Development of Nanofibers based Water Filter to get Safe and Pure Drinking Water for Human Beings

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Abstract: ***There are lots of finished products for water filters available in the market. It is quite desirable that the continuous or porous membrane, which we intend to developed with nanofibers-based surface coating on fabric, will contribute to finer degree of filtration. The process of creation of PA-6/nAg Nanofiber coated filter fabric media with a free surface Electrospinning pilot plant. Nanofibers filters media developed will be extensively studied using water samples from different sources. PA-6/nAg Nanofiber coated filter fabric media which will have average microbial filtration efficiency of 99.9% compared against neat fabric and heavy metal filtration efficiency as stated in the results. The polysachharide padding with ferrous and alumina nanoparticles also act as the antifouling agents, which prevent the biofouling of the filter cartridge. Such a filter media with PA-6/nAg Nanofiber, is the latest in the area of gravity-based filtration,***

Keywords: Nanofibers, Free surface Electrospinning, biofouling, filtration

1. Introduction

Polyamide-6 (PA-6) is a well known commodative polymerwhich has very good mechanical properties and low water absorption (0.1 %), yet is inert, nontoxic, and is used invarious application in general industry, filtration products, consumer, and medical field.

PA-6 is very easy to process for nanofiber production, due to its high solubility in respective solvent and stable functioning of the equipment during the process. The nanofibers of PA-6 were coated on polypropylene (PP) meltblown fabric having moderate porosity. Additional nanosol of alumina and ferrous oxide nanoparticle prepared in polysachharide is applied on PP spun-bond by pad-dry-cure system. The composition of padding solution includes polysachharide, alumina nanoparticle and ferrous nanoparticle in 0.25% by weight ratio to polyscaccharide. The 7 layer combination is used for the development of nanofiber based filtration media.

The nanofiber-based water filter system can filter colloidal impurities to 99.9 % and heavy metals as Arsenic, Chromium, Cadmium, Lead, Copper and Iron. The average filter life of the gravity-based filter cartridge will be 2500 liters with moderate flow rate.

2. Materials and Methods

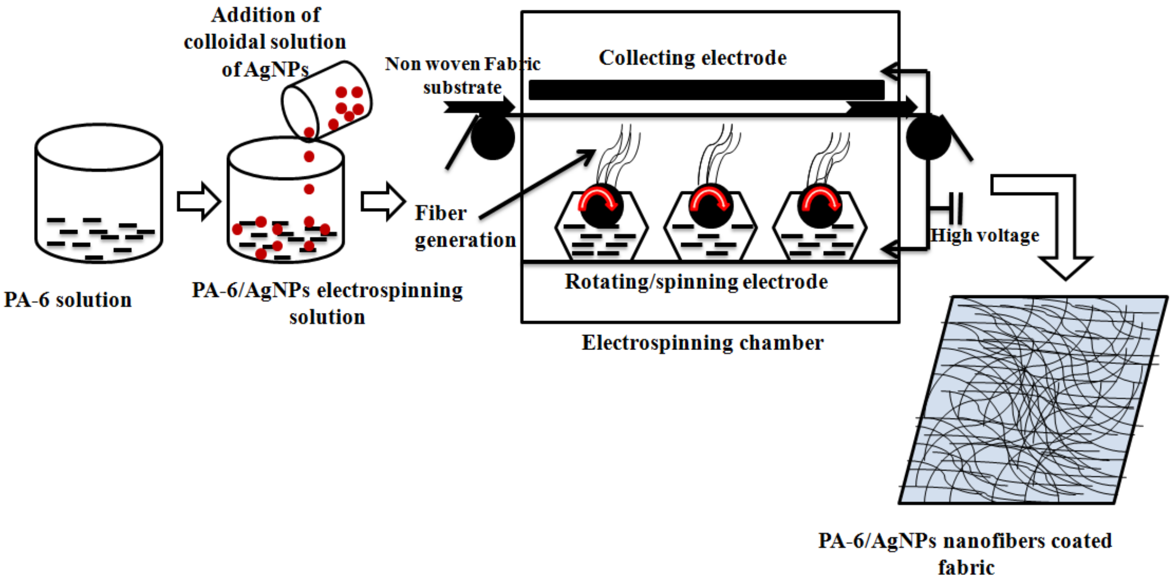
- PA-6 solution in acetic and formic acid (12%)
- Medium molecular weight polysaccharide
- Formic acid, LR, 99% pure
- Acetic acid, LR, 99% pure
- Silver nanoparticles
- Alumina nanoparticles
- Ferrous oxide nanoparticles
- Hydrochloric acid, LR, 99% pure

