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Production and characterization of polyetherimide mats by an electrospinning process

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Abstract

Polyetherimide (PEI) is an amorphous, thermoplastic polymer with high heat resistance and high strength. The production of PEI fibers using electrospinning process is very attractive because this process can produce fibers with nanometric diameters, high strength and good flexibility. Polymeric solutions of PEI with 1-methyl-2-pyrrolidone (NMP) were prepared at fixed proportions (18/82, 20/80 and 22/78% w/v) and were used to produce mats using an electrospinning process. The effect of solution concentration, applied voltage and tip-to-collector distance on the properties of the PEI mats were examined. The goal of this work was to understand the effect of the various electrospinning parameters on the properties of the PEI mats. The thermal degradation behavior, chemical structure and morphology of the PEI mats were characterized by thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM), respectively. Fibers with diameters around 150 nm were produced by the electrospinning and the most appropriate processing conditions were: 20/80% w/v of PEI/NMP, collector distance of 5 cm and voltage of 25 kV.

Introduction

Polyetherimide, from the family of polyimides, is an amorphous, thermoplastic polymer (T_g between 212 °C and 220 °C). This polymer has good chemical, electrical and thermal stability (degradation above 480 °C) as well as good mechanical properties [1]. The chemical structure of PEI consists of aromatic imides and ether units, as depicted in figure 1. Due to its stability at high temperatures and amorphous nature, PEI has applications in many areas. This polymer can be used for printed circuit boards and hard disks for computers, under-the-hood automotive uses, in reinforced composites for aerospace applications [1], in membranes to protect magnesium alloys against corrosion [2, 3] and for biohybrid organs such as the biohybrid liver support system [4].

PEI can be processed by extrusion, injection molding, casting and electrospinning [1, 5]. Electrospinning is a technique often used to produce mats with fibers having diameters of a few nanometers and large surface area. This technique, using a polymeric solution, is done by applying an electrical potential between the solution and a ground collector.

The nanofibers in the mats produced by electrospinning have a high aspect ratio (length/diameter); high flexibility in the chemical functionality of their surfaces and good mechanical properties (tensile strength and toughness). Thus, nanostructured mats have good potential to be used as reinforcement impregnated in a composite.

The properties of the fibers, like average diameter, morphology, porosity, uniformity and mechanical properties are dependent on several parameters, including processing parameters and solution properties.

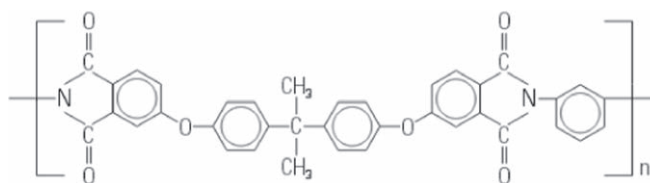


Figure 1. Chemical structure of polyetherimide (PEI) [1].

The resulting electrospun fibers can be assessed systematically by varying the main electrospinning parameters: (i) for instance, those related to the polymer: molar weight, distribution of molar weight, architecture of the polymer (linear, branched); (ii) the properties of the polymeric solution: viscosity, conductivity, dielectric constant, superficial tension and charge of the jet; (iii) the process parameters: electric potential, solution feeding rate, solution concentration, needle diameter and distance between the capillary (or tip) and the collector (known as working distance, WD); and (iv) the environment parameters: temperature, moisture and exhaust hoods [5].

Electrospun PEI has the advantage in structural applications like composites because these nanofibers can provide better adhesion in a thermoplastic or thermoset matrix resulting in mechanical properties better than in composite made with a film reinforcement of PEI due its large surface area to volume ratio. The nanofibers of PEI also have malleability to conform to a variety of sizes and shapes and can be produced by electrospinning directly into the material like some metal alloy or carbon mats. Thus, electrospinning process makes possible the ability to control the nanofiber composition to achieve the desired properties.

Given the industrial and scientific importance of this polymer, studies have been reported, to our knowledge, for at least 13 years, especially concerning the use of PEI to produce fibers and mats by electrospinning [6–14]. For instance, Han *et al* [6] evaluated the thermal stability of electrospun mats formed by poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV)/PEI blends. They produced fibers with tape-like morphology. The authors found that with an increase in the amount of PEI, the degradation temperature of the mats increased. Seok *et al* [7] produced blends of PEI and poly (vinylidene fluoride) by electrospinning. Hot-pressing and heat-process stretching were used on the mats to improve their mechanical properties. The treated mats, in comparison to the un-treated mats, exhibited an improvement in the mechanical strength from between 400 to 500%. Lee *et al* [8] produced a new class of electrospun nanofiber mat-reinforced permselective composite membranes (ERC membrane) impregnating polyvinyl alcohol (PVA) into electrospun polyetherimide (PEI) nanofiber mat. The PEI nanofiber mat acted as a compliant framework to endow dimensional stability and mechanical strength. The PVA matrix, after being swelled with electrolyte solution, provided ion size (OH versus $\text{Zn}(\text{OH})_4^{2-}$) dependent conductive pathways being this composite suitable for rechargeable zinc-air batteries. Vojtěch *et al* [9] evaluated the electrospun polyetherimide (PEI) nanofibres in application as sorbents for organochlorinated pesticides (hexachlorocyclohexanes and chlorobenzene). The gas chromatography/mass spectroscopy (GCMS/MS) analyses showed better performance of electrospun PEI nanofibres than three commercial SPME fibers for representatives of organochlorinated pesticides. Thus, the extraction time could be shortened from 50 to 10 min by switching the PEI fibre for the 100 μm PDMS fiber while maintaining the required sensitivity.

