INVESTIGATION OF THE EFFECT OF PRODUCTION PARAMETERS ON POLYSTYRENE NANO FIBER FORMATION FOR 12 WT %, 14 WT % AND 16 WT %

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Abstract— *Polystyrene (PS) is a versatile plastic used to produce a wide variety of consumer products. It is used as a hard, solid plastic, mostly as food packaging and laboratory products. When polystyrene is mixed with various colorants, additives or other plastic materials, it is used to make electronic parts, automobile parts, toys, pots and equipments and more. Polystyrene is a vinyl polymer. It is structurally a long hydrocarbon chain with a phenyl group attached to the carbon atom. Polystyrene is produced by free radical vinyl polymerization from monomer styrene. In this study, the effect of production parameters on the formation of PS nanofibers was investigated. For this purpose, solutions were prepared at various mixing ratios (12 wt %, 14 wt % and 16 wt %) consisting of PS + dimethylformamide (DMF). The nanofiber structure was determined from these solutions. Electrospin method was used in production of nanofibers.*

KEYWORDS*:* ELECTROSPIN METHOD, NANO FIBER, POLYSTYRENE.

1.Introduction

Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering. The ideas and concepts behind Nanoscience and nanotechnology started with a talk entitled “There’s Plenty of Room at the Bottom” by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (CalTech) on December 29, 1959, long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. Over a decade later, in his explorations of ultra precision machining, Professor Norio Taniguchi coined the term nanotechnology. It wasn't until 1981, with the development of the scanning microscope that could "see" individual atoms, that modern nanotechnology began [1]. Nanotechnology is also being applied to or developed for application to a variety of industrial and purification processes. Purification and environmental cleanup applications include the desalination of water, water filtration, waste water treatment, groundwater treatment. In industry, applications may include construction materials, military goods, and nano-machining of nano-wires, nano-rods, few layers of graphene, etc. Also, recently a new field arisen from the root of nanotechnology is called nanobiotechnology [2].

2.Nanofiber

Nanofibers are fibers with diameters in the nanometer range. Nanofibers can be generated from different polymers and hence have different physical properties and application potentials. Polymer chains are connected via covalent bonds. The diameters of nanofibers depend on the type of polymer used and the method of production. All polymer nanofibers are unique for their large surface area-to-volume ratio, high porosity, appreciable mechanical strength, and flexibility in functionalization compared to their microfiber counterparts [3]. There are 8 methods of producing nanofiber. These are presented below

- Drawing method
- Phase separation method
- Self attachment method
- Chemical vapor deposition method (CVD)
- Nano-mold method
- Melt spray method
- Laser evaporation method
- Electrospin method

In this study, electrospin method was used.

Fig.1. illustrates the broad domains of polymer nanofibers that are being actively researched on. About 50% of the papers are focused on the electrospinning process development and characterization of fibers. Others are focused on innovative use of polymer nanofibers for a variety of applications in medicine, biotechnology, and engineering [4].

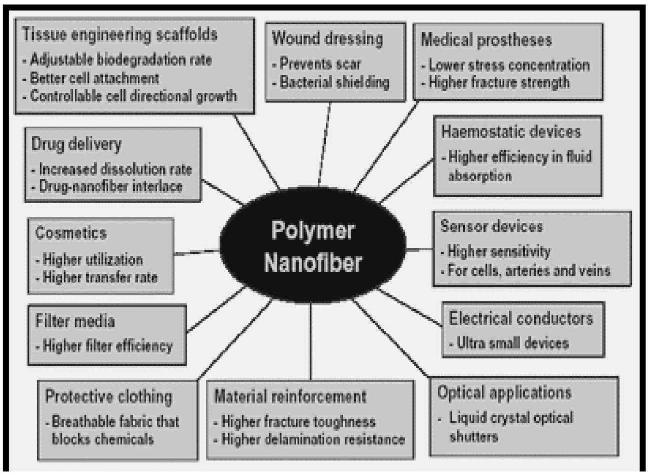

Fig. 1. *Potential applications of polymer nanofibers. Polymer nanofibers are candidates for a number of applications in medicine, biotechnology, and engineering, because of their large surface area to volume ratio and unique nanometer scale architecture*

