Permeability of Polyamide6 Nanofiber for Air Filtrations

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Abstract:

Polyamide6(PA6) nanofibers are prepared in this study for air filter applications by electrospinning technique. The electrospun solution (21% PA6 concentration) is prepared by dissolving PA6 powder in formic acid. Permeability, filter efficiency, thickness of filters and pores size are measured to characterize the air filter membranes. Results prove that the efficiency of filter is ranging between (93-95%), AFM test shows that all samples have a pore size between (71-101 nm), that is corresponding with(ASHRAE Standard 52.1 and 52.2) which makes the air filters in this search working at hospital care, smoke lounge and general surgery applications.

Keywords:-Polyamide6, Nanofibers, Air Permeability, Efficiency, Hospital Care, Smoke Lounge.

الخلاصه

في هذا البحث تم تحضير نسيج نانوي من الياف بولي أمايد 6 (PA6) النانوية بتقنية الغزل الكهربائي لاستخدامه في تطبيقات فلتره الهواء. حيث تم تحضير محلول البولي امايد بتركيز 21% بإذابة البولي امايد في حامض الفورميك. تم قياس النفاذية ، الكفاءة، السمك، وحجم المسام لأغشية الفلتر الهوائي. اثبتت النتائج إن كفاءة الفلتر تتراوح ين (93%-95) ، ومن خلال فحص AFM وجد إن جميع العينات يكون معدل حجم المسام تتراوح بين (101- 71 نانومتر) وهذا يتطابق مع (ASHRAE Standard 52.1 and 52.2) مما يجعل الفلاتر الهوائية المحضرة في هذا البحث تستخدم في تطبيقات غرف عناية المستشفيات وغرف التدخين والجراحة العامة.

الكلمات المفتاحية :- بولي امايد 6، ألياف نانوية، نفاذية الهواء، كفاءة، عناية المستشفيات،غرف التدخين.

Introduction:

At present, the removing of contaminations from air becomes on important issue due to the large quantities of dust and smoke and pollutions materials in air which have a large effect on human health.(Jalava *et.al*., 2015).

Nanofibers materials which can produced by the electrospining technique are the best solve to the problems that caused with by tiny particles that have a very fine diameter because it will clear the air by separating the contaminations from air depending on the air filtration mechanisms (Interception, Diffusion, Inertial impaction, Electrostatic deposition)(Barhate *et.al*., 2006; Suryamas *et.al.*, 2010; Wang & Otani, 2013).

Electrospinning is a simple method to produce a thin fiber with high surface area and high porosity that used in different applications such as protective clothing, medical applications, sensor and filtration. Electrospinning process depends on the strong electrical forces that conquer weaker surface tension of a polymer solution at definite threshold to throw out a liquid jet(Lu & Ding, 2008).

PA6 is synthetic polymer has good mechanical properties, biodegradable and biocompatible with good resistance to the humidity. Also, PA6 nanofibers can easily produce, besides that its capability to dissolve in formic acid or formic acid/acetic acid solvent which they are non toxicity solvents that make PA6 good candidate in preparing filtration membranes to increase the efficiency of filter(Hung& Leung, 2011; Zhang *et.al.*, 2009; Heikkil *et.al*., 2008).

Many of research about electrospinning nanofibers such as in 2010, Mohammad Chowdhury and George Stylios used the electrospinning process to produce Nylon 6 nanofibers with diameter (150nm-1300 nm), it is found that the fiber diameter is vary when the concentration is (15wt%-25wt%) in formic acid ,conductivity of the polymer solution, field collection distance and applied electric. PA6 with 20 wt.% is the optimal sample with 924 nm diameter and 15 kV applied voltage, 0.20 ml/hr volume feed rate and 8 cm spinning distance. SEM microscopic techniques examine the morphology of the nanofibers(Mohammad& George, 2010).

In 2011 Hong *et.al.*, prepared composite nano fibers from integrating nano silver in nylon solution through electrospinning method for using in filtration. Different parameters of the electrospinning fibers is studied and establish that adding nano silver is suitable for antibacterial property in nylon composite fibers as well as, the morphology of nanofiber and nanofiber diameters are affect when solution concentration and the amount of nanosilver changes(Hong *et.al*., 2011).