Zhang *et al* [10] functionalized electrospun mats of poly (vinyl alcohol)/PEI with carbon disulfide to produce poly (vinyl alcohol)/dithiocarbamates (PVA/DTC). The authors evaluated the absorption of heavy metals by PVA/DTC. Moon *et al* [11] studied the influence of the rotation velocity of the collector, tension, solution concentration and WD on the processing of electrospun nanofibers using a solution of PEI/NMP. The authors concluded that aligned fibers in the direction of collector with diameters between 0.58 and 0.90 μm could be obtained using solutions with concentrations of 20 wt%, electrical tensions of 8 to 10 kV and collector rotation velocity equal to 9.8 m s^{-1} . Krasteva *et al* [12] produced nanofibers of PEI with adhesive proteins with the goal of obtaining better compatibility with cellular growth in wound dressings. Zhao *et al* [13] studied the dielectric properties of nanofibers of PEI processed by electrospinning. The authors found that the dielectric constants of PEI oriented fibers were very low with values in the range of 1.1. Fashandi and Karimi [14] evaluated the nanofibers produced by electrospinning using various solvents, including dimethylformamide (DMF), dimethylacetamide (DMAc) and NMP. The authors produced nanofibers with thicker fibers with rough surfaces and pores using NMP or DMAc as solvent.

Considering the technological importance of PEI and electrospinning, this article presents the effect of solution concentration, applied voltage and tip-to-collector distance on the production of nanofibers of PEI. The goal of this work was to understand the effect of the various parameters on the properties of PEI nanofibers

Table 1. Processing conditions used to produce PEI fibers by electrospinning.

Sample	Concentration (% w/v)	Voltage (kV)	WD (cm)
A1	18	15	5
A2	18	20	
A3	18	25	
A4	20	15	
A5	20	20	
A6	20	25	
A7	22	15	
A8	22	20	
A9	22	25	
B1	18	15	10
B2	18	20	
B3	18	25	
B4	20	15	
B5	20	20	
B6	20	25	
B7	22	15	
B8	22	20	
B9	22	25	

produced by the electrospinning technique. The morphology, thermal degradation and chemical structure of the fibers were evaluated aiming to find some applications potentials of this material.

Experimental

Materials

The pellets of polyetherimide used in this work (PEI Ultem® 1000, melt flow index of 9 g/10 min at 337 °C/ 6.6 kgf), were supplied by General Electric Plastics Co., Brazil and dried under vacuum before use. The solvent used was 1-methyl-2-pyrrolidone (NMP) supplied by Synth—Acessórios e Equipamentos para Laboratórios Ltda, Brazil.

Preparation and characterization of the PEI/NMP solutions

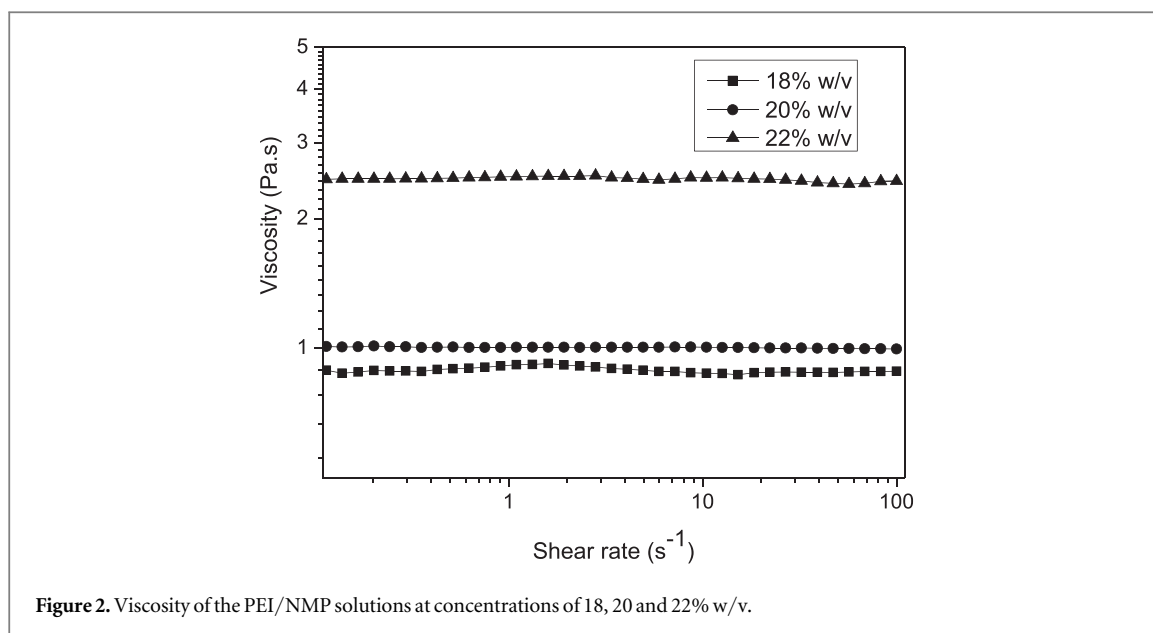
Solutions containing different proportions of PEI/NMP (18/82, 20/80 and 22/78% w/v) were prepared at 70 °C under constant stirring for 2–4 h. The dissolution time depended on the concentration of the solution. After dissolution, the concentration was determined by gravimetric analysis at 210 °C. The viscosities of the solutions were evaluated at (20 ± 0.5) °C using a rotational rheometer, RheoStress 6000 (Thermo Scientific, Germany) with concentric cylinders geometry (2 mm gap) and shear rates between 0.1 and 100 s⁻¹.

Electrospinning

The electrospinning of the polymeric solutions was carried out at room temperature and relative humidity (RH) of (55 ± 5) % with a system composed of a high voltage supply (Faisca Electronic Co., Brazil), a grounded cylindrical collector with of 20 cm diameter covered with aluminum foil, and a glass syringe of 20 ml with a Hamilton needle of 0.8 mm diameter and 1.2 mm length. The applied electrical tensions were 15, 20 and 25 kV. The working distances (WD) were 5 and 10 cm. The electrospun fibers mats of PEI were collected on the aluminum foil during 30 min of spinning with a collector rotation rate of 26 rpm. Table 1 shows the processing conditions to produce the PEI mats. The samples were analyzed after conditioning at 20 °C and relative humidity of (60 ± 5) °C for 4 h.

