Revolutionizing Industry Applications through Solution Blow Spinning (SBS): Innovations, Challenges, and Future Perspectives

Peipei Qin

School of Physics and Astronomy, University of Glasgow, Scotland, British

fahimaqin@outlook.com

Abstract. This review aims to discuss the development, issue, challenges and prospects of Solution Blow Spinning (SBS) for fabricating nanofibers. SBS has a combination of melt blowing and electrospinning where the process can be easily scaled up without the help of an electric field. It describes SBS's usage in cleaning up contaminated environments, electronics, and the biomedical industry to show its versatility in different industries.

Keywords: Nanofibers, Solution Blow Spinning (SBS), Scalable Production.

1. Introduction

Nanofibers, compared to conventional nanomaterials, are distinguished by their extremely high surface-to-volume ratio and high porosity [1]. These characteristics enable their application in numerous fields, such as electrode materials, filtration and adsorption materials, and biomedical materials [2].

Currently, the most widely applied method for preparing nanofibers is electrospinning [3], with other techniques including melt blowing [4], wet spinning, centrifugal spinning, self-assembly, and solution blow spinning also being utilized. However, in the preparation of biopolymer fibers, methods like melt blowing are not feasible due to the denaturation of biopolymers at high temperatures, necessitating the use of non-thermal processes for fiber fabrication. Solution blowing spinning (SBS) is a new fiber manufacturing technology which combined melt blowing and electrospinning principles to produce micro- or nanoscale fibers from polymer solutions without the need of an electric field, thereby simplifying the equipment and permitting continuous fiber production without drying or cooling, allowing scalability [3, 4].

Solution blow-spinning allows nanofibers to be sprayed on the fiber and material substrates, including cotton, rabbit fur, and silk. This attribute further expands the scope of nanofiber technology application. Due to the high permeability of nanofibers, solution blow spun ones are not preferred as ideal scaffold for cells as they are not encouraging cell proliferation, differentiation and infiltration. Research revealed that solution blow spinning can yield nanofiber materials with exceptional accuracy, efficiency, and reliability. The simplicity of setting up the equipment and the direct deposition of fibers provide a foundation for the use of nano fiber in manufacturing of functional polymer nanofiber coatings and stretchable electronics. In the past years, publications on the trend have increased and this can be attributed to the maturing technology with huge potential in it. This review considers its recent developments and impact on environmental remediation, flexible electronics, energy storage, and biomedical engineering by emphasizing on the diversity and efficiency of SBS technology in the production of ultrafine fibers; this is shifting the fields in new directions. The objective of the review is to provide a complete and balanced survey of the wide areas in which SBS could be usefully put into practice and how it could help address current sector challenges (Figure 1).

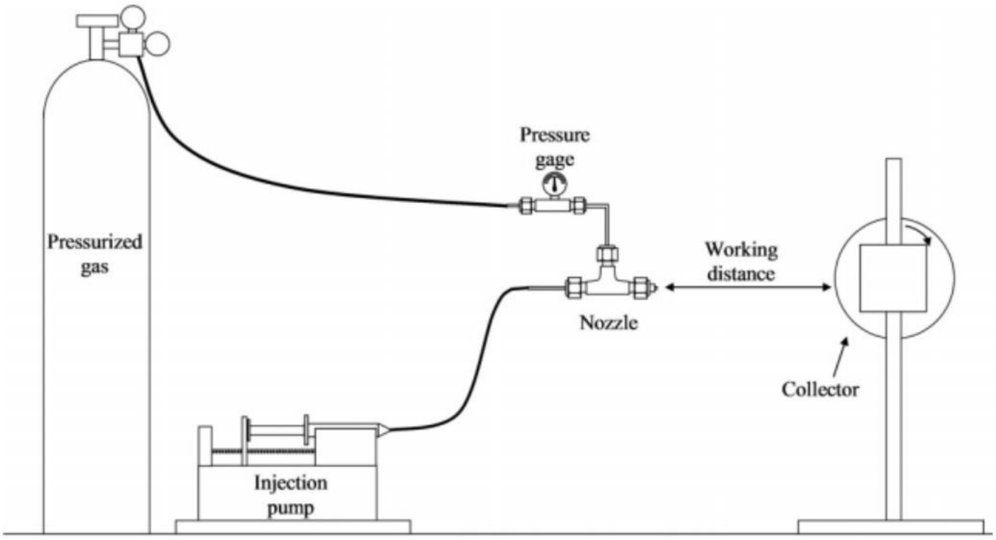

Figure 1. Solution blow spinning setup. (Source: Medeiros et al., (2009))