In 2012, Sarfaraz *et.al.*, electrospun poly(4-methyl-1-pentene) to produce superhydrophobic mats using a variety of solution concentrations(1 - 4wt %). The results show that the fibers are taking ribbon and circular shaped with beads. The diameters are between 200nm – 700nm with contact angles exceeding 150 degrees (superhydrophobic). Water contact angles reduce when fiber diameter increase other than are not a lot affect with the fiber mat basis weight and the permeability is weakly related to the fiber diameter but has linear relation with the mat basis weight. The air permeability measured was larger than the permeability calculated with the Kuwabara model used for fibrous media(Sarfaraz *et.al*., 2012).

In 2014 Noorpoor *et.al*., produced Nylon-6 nanofiber mats membranes by electrospinning method. They study the effect of nylon concentrations with thickness of nanofilters media. They found that the porosity pass a smallest amount at 10% concentration through using SEM micrographs of specimens treated by ImageJ software reveal. The diameters of nanofiber are in the range 47nm to 89 nm as the concentrations of PA6 are between 7.5% to 15%. They found that for the all concentrations the efficiency is improved by electrospinning technique for three times. However, the maximum efficiency find is 99.96% at 10% PA6 concentration at electrospinning time (45 min)(Noorpoor *et.al*., 2014).

In 2016, Abdul *et.al*., synthesized nanofibers membranes of polyacrilonitrille (PAN) by using electrospinning technique to examine the relation between the PAN the pressure drop with the concentrations .They used (6, 9, and 12 wt.%) concentrations from PAN solution to use in air filtration application. It demonstrated that the fibers diameter increase with the increasing of concentration as well as the fibers diameter distribution have further uniform. 12 wt.% from PAN solution has the best membrane morphology due to its homogeneity in fiber diameter, but the highest pressure drop as compared to the concentrations of 9 and 6 %wt . Scanning electron microscope (SEM) measures the fiber diameter distribution of membranes(Abdul Rajak *et.al*.,2016).

The aim of this study is preparation air filter through electrospinning process as well as to measure the permeability of air filter.

Experimental Part:

This part includes the materials used and the method to prepare the nanofibers membranes as well as the tests on the membranes.

Materials:

Polyamide 6 (PA6) with molecular weight (80-100) g/mol produced from China is dissolved in formic acid (85%) at room temperature to get the electrospun solution with a concentration (21%), the concentration puts on magnetic starrier for 24 hr to produce a homogenous solutions before electrospinning process**.**

Electrospinning Process:

In this study Nano-azma direct system is used that consists of direct high voltage power supply (DC-HV with 0 Kv & 50 kV) with a syringe pump with deionize rate (0.1 – 10) ml/hr and metallic collector stainless steel rotate cylinder collector with (8 cm as a diameter and 13 cm as a length).

A syringe with polymer solution is placed in a syringe pump to generate a constant flow of fluid through the needle. This needle was connected to a positive electrode of HV. A negative electrode of the HV was connected to the metallic collector and the metallic collector was connected to the earth. Table(1) shows The conditions used to produce electrospinning nanofibers.

Table (1): The conditions used to produce electrospinning nanofibers.

Sample number	Voltage (KV)	Injection Rate (ml/h)	Distance (cm)	Time (hour)
1	19	5	11	4
2	25	5	11	4
3	34	5	11	4

Results and discussions:

Table (2) shows the result of testing (PA6) membranes, permeability and efficiency of membranes are measured by using permeability and efficiency test device in Ministry of Sciences and Technology. The thickness is measured by Coating Thickness Gauge test of type (model TT260, TIME GROUP Inc), many reading is taken and the average value is considered due to the changeable thickness of the same filter. The morphological studies of the samples are conducted by tapping mode SPM model AA3000 ANGSTROM ADVANCED INC., USA, 2008 (AFM-Contact Mode), while the porosity% is measured by using Image J software program.

Table (2): The result of testing PA6 samples.

Sample number	Thickness (µm)	Flow Rate (Q) (ml/min)	ΔP (Pa)	Permeability $*10^{-11}$ (m^2)	Average Pores Diameter (nm)	Porosity (%)
1	8	100	29.4	0.439	101	39.514
2	7.5	100	9.8	1.23	87	46.786
3	6	100	6.86	1.41	71	48.361

To determine the permeability, Darcy's equation(1) is used[Sarfaraz, *et al*., 2012]:

$Q = A K \Delta P / \mu L$ …………..(1)

Where:

Q is the flow rate (ml/min), A is the area of filter(cm^2), K is the permeability (m^2), ΔP is the pressure drop, µ is the air viscosity($18.27*10^{-6}$ Pa. s) and L is the thickness of filter (µm).

$K = Q \mu L / A\Delta P = (100*10^{-3}*18.27*10^{-6}*8*10^{-6})/(60*1884*10^{-6}*29.4)$

$=0.439*10^{-11}\ m^2$ (permeability of sample No. 1).