Fourier transform infrared (FT-IR)

The chemical structure of the electrospun PEI was analyzed by FT-IR spectroscopy (Shimadzu Scientific Instruments Co., IR Affinity-1 Spectrometer, Japan) with a universal ATR accessory (attenuated total reflectance). All the samples were scanned in the range from 4000 to 650 cm⁻¹ and 32 scans per sample were collected with resolution of 2 cm⁻¹.



Thermogravimetric analysis (TGA)

The thermal degradation behaviors of the mats processed at a working distance of 5 cm of the electrospun mats and PEI pellets were investigated using a TGA (SII Nanotech. Exstar, 6000, SEIKO Co., Japan). All analyses were conducted between 30 °C and 700 °C at the heating rate of 10 °C/min under N₂ atmosphere. Approximately (9.0 ± 0.2) mg of the samples were used for the TGA analyses.

Scanning electron microscopy (SEM)

The morphologies of the electrospun mats of PEI were observed using a scanning electron microscope (EVO LS-15, Carl Zeiss). The nanofibers mats were deposited on a double-face carbon adhesive and glued to the sample holder. The average diameter of the fibers and their diameter distribution were determined by measuring a sample set of over 100 fibers selected from the SEM images using image analysis software (Image J, National Institute of Health, USA), according to the method of Ghasemi-Mobarakeh *et al* [15]. To confirm the existence of significant differences between the average diameters of the fibers, statistical analysis (one-way ANOVA and Tukey test) was performed to a 5% confidence level.

Results and discussion

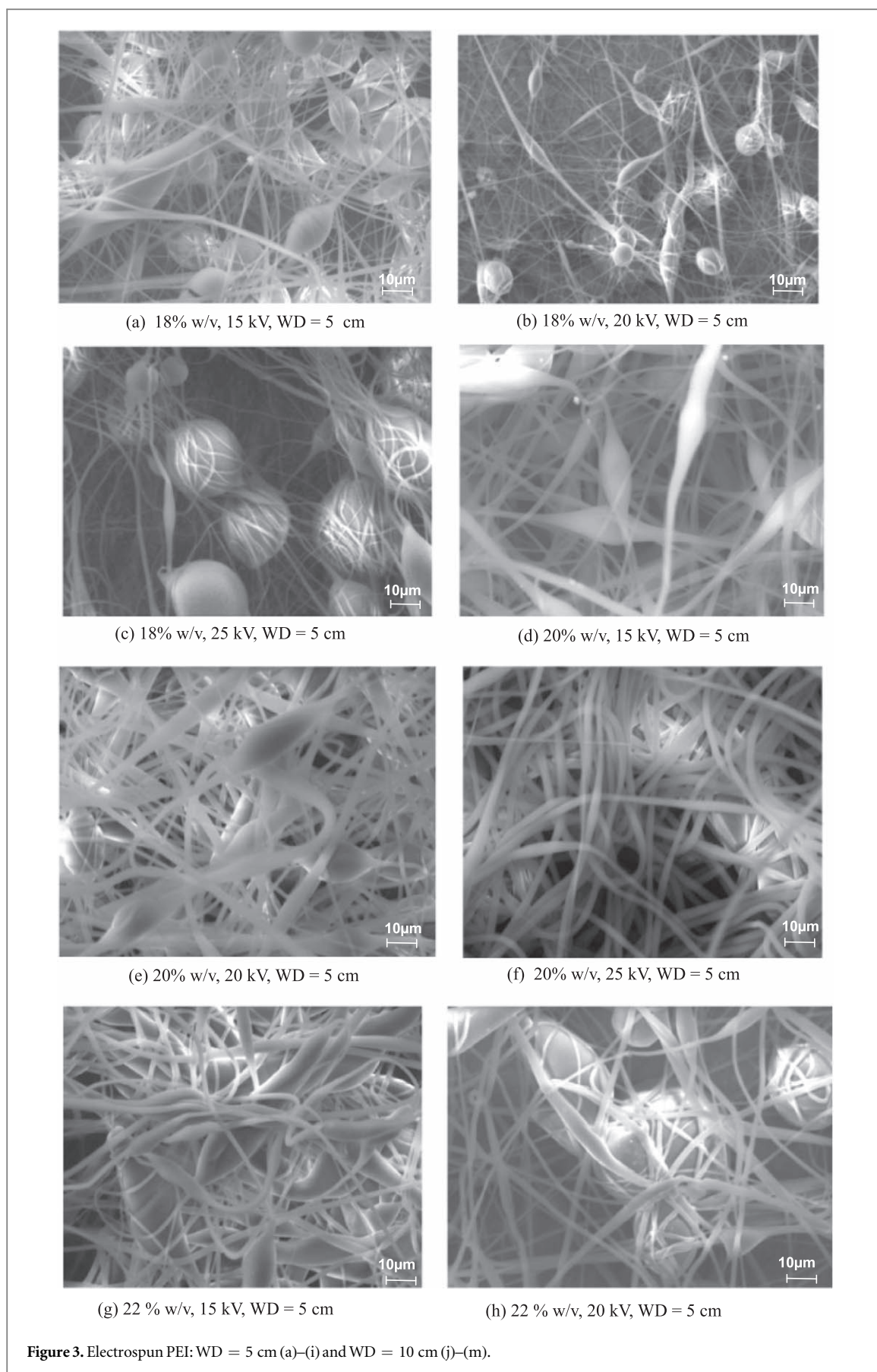
The choice of solvent and polymer concentration is important factors that influence the solution properties of the polymer, like the viscosity and rheological behavior, which, in turn, define the electro-spinnability and influence the diameters of the obtained fibers. Figure 2 shows the viscosity analysis of PEI/NMP solutions with concentrations of 18, 20 and 22% w/v.