Methodology

Nanofiber based filter media are known for finer degree of filtration and are highly efficient. A popular method of production of Nanofibers is by the needle electrospinning technology. This process is suitable for small scale production, where uniformity of Nanofiber layer can be maintained to a reasonable extent. The more versatile process of production of Nanofibers, is free-surface electrospinning technology, in which very uniform Nanofiber layers of large dimensions can be produced very conveniently. In this development use has been made of the ELMARCO, Czech Republic make Nanospider TM Model NS 1100, for production of nanofibers on the different required substrate surfaces.

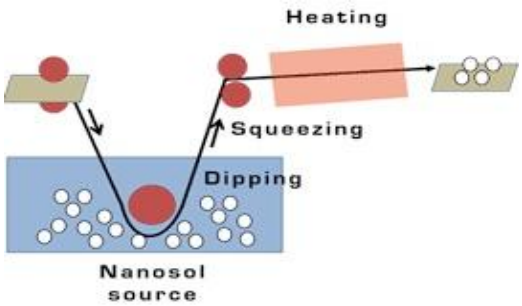
For the purpose of electrospinning, polymers are first made soluble in a specified concentration range, which results in a honey like viscous solution, within a defined viscosity range. In order to make the resultant Nanofiber layer antimicrobial, very effective antimicrobial agent like nanosilver has been introduced into the polymer solution to be Electrospun. The process of making nanosilver sol has been adopted as shown:-

Schematic representation of PA6/silver nanoparticle Nanofiber



Polyamide 6 granules were dissolved in the formic & acetic acid solution, for making of PA-6 Electrospinning solution. For imparting antibacterial property, Silver nanoparticles (nAg) were added to the above solution. This electrospinning solution was then filled into the Electrospinning chamber set up. On application of a high electrostatic voltage of around 90 KV in the machine, it creates a Nanofiber flow from spinning solution and deposited on the substrate fabric. The electrospun nanofiber flow moves from the rotating electrode towards the collecting electrode and thus "coating" the fabric, which acts as a barrier between the two electrodes. PA6/nAg Nanofiber coated web created is fully porous and its' fiber diameter is around 84-100nm.

Schematic representation of polysaccharide nanosol padding procedure:



The polysaccharide sol was prepared by adding 10% of polysaccharide in 0.6 ml acetic acid solution. The alumina and ferrous oxide nanoparticles were dispersed uniformly in this sol by high speed mechanical stirring at 5000 rpm. The concentrations of nanoparticles were 0.25 % weight by weight of polysaccharide. The schematic representation of the procedure is shown in the above figure.

Structure of Nanofiber based water filter media:

The 6-layers structure when opened is as follows-
Layer 1: Polyester viscose blended spun nonwoven
Layer 2: Nanosol coated PP meltblown nonwoven
Layer 3: PA-6/nAg coated PP meltblown
Layer 4: Pa-6/nAg coated PP meltblown
Layer 5: Plain PP spun bond nonwoven
Layer 6: Polyester viscose spun blended nonwoven

3. Results and Discussion

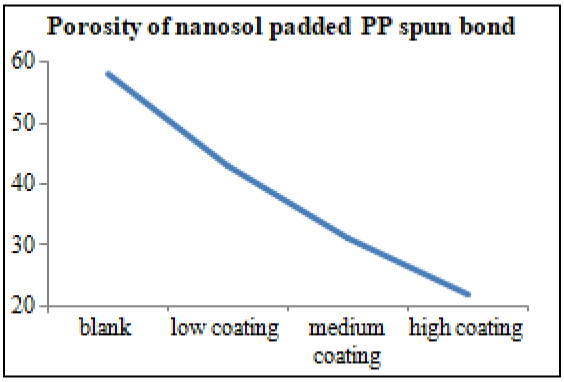
Porosity measurement

Porosity measurement study was carried out on the PP spun bonded nonwoven, nanosol padded PP spunbond nonwoven, PP melt blown nonwoven and PA-6/nAg nanofiber coated PP melt blown nonwoven, using standard ASTM D 6767. The results of the porosity of the coated and the plain nonwoven fabrics helped in finalizing the quantity of coating to be applied on layers to be used in preparation of the final combination of layers to be used in the cartridge. Porosity study of PP Spunbond and nanosol padded PP Spunbond nonwovens:

The following table gives the information of the change in the porosity of the PP spun bond fabric after nanosol padding

Sample description	Porosity (in micron)
Blank	58
low coating	43
medium coating	31
high coating	22

The results, shown graphically, indicates, a decrease in the porosity index against amount of nanosol deposition on the PP spun bond substrate.



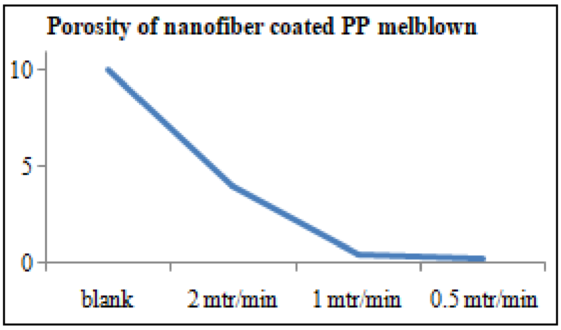
Graphical representation of porosity index of nanosol padded PP spun bonded nonwoven.

Porosity measurement of PP meltblown coated with PA-6/nAg nanofiber coated nonwoven:

Results show that as the amount of nanofiber coating increases, due to reduction in the fabric speed, there is a drastic decrease in the porosity of the meltblown nonwoven. As the least count of the instrument is 0.2 micron, hence the actual porosity of the 0.5 mtr/min coated meltblown nonwoven is expected to be much less than measured level of 0.2 micron.

Sample description	Porosity (in micron)
Blank	10
2 mtr/min	4
1 mtr/min	0.4
0.5 mtr/min	0.2

The following graph shows the trends of the nanofiber coating on the porosity of the PP meltblown nonwoven fabric. It clearly shows that more amount of coating of nanofiber leads to an exponential drop in the average porosity of the PP meltblown nonwoven fabric

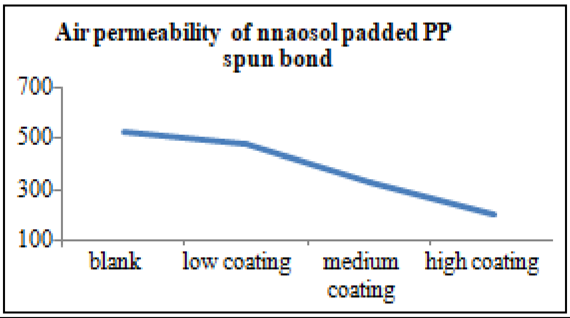


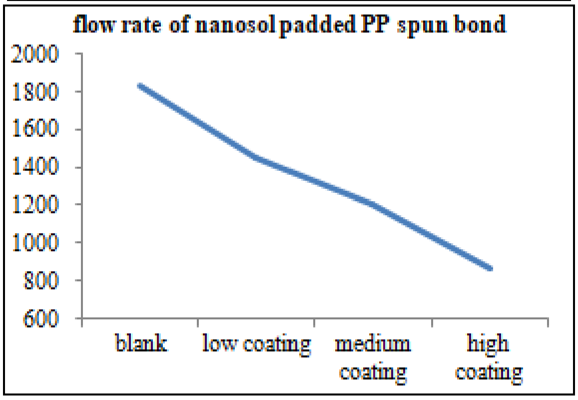
Air permeability and flow rate study
Air permeability measurement study was carried out for the PP Spunbond, nanosol padded PP Spunbond, PP meltblown and PA-6/nAg nanofiber coated PP melt blown nonwovens, as per ISO 9237 standard. The results show that air permeability decreases with increase in coating over the substrate, which clearly results in the loss of the flow rate of the water through the media as shown in the following test results.

Air permeability and flow rate of PP spun bond: Air permeability of the nanosol padded PP Spunbond nonwoven decreases with increasing amount of coating.