3.Electrospinning theory and process

The schematic diagram of the electrospinning is illustrated in Fig.2 [5]. Electrospinning is a unique approach using electrostatic forces to produce fine fibers. Electrostatic precipitators and pesticide sprayers are some of the well known applications that work similarly to the electrospinning technique. Fiber production using electrostatic forces has invoked glare and attention due to its potential to form fine fibers. Electrospun fibers have small pore size and high surface area. There is also evidence of sizable static charges in electrospun fibers that could be effectively handled to produce three dimensional structures. Polymer solution or the melt that has to be spun is forced through a syringe pump to form a pendant drop of the polymer at the tip of the capillary. High voltage potential is applied to the polymer solution inside the syringe through an immersed electrode, thereby inducing free charges into the polymer solution. These charged ions move in response to the applied electric field towards the electrode of opposite polarity, thereby transferring tensile forces to the polymer liquid. At the tip of the capillary, the pendant hemispherical polymer drop takes a cone like projection in the presence of an electric field. And, when the applied potential reaches a critical value required to overcome the surface tension of the liquid, a jet of liquid is ejected from the cone tip [6, 7].

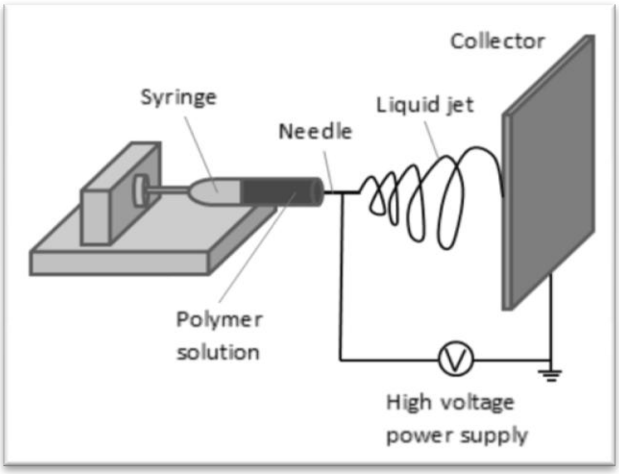

Fig. 2. *The schematic diagram of the electrospinning experimental setup*

It is essential to adjust electrospinning parameters to obtain uniform nanofibers. The parameters affecting the electrospinning process are represented in Fig. 3 [8].

