recent developments happened in the membrane technology and the capacity to enhance the filtration efficiency in the presence of a supporting material are highlighted.

Results and Discussions

High way motor vehicles contribute majorly to the air pollution. The most commonly found gas pollutant in the urban ambient air is Nitrogen dioxide which is a brownish, highly reactive gas. It is formed in the higher layers of the atmosphere as secondary air pollutant by the oxidation of Nitric Oxide (NO). NO is formed when the fuel containing nitrogen is burnt at high temperature. The various oxides of Nitrogen play a major part in the formation of acid rains. This affects the land and water ecosystems. Nitrogen is present as the non-combustible matter in the petrol or diesel and on combustion it is liberated out as oxides of Nitrogen. Carbon present as fixed carbon is responsible for the high calorific value of a fuel. Petrol and diesel containing carbon on combustion liberates CO_2 gas along with large amount of heat. Both CO_2 and NO_2 are responsible for air pollution hence membranes that can filter these gases are to be designed manufactured extensively. Usage of Nano membranes for air filtration has been started in 1980 [18]. Membranes with an average pore size of 40-2000nm and diameter of 100 – 1000nm can remove particulates of size microns to sub-microns from the ambient air [19-21].

Nano membranes are usually fabricated by three methods like Multi component fiber spinning Modular melt blown [22-25] and electro spun method. Nanocomposite polymers are developed to increase the efficiency of Nano fibrous membranes. Most commonly used nanoparticles are CNTs, ZnO and TiO_2.

Previous research works proved carbon dioxide and nitrogen dioxide molecules differ in their size. Due to the difference in their molecular sizes, oxides of carbon and nitrogen can be eliminated as different layers by suitable Nano membranes. Calcium, Sodium and potassium hydroxides can be used to absorb carbon-dioxide. The CO_2 that is absorbed in the sieves will be released in a controlled environment by treating the membrane at high temperatures [26].

Membrane contactor is another commonly used mechanism for carbon capture by physical and chemical adsorption mechanism.[27] The membrane contactor has been applied for acid gas removal from flue gas [28].

Membrane bioreactor is another method of removing aerosols from the ambient air. Development of antibacterial properties or formation of a biofilm on the Nano membrane will adsorb the organic pollutants and other aerosols into the membrane. Introducing antibacterial agents like Ag, Cu, ZnO, TiO_2 into polymeric solution to develop antibacterial properties in the membrane structure is studied by Aryanti. P et.al [29].

This also reduces the biofouling vanangamudi.etal used Al_2O_3 and Ag as antibacterial agents to prepare Nano fibrous membrane by electrospinning technique and the efficiency was increased by 94%.

From the literature studies it is found that to have an effective CO_2 capture the membranes or adsorbents should possess high CO_2 adsorption capacity and high CO_2 sensitivity along with high thermal, high chemical inertness, high mechanical stability and should be most economical [30].

Some of the recent studies showed that nanocrystalline zeolite works effectively for the removal of air pollutants. They convert CO_2 to more useful products [31].

Few authors studied on Electrospun nanofibers which can adsorb volatile organic compounds which causes pollution in the ambient air. Scholten et al reported that adsorption and desorption of VOC by electro spun Nano fibrous membranes Fig;1 was faster compared to conventional activated carbon [32, 35].

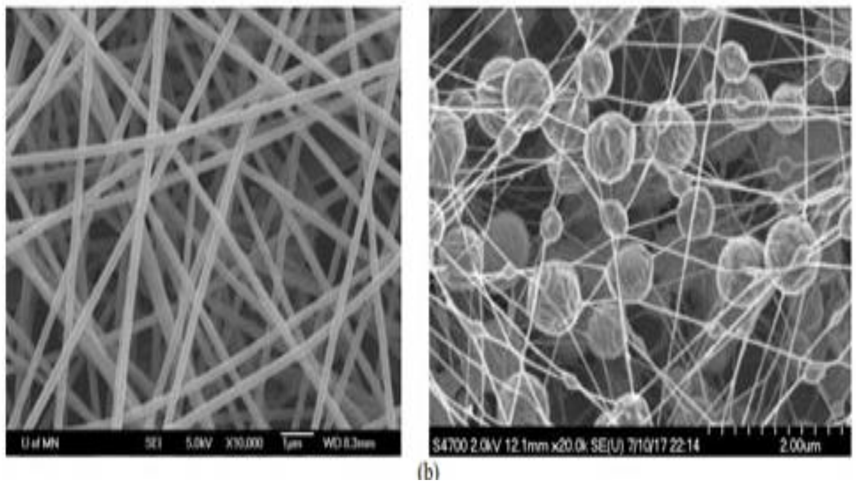

Figure 1 Electro spun nanofiber for Air filtration

Reactive organic materials like 3-carboxy-4-iodosobenzyl and oxy-b-cyclodextrin are incorporated into nanofibers along with polymers in electrospun process and tested for purification of chemical warfare agents [33-34] and the results was impressive and found to be more effective than normal activated charcoal adsorption method [36-38].