Sample description	Air permeability (in l/m2/sec)	Flow rate (ml/min)
Blank	521	1830
low coating	476	1450
medium coating	325	1210
high coating	200	870

The same results were replicated in the flow study measurement. In-house cylindrical arrangements were made to conduct the gravity based flow study. The flowing table gives the air permeability and the flow rate measurements of the nanosol padded PP spun bond nonwoven fabric.
The graphical representation suggests that the nanosol deposition after padding is inversely proportional to the air permeability index and flow rate of the water as well. After curing the nanosol, it tends to block the open pores present in the plain nonwoven fabric, which causes the decrease in the air permeability and flow rate as well.



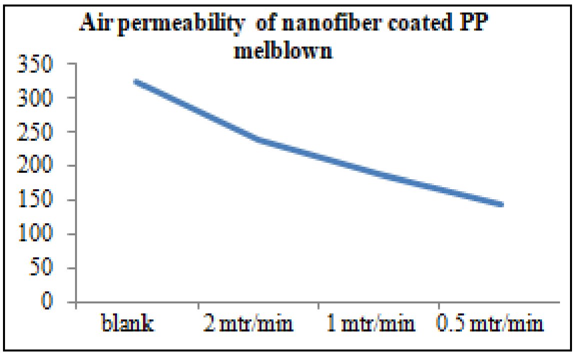


Air permeability and flow rate of PP meltblown:

The air permeability test of the blank meltblown and coated melt blown nonwoven fabrics show that as amount of nanofiber coating is increased, much resistance gets created due to the nanofiber layer, which leads to decrease in the air permeability of the nanofiber coated nonwoven, as also the flow rate of different combinations of the nanofiber coated nonwoven layers.

Sample description	Air permeability (l/m2/sec)
Blank	325
2 mtr/min	240
1 mtr/min	190
0.5 mtr/min	145

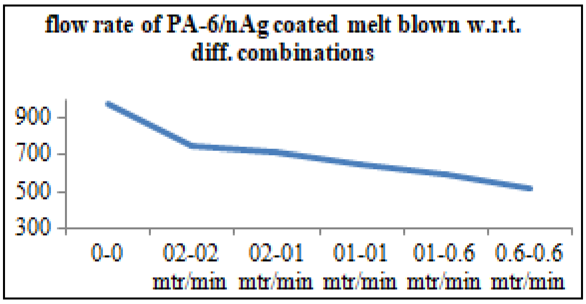
The graphical representation below shows same trend - as the nanosol padded PP spun bond nonwoven. It is seen clearly reveals that there is decrease in the air permeability, but this decrease is much less as compared to the padding method. It shows that there is decrease in the porosity to a large extent, but with less pressure drop as compared to conventional methods.



Different combinations of the nanofiber coating media were taken for optimizing the flow rate to achieve maximum efficiency. The two layer combination of the PP meltblown coated nanofiber was found to be optimum and was considered for the combinational trials. The results are shown below:

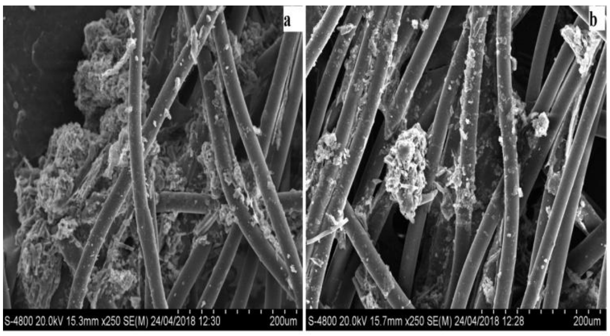
Sample description	Flow rate (ml/min)
0-0	980
02-02 mtr/min	740
02-01 mtr/min	710
01-01 mtr/min	650
01-0.6 mtr/min	590
0.6-0.6 mtr/min	520

The same trend as air permeability is repeated in the flow rate study. This suggests that the flow of liquid will be filtered at nano filtration but without affecting the flow rate much.



Surface morphology of the nanosol padded PP spun bond and nanofiber coated PP meltblown fabric
FESEM images of Nanosol padded PP spun bond fabric

The following picture shows the FE-SEM image of the nanosol padded nonwoven fabric. The high level of coating seen in the image clearly indicates that it will block the flow of water due to which there will be reduction in the overall life of the cartridge.