2. Environmental Remediation and Pollution Control

The development of Solution Blow Spinning (SBS) technology denotes a radical step forward for the efforts of environmental remediation and pollution control. In this section the studies adopted the SBS technology for air filtration and uranium recovery are compared revealing the flexibility and efficiency of this technology when dealing with pollution problems and waste recovery.

Li et al. (2020) have investigated the PI nanofibrous membrane synthesis by using the SBS process, with the interested in the excellent particulate matter (PM2.5) removal, especially even in high-temperature operation conditions, where other methods are almost inefficient [5]. The study showed the membranes' exceptional technological thermal stability up to 420°C and the ability to maintain their high filtration efficiency (>97%) for PM0.3-10 particles at elevated temperatures, which means that these would be promising solutions for industrial settings with high-temperature emissions.

In contrast, Khalid et al. (2017), there were nanofibers spun directly on window screens producing the new approach to air quality indoors improvement. Their study accentuated the gravity of fabrication and its scalability as well as cost effectiveness, with transparent filters eliminated over 90% efficiency PM2.5 removal, presenting a practical solution for urban environments affected with air pollution [6].

Wang et al. (2018) proposed a novel method of uranium extraction from seawater by generating a new adsorbent called poly (imide dioxime) (PIDO) nanofiber through SBS strategy. Their research highlighted the prominence of the adsorbents in terms of their efficiency, with significantly higher uranium adsorption capacities than fiber-based solutions that are currently used, demonstrating sustainability as an alternative to conventional uranium sources [7].

Both Li et al. (2020) and Khalid et al. (2017) use SBS for air filters, but Li et al. (2020) is distinctive in applying it to high-temperature pollution sources, showing SBS's adaptability when the emission comes from the challenging industrial conditions [5]. Khalid et al. (2017) methodology on indoor air quality brings out the technology's capability of solving outdoor and indoor issues [6]. Wang et al. (2018) on uranium extraction extend the applicability of SBS for the mainstream techniques beyond the air filtration, demonstrating its usefulness for resource recovery and environmental protection [7].

Through the PI nanofibrous membranes, Li et al. (2020) obtained the remarkable thermal stability which is the key attribute for their high-temperature applications and this attribute is not available in polymer-based filters as Khalid et al., (2017) designed their filters for normal conditions [5, 6]. Wang et al. (2018) map a new road to the SBS – that is PIDO nanofibers – by demonstrating the viability of producing materials with a desired chemical functionality imperative for the uranium extraction [7].

The open-air filters from Khalid et al. (2017) offer an immediate remedy to the deterioration of the indoor air quality that can be felt the most in urban areas [6]. While the heat-resistant filters by Li et al. (2020) focus on occupying a very niche yet significant market segment [5], this is in contrast to the only flame retardant filters. The work by Wang et al. (2018) concerning uranium extraction has mapped out new paths for sustainable energy resource development, illustrating the broad-spectrum environmental applications of SBS technology [7].

These studies collectively exemplify the massive impact of SBS technology in remediation and pollution control. The fabrication technique of SBS excels in many ways such as cooling and purification of the air in varying wide temperature ranges or in pioneering methods for sustainable utilization of resources.

