RESEARCH TECHNOLOGY OF THE CORE NANOYARN FOR FILTRATION APPLICATION

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Abstract

The paper focuses on the technical application of polymeric nanofiber materials. It introduces the usage of linear nanofiber structures, e.g. nanoyarns, for producing filter candles with the capacity of water or air filtration. The research focuses on producing composite nanofibrous yarn containing a micro-fibre core covered with a nanofiber sheath prepared by the highly effective technology: electrospinning in alternating electric field (AC electrospinning). The core of the composite yarn is used to provide sufficient mechanical strength, while the nanofibrous sheath offers an additional function, e.g. for advanced filtering capacity. The filter cartridges are made using a unique winding device, enabling the production of filters of various sizes as well as with different winding parameters. At the same time, the production line is designed to eliminate any mechanical or chemical irregularities in the nanofiber sheath.

The work describes the technology of production of core nanoyarn with polyester core fibres and poly-vinyl-butyral nanofibrous cover wounds on filter cartridges. The filter cartridges were measured on a custom-made laboratory setup. Experimental tests of microplastic filtration with various sizes confirmed the filter efficiency for this application. Based on measurement results, filter cartridges with different structural as well as material compositions are discussed and suggested. Filters based on natural and biodegradable materials as the next step in the research of the usage of sustainable nanotechnologies are also discussed in the paper.

Keywords: AC electrospinning, polymeric nanofibers, nanofiber yarn, filter candles

1. INTRODUCTION

Nanofibers are fibres with diameters lower than 10^{-6} m. Nanofiber materials are then characterized by high specific surface and porosity. These functions of nanofibers are especially used in applications related to medicine, e.g. scaffolds for cell cultivation, or in technical applications, e.g. for filtration [1-6].

Polymeric nanofibers can be produced by various technologies, e.g. drawing, forcespining, and electrospinning. There are many techniques for the production of nanofibers on a laboratory scale, while in the industry, the technology of electrospinning is primarily used [7]. Electrospinning in the alternating electrical field (AC electrospinning) represents a highly efficient technique for the production of polymeric nanofibers without any need for a mechanical counter electrode. This needleless and collector-less technology opens up new ways of producing unique nanofiber structures with considerably high productivity.[8-11].

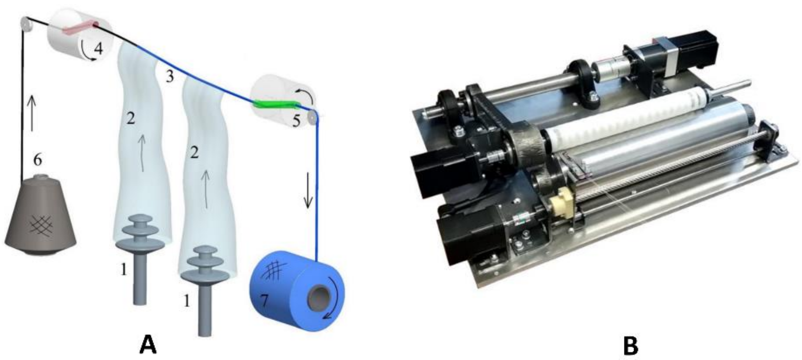
AC electrospinning is a versatile technology capable of spinning a high number of polymeric materials with added functions, e.g. biodegradability or biocompatibility [12-14]. Most types of polymeric materials are spinable under ambient temperature and atmospheric pressure, enabling the usage of bio-active or natural dopants, e.g. nanocellulose, in order to enhance the functionality of the final nanofiber product.

The limitation of nanofiber materials for technical applications lies mainly in the high costs of their production. The AC electrospinning, however, represents a highly effective method with the potential of usage of nanofibers and nanofiber structures in technical applications. This work is focused on technological research of nanofibrous yarns prepared by the AC electrospinning and formed in the candle filters for wastewater filtration [15].