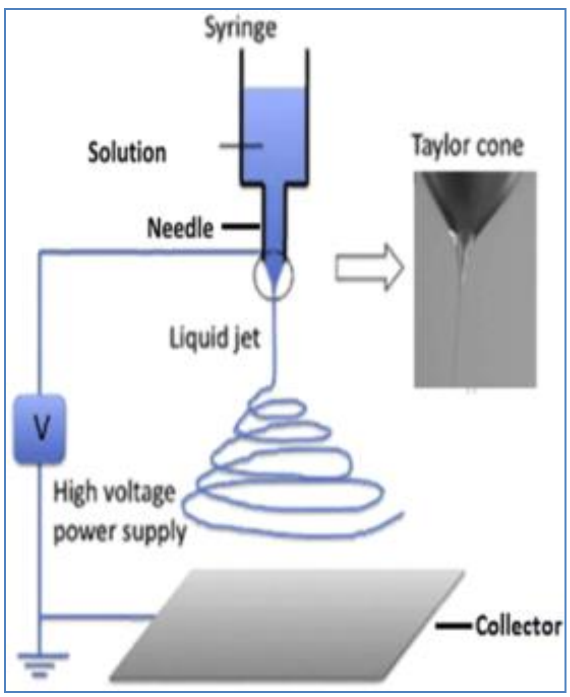

Figure 2 Electro spun nanofiber mechanism

In another research work it is found that when small amounts of TiO_2 nanoparticles were electro sprayed over increases the mechanical properties (0.36 MPa for polyimide and 0.65 MPa for polyimide/TiO_2 membrane) of Nano fibrous membrane.

Conclusion

With increased pollutant levels in ambient air the demand for air purifiers is increasing day by day. Residential and highly populated enclosed areas are the targeted places to focus on the requirement of air purifiers. Nano fibrous membranes are found to be the most interesting features for air filtration process due to their unique properties like high surface area, high porosity, low pressure. Research on low cost, corrosion resistant, antibacterial properties is in progress. Usage of conventional glass fibers and charcoal filters are now being replaced with various nanofiber filters or a combination of both for more efficiency. The filtration efficiency has been improved many folds with enhanced protection and sustainability. Nano membranes help to mitigate pollution existing in ambient air and reduce health problems like asthma and respiratory diseases. Improved air filter membrane fabrication techniques also reduces the usage of hazardous chemicals employed for removing air pollutants. Green electrospinning technology is introduced to overcome these problems.

Acknowledgement

We thank the Center for Nanoscience and Technology of VNRVJIET for their support.

References

[1] Lackner K.S., Grimes P. and Ziock H.J., Capturing Carbon Dioxide from Air, Colombia University (2007).

[2] DeWeerdt, S. (2016). Mobility: The urban downshift. Nature, 531(7594), S52-S53. Ding, B., & Yu, J. (2014). Electrospun Nanofibers for Energy and Environmental Applications. Springer Berlin Heidelberg.

[3] Shan, W., Zhao, X., Xia, Y., Yu, J., & Ding, B. (2016). Electret Polyvinylidene Fluoride Nanofibers Hybridized by Polytetrafluoroethylene Nanoparticles for High-Efficiency Air Filtration. Acs Applied Materials & Interfaces, 8(36). Biomedical Applications, Macromolecular Bioscience 12, 286-311.

[4] Sundarrajan, S., Ramakrishna, S., 2013. New Directions in Nanofiltration Applications – Are Nanofibers the Right Materials as Membranes in Desalination?, Desalination 308, p 198-208

[5] Wang, C.; Yan, E.; Huang, Z.; Zhao, Q.; Xin, Y. Fabrication of highly photoluminescent

[6] TiO2/PPV Hybrid nanoparticle-polymer fibers by electrospinning. Macromol. Rapid Commun. 2007, 28, 205–209.

[7] Gopal, R.; Kaur, S.; Ma, Z.; Chan, C.; Ramakrishna, S.; Matsuura, T. Electrospun nanofibrous filtration membrane. J. Membr. Sci. 2006, 281, 581–586.

[8] IPCC (2007) Intergovernmental Panel on Climate Change. Climate Change 2007, Fourth Assessment Report, Synthesis.

[9] Gopal, R.; Kaur, S.; Chao, Y.F.; Chan, C.; Ramakrishna, S.; Tabe, S.; Matsuura, T. Electrospun nanofibrous polysulfone membranes as pre-filters: Particulate removal. J. Membr. Sci. 2007, 289, 210–219.

[10] Li, F.; An, Q.F.; Zhou, H.P.; The dependence of structure of polysulfone ultrafiltration membrane on the properties of casting solution, Technology of Water Treatment, Vol. 3, 2009, pp. 23-26.

[11] Kim, I. C.; Lee, K. H.; Effect of various additives on pore size of polysulfone membrane by phase-inversion process， Journal of Applied Polymer Science, Vol.89, 2003, pp. 2562-2566.

