The Influence of Humidity-Control Addition on Electrospinning System for Nanofiber Formation

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Abstract: This research was conducted to determine the effect of humidity control system and collector rotational speed on electrospinning during PVA nanofiber fabrication. The humidity control system is controlled by Arduino Uno and the actuator is an air pump, and modifications are made to the air pump by adding silica gel as a more optimal humidity reducing agent. A 12 V DC-motor and L293D driver are used to control the direction and speed of rotation of the collector. The collector speed control uses the principle of Pulse Width Modulation (PWM). The humidity control system that has been made has an accuracy rate of more than 88%, and the lowest relative humidity achieved is 30%. The collector control system that has been made has an accuracy rate of more than 95%, and the lowest rotational speed is 125 RPM. Carbon nanofiber was successfully fabricated with an average diameter distribution of 43.4 nm and 79.2 nm at 30% and 40% humidity, respectively.

Keywords: PVA nanofiber; Electrospinning; Humidity

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I. INTRODUCTION

Nanofiber is a product of nanotechnology. Nanofiber is defined as an ultra-fine dense fiber that has a very small diameter. The diameter of nanofibers is tens to hundreds of nanometers, so they are called ultrafine dense fibers [1]. Research related to nanofibers is often carried out because nanofiber has a large surface area per unit mass and small pore size and has superior mechanical properties [2]. Electrospinning technique is a technology to make 1-dimensional nano-sized particles derived from materials in the form of solutions or liquids. Electrospinning technique is done by using a high voltage source [3]. The voltage source that can be used in electrospinning between 7 to 32 kV [4]. Nanofiber resulting from the electrospinning process has many advantages, namely having a high porosity and a larger surface area per unit volume [5]. The manufacture of nanofibers with diameters in the nanoscale can be done by controlling several parameters in the manufacturing process by electrospinning. As in Fig. 1, the main part of the electrospinning device is composed of a DC high voltage source, a syringe tube, a small diameter needle, a humidity control system, and a metal collector [6].

The electrospinning method is a method that provides many advantages among the existing methods. The advantage is that the electrospinning technique can produce nano-sized fibers [7]. The formation of polymer jets in the electrospinning method affects the morphology of the nanofiber, the polymer jet is influenced by environmental conditions, one of which is humidity, but most of the existing studies do not explain the effect of relative humidity from the electrospinning environment. In addition to the relative humidity parameter, the rotating speed of the collector affects the morphology of the fiber. The rotational speed of the collector will affect the continuity of the fiber [8].

The size of the nanofiber diameter is strongly influenced by the humidity during the spinning process [9]. An environment that has high humidity helps the formation of skin quickly with clear boundaries, whereas if there is not enough moisture the solvent will evaporate easily [10]. When the polymer is hydrophobic, water acts as a non-solvent so that the fiber skin is easier to be formed [11]. This makes PMMA, PVC or PS in DMF, PMMA or PS in toluene have a porous fiber when electrospun in an environment of more than 30% of relative humidity, while PVA is a hydrophilic polymer solution. Water acts as a solvent so that skin formation is easy to form at 20% humidity [12] and no pore formation at all at 20-80% of relative humidity values. PVA nanofibers were successfully produced in the relative humidity range of 20-80% but at high relative humidity the morphology of the fiber contained more beads [13]. Air humidity describes the water vapor content in the air which can be expressed as absolute humidity, relative humidity or water vapor pressure deficit. Relative humidity compares the actual water vapor content/pressure with its saturation state or the air's capacity to hold water vapor. The capacity of air to hold water vapor (at saturation state) depends on the air temperature [14]. Condensation will occur when the relative humidity reaches 100%. The air in a normal environment always retains moisture. The number of water molecules in the air can vary, the perceived conditions can occur such as in a desert with low humidity levels or in tropical areas with high humidity levels [15]. There is a limit to the amount of air humidity that is affected by a certain temperature. The amount of moisture is expressed in the physical form of water vapor pressure in the air. According to Dalton's