3. Electrode Materials

Huang et al. (2020) used the same solution blow spinning technique as creating a 3D nanofiber scaffold with lithium lanthanum titanate, which remained stable in its polymer form and increased the lithium ion channels [8]. The formed polymer electrolyte which consists of composite nature is capable to have the room-temperature ionic conductivity level above 70% higher than electrospun type of fibers which can elongate the lifespan of Lithium batteries. Silva et al. (2019) prepared a new material, NiO-HF, based on the solution blow spinning method and demonstrated that its performance for electrocatalysis was the best and the stability of the prepared electrodes was maintained for over 15 hours [9]. Ruiz et al. (2020) were the first to prepare gradient nanocomposites of polymer-based materials with solution blowing, as an enhanced material with optimal dielectric properties [10]. The solutions or suspensions were constantly sprayed using specific solutions, and the materials were layer by layer manufactured to obtain a PVDF gradient polymer-based composite material with high dielectric constants and low dielectric losses. Unlike electrospinning and melt spinning, solution blow spun nanofiber mats are porous, fluffy and with no limitations on solutions used. This offers the possibility for generating higher surface charge, leading to more friction and hence greater power. On this basis, the nanofiber mats with raw materials such as soy protein and lignin were prepared by An et al. (2018), and the vine-like structure was also added in to ensure good elasticity and conductivity [11]. Wang et al (2018) developed ITO nanofiber transparent electrodes that are highly flexible by blow spinning, resulting in greater flexibility and durability under bending operation that, in turn, increases the performance and the rife of the flexible electronic devices [7].

4. Filtration and Separation Materials

Khalid et al. (2017) synthesized a nanofiber-composite, transparent air filter by way of a screen window detention method through the solution blow spinning technique with 80% of the transparency accomplished [6]. Doubled experiments demonstrated that this nanofiber air filter has a removal rate of 90.6% for PM2.5 under extreme pollution condition of PM2.5>708g/m^3 within 12 hours, and it is very easy to clean. Ye at al. (2020) prepared a PLA nanofiber membrane modified with metal oxide through solution blow spinning and demonstrated outstanding water-oil separation efficiencies. Tan et al. (2019) dispersed cellulose diacetate (CDA), polyacrylonitrile (PAN) and polyvinylidene fluoride (PVDF) on the needle of the spinning machine filtering PM2.5 via solution blow spinning technique [12]. Studies have proved that composite masks made from solution blow spun nanofiber filters reportedly have a coat with incredible filtration performance and surpassing commercial masks. Alvarenga and Correa (2021) prepared composites of polyamide 6 nanofibers (PA6) mixed with sugarcane bagasse fly ash at 800°C in the atmosphere of CO2, which were used to make nanofiber membranes that can absorb efficiently at high flow rates and low pressure drops, with high reusability [13]. This adsorbent, which is economical and highly functional, seeks to substitute traditional methods that were costly and inefficient in the process of removing water pollutants. Li et al. (2020) produced an air filter consisting of heat resistant polyimide (PI) nanofiber via solution blow spinning with very good thermal stability at 420°C and high efficacy of filtration reaching 99.73%, plus airflow resistance being lowerable, with 97% of the particulates in vehicle exhaust being removed [14]. This feature exhibits the high resolution of solution blow spinning technology in development of materials for high temperature filtration applications. Khalid et al., (2017) devised a new coating technique on window screen through direct blow-spinning, getting more than 99.7% filtration efficiency of PM2.5 in severe pollution condition [6]. The method is useful, and the coated screen can be maintained in transparent form and ease of cleaning. The breakthrough method of Wang et al. (2018) for the extraction of uranium from seawater using mass-produced aggregate fully amidoximated nanofiber adsorbents was presented, showing exceptional absorption capacities [7]. The scalability and reliability of this technique make it promising for the sustainable supply of energy resources. Li et al. (2020) designed the heat-resistant polyimide nanofibrous air filters that can withstand the highest temperature up to 420°C removing more than 97% of the particulates from the vehicle exhaust, implying the wide range of applicability of this technology in heat intensive environments [14]. Using the same principle, Jia et al. (2020) developed eco-friendly aqueous solution blow spinning to weave polyamidoxime/alginate fibers for large-scale uranium extraction from seawater, which has excellent adsorption capacities without using toxic organic solvents, indicating the sustainability of this approach in energy resource recovery [15].