[12] Kaur, S.; Barhate, R.; Sundarrajan, S.; Matsuura, T.; Ramakrishna, S. Hot pressing of electrospun membrane composite and its influence on sepration performance of thin film composite nanofiltration membrane. Desalination 2011, in press

[13] 12.R. Baciocchi, G. Storti, M. Mazzotti, Process design and energy requirements for the capture of carbon dioxide from air, Chem. Eng. Proc. 45, 1047–1058 (2006)

[14] Praus P., Dvorsky R., Kozak O. and Koci K., Zinc Sulphide Nanoparticles for Photochemical Reactions: Reduction of Carbondioxide and Oxidation of Phenols, Nanocon, Czech Republic (2011

[15] Albo J., Luis P. and Irabien A., Carbon Dioxide Capture from Flue Gases Using a Cross-Flow Membrane Contactor and the Ionic Liquid 1-Ethyl-3-methylimidazolium Ethylsulfate, Ind. Eng. Chem. Res., 49(21), 11045-11051 (2010).

[16] 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

[17] K. Lackner, H.-J. Ziock, P. Grimes, Los Alamos National Lab., NM (US), 1999.

[18] A silk fibroin based green nano-filter for air filtration Xiaochao Gao,a Jing Gou,a Ling Zhang,*a Shasha Duana and Chunzhong Li,RSC ADVANCES, ISSUE 15,2018.

[19] Thavasi V, Singh G, and Ramakrishna S 2008 Energ. Environ. Sci. 1 (2) 205-221.

[20] Zhu M, Han J, Wang F, Shao W, Xiong R, Zhang Q, Pan H, Yang Y, Samal S K, and Zhang F 2017 Macromol. Mater. Eng 302 (1) 1600353.

[21] Aussawasathien D, Teerawattananon C, and Vongachariya A 2008 J. Mem. Sci. 315 (1-2) 11-19.

[22] Gopal R, Kaur S, Feng C Y, Chan C, Ramakrishna S, Tabe S, and Matsuura T 2007 J. Mem. Sci.(1-2) 210-219.

[23] Takajima T, Kajiwara K, and McIntyre J E, Adv. Fiber Spinning Technol. 1994: Woodhead Publishing. Uppal

R, Bhat G, Eash C, and Akato K 2013 Fibers Polym. 14 (4) 660-668.
[24] Ward G 2005 Filtr. Sep. 42 (7) 22-24.
[25] Hassan M A, Yeom B Y, Wilkie A, Pourdeyhimi B, and Khan S A 2013 J. Mem. Sci. 427 336- 344.
[26] Abanades J.C. and Alvarez D., Conversion Limits in the Reaction of CO2 with Lime, Energy Fuels 17(2), 308–315, (2003).
[27] Mansourizadeh A, Ismail A, and Matsuura T 2010 J. Mem. Sci. 353 (1-2) 192-200.
[28] Yan S-p, Fang M-X, Zhang W-F, Wang S-Y, Xu Z-K, Luo Z-Y, and Cen K-F 2007 Fuel Processing Technol. 88 (5) 501-511.
[29] Aryanti P, Sianipar M, Zunita M, and Wenten I 2017 Mem. Water Treat. 8 (5) 463-481.
[30] Praus P., Dvorsky R., Kozak O. and Koci K., Zinc Sulphide Nanoparticles for Photochemical Reactions: Reduction of Carbondioxide and Oxidation of Phenols, Nanocon, Czech Republic (2011)
[31] .Albo J., Luis P. and Irabien A., Carbon Dioxide Capture from Flue Gases Using a Cross-Flow Membrane Contactor and the Ionic Liquid 1-Ethyl-3-methylimidazolium Ethylsulfate, Ind. Eng. Chem. Res., 49(21), 11045-11051 (2010).
[32] 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
[33] 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.
[34] 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.
[35] Zhang, L., Li, L., Wang, L., Nie, J., & Ma, G. (2020). Multilayer electrospun nanofibrous membranes with antibacterial property for air filtration. Applied Surface Science, 515, 145962.
[36] Devarayan, K., & Kim, B. S. (2015). Reversible and universal pH sensing cellulose nanofibers for health monitor. Sensors and Actuators B: Chemical, 209, 281-286.
[37] Devarayan, K., Nakagami, S., Suzuki, S., Yuki, I., & Ohkawa, K. (2020). Electrospinning and post-spun chain conformations of synthetic, hydrophobic poly (α-amino acid) s. Polymers, 12(2), 327.
[38] Devarayan, K., Lei, D., Kim, H. Y., & Kim, B. S. (2015). Flexible transparent electrode based on PANi nanowire/nylon nanofiber reinforced cellulose acetate thin film as supercapacitor. Chemical Engineering Journal, 273, 603-609.

Publication History

Received	23.10.2021
Revised	07.01.2022
Accepted	08.01.2022
Online	19.01.2022