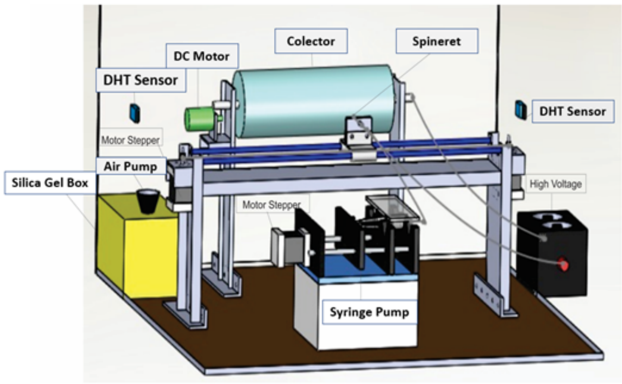

FIG. 1: Schematic drawing of the whole electrospinning diagram.

law, the total air pressure is the sum of the partial vapor pressures of several components, with the vapor pressure of water [16]. Here, we study the effect of humidity control system on our electrospinning system during PVA nanofiber fabrication.

II. METHOD

A. Preparation of Polymer Solutions

The polymer solution in this study was made from PVA powder. PVA is used as solute and distilled water is used as solvent. The steps in making a polymer solution are to determine the concentration of the solution. The concentration of the solution used in this study was 5% wt. Furthermore, measurements of PVA mass and distilled-water volume were carried out. PVA was weighted using digital scales and the volume of distilled water was measured using a beaker. After being measured, PVA and distilled water were mixed in one beaker. Then the magnetic stirrer is inserted into the beaker, which then placed on the hotplate of the magnetic stirrer that has been activated. The temperature magnetic stirrer was set to reach 80-90 °. After the temperature has been adjusted, the stirrer was turned on and the stirring process was carried out for one hour. When finished, the tool was turned off and the solution was then cooled.

B. Humidity-Control System Design and Collector-Motion Control System

Base on Fig. 1, the humidity control system consists of an air pump, relay module and Arduino Uno, silica gel and push buttons, and resistors. The push button functions as an input pulse to adjust the amount of humidity. There are two push buttons to adjust the humidity to either increase or decrease. At each HIGH input it will add the desired humidity value. After setting the speed and range of motion, the command will be executed by the air pump actuator. The air pump will drive to suck in environmental air and throw it into a box containing silica gel as a moisture absorbent. The collector drive system

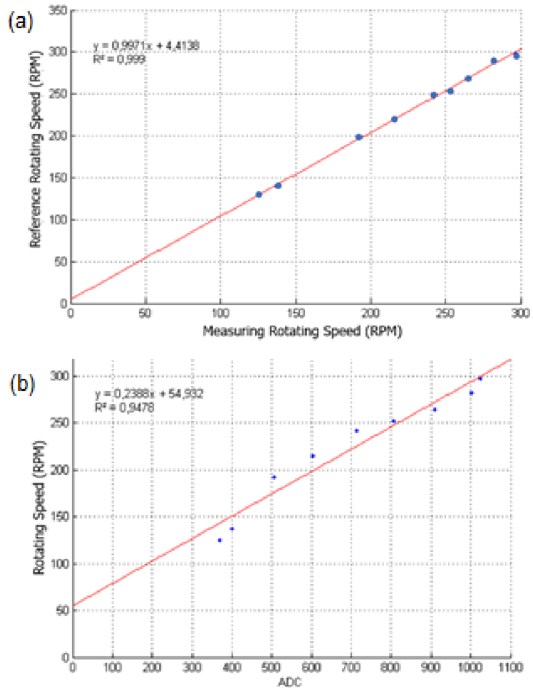

FIG. 2: Graph of (a) the relation between the reference collector rotational-speed and measurement and (b) the conversion of rotational speed with ADC.

consists of a 12 V DC-motor, L293D motor driver IC, Arduino Promini microcontroller, and a potentiometer as a pulse width modulation (PWM) regulator. In this system the collector is driven by a 12 V DC-motor. The direction of rotation of the collector is determined from the HIGH or LOW input on pins 2 and 7. Between the two pins there must be a different state of the given input, HIGH and LOW. The rotational speed of the collector is controlled using the PWM by engineering the width of the electrical voltage signal to rotate the collector. The PWM setting is done using a potentiometer.