Figure(1): air filter membrane after air filtration.

To determine the particle collection efficiency, efficiency equation (2) is used (Francesca, 2014):

$E\% = \{(Q_{in} - Q_{out})/Q_{in}\}*100\%$ …………..(2)

Where E is the efficiency, Q_{in} is the air flow in and Q_{out} is the air flow out.

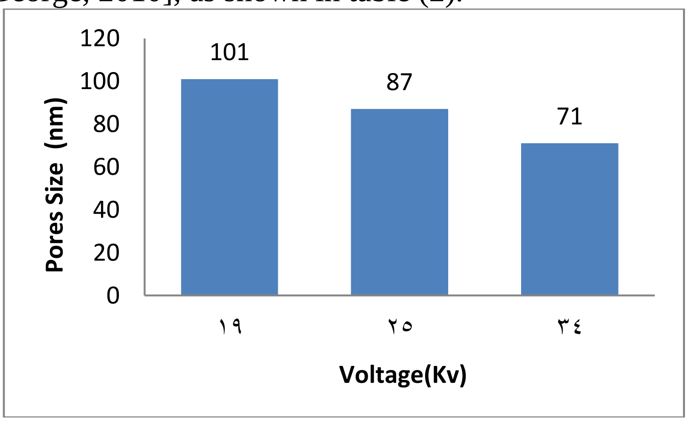
E%={(150-10)/150}*100%=93% (efficiency of sample No. 1)

Table(3): show the result of the efficiency.

Sample No.	Q_{in} (ml/min)	Q_{out} (ml/min)	Efficiency (%)
1	150	10	93
2	200	10	95
3	150	8	94.6

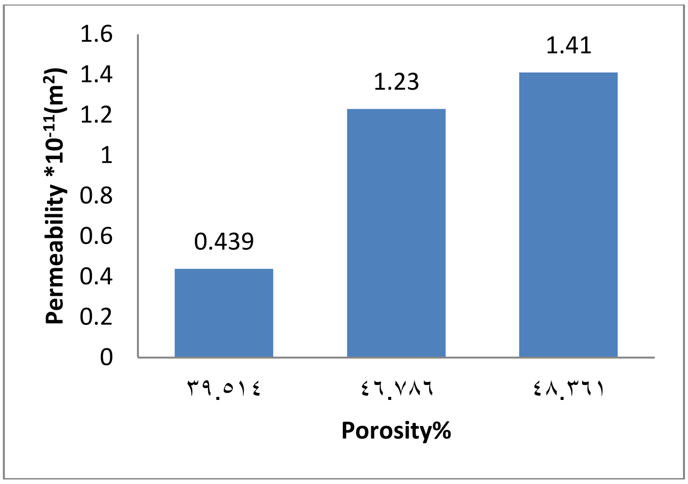
The pore size result from AFM test show that all pores size ranging from 101 to 71 nm, this ensure that small particles (0.3–1.0 μm) will not inter during filtration process, especially that the efficiency of filters obtained is between 93 to 95%, this is corresponding with ASHRAE Standard 52.1 and 52.2 which makes the air filters in this search working at hospital care, smoke lounge and general surgery applications(California Air Resources Board, 2014).

Figure (2) shows that the voltage has a large effect on pores size of membranes, the pores size decreasing with the increasing of the voltage, Increasing the applied voltage induces upper electrostatic forces on the jet and the higher repulsive forces help the formation of the thinner fibers that leads to lesser pores diameter [Mohammad& George, 2010], as shown in table (2).



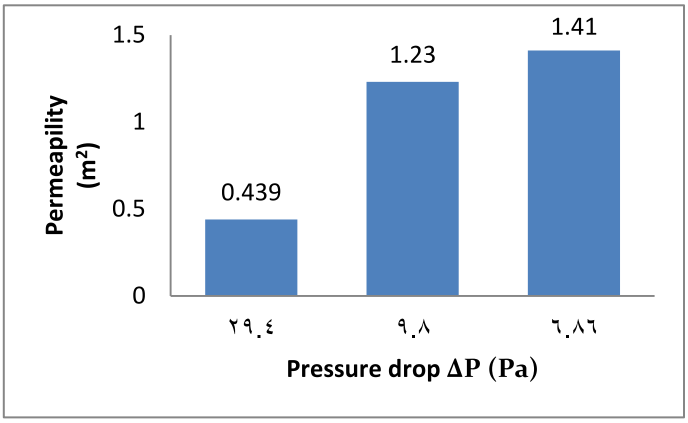
Figure(2):decreasing of pores size of filters with increasing of the voltage.

