Study The Effect of Conditions of The Electro Spinning Cabin (Humidity) on Electro-spun PolyVinyl Alcohol (PVA) Nano-fibers

Samara Alswid
Textile Engineering Department
Faculty of Petroleum and Chemical Engineering
Albaath University, Syria
smr.swe.85@gmail.com

Manal Issa
Textile Engineering Department
Faculty of Petroleum and Chemical Engineering
Albaath University, Syria
dr.issa1976@hotmail.com

Abstract:

Electrospinning is a simple and highly versatile method for generating ultrathin fibers (mainly polymers) with diameters ranging from a few micrometres to tens of nanometres. This technique has attracted tremendous recent interest in both academia and industry, owing to its unique ability to produce ultrafine fibers of different materials in various fibrous assemblies. Electrospinning is a process that uses an electric potential to overcome the surface tension of a solution to produce an ultra-fine jet, which elongates, thins and solidifies as it travels through the electric field to a collector.. In this research, we studied the effect of conditions of the cabin "specifically humidity" on the diameter of nanofibers manufactured by electrospinning. We used Polyvinyl alcohol (PVA) polymeric solution with weight concentration of 10%, voltage 20 kv, under different values of relative humidity. Fiber morphology and fiber diameter were determined using scanning electron microscope, and measuring the fiber diameter by using image j program. It was found that the diameter of the fibers increased with increasing the relative humidity within our studying area .

Key words: Nanofibers, Electrospinning, Nanotechnology, process conditions, Relative Humidity.

1. Introduction:

Electrospinning, which may be considered to be a variant of the electrostatic spinning (or spraying) process, is currently the only technique that is able to produce continuous ultrafine fibers from submicrometre to nanometer diameters. The original idea of using high electric potentials to induce the formation of liquid drops can be traced back more than 100 years [1][2][3]. The first patent that described the operation of electrospinning appeared in 1934, when Formhals disclosed an apparatus for producing polymer filaments by taking advantage of the electrostatic repulsions between surface charges[4]. Despite these early discoveries, the procedure was not utilised commercially with any great success. In the early 1990s, several research groups revived interest in this technique by demonstrating the fabrication of thin fibres from a broad range of organic polymers[5]. At this time the term 'electrospinning' was coined and is now widely used in the literature. In recent years, many publications in this field has grown exponentially owing to a number of factors: improvements in imaging techniques, the ability to fabricate complex scaffolds and the convergence of nanotechnology and biotechnology for the application of tissue engineering[3].

2. Research Goal:

The goal of the research is studying the effect of changing value of the humidity of the electrospinning cabin on the final nanometer diameter.

3. Basic concepts:

In a typical electrospinning process a high voltage is used to create an electrically charged jet of polymer solution or melt, which dries or solidifies on extrusion to leave a polymer fibre [6]. Three major components are needed to complete the process (Fig. 1): a high voltage power supply, a capillary tube with a spinneret and a collector which is normally earthed [4]. Most often the spinneret is connected to a syringe which supplies the polymer solution and the solution can be fed through the spinneret at a constant rate using a syringe pump. When a high voltage is applied, the pendant drop of polymer solution at the nozzle of the spinneret becomes statically charged and the induced charges are evenly distributed over the surface[7]. The surface tension of the droplet would normally result in a sphere at equilibrium but it is distorted in the electric field, because charges within the droplet migrate to the surface that faces the collector. The accumulation of charge causes a protrusion to appear on the end of the droplet, distorting the droplet into a conical shape known as the Taylor cone [8]. With increasing field strength, the repulsive electrostatic force overcomes the surface tension and a charged jet of fluid is ejected from the tip of the Taylor cone when a critical value is attained. The polymer solution is discharged as a

jet which then undergoes a stretching and whipping process (a series of connected loops) [5, leading to the formation of a long thin thread. As the solvent evaporates, solid polymer fibers with diameters ranging from micrometers to nanometers are formed and lay themselves on a grounded collecting metal screen or drum. Theoretical understanding of the electrospinning process has advanced greatly in the last few years and has been discussed in detail [1][2][5].