Newtonian behavior was exhibited by all solutions. Similar values of viscosity (0.9 and 1.0 Pa.s) were observed for the solutions with 18 and 20% w/v. On the other hand, the viscosity of the 22% w/v of PEI solution was much higher than that of the 18 and 20% w/v solution. The viscosity, which is related to the solution concentration and to the interactions between polymer and solvent, is the most important parameter for the production of mats by electrospinning. Thus, to control the morphology and diameter of the mat fibers, the viscosity and rheological behavior should be taken into consideration.

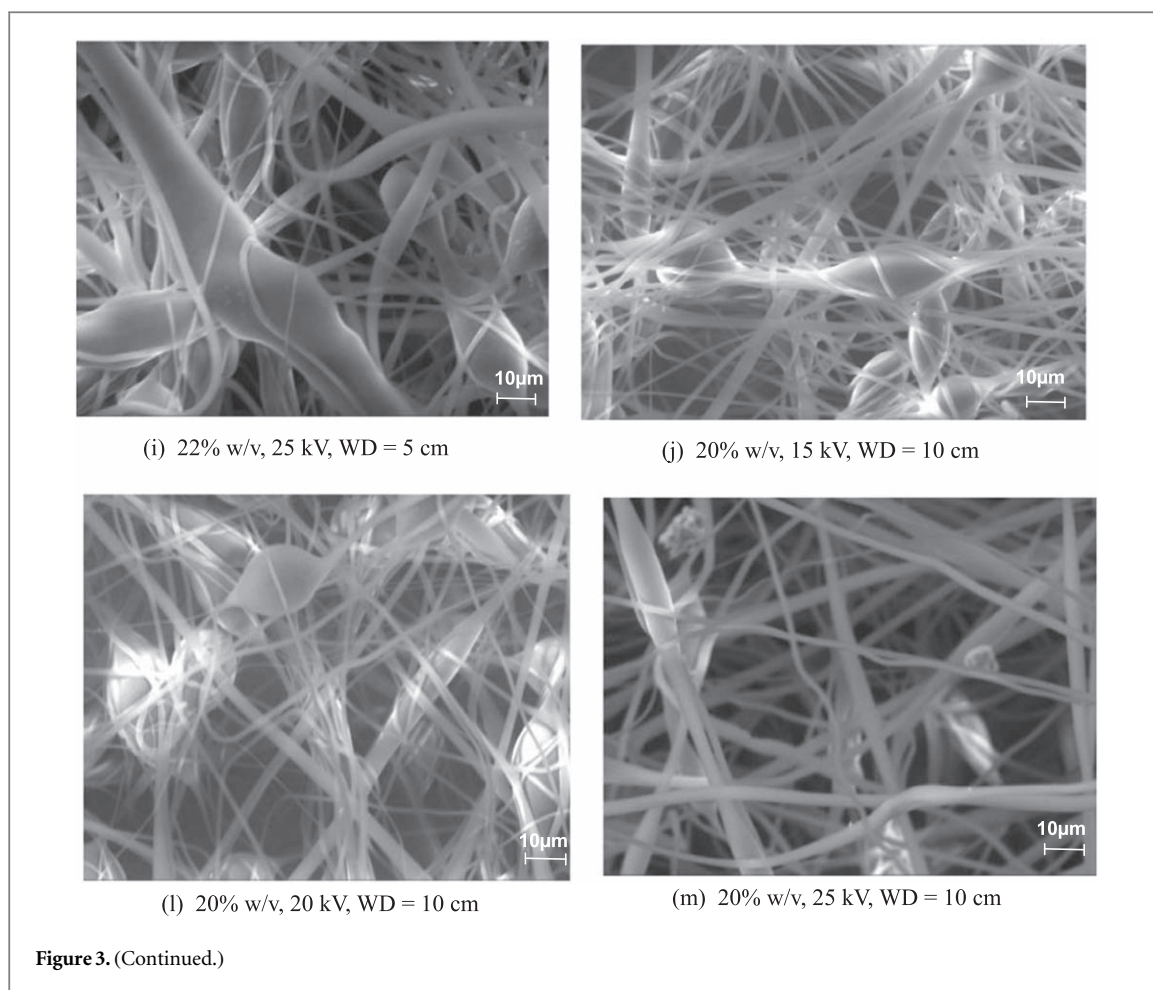
The solution viscosity must support sufficient forces to elongate the drops and to form the jet in the electrospinning process. Recently, researchers have shown that Newtonian behavior of the polymer solution plays a vital role in producing mats by electrospinning using polyesters [16] and poly(D,L- lactic acid) [17]. Moon *et al* [11], for instance, found the viscosity values of 0.932 Pa.s and 1.808 Pa.s in the solutions of PEI/NMP with 18 and 20 wt% PEI permitted obtaining electrospun mats. These values are very close to the viscosities measured in this work (0.9, 1.0 and 2.4 Pa.s, figure 2, for 18, 20 and 22% of PEI).

The morphologies of the mats of the electrospun PEI produced with the concentrations of 18, 20 and 22% w/v, WD of 5 cm and with voltages of 15, 20 and 25 kV are shown in figures 3(a)–(i). Figures 3(j)–(m) show the morphology of the electrospun PEI processed at 20% w/v, WD of 10 cm and voltages of 15, 20 and 25 kV.