5. Biomedical Materials

Paschoalin et al. (2017) fabricated nanofibers mixing polylactic acid and polyethylene glycol with solution blow spinning [16]. Immature phenotype of these dendritic cells was conserved during their interaction with the fibers and the result was that solution blow spun nanofibers could be used as flexible, immunologically inert biomaterials. El-Newehy et al. in 2021 prepared cellulose acetate nanofibers (CANF) by solution blow spinning method and subsequently deacetylated CANF to introduce nanocellulose [17]. They immobilized urease and cyanuric acid hydrazone molecular probes onto the cellulose nanofibers (CNF), therefore, created a nano-fiber membrane sensor with a short response time (5~10min). Lee et al. (2020) used Nanofiber mats provide a simple method to rapidly repair disposable masks and extend their life to be reused through adjusting the fiber size and the thickness, therefore, environmental protection [18]. Bijarimi et al. (2013) prepared fibrous mat biocomposites with band-like structure by using different amounts of 45S5 bioactive glass (BG) and rubber from natural sources, (NR) [19]. XRD results confirmed BG particles evenly spread on the surface and inside of microfibers made by NR, showing very good thermal stability in the range of 200°C, hence the successful application of solution blow spinning process in biomedicine.

6. Smart Wearables

Raimundo et al. (2020) manufactured NiFe-NiFe2O4 composite nanofibers via the solution blow spinning method [20]. Test results revealed that the composite also has excellent chemical stability in addition to being able to respond to fluctuations in magnetic fields very quickly, meaning that solution blow spinning could have in magnetic sensor applications. Khattab et al. (2017) produced a TCF-H sensor by encapsulating this in polyacrylonitrile nanofibers by solution-blow spinning [21]. The nanofibrous film was proven to be fast in response, highly sensitive to the concentration of the alkaline solution, and has reversibility, which account for numerous cycle applications. Soares et al. (2020) have created nanofibers by dissolving PLA into solvent and then spinning it out in the solution blow-spinning process [22]. This type of sensors proved to be highly sensing and selective and, at the same time, most precise at the measurement which was 60-second impedance time. In addition to this, on the contrary to the other films that have less focus on the biosensing and an LoD (p35) of 11pg/mL, the lower screening capacity of this kind might be used. Agriculture and sci-tech specialists Medeiros et al., described the technology in their work (2009) used in carding as a means of creating thin fibers with controlled geometry and morphology and presented it as a solution for the filtration of diverse applications including smart wearables [23]. Generally, this approach can incorporate the production of core fibers that later can be used for the purpose of environmental change monitoring and acting physically upon changes in the environment, but at the same time keeping the fibers physically stable. Among all the spinning methods for ultrafine fibers, solution blowing is the most powerful and can be applied to make various materials. The fibers made this way may be used in advanced devices such as magnetic sensors and biosensors which only lend support to future smart wearables application.

7. Other Applications

Kolbasov and al. (2017) spun fibers made of lignin, chitosan, and different biopolymers with the help of solution blow spinning [24]. The experiments showed that such nanofiber films possess the highest absorption capacity for lead in aqueous solutions. Walton et al. (2016) produced nanofiber membranes of PMMA doped with modified reduced graphene oxide (rGO) by means of a solution blow spinning method [25]. Compared to other composite adsorbents, these not only possess superior dye adsorption performance, achieving a decolorization rate of 92% within an hour, but the solution blow spinning process is also more environmentally friendly, easy to operate, and scalable for industrial production. Leite et al. (2020) used sol-gel process and solution blow spinning to prepare titanium dioxide fibers and silver-modified titanium dioxide fibers, forming cottony fibrous structures [26]. SAED analysis revealed that silver nanoparticles were uniformly distributed on the surface of polycrystalline titanium dioxide. Under UV light irradiation, titanium dioxide fibers showed good microbial inactivation performance, and silver-modified titanium dioxide fibers enhanced the photodegradation of dyes. Poly (phenylene ether sulfone ketone) (PPESK) is a newly designed kind of high-performance plastics that contains anthraquinone structures which are both durability and heat resistance.