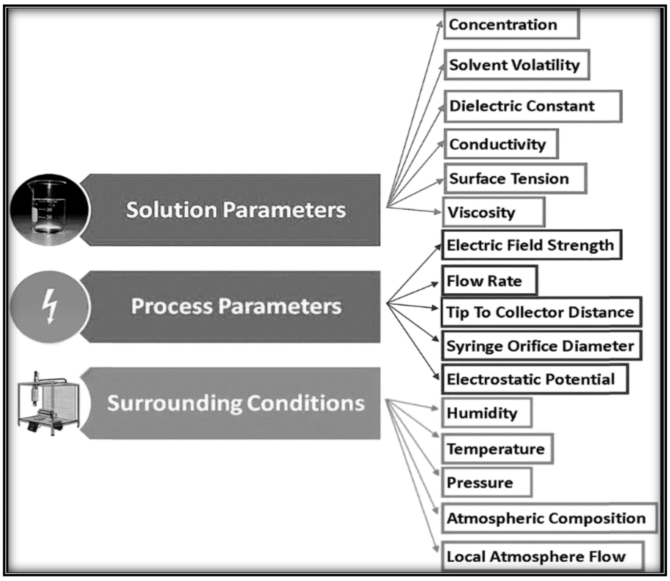

Fig. 3. *Parameters affecting the electrospinning process*

4. Experimental

In this study, PS and DMF were used. Polystyrene can be solid or foamed. General-purpose polystyrene is clear, hard, and rather brittle. It is an inexpensive resin per unit weight. It is a rather poor barrier to oxygen and water vapor and has a relatively low melting point [9]. Polystyrene is one of the most widely used plastics, the scale of its production being several million tons per year [10]. Polystyrene can be naturally transparent, but can be colored with colorants. Uses include protective packaging (such as packing peanuts and CD and DVD cases), containers (such as "clamshells"), lids, bottles, trays, tumblers, disposable cutlery [9] and in the making of models. As a thermoplastic polymer, polystyrene is in a solid (glassy) state at room temperature but flows if heated above about 100 °C, its glass transition temperature. It becomes rigid again when cooled. This temperature behaviour is exploited for extrusion (as in Styrofoam) and also for molding and vacuum forming, since it can be cast into molds with fine detail. Polystyrene is slow to biodegrade and is therefore a focus of controversy among environmentalists. It is increasingly abundant as a form of litter in the outdoor environment, particularly along shores and waterways, especially in its foam form, and also in increasing quantities in the Pacific Ocean [11]. The molecular structure of PS is shown in Fig. 4.

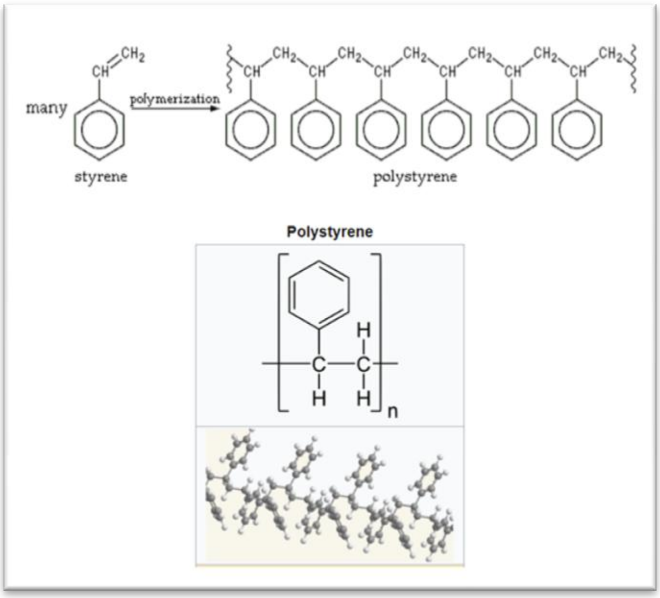

Fig.4. *The molecular structure of PS [11]*

N,N-Dimethylformamide is the commonly employed solvent for chemical reactions. DMF is a useful solvent employed for the isolation of chlorophyll from plant tissues. It is widely employed reagent in organic synthesis. It plays multiple roles in various reactions such as solvent, dehydrating agent, reducing agent as well as catalyst. It is a multipurpose building block for the synthesis of compounds containing O, -CO, $-NMe_2$, $-CONMe_2$, -Me, -CHO as functional groups. N,N-Dimethylformamide is a polar solvent commonly used in organic synthesis. It also acts as a multipurpose precursor for formulation, amination, aminocarbonylation, amidation and cyanation reactions [23]. The molecular structure of DM is shown in Fig. 5.

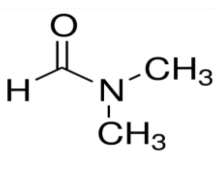

Fig.5. *The molecular structure of DMF [12]*

A PS with an average molecular weight (Mw) of 192000 g/mol and N, N-Dimethylformamide anhydrous, 99.8% were purchased from the Sigma Aldrich Co. all the materials were used as- received without further purification. The experimental setup is shown in

Fig.6. In this study, four types of solutions were prepared. These are 12 %, 14 %, 15 %, 16 % by weight. Then the mixture was stirred in a magnetic stirrer. Once the homogenization process ended, the solution samples were brought to the room temperature. After reaching the room temperature, the prepared electrospinning solutions were poured into a 2.5 mL syringes with 0.8 mm as inner diameter in order to proceed with the electrospinning setup.