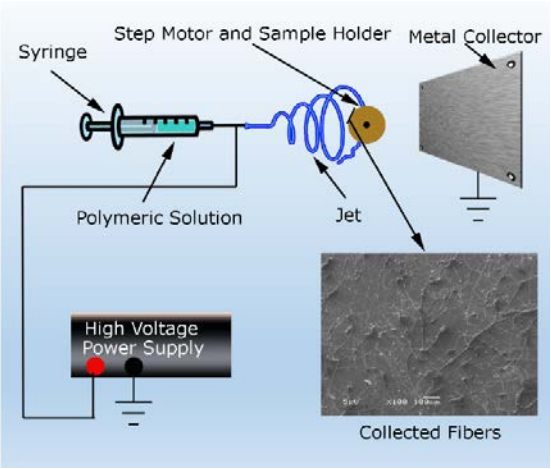


Figure 1: Conventional electrospinning setup[6]

4. Processing conditions:

Process control in the electrospinning process is typically limited to identifying the operating conditions that produce fibres with acceptable properties. However, within a laboratory setting, even with these conditions identified, it is reported that there still remains significant variation in the quality of the produced materials[3][4]. These variations are a result of an incomplete understanding or consideration of all the process variables. There are many factors influencing the morphology of the fibres or fibrous constructs produced and these can be divided into solution parameters, process parameters and ambient parameters which are listed in Table 1[8].

Table.1: Variables of the electrospinning process divided into classifications

Solution parameters	Process parameters	Ambient parameters
Material selection	Electromagnetic fields	Humidity
Solvent selection	(strength and orientation)	Temperature
Concentration Viscosity	Spinning distance Solution flow rate	Atmosphere Air movement
Dielectric	Spinneret	
constant	morphology	
Conductivity	Collector morphology	
Surface tension		
Elasticity		

5. Experiments:

5.1. Device, equipment and Materials :

A-Electrospinning Device:

We worked on a device have been designed in Albaath University- Chemical and Petroleum Engineering Faculty- Textile and Spinning Department as shown in fig(2).

Electrospinning device consists of:

- **Extrusion equipment:** a pump and the syringe and needle.

  The syringe pump of this device has been designed in order to use of a variety of syringes. The system is able to inject the certain volume of solution with different rates
- **The collector:**

  We used a rotating chrome cylinder.
- **High voltage power supply:**

  In our experiments, the volt was about 5–25 kV.

Figure 2: Illustrate Electrospinning device

B-Controlling Humidity of the electrospinning room:

The Humidity is controlled by using a device consists of two copper probes, at the top and bottom of the cabin, so we can get an average value of moisture, hot air source, and heater (coil) with bicker contains water. we define the value of humidity on Set Point using a systematic and determine the value of the permittivity (3%), when the humidity is higher than desired value, the drier works (hot air source) and reduce humidity, when the humidity is lower than desired value the heater works to raise the

temperature of water to boil, then vapor increase humidity to reach the desired value.

C-Scanning Electron Microscopy (SEM):

Fiber morphology and fiber diameter were determined using scanning electron microscope, which have magnification ability up to 5000 times.

Figure 3: Scanning Electron Microscopy (SEM)

Chemical Materials:

-Polyvinyl alcohol (PVOH, PVA, or PVAl):

Poly vinyl alcohol is a water-soluble synthetic polymer. It has the idealized formula $[CH_2CH(OH)]_n$. It is used in papermaking, textiles, and a variety of coatings. It is white (colourless) and odorless. It is sometimes supplied as beads or as solutions in water.

Table 2. Properties of Polyvinyl alcohol

Chemical formula	$(C_2H_4O)_x$
Density	1.19-1.31 g/cm^3
Melting point	200°C (392 F; 473 K)
Boiling point	228°C (442 F; 501 K)

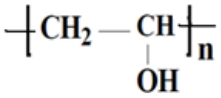


Figure 4: Chemical formula of Polyvinyl alcohol

- **The solvent:** Distilled water was used as a solvent for the polymer. It should be used in order to be free of impurities and electrolytes, which can change the electrical conductivity values.

6. Experiments Parameters:

Four experiments have been done with five different electrospinning room humidity, but same else parameters as shown in table 3.

Four samples (non woven nano-fibers mats) were prepared then scanned under scanning electron microscope (SEM) and analyzed using Imagej program to get the average nano-fibers diameter for each sample at each different electrospinning room humidity.

Table 3: Experiments Parameters

No. experiment	1	2	3	4
Humidity %	40	50	60	65
Polymer concentration % wt	10	10	10	10
Flow rate ml/h	6	6	6	6
Distance between syringe needle and collector cm	10	10	10	10
voltage supply kV	22	22	22	22
Collector rotating speed rad/sec	207.24			
Temperature C	25-28			

7. Results and Discussion

The results are taken from the electro-spun nonwoven nano-fibers mats fabricated under specified parameters mentioned above.

Nonwoven nano-fibers mats produced by electrospinning device shown in fig. (5) using amplification between 1800X – 3000X.

The average diameter of each sample was measured and calculated, as listed in table (4).

While the relation between humidity and diameter of fibers shown in fig. (6).

From the table and chart, while the humidity of the room increase the average diameter of the nano-fibers increase within our studying area.