The micrographs of mats of PEI processed with 18% w/v solution, WD = 5 cm and the three voltages (figures 3(a)–(c)) show fibers with numerous beads and many variations of the fiber diameter. This behavior was



also found in mats of PEI processed at 10 cm using the solution with the same concentration and the three voltages (not shown in this paper). The presence of beads is probably due to insufficient viscoelastic force on the drops to elongate and form the jet during the electrospinning process. However, for the solution of 20% w/v PEI

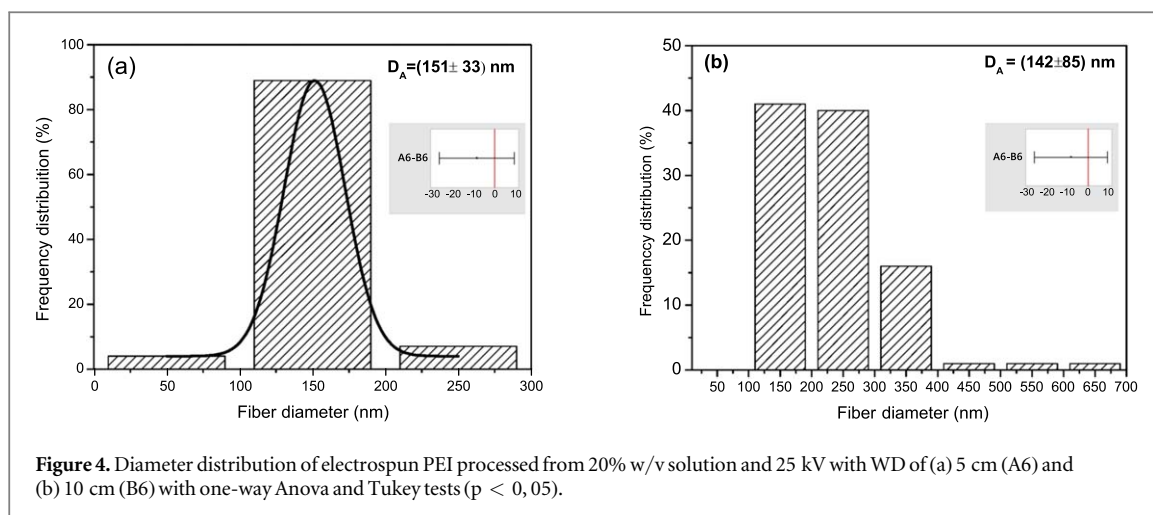


(d)–(f), whose viscosity increased from 0.9 to 1.0 Pa.s, and that exhibited Newtonian behavior like the other solutions (18 and 20% w/v), there was more viscoelastic force to elongate the drops, forming fibers with fewer and smaller beads (figures 3(d)–(f)). However, there were still variations in the fiber diameters, mainly in the samples processed at 15 and 20 kV (figures 3(d)–(e)).

Figure 3(f) presents a mat obtained with the voltage of 25 kV, concentration of 20% w/v and WD of 5 cm. The figure shows the formation of fibers without beads but still with some variation of the fiber diameter. For this concentration and a working distance of 10 cm, we found the formation of mats with the presence of beads and many variations in the fiber diameter for all voltages (figures 3(j)–(m)). During the processing using the solution with 22% w/v PEI, and a WD of 5 cm (figures 3(g)–(i)), we found partial solidification of the solution on the tip of the needle. Thus, this processing condition was judged to be inappropriate. Even with a high value of viscosity (2.5 Pa.s), the mats exhibited a high occurrence of defects. When the working distance was 10 cm and the solution concentration was 22% (images not shown in this work) similar behavior was observed. White spots were observed, without microscopy, in the mats after processing and they occurred due to partial solidification of the solution on the tip of the needle.

For instance there are numerous reports in the literature describing the effects of solution concentration and polymer/solvent interaction on the results of electrospinning.

Rosic *et al* [18] produced mats by electrospinning solutions of poly (vinyl alcohol)/water with concentrations of 2 to 14 wt%. However, nanofibers were not formed in their solutions with concentrations above 12 wt%. Thus, there was a range of viscosities that resulted in the formation of nanofibers. Casasola *et al* [19] also correlated the viscosity with the diameter of the fibers in PLA solutions. They observed that the change in fiber morphology with increasing concentration can be attributed to competition between the surface tension and viscosity. An increase in the polymer concentration and solution viscosity result in more chain entanglements, an increase in the viscoelastic force resulting in nanofibres with fewer beads and larger fibers diameters. However, in very concentrated solutions, fibers were not formed. The Newtonian behavior also was found to be a requisite to produce electrospun mats in solutions with various polyesters in chloroform/dimethylformamide [16] and in solutions of 5, 7 and 10% w/v of poly (D,L-lactic acid) with two systems of solvents: chloroform/dimethylformamide and chloroform/acetone [17]. Moon *et al* [11] produced PEI



nanofibers without defects by electrospinning using solutions with NMP at 20 wt%, with viscosity of 1.808 Pa.s. However, the mats produced with solutions of 18 wt% (0.932 Pa.s) had some beads and those produced with solutions of 15 wt% (0.336 Pa.s) had many beads. These viscosities corroborate the values found in this paper. In this work, the solution with a viscosity of 1.0 Pa.s (20% w/v) produced mats with only a few defects and some variation in the fiber diameter at WD = 10 cm and mats with some variations of diameters and without defects at WD = 5 cm. The solution with a viscosity of 0.9 Pa.s (18% w/v) produced mats with many defects. Pseudoplastic behavior of the solutions of poly (vinyl alcohol) has also been shown to produce nanofibers without defects by electrospinning [20, 21]. Thus, the solution concentration and the interaction of the polymer and solvent are the main parameters for good performance of the electrospinning process.