8. Conclusion

In conclusion, SBS has been shown to be a powerful and efficient method capable of building nanofiber morphologies that find utility in a lot of technology areas including environments, batteries, separators and filters, biological materials and sensors. Those studies revealed the capacity of SBS not to be limited in the respect of nanofiber properties been optimized for a specific application such as for instance, the high temperature resistant polyimide nonwovens air filters or the unique PCrFam/alginate nanofibers used for the sustainable uranium extraction from seawater.

The SBS fibers with the added feature of high temperature stability, electrocatalytic activity, and dielectricity reveals a cutting-edge technology that SBS can be used in energy storage, air filtration, and resource recovery. Additionally, the SBS technology reveals over its multipurpose while using it to produce biomedical fabrics and smart wearables where it is responsive and biocompatible.

The design of the equipment for the synthesis of the SBS material in its simplicity makes use of its scalability and possibility of fiber deposition for direct industrial production of nanofiber technology. With the improvement of the technology, more research and development in SBS will probably be done in the future, and the applications will be widespread in material science and engineering, and the further breakthrough will overcome the various challenges.

References

[1] Kenry, Lim CT. (2017). Nanofiber technology: current status and emerging developments. Progress in Polymer Science, 70, 1-17.

[2] Dadol, G. C., Kilic, A., Tijing, L. D., et al. (2020). Solution blow spinning (SBS) and SBS-spun nanofibers: materials, methods, and applications. Materials Today Communications, 25, 101656.

[3] Medeiros, E. S., Glenn, G. M., Klamczynski, A. P., et al. (2009). Solution blow spinning: a new method to produce micro- and nanofibers from polymer solutions. Journal of Applied Polymer Science, 113 (4), 2322-2330.

[4] Da Silva Parize, D. D., Foschini, M. M., De Oliveira, J. E., et al. (2016). Solution blow spinning: parameters optimization and effects on the properties of nanofibers from poly (lactic acid) / dimethyl carbonate solutions. Journal of Materials Science, 51 (9), 4627-4638.

[5] Li, Z, Song, J, Long, Y, Jia, C, Liu, Z, Li, L, et al. 2020, 'Large-scale blow spinning of heat-resistant nanofibrous air filters', Nano Research, vol.13, pp.861-867.

[6] Khalid, B, Bai, X, Wei, H, Huang, Y, Wu, H & Cui, Y 2017, 'Direct blow-spinning of nanofibers on a window screen for highly efficient PM2. 5 removal', Nano letters, vol.17, no.2, pp.1140-1148.

[7] Wang, D., Song, J., Wen, J., Yuan, Y., Liu, Z., Lin, S., ... & Wu, H. (2018). Significantly enhanced uranium extraction from seawater with mass-produced fully amidoximated nanofiber adsorbent. Advanced Energy Materials, 8 (33), 1802607.

[8] Huang, Z, Kolbasov, A, Yuan, Y, Cheng, M, Xu, Y, Rojaee, R, et al. 2020, 'Solution blowing synthesis of Li-conductive ceramic nanofibers', ACS applied materials & interfaces, vol.12, no.14, pp.16200-16208.

[9] Silva, VD, Simoes, TA, Loureiro, FJ, Fagg, DP, Figueiredo, FM, Medeiros, ES, et al. 2019, 'Solution blow spun nickel oxide/carbon nanocomposite hollow fibres as an efficient oxygen evolution reaction electrocatalyst', International Journal of Hydrogen Energy, vol.44, no.29, pp.14877-14888.

[10] Ruiz, VM, Sirera, R, Martínez, JM & González-Benito, J 2020, 'Solution blow spun graded dielectrics based on poly (vinylidene fluoride) / multi-walled carbon nanotubes nanocomposites', European Polymer Journal, vol.122, pp.109397.

[11] An, S, Sankaran, A & Yarin, AL 2018, 'Natural biopolymer-based triboelectric nanogenerators via fast, facile, scalable solution blowing', ACS applied materials & interfaces, vol.10, no.43, pp.37749-37759.

[12] Tan, NPB, Paclijan, SS, Ali, HNM, Hallazgo, CMJS, Lopez, CJF & Ebora, YC 2019, 'Solution blow spinning (SBS) nanofibers for composite air filter masks', ACS Applied Nano Materials, vol.2, no.4, pp.2475-2483.