The explanation of the reason of the effect can be due to the fact that increased humidity slows the solidification process for aqueous solutions, increasing both beading defects and fiber diameters [7].

Generally, the surrounding humidity will affect each solution differently, depending on the solvent used and the hydrophilicity of the polymer solution. Aqueous solutions are obviously most affected as the humidity is a measure of the vapor pressure of the solvent in the atmosphere and it can be expected that the water in solution and in the atmosphere will interact [7][9]. The evaporation rate for a pure liquid from a free surface is proportional to the difference between the saturated vapor pressure (100% humidity in the case of an aqueous solution)

and the vapour pressure of the surrounding environment. A higher humidity will slow the evaporation rate of water, thus increasing the drying time, which would produce thinner fibers given enough time for the water to evaporate completely before the jet hits the collector [10][11].

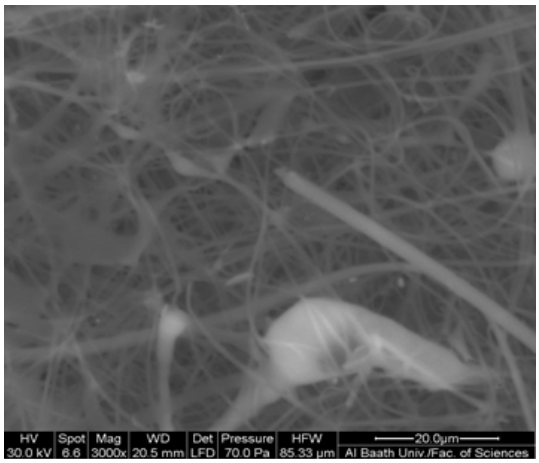
Another impact that humidity will have on non-aqueous solutions is that the solution can absorb water during flight [10]. The rate of absorption will be dependent on the material's affinity for water and the solution's ability to absorb water. This phenomenon could cause a slowing in evaporation, which may cause an increase in fiber diameter, introduce pores on the fiber surface owing to solvent concentration variations, or produce congealed mats instead of unwoven fibers. According to Jeun *et al.* (2007), increasing the humidity from 30% to 50% caused PLLA fibers to display porosity when spun from a chloroform solution [10][12].

It was noted from figure (5) that the most uniform nano-fibers having the least amount of beads were at the humidity 50% .

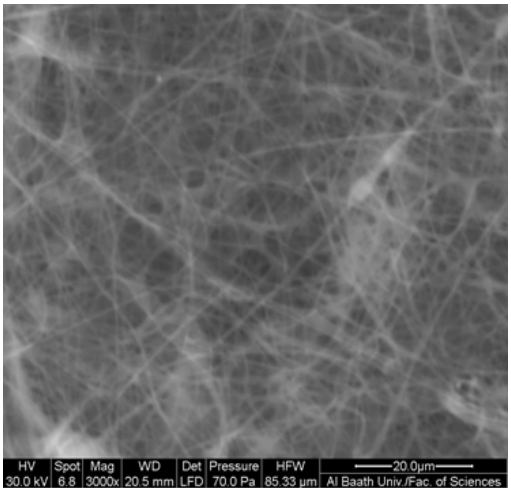
The fibers spun at low relative humidity are long, continuous, relatively straight fibers with uniform diameters and very few beaded defects. The fibers spun under high relative humidity conditions are curved, discontinuous, and very thin and contain a concentration of beaded defects. It appears that in the case of excess humidity, the solution is not evaporating from the jet as it travels towards the collector plate and since the fibers are still wet with solvent, the surface tension of the water remains a dominant force resulting in the formation of the beads in the fibers, since surface tension wants to minimize the surface area of the jet into spheres.

From the chart (figure (6)) we can find the relationship between humidity and average diameter of nano-fibers, which can represent by the equation:

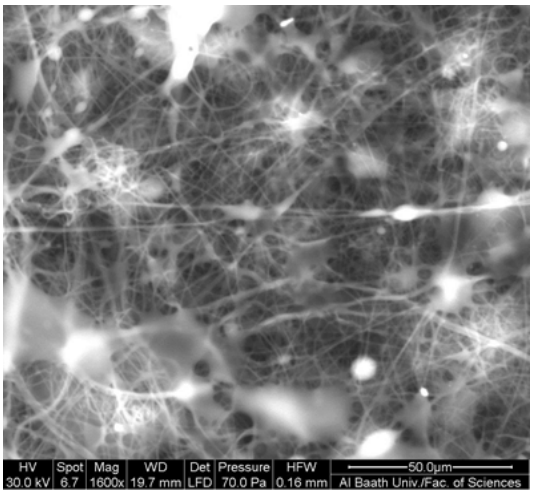
$$y = 0.699\,x^2 - 59.514x + 182.9$$



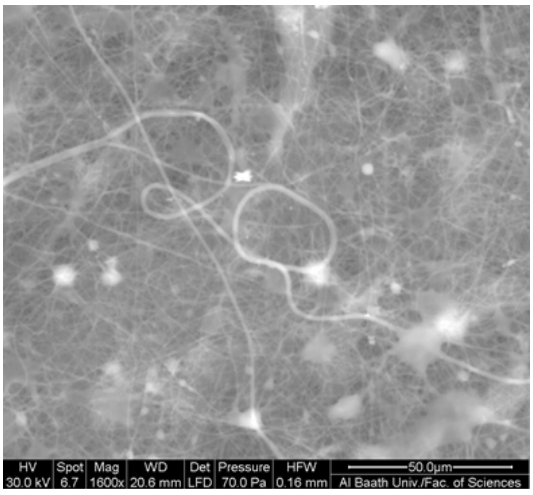
At electrospinning room humidity 40%



At electrospinning room humidity 50%



At electrospinning room humidity 60%



At electrospinning room humidity 65%

Figure (5): SEM photos of nonwoven nano-fibers mats samples prepared at different electrospinning room humidity

Table(4): the values of average nano-fibers diameter at different electrospinning room temperatures

Average nano-fiber diameter (Nm)	Electrospinning room humidity %
556.98	40
637.31	50
721.79	60
943.17	65

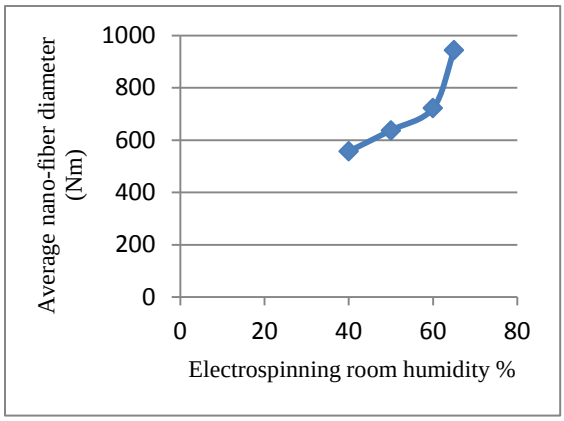


Figure (6): The relation between humidity and average diameter of fibers

8. Conclusion

PVA nano-fibers were electro-spun under a controlled humidity. The effects of electrospinning device room humidity on nano-fibers were investigated. The result obtained by SEM indicated the impact of: with increasing process humidity, the average of nano-fibers diameters and beading effect increasing. The average fiber diameter increased from 556.98Nm to 943.17 Nm for process humidity 40% and 65% respectively. Electrospinning room humidity for nano-fiber production in this work which yield the most suitable fiber mats for a membrane purpose are 50% because of the highest level of fiber diameter uniformity.

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دراسة تأثير شروط حجرة الغزل الكهربائي (الرطوبة) على ألياف بولي فينيل الكحول المغزولة كهربائياً

سمارة السويد منال عيسى
قسم هندسة الغزل و النسيج, كلية الهندسة الكيميائية و البترولية جامعة البعث، سوريا

ملخص البحث:

تعتبر عملية الغزل الكهربائي عملية سهلة و بسيطة لإنتاج ألياف نانوية بأقطار تتراوح بين بضعة ميكرومترات و عشرات النانو مترات. وقد لاقت هذه الطريقة اهتماماً كبيراً مؤخراً في المجالات الأكاديمية و الصناعية, وذلك بسبب قدرتها على إنتاج ألياف متناهية في الصغر من مواد مختلفة وبأشكال مختلفة. يتم في هذه التقنية استخدام تيار كهربائي عالي الجهد يتغلب على التوتر السطحي للمذيب فيتشكل تيار بثق عالي الدقة, ويستطيل ثم يتصلب أثناء انتقاله إلى مجمع مأرض أو مشحون عكسياً. تم في هذا البحث دراسة تأثير شروط الحجرة وتحديداً الرطوبة على قطر الألياف النانوية الناتجة عن عملية الغزل الكهربائي حيث تم استخدام محلول بوليميري من الPVA بتركيز وزني % 10, و فرق كمون 20 kV و تم تطبيق قيمة مختلفة للرطوبة النسبية. تم تحديد شكل و قطر الألياف الناتجة باستخدام المجهر الالكتروني و قياس أقطار الألياف الناتجة باستخدام برنامج Image j, و تم ملاحظة تزايد القطر مع زيادة نسبة الرطوبة وذلك ضمن المجال المدروس.

الكلمات المفتاحية: الألياف النانوية, الغزل الكهربائي, تقانة النانو, شروط العملية, الرطوبة النسبية.