Figure 4 shows the diameter distributions of the electrospun PEI processed with 20% w/v solutions at 25 kV; (a) 5 cm (A6) and (b) 10 cm (B6) working distances. The values of the average diameters (D_A) of the fibers and Tukey test are listed at the top of the graphs of the diameter distributions. As a function of the difference in working distance, figures 3(f), (m) show the influence of the electrical field (E) on the morphology and fiber diameter distribution in the mats. When work distance change of 10 cm to 5 cm, fewer beads were formed, and less variation of the diameter was observed. Further, in accordance with figure 4(a) and (b), the standard deviation of the diameter was smaller (± 33 nm) than that of the mat with work distance of 10 cm (± 85 nm) and the average diameter of fibers in this mat was slightly greater (151 nm) than that of the mat produced at 10 cm (142 nm). In accordance with Tukey test, the average diameters of the samples A6 and B6 did not change significantly. Thus, the morphology without beads and the smaller variation in the distribution of the diameter of the fiber were considered in this work to be the key parameters to produce PEI mats. The figure 4 shows that despite of the average diameter not be significantly different between the samples, the sample A6 has distribution of the diameter (between 10 nm to 300 nm) narrower than sample B6 (between 100 nm and 700 nm). Thus, processing a solution with concentration of 20% w/v of PEI/NMP, WD of 5 cm and voltage of 25 kV were the most appropriate processing conditions to produce mats due this mat showed fewer defects and a narrow variation in the distribution of the diameter of the fibers.

The FT-IR spectra of electrospun (WD = 5 cm, 20% w/v) and neat PEI are shown in figure 5. The spectra in figures 5(a) and (b) show the following bands: 1780 cm^{-1} and 1721 cm^{-1} related to asymmetrical and symmetrical stretching of C=O groups (carbonyls bands); 1356 cm^{-1} and 744 cm^{-1} related to stretching and deformation of C-N groups and bands 1270 cm^{-1} and 1237 cm^{-1} related to stretching of ether groups in the aromatic rings. All these bands, characteristic of the PEI [2, 3, 22–24], were found in the electrospun PEI and neat PEI.

Conceição *et al* [2, 3] investigated the effectiveness of PEI coatings on solid magnesium alloys. The coatings were formed by films obtained from the solutions of PEI with NMP and dimethylacetamide (DMAc). They analyzed the effect of residual solvent comparing neat PEI and a film of PEI/NMP with 20 wt% of PEI using FTIR. They observed that the spectra of the PEI/NMP film presented similar intensities for both the asymmetrical and the symmetrical carbonyl bands (1780 and 1725 cm^{-1}), two additional peaks with weak intensity together with the carbonyl bands, and, in the region of aromatic rings (between 1200 to 1300 cm^{-1}), the presence of three peaks. For neat PEI, they found that the band at 1725 cm^{-1} was more intense than the band at 1780 cm^{-1} and there were only two peaks in the aromatic region. According to the authors, when the band at 1725 cm^{-1} is more intense than the band at 1780 cm^{-1} , both imide rings are in the same plane, resulting in the presence of additional dipole moments. If both imides are not in the same plane in the molecule, the asymmetrical and symmetrical bands have similar intensities. Thus, in the films made from their solutions, the

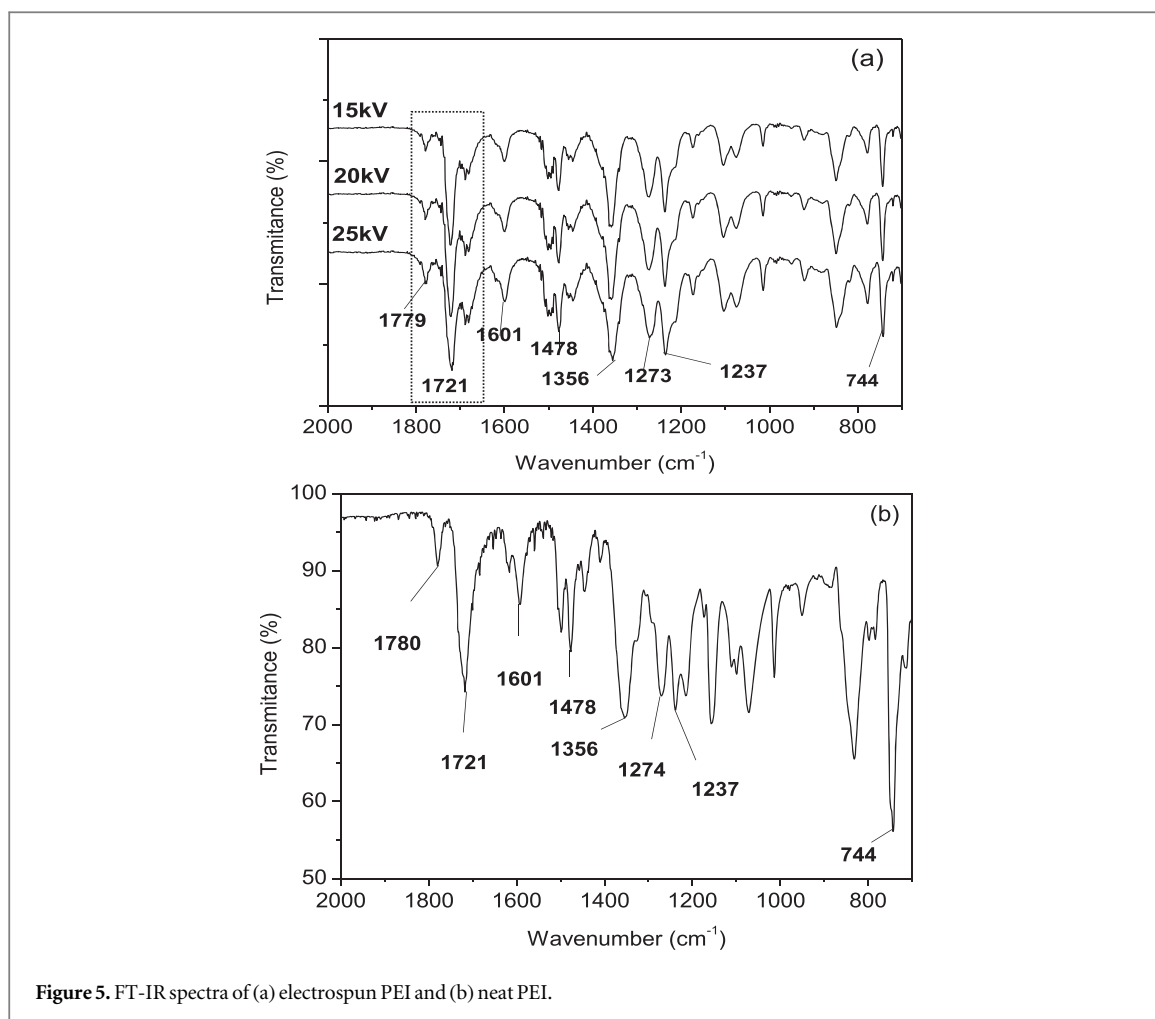


Figure 5. FT-IR spectra of (a) electrospun PEI and (b) neat PEI.