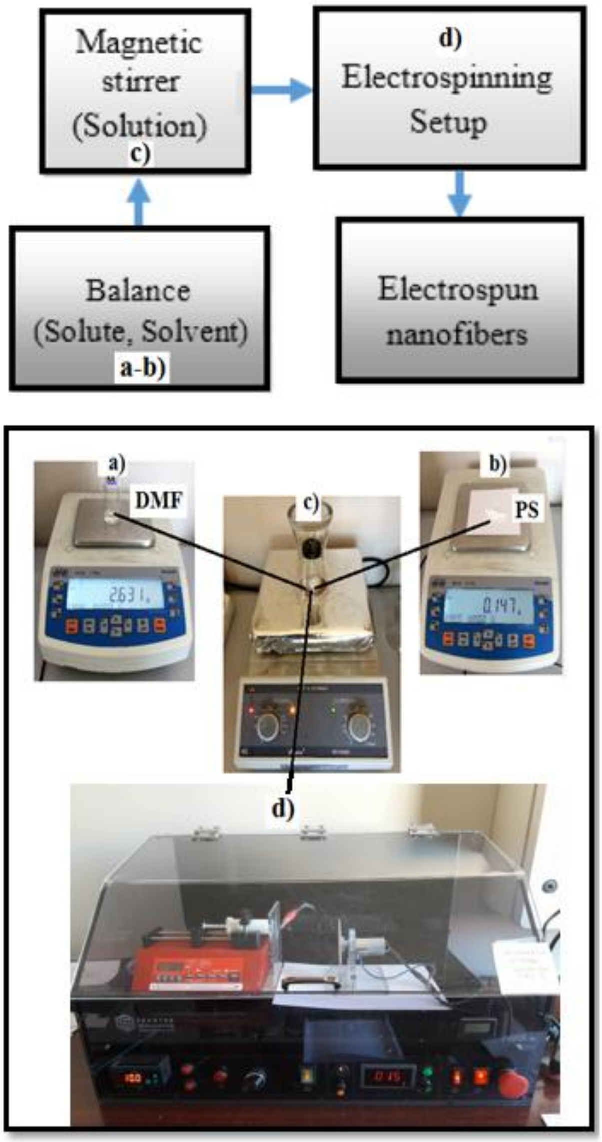

Fig.6. Experimental setup

Sample No : 1 (12 wt. % PS polymer content)

At 50 °C and 500 rpm, the solution was stirred for 1 hour.
Applied voltage (kV) : 20
The mass flow rate : 1 mL / h
Distance between pipette and collector : 14 cm
Collector Speed : 750 rpm (15%)
Result : The homogeneous surface did not occur (Fig.7)

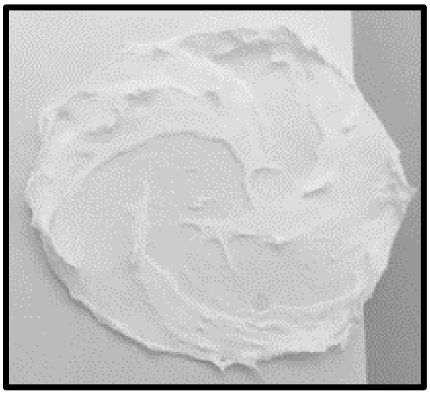

***Fig. 7.** Pictures of PS nanofibers for 12 wt. %*

Sample No : 2 (14 wt. % PS polymer content)

At 50 °C and 500 rpm, the solution was stirred for 2 hour
Applied voltage (kV) : 15
The mass flow rate : 1 mL / h
Distance between pipette and collector : 14 cm
Collector Speed : 750 rpm (15%)
Result : The homogeneous surface did not occur. Also, in the middle part of the sample, a filamentous structure was observed (Fig. 8).