[13] Alvarenga, AD & Correa, DS 2021, 'Composite nanofibers membranes produced by solution blow spinning modified with CO2-activated sugarcane bagasse fly ash for efficient removal of water pollutants', Journal of Cleaner Production, vol.285, pp.125376.

[14] Li, Z., Song, J., Long, Y., Jia, C., Liu, Z., Li, L., Yang, C., Liu, J., Lin, S., Wang, H. and Liu, Y., 2020. Large-scale blow spinning of heat-resistant nanofibrous air filters. Nano Research, 13, pp.861-867.

[15] Jia, C., Li, L., Song, J., Li, Z. and Wu, H., 2021. Mass production of ultrafine fibers by a versatile solution blow spinning method. Accounts of Materials Research, 2 (6), pp.432-446.

[16] Paschoalin, RT, Traldi, B, Aydin, G, Oliveira, JE, Rütten, S, Mattoso, LH, et al. 2017, 'Solution blow spinning fibres: New immunologically inert substrates for the analysis of cell adhesion and motility', Acta biomaterialia, vol.51, pp.161-174.

[17] El-Newehy, MH, El-Hamshary, H & Salem, WM 2021, 'Solution blowing spinning technology towards green development of urea sensor nanofibers immobilized with hydrazone probe', Polymers, vol.13, no.4, pp.531.

[18] Lee, JS, Kim, HJ, Jung, S, Kim, J & Lee, MW 2020, 'Repair of disposable air filters by solution-blown nano/micro fibrous patches', ACS Applied Nano Materials, vol.3, no.11, pp.11344-11351.

[19] Bijarimi, M, Ahmad, S & Rasid, R 2013, 'Mechanical, thermal and morphological properties of poly (lactic acid) / natural rubber nanocomposites', Journal of Reinforced Plastics and Composites, vol.32, no.21, pp.1656-1667.

[20] Raimundo, RA, Silva, VD, Medeiros, ES, Macedo, DA, Simões, TA, Gomes, UU, et al. 2020, 'Multifunctional solution blow spun NiFe–NiFe2O4 composite nanofibers: structure, magnetic properties and OER activity', Journal of Physics and Chemistry of Solids, vol.139, pp.109325.

[21] Khattab, TA, Rehan, M, Aly, SA, Hamouda, T, Haggag, KM & Klapötke, TM 2017, 'Fabrication of PAN-TCF-hydrazone nanofibers by solution blowing spinning technique: Naked-eye colorimetric sensor', Journal of environmental chemical engineering, vol.5, no.3, pp.2515-2523.

[22] Soares, AC, Soares, JC, Paschoalin, RT, Rodrigues, VC, Melendez, ME, Reis, RM, et al. 2020, 'Immunosensors containing solution blow spun fibers of poly (lactic acid) to detect p53 biomarker', Materials Science and Engineering: C, vol.115, pp.111120.

[23] Medeiros, ES, Glenn, GM, Klamczynski, AP, Orts, WJ & Mattoso, LH 2009, 'Solution blow spinning: A new method to produce micro-and nanofibers from polymer solutions', Journal of applied polymer science, vol.113, no.4, pp.2322-2330.

[24] Kolbasov, A, Sinha-Ray, S, Yarin, A & Pourdeyhimi, B 2017, 'Heavy metal adsorption on solution-blown biopolymer nanofiber membranes', Journal of Membrane Science, vol.530, pp.250-263.

[25] Walton, IM, Cox, JM, Benson, CA, Patel, DDG, Chen, Y-S & Benedict, JB 2016, 'The role of atropisomers on the photo-reactivity and fatigue of diarylethene-based metal–organic frameworks', New Journal of Chemistry, vol.40, no.1, pp.101-106.

[26] Leite, R, Santos, A, Severo, L, Neto, JD, Castellano, L, Neves, G, et al. 2020, 'Photocatalytic degradation of dyes and microorganism inactivation using solution blow spun silver-modified titania fibers', Ceramics International, vol.46, no.9, pp.13482-13490.