The maximum amount of humidity that is maintained is the water vapor pressure in the saturated air which is strongly influenced by temperature. If the partial vapor pressure is the same as the saturated water vapor pressure, solidification will occur [17]. The mathematical relative humidity (RH) is defined as the ratio between partial water vapor pressure and saturated water vapor pressure. To get the amount in the form of a percent, the comparison was multiplied by 100% as indicated in Eq. 1.

$$RH\ (\%) = \frac{P_r}{P_S} \times 100\% \tag{1}$$

where RH(%) is relative humidity, P_r represents partial water-vapor pressure, and P_S describes the saturated water-vapor pressure.

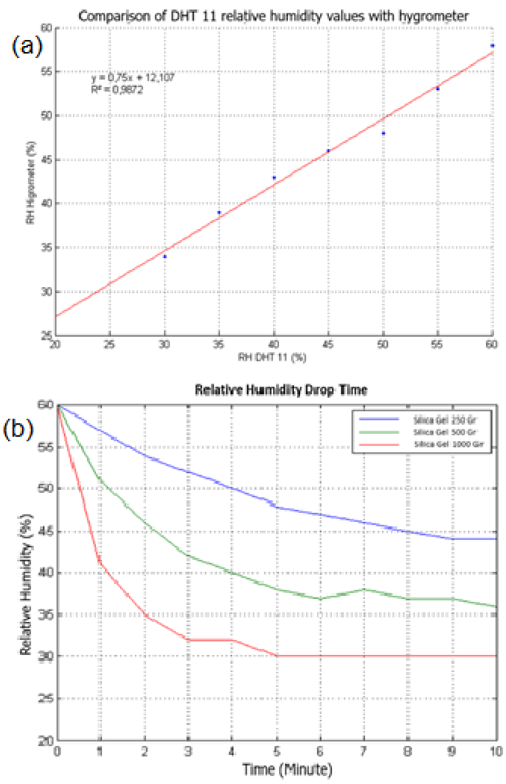

FIG. 3: (a) Comparison graph of the DHT 11 relative humidity readings with the hygrometer and (b) relative humidity-drop time.

III. RESULTS AND DISCUSSION

The collector is driven by a 12 V DC-motor. The collector is made of stainless steel with a diameter of 10 cm and a length of 32 cm. This motor is a motor with the smallest voltage specifications capable of rotating the collector. This DC-motor is equipped with a gearbox that aims to create large torque. The greater the gearbox ratio, the greater the torque and the lower the rotational speed. During the fabrication process, the direction of the collector must not be changed in the direction of rotation, so the weakness of the slow response of the DC-motor is not a problem in the design of this system. The driver used in the design of the collector controller system is IC L293D. The IC L293D has a maximum current limit of 1 A. The required collector speed is not too high. With an electric current of 1 A, the power generated is enough to drive the collector.

The graph in Fig. 2(b) shows that the linearity between the ADC value and the collector rotational speed is quite good, the R^2 value reaches 0.9478. These results can be used as a basis for mapping the Arduino program code in determining the collector rotational speed at a certain ADC value. After mapping the program code on the Arduino. Collector rotational speed is mapped the reference speed of the collector and the reference rotational speed, and then measurements from the collector are re-measured. Based on the measurement results,

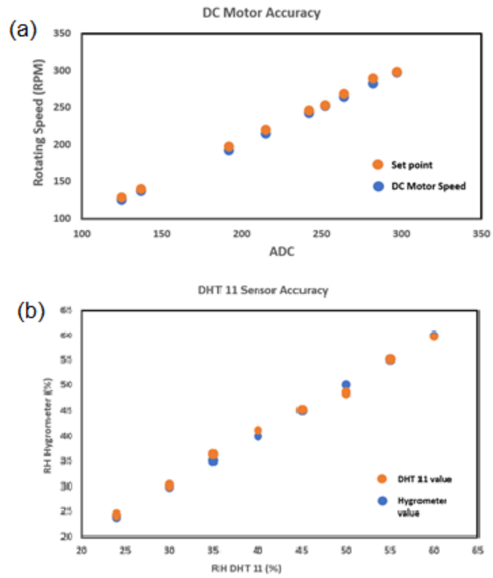

FIG. 4: Precision graph of (a) collector rotational speed and (b) DHT 11 sensor.

the relations between the reference collector rotational speed and the measurement is obtained as shown in Fig. 2(a).