2. TECHNOLOGY OF PRODUCTION OF CANDLE FILTRES WITH NANOFIBER YARNS

For this research, the technology of production of composite yarn with nanofiber sheath produced by AC electrospinning was used [16]. The core nanofiber yarn was produced according to the scheme shown in the **Figure 1A**. It comprises core yarn (PES multifilament, 333 dtex) and a nanofiber sheath (PolyVinylButyral wt10% EtOH).

The final core nanoyarn was wound using a custom-made winding device capable of winding bobbins with variable types of winding and sizes [17], see the **Figure 1B**. Processing parameters of core nanoyarn production, as well as candle filter winding, are shown in the **Table 1**.



A **B**

Figure 1 A) Schematic layout of production of core nanofiber yarn using the AC electrospinning technology, 1- rod electrode, a plume of nanofibers, 3- core yarn, 4- input twirling device, 5- output twirling device, 6- input bobbin, 7- output bobbin [16] **B)** Custom-made winding device for candle filter production [17]

Table 1 Parameters of core nanoyarn production and candle filter winding

Parameter	Set value	Note
U_{ef}	35 000 [V]	Effective voltage (sinus waveform)
f	50 [Hz]	Frequency of alternating current
v	12 [m/min]	Core nanoyarn production speed
H	227 [mm]	Electrode – core yarn distance
n_1	10 000 [rpm]	Input spindle rpm
n_2	4 000 [rpm]	Output spindle rpm
e_1	3 [mm]	Eyelet excentricity on spindle 1
e_2	3 [mm]	Eyelet excentricity on spindle 2
T_1	90° [C]	Drying zone temperature
T	30 [cN]	Core yarn tension
D_i	17.5 [mm]	Bobbin inner diameter
D_o	20.5 [mm]	Bobbin outer diameter
R	2.19796 [-]	Winding ratio
W	52 [mm]	Bobbin width

With respect to the winding speed, 31 – 37 wt% of the filter is composed of the PVB nanofibers, while 63 – 69 wt% of the filter is composed of the PES core microfibers. For the measuring of filtration tests, several sets of filters were produced.

3. MEASUREMENT OF CANDLE FILTER CAPACITY

For the measuring of filter capacity, the custom-made housing was designed and manufactured. A candle filter placed in a 3D printed cartridge inside filter testing housing is shown in the **Figure 2**. The aim of the preliminary tests is to prove the efficiency of manufactured filters for filtering plastic micro particles in water. Filter testing was carried out according to the scheme shown in the **Figure 3.**

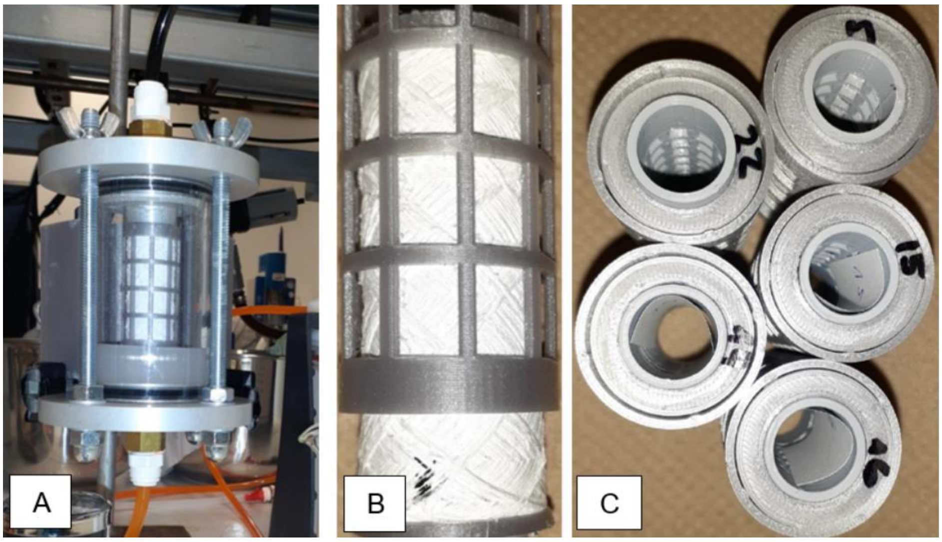


Figure 2 **A**) Candle filter placed in the custom-made testing housing, **B**) Candle filter partially secured in the 3D printed cartridge – front view, **C**: Side view of candle filters placed in cartridges.