***Fig. 8.** Pictures of PS nanofibers for 14 wt. %*

Sample No : 3 (15 wt. % PS polymer content)

At 90 °C and 500 rpm, the solution was stirred for 1 hour
Applied voltage (kV) : 20
The mass flow rate : 1 mL / h
Distance between pipet and collector : 10 cm
Collector Speed : 750 rpm (15%)
Result : The homogeneous surface did occur. But no nanofibers formed in the middle (Fig. 9).

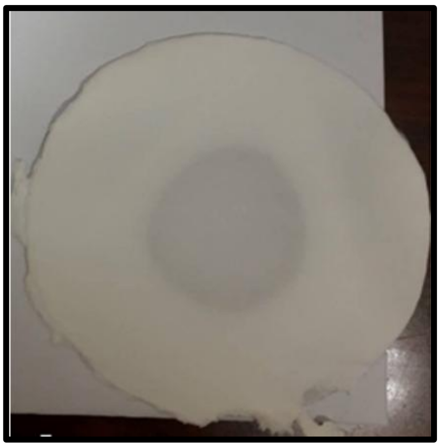

***Fig. 9.** Pictures of PS nanofibers for 15 wt. %*

Sample No :4 (16 wt. % PS polymer content)

At 90 ^{o}C and 500 rpm, the solution was stirred for 1 hour
Applied voltage (kV) : 20
The mass flow rate : 0.5 mL / h
Distance between pipette and collector : 16 cm
Collector Speed : 750 rpm (15%)
Result : The homogeneous surface occurred
The average diameter of nanofibers PS = 1591 nm (Fig.10).

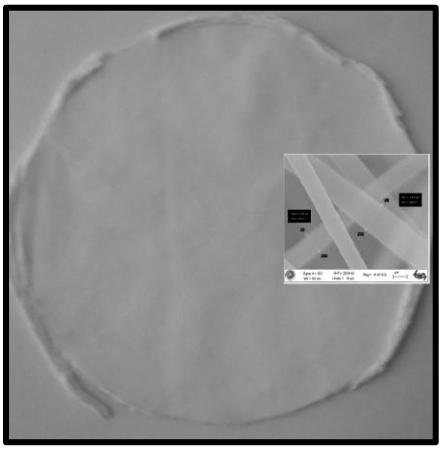

Fig. 10. *Pictures of PS nanofibers for 15 wt. % and sample no : 4*

Sample No : 5 (16 wt. % PS polymer content)

At 90 ^{o}C and 500 rpm, the solution was stirred for 1 hour
Applied voltage (kV) : 20
The mass flow rate : 1 mL / h
Distance between pipette and collector : 16 cm
Collector Speed : 750 rpm (15%)
Result : The homogeneous surface occurred
The average diameter of nanofibers PS = 1237 nm (Fig.11).

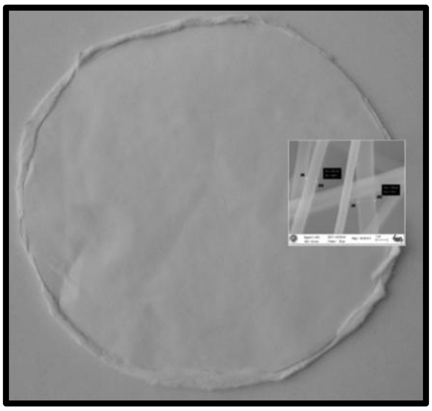

Fig. 11. *Pictures of PS nanofibers for 15 wt. % and sample no : 5*

Sample No : 6 (16 wt. % PS polymer content)

At 90 ^{o}C and 500 rpm, the solution was stirred for 1 hour
Applied voltage (kV) : 20
The mass flow rate : 1.5 mL / h
Distance between pipette and collector : 16 cm
Collector Speed : 750 rpm (15%)
Result : The homogeneous surface occurred
The average diameter of nanofibers PS = 1190 nm (Fig.12).