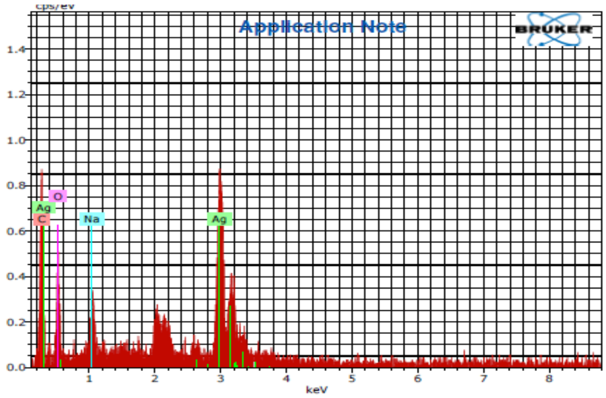


FE-SEM images of nanosol padded PP spun bond a. Heavy coating b. Medium level coated

Surface morphology:

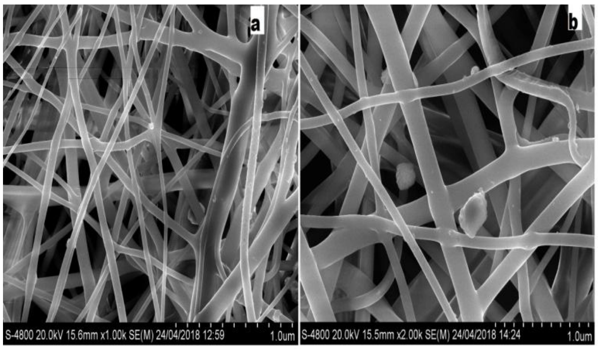
Surface morphology was determined by using a scanning electron microscope. Images showed clear view of formation of nanofibers on the surface of the substrate. The nanofibers form a uniform mat or mesh on the substrate. The fibers exhibited uniform fiber diameters ranging from 80 - 100 nm and had very few pores of size ~50 nm in between nanofibers. This helps to retard suspended particles, bacteria and viruses present in the air.

The energy diffraction analysis (E-DAX) confirms the presence of silver nanoparticles embedded over the surface of PA-6 nanofibers.

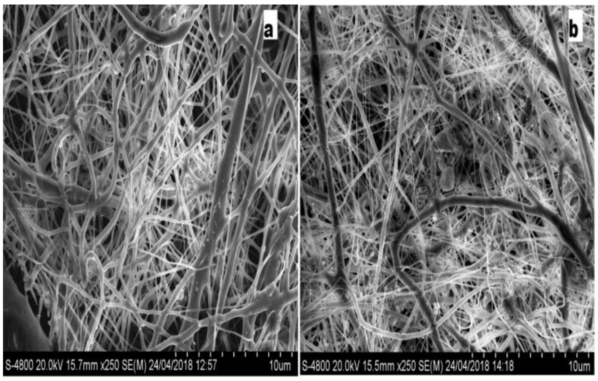


FE-SEM images of PA-6 nanofibers.

The FES-EM image of PA-6 nanofiber media shows the trapping of minute sub micron size dust and contaminant particles through the small pores of the Nanoweb.



FE-SEM images of PA-6 nanofiber web a. before filtration b. After filtration



FE-SEM images of PA-6 nanofiber web a. before filtration b. After filtration

Prototype development

Based on the multiple trials and results of the nanosol padded PP spun bond and nanofiber coated PP meltblown the six layer design with following set of combination was considered for the preparation of filter cartridge (layers by out to in format)

Layer 1: Polyester viscose blended spun nonwoven
Layer 2: Nanosol coated PP meltblown nonwoven
Layer 3: PA-6/nAg coated PP meltblown
Layer 4: Pa-6/nAg coated PP meltblown
Layer 5: Plain PP spun bond nonwoven
Layer 6: Polyester viscose spun blended nonwoven

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor (2018): 7.426

Considering following performance characteristics:
1) Filtration efficiency
2) Flow rate
3) Life of the cartridge
4) Simple and portable design
5) Cost effectiveness

The pleated type of the filter cartridge, as shown in the following picture,

Pleated form of the 6 layered cartridge

This pleated cartridge has been tested for turbidity, flow rate, biological filtration and heavy metal removal test in the laboratories. The summarized results are shown as follows:

Turbidity study of filtered water

By pressing the wash bottle, the filtered water received is turbidity free. All suspended particles and turbidity are totally removed via filtration. Results show that the turbidity limit of filtered water is well below the acceptable limit, i.e. 1 NTU and the permissible limit in absence of any alternative source is 5 NTU as per Indian standard IS 10500:2012. Filtered water shows excellent results for turbidity removal.