Figure(3) show that the permeability is increasing as the porosity% increasing, because the large porosity promotes to inter a large amount of air, that will enhances the permeability of air filters..

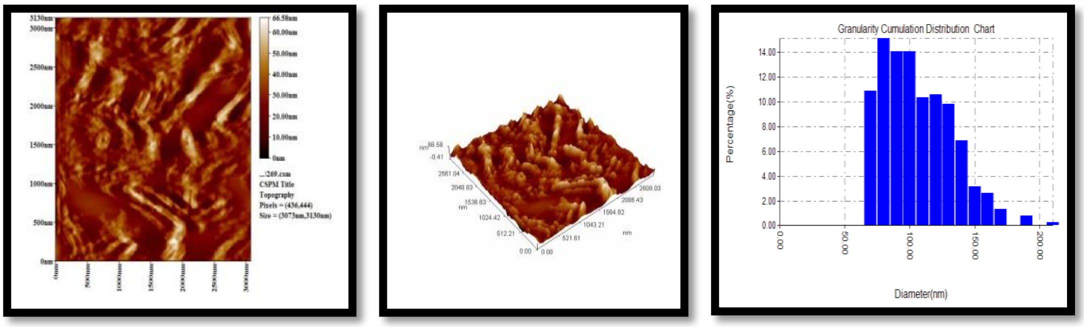


Figure(3):increasing of the permeability with increasing of the porosity% of the filters.

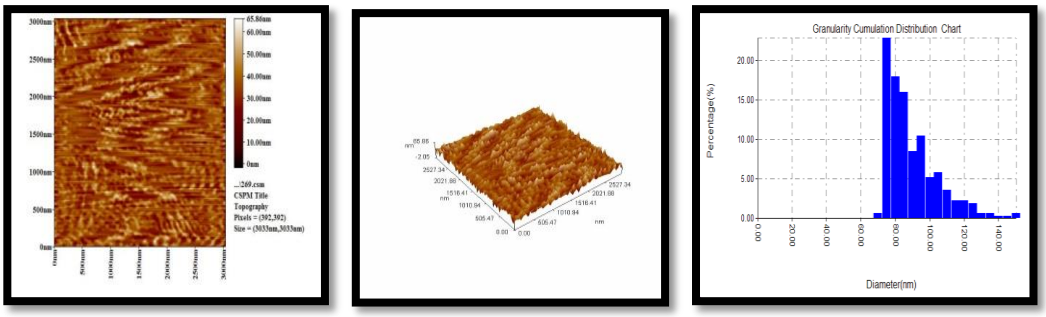
Figure(4) show the increasing of the permeability with the decreasing of the pressure drop, that's corresponding with Darcy's law (equation1).



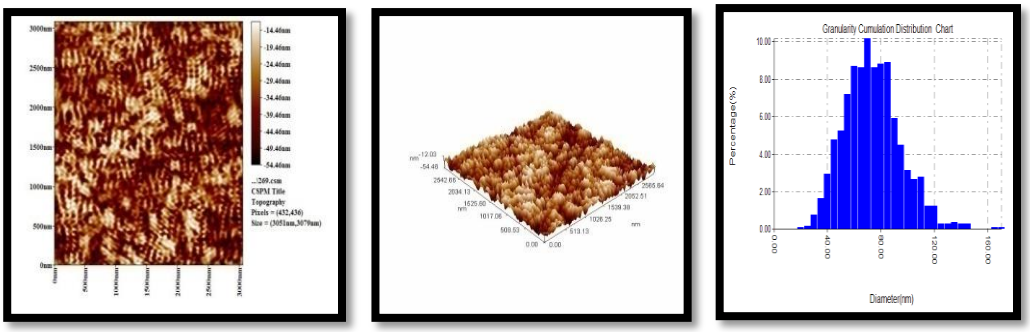
Figure(4):increasing the permeability with the decreasing of the pressure drop.



(A)



(B)



(C)

Figure(5):AFM test image:(A):sample1,(B):sample2,(C):sample3.

Conclusion:

1.The small pores diameter is between 101-71 nm giving efficiency between 93 to 95% which makes the air filters in this search working at hospital care, smoke lounge and general surgery applications.

2.The voltage has a large effect on the pore size when the voltage increasing, the pore size decreased.

3.The high efficiency is obtained at sample No.2 with applied voltage(25 KV), permeability(1.23m^2), pore size(87nm) and the porosity (46.786%).

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