imides were not in the same plane whereas, in the neat PEI, the imides were in the same plane. Also, according to these authors, the change in number of peaks between 1200 and 1300 cm^{-1} suggested a distortion of the ether linkage angle (Ar–O–Ar). Based on their FTIR results, they suggested strong interactions of PEI with NMP. In figures 5(a)–(b), in the carbonyl region, the 1721 cm^{-1} band was much more intense than the band at 1780 cm^{-1} for both samples. This behavior indicated that the imide rings were in the same plane for electrospun PEI and neat PEI. We also observed a new peak at 1681 cm^{-1} only for electrospun PEI, as Conceição *et al* [2, 3] found in the films made with NMP and DMAc. This peak could be attributed to the presence of NMP in the electrospun PEI. We also found a change in signals between the electrospun PEI (figure 5(a)) and neat PEI (figure 5(b)) between 1200 and 1300 cm^{-1} . There were three peaks in the neat PEI, as reported by Conceição *et al* [2, 3], and two peaks with a shoulder at 1200 cm^{-1} in the electrospun PEI. Thus, the FTIR results suggest some interactions of PEI with NMP in the electrospun PEI. Analyses by FTIR were performed for all electrospun PEI and their spectra were all similar to the spectra shown in figure 5(a).

The thermal degradation behaviors of the mats and of neat PEI were analyzed by thermogravimetric analysis (TGA). The thermograms (TGA and DTGA) curves of the neat PEI and electrospun PEI processed at WD = 5 cm with solution concentrations of (a) 18% w/v (A1–A3), (b) 20% w/v (A4–A6) and (c) 22% w/v (A7–A9) are presented in figures 6(a)–(f). Table 2 shows the results of TGA and DTGA analyses for these samples.

There was one temperature of degradation, at 540 $^{\circ}\text{C}$, for the neat PEI. This behavior is in accordance with the literature [6, 25–27]. Some authors [26] attribute the PEI degradation temperature to the evolution of CO , CO_2 and CH_4 during heat treatment which causes cleavage of the rings of the PEI. The PEI fibers produced by electrospinning (A1–A9) showed two and, in some specimens, three maxima of decomposition rate, at various temperatures. The samples A1, A2 and A4 show loss weight in the range of 15 to 20% below 150 $^{\circ}\text{C}$. Also below this temperature, to the others mats can be observed high loss weight, in the range of 58% to 70%. To the mats A1, A2 and A4, this range temperature can be attributed to residual solvent or loss of water that remains adsorbed on the polymer fibers and were not completely evaporated during the electrospinning process. The boiling temperature of the NMP is 202 $^{\circ}\text{C}$. Thus, the degradation temperature observed in below 150 $^{\circ}\text{C}$ cannot be attributed to solvent evaporation. In this light, we attributed this degradation temperature range to the loss of water and other volatile organic components of the PEI because the sample was not previously dried. However,