Turbidity study results are as follows:

Sr. no.	Samples	Turbidity (NTU)
1	Stock sample (without filtration)	110
2	Low nanofiber deposition(2 meter/min)	0.58
3	Medium nanofiber deposition (1 meter/min)	0.22
4	High nanofiber deposition (0.6 meter/min)	0.08
5	Two layer medium nanofiber deposition (1 meter/min)	0.05
6	Nanofiber based water filter media (6 layer system)	0.03
6	Distilled water	0.0

Bacterial assay study of filtered water

Bacterial assay of water samples was carried out of filtered water through the filter. Assay was carried out at an FDA approved License no GTL/37/33 Laboratory at Ahmedabad. Bacteriological water analysis was carried out by pour plate method. The results show that for the different stages of purification, different types of micro-organisms as E-coli,Salmonella typhi, S. aureusand Pseudomonas aeruginosawere absent. This shows that the developed water filter cartridge is capable of removing almost all types of microbes present in the ground water.

Results are summarized in below table:

	Sample	Total bacterial count	E-coli	Salmonella typhi	S. aureus	Pseudomonas aeruginosa
1	Stage 0	180cfu/ml	Present	Present	Present	Present
2	Stage 1 (1 Liter filtered water)	50cfu/ml	Absent	Absent	Absent	Absent
3	Stage 2 (2.5 liter filtered water)	10cfu/ml	Absent	Absent	Absent	Absent
4	Stage 3 (5liter filtered water)	30cfu/ml	Absent	Absent	Absent	Absent

Heavy Metal Filtration efficiency

Filtration efficiency has been tested from Bhagwati Enviro Care Pvt. Ltdby using Atomic Emission Spectroscope instrument. The final optimised efficiency of the filter cartridge is considered as a general need. The concentration of nano alumina and ferrous oxide strongly affects the filtration efficiency and the binding properties of polysaccharide over the PP spun bond nonwoven fabric.The results shows that ATIRA developed filter cartridge is capable of removing lead, cromium, cadmium and iron to very effectively while it removes arsenic and copper to large extent from the running water. Summarized result is shown in table below:

Sr. no.	Heavy metal	Filtration efficiency
1	Pb	99.90%
2	Cr	99.90%
3	Fe	80.00%
4	As	60.03%
5	Cd	96.40%
6	Cu	58.90%

4. Conclusions

All basic studies related to the selection of substrate, treatment of the substrate, compositions of two different systems of PA-6/nAg and nanosol padding solution, electrospinning parameters, and designing have been completed.

The flow rate of the developed filter cartridge is higher than any other gravity based filtration devices available in the market.

Filtration efficiency of nanofibers-based nonwoven fabric is excellent as compared to the marketed product and neat/uncoated fabric.

Generally in conventional gravity based filters the efficiency varies from 90 to 99 %.this developed Nano filtration filter fabric has efficiency of 99.9 % which is very good as compared to conventional filter fabrics in the market.

References

[1] Method Development for Flow Adsorption and Removal of Lead and Copper in Contaminated Water Using Electrospun Nanofibers of Chitosan Blend :Richard M. Nthumbi,J.catherine,Ngila.Andew,KindnessLangmuir, 200 2, 18 (25), pp 9765–9770 DOI: 10.1021/la025917l, October 30, 2002

[2] Chowdhury M, Stylios G. 2010. Effect of experimental parameters on the morphology of electrospun Nylon 6 fibers. IJBAS-IJENS. 10:116–131

[3] Diallo MS, Christie S, Swaminathan P, Johnson JH, Godda rd WA. 2005. Dendrimer Enhanced Ultrafiltration. Recovery of Cu (II) from Aqueous Solutions Using PAMAM Dendrimers with Ethylene Diamine Core and Terminal NH2 Groups. Environ Sci Technol. 39:1366–1377.

[4] Thavasi V, Singh G, Ramakrishna S. 2008. Electrospun nanofibers in energy and environmental applications. Energy Environ Sci. 1:205–221