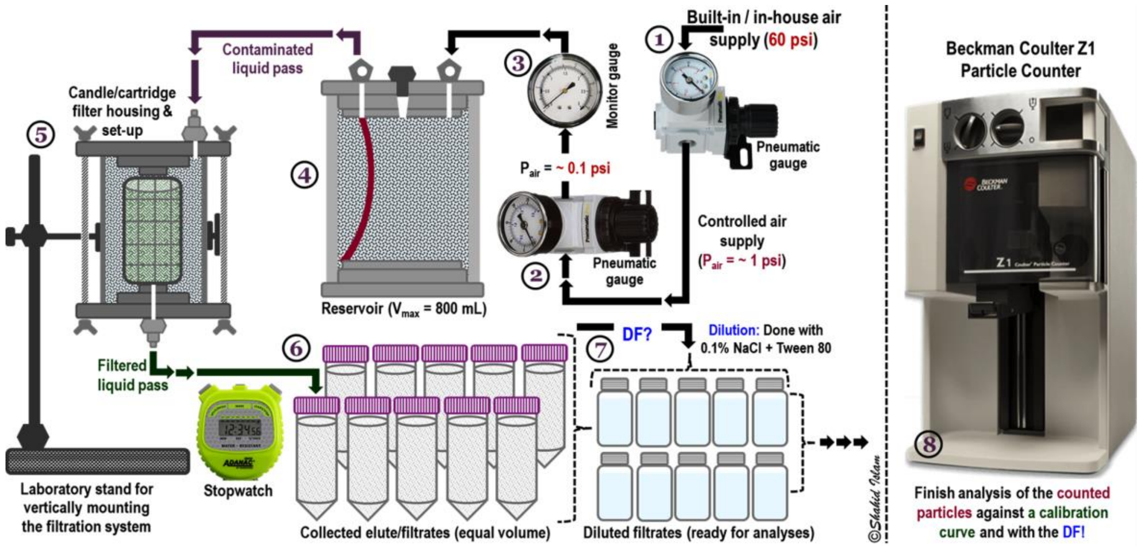


Figure 3 Schematic layout of filter testing facility. The built-in air pressure (60 psi) passes through the reducer pressure gauge (step-1) and ejects approximately 1 psi air which is then guided through another pneumatic gauge (step-2) to reduce the air pressure further (~ 0.1 psi). Such low pressure is then guided through a monitor gauge (step-3) prior to passing into the contaminant's (microplastic in this case) reservoir, through which the 'reverse built pressure' can be monitored. From the microplastic reservoir (step-4) the liquid is then passed through the candle filter housing (step-5) in a top-down mode where the filtration is being processed in an outward to inward direction. The fixed/equal volume of filtrate is then collected (step-6) recording the 'exact' collection time and the filtrate samples were then diluted (step-7) wherever necessary prior to analysis via the particle counter (step-8).

4. RESULTS

Measurements for micro-plastic filtration capacity were carried out for several candle filters produced. Selected results were compared and discussed. The results presented in the **Figure 4** show the flow rate reduction in the filter during the time of filtration for two different concentrations of microplastics. To maintain uniformity, an equal volume of the filtrate was collected each time for all the samples (denoted as S#) presented on plots 5A and 5B. The filtrate collection was terminated whenever the air entered the candle filter housing to avoid any outlier on the collection time.