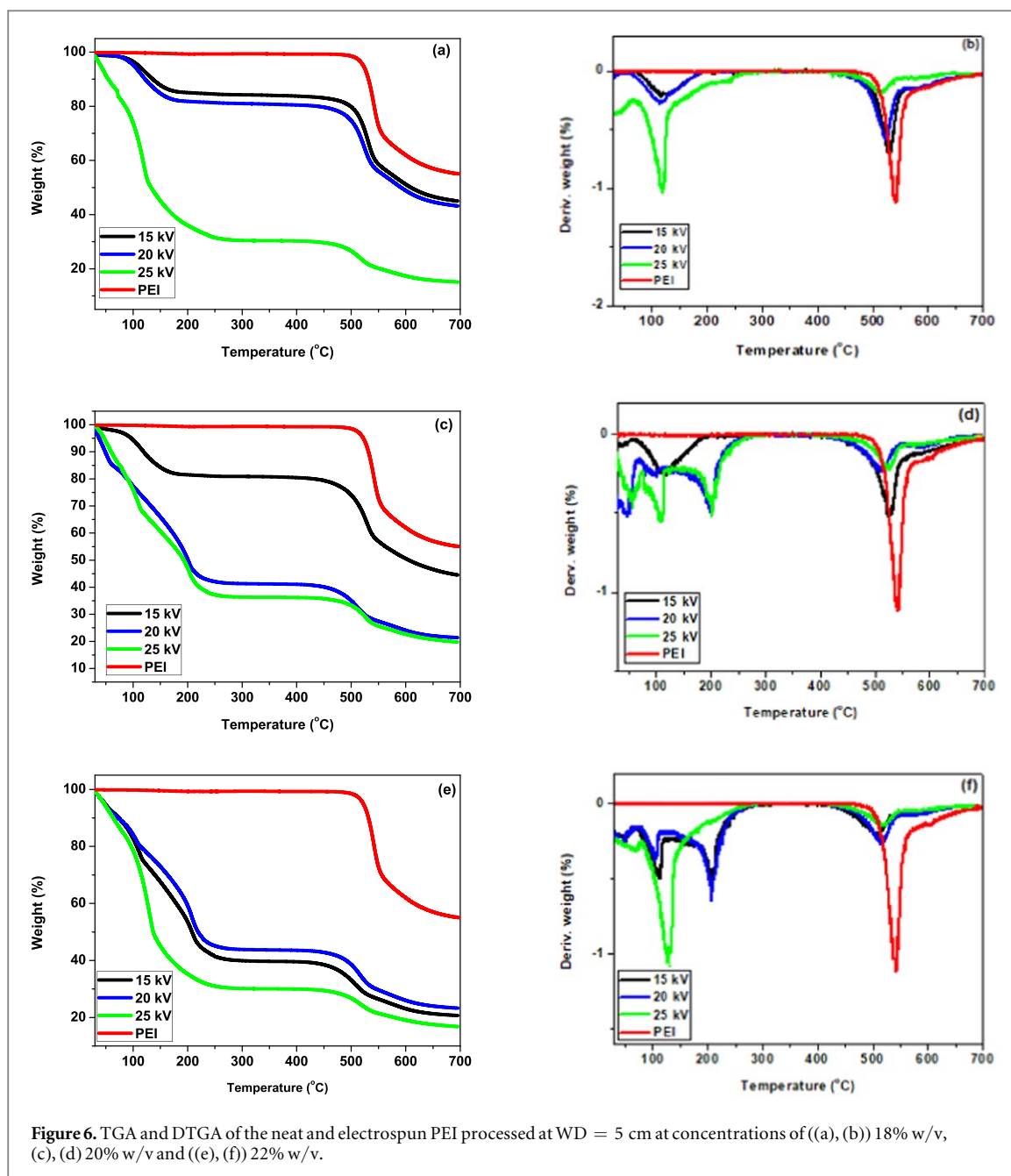


Figure 6. TGA and DTGA of the neat and electrospun PEI processed at $WD = 5$ cm at concentrations of ((a), (b)) 18% w/v, (c), (d) 20% w/v and ((e), (f)) 22% w/v.

Table 2. Decomposition temperatures and residual weight (R) of neat and electrospun PEI.

Sample	T_1	T_2	T_3	T_4	%R
PEI	—	—	—	540	56.2
A1	120	—	—	530	35.0
A2	115	—	—	525	43.0
A3	119	—	—	517	15.0
A4	117	—	—	529	45.1
A5	98	205	—	512	21.9
A6	79	110	205	528	20.5
A7	105	207	—	516	21.5
A8	110	205	—	505	24.0
A9	131	—	—	517	17.8

polyimides are hygroscopic polymer so the presence of water can be change the process of degradation of PEI to lower temperatures. The high loss of weight observed to the others mats possible can be attributed to the change of degradation process of the mats due to the presence of water that contributed to begin the process degradation

of the polymer of the samples A3, A5–A9. In samples A5–A8, we observed a decomposition temperature in the range from 201 °C to 207 °C that can be associated with residual solvent. We also observed decomposition temperatures of samples A1–A9 in the range from 505 °C to 530 °C that are attributed to the final step of the polymer degradation. However, as reported previously, the degradation process of the polymer to the samples A3, A5–A9 begin before this temperature (below 150 °C). The residual weight of all electrospun samples was in the range from 45% to 15%. It is possible to attribute this residual weight to the presence of aromatic rings in the structure of PEI. Han *et al* [6] found residual weight of electrospun PEI above 50% after TGA analysis (20 °C to 700 °C). Most authors have reported two decomposition temperatures in PEI nanofibers [5, 22, 28]. Choi *et al* [28], for instance, found two degradations steps in PEI nanofibers produced using 1,1,2-trichloroethane (TCE) as solvent. They attributed the weight loss in the range of 100 °C to 160 °C to the evaporation of the TCE. Li *et al* [25] also observed two decomposition temperatures in electrospun PEI. The first step was found between 100 and 200 °C with percentage of 2.6% and was attributed to the evaporation of volatiles and water. The second decomposition temperature occurred between 500 and 650 °C. The authors proposed applications of these mats as filters used in high temperature environments. However, Salleh *et al* studied PEI membranes produced by solvent casting and found only one degradation temperature, between 480 and 570 °C [26]. The presence of one step was also reported by Wang *et al* [27] in membranes of PEI. They showed a degradation temperature in the range of 450 °C to 650 °C ($T_d = 508$ °C). These two last works reported that the membranes were dried before TGA analyses and thus the first peak would not be expected.

The electrospun PEI (A1–A9) exhibited lower PEI decomposition temperatures and lower residual weights than neat PEI. Thus, the degradation behavior of the electrospun PEI was less stable. This could be because of the higher surface area the microfibers increased the effect of exposure to heat, and the presence of solvent and water created apparent instability at lower temperatures.

Conclusions

Mats formed with nanofibers with diameters around 150 nm were produced by electrospinning. The most appropriate processing conditions were: 20% w/v of PEI/NMP, WD of 5 cm and voltage of 25 kV due this mat showed fewer defects and a narrow variation in the diameter of the fibers. It was found that in spite of very little increase in viscosity over that 0.9 to 1.0 Pa.s, it was possible to obtain significant improvement in the characteristics of the electrospun PEI to produce fibers having good morphologies. However, due to the higher loss of weight of this nanofiber below 150 °C, this mat can be only be used in temperature in the range of 20 °C to 50 °C.

The electrospun PEI had lower degradation temperatures and exhibit degradation behavior different from that of the neat PEI. When compared with neat PEI, the electrospun samples showed a peak at 1681 cm^{-1} and the bands showed a doublet with a shoulder in the range of 1200 to 1300 cm^{-1} that could possibly be attributed to the presence and some interaction of the NMP with PEI in the electrospun nanofibers. In conclusion, nanofiber of PEI were produced and can be considered as a promising material to be evaluated some applications considering temperatures between 20 and 50 °C such as: sorbent for organochlorinated pesticides, to protect magnesium alloys against corrosion and for bio-hybrid organs like liver support system.

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