The characterization of the DHT 11 sensor was carried out to determine the character of the DHT 11 sensor, in addition to knowing the linearity relationship between the DHT 11 sensor and the hygrometer. In this characterization, measurement of the relative humidity value or often called Relative Humidity (RH) between the DHT 11 sensor and hygrometer is carried out in the work area of the electrospinning humidity control system, which is 30 to 60%. Data collection is done by placing the DHT 11 sensor and hygrometer inside the electrospinning chamber, which is then set pointed at 30-60% of relative humidity. When the set point has been reached, one must wait for 10 minutes for the sensor and hygrometer to be completely stable. This is done because the hygrometer reading response is slower than DHT 11. The results of the comparison of relative humidity values of the DHT 11 with the hygrometer can be seen in Fig. 3.

Fig. 3 shows that the reading of the relative humidity value between DHT 11 and the hygrometer has a pretty good linearity, reaching a value of 0.9872. With these results, the DHT 11 sensor is suitable to be used to read the relative humidity value in the relative humidity control-system in the electrospinning system.

Based on Fig. 4, it can be seen that the average accuracy of the collector rotational speed measurement and the relative humidity value of the DHT 11 sensor shows a good value, which is above 99%. This value is obtained from the calculation of accuracy and relative error. This accuracy is also depicted from the graph in Fig. 4, showing that for each repetition performed on each variation the value is almost the same. The precision data is also taken, because more and more repeated measurement results are collected at one point value, indicating that the precision is getting better.

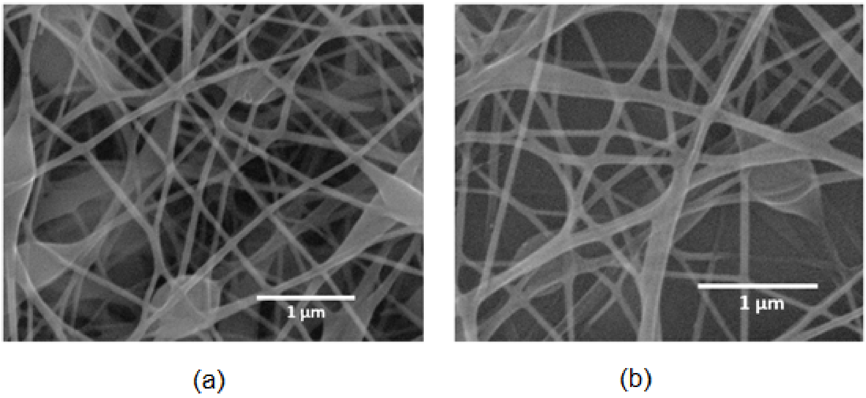

FIG. 5: Electrospinning nanofiber with the 0.1 ml/hour flowrate and relative humidity of (a) 40% and (b) 30% with fixed parameters. The average diameter of the obtained nanofibers for 40% and 30% humidity is 79.2 and 43.4 nm, respectively.

Micro-structures of the obtained nanofibers prepared at the humidity variations of 40% and 30% with the fixed parameters are shown in Fig. 5. The parameters of 10 KV voltage, 0.1 ml/hour flow rate, 150 RPM collector rotational-speed, 5 cm spinnert needle range, 0.2 cm/s speed , 5 wt% concentration of the PVA solution, and the 15 cm distance of the spinnert needle to the collector were set to be constant during the nanofibers fabrication. The difference in morphology and diameter of the resulted nanofibers was observed. This is because higher humidity has water vapor partitions which causes the polymer evaporation during the spinning process tend to be slower, thus the diameter shrinkage is also become slower. As a result, this affects the diameter size and morphology of the carbon nanofiber.

IV. SUMMARY

The humidity control system is made using an air pump and silica gel. The input pulse is set to the desired humidity by using a push button, in which the humidity control system can be set at 30 to 50% humidity. The effect of relative humidity on the morphology of carbon nanofibers is directly proportional to the diameter. At low humidity the surface of the fiber formed is not smooth. In the electrospinning system, the collector motion control-system is made of 12 V DC-motor with L293D driver IC. The collector speed control is carried out using the pulse width modulation principle. Moreover, the rotating speed of the collector can be set at a speed of 125 to 296 RPM.

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