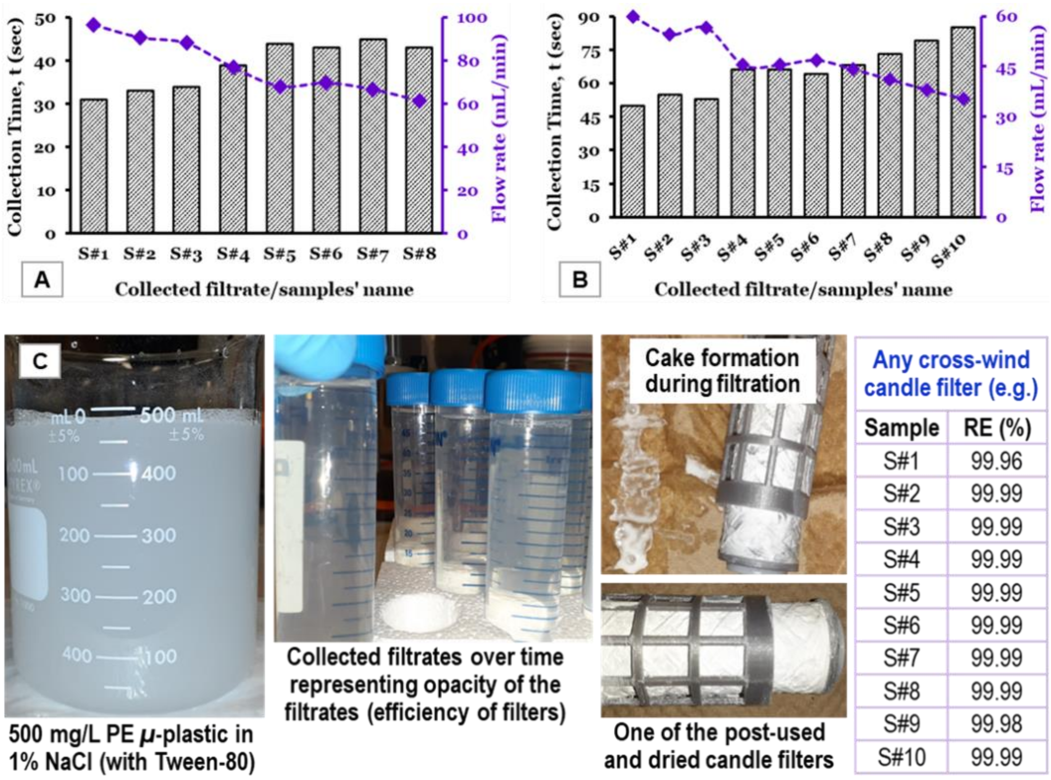


Figure 4 Comparison of candle filter capacity for filtering PE μ-plastic in NaCl. A: 100 ppm, B: 500 ppm, C: represents a series of fragments of overall experimental details (legends are within the fragments).

While conducting the experiments, it was observed that significant cake formation occurs across the candle filters from the suspended (opaque) PE μ-plastics and consequently the collected filtrate (denoted as samples, S#) was seen as exceptionally transparent (**Figure 4C**). These phenomena also forecast the insight regarding the filtration efficiencies of the candle filters. In all the cases for the cross-wind candle filters, the filtration efficiencies (removal efficiencies of the PE microplastic particles) of the filters were found >99% starting from the 1st collected samples, regardless of the inlet concentration of the PE microplastics used. A snapshot of the removal efficiencies (RE%) of one of the candle filters is represented in the **Figure 4C**.

5. CONCLUSION

The presented results proved the efficiency of candle filters made from the composite yarn with nanofiber sheath for physical filtration of any sort of micro-particles/macro particles as part of wastewater treatment. The design of filter candles allows filtration under pressure 0,1 psi with the flow rate within the range 37 ÷ 90 ml/min. The versatility of the production technology of these filters enables modification of both AC electrospinning as well as winding parameters and thus further improvement of filter capacity. It also allows the selection of various materials for the core and the nanofiber sheath or the usage of pure nanofiber yarn. Modifications of such nanofibers with functionalized nano-additives before electrospinning should provide an excellent platform for these candle filters to remove charged molecular contaminants. This opens up possibilities of low-pressure filters for water or air micro-size contaminants. Application of natural materials, e.g. cotton core yarn and functionalized nanocellulose doped nanofibers can contribute to introducing efficient sustainable filters.

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