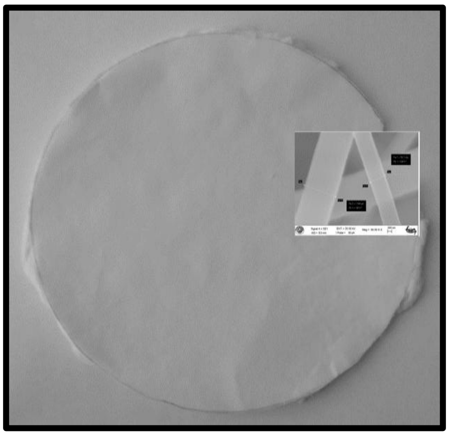

Fig. 12. *Pictures of PS nanofibers for 15 wt. % and sample no : 6*

5. Conclusions

In this study, the effect of production parameters on the formation of PS nanofibers was investigated. For this purpose, solutions were prepared at various mixing ratios (12 wt %, 14 wt %, 15 wt % and 16 wt %) consisting of PS+DMF. The nanofiber structure was determined from these solutions. Electrospin method was used in production of nanofibers. The homogeneous surface did not occurred for 12 wt %, 14 wt %, 15 wt % PS polymer content. At 16 wt % PS polymer content, the homogeneous surface occurred. At 16 wt % PS polymer content, it was determined that the average nanofiber diameter decreased as the mass flow rate increased.

5. References

[1] https://www.nano.gov/nanotech-101/what/definition.

[2] https://en.wikipedia.org/wiki/Applications of nanotech.

[3] https://en.wikipedia.org/wiki/Nanofiber

[4][https://www.azonano.com/article.aspx?ArticleID=1280] .

[5] Thi Thu Trang Mai, Thi Thu Thuy Nguyen, Quang Duong Le, Thi Ngoan Nguyen, Thi Cham Ba, Hai Binh Nguyen, Thi Bich Hoa Phan, Dai Lam Tran, Xuan Phuc Nguyen and Jun Seo Park, A novel nanofiber Cur-loaded polylactic acid constructed by electrospinning, Adv. Nat. Sci.: Nanosci. Nanotechnol. 3 (2012) 025014.

[6]Thandavamoorthy Subbiah, G. S. Bhat, R. W. Tock, S. Parameswaran, S. S. Ramkumar, Electrospinning of Nanofibers, Journal of Applied Polymer Science, Vol. 96, 557-569, 2005.

[7] Kevser Dincer, Basma Waisi, M. Ozan Ozdemir, Ugur Pasaogullari, Jeffrey McCutcheon, Experimental Investigation of Proton Exchange Membrane Fuel Cells Operated with Nanofiber and Nanofiber/Nanoparticle, World Academy of Science, Engineering and Technology International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering Vol:9, No:12, 2015.

[8] M. V. Vellayappan,J. R. Venugopal,b S. Ramakrishna, S. Ray, A. F. Ismail, M. Mandal, A. Manikandan, S. Sealg and S. K. Jaganathan, Electrospinning applications from diagnosis to treatment of diabetes, RSC Adv., 2016, 6, 83638–83655.

[9] Common Plastic Resins Used in Packaging. *Introduction to Plastics Science Teaching Resources. American Chemistry Council, Inc*. Retrieved 24 December 2012.

[10] Maul, J., Frushour, B. G., Kontoff, J. R., Eichenauer, H., Ott, K.-H. and Schade, C. (2007). Polystyrene and Styrene Copolymers. in Ullmann's Encyclopedia of Industrial ChemistryWiley-VCH,
Weinheim, doi:10.1002/14356007.a21_615.pub2.

[11] https://en.wikipedia.org/wiki/Polystyrene.

[12]https://www.sigmaaldrich.com/catalog/product/sial/227056?lang=en&region=TR.