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Development of a Rotary Collector of Fibers for a Wet Spinning Machine

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Abstract: The wet-spinning machine was used in biomedical engineering field widely used. This project intends to design a rotary collector implemented on wet-spinning machine and Polyacrylonitrile (PAN) as a test. The main reason for focusing this project on the development of a rotary collector of fibers processes is because the process of wet spinning producing soft fibers is crucial. Nowadays, the worker must typically supervise the process on a constant basis because it is prepared manually. The old approach required more facilities, which consumed a lot of time and energy. The aim of this project is to improve wet spinning machine. The main objective is to design and program a microcontroller that controls the stepper motor of a rotary collector. To fulfil the objectives as stated above, the scope for this project is to study on the limit to the wet spinning processes to develop the rotary collector. In this project, a rotary collector will control by a stepper motor and fixed to the existing extruder machine. The length and size fiber produced can be useful in biomedical engineering by allowing to produce precise and uniform fiber structures as appropriate for use in biomedical applications such as tissue engineering and regenerative medicine. These fibers can be used as scaffolds for cellular growth, helping to create functional tissue structures for repairing or replacing damaged or diseased tissue. The uniformity and precision of the fiber structure produced by a rotary collector can also enhance the mechanical properties of the final tissue-engineered product, making it more suitable for use in biomedical applications. However, there are improvements needed to improve and optimize the functionality of this rotary collector. For example, by adding a function of several selections for time duration of the rotary collector rotation.

Keywords: Wet Spinning Machine, Rotary Collector, Extruder Machine, Stepper Motor

1. Introduction

Wet spinning in Figure 1 was initially established in the biomedical industry as acceptable technology for producing fibers consisting of polymers originating from natural sources, such as chitosan and collagen, that are prone to heat deterioration when handled by conventional fibers spinning

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technique [1]. Wet spinning has increased the variety of polymers from natural or synthetic sources that can be processed. This is because of the ease with which a wide variety of therapeutics such as antibiotics and chemotherapeutics can be loaded onto wet-spun fibers using drug incorporation methods well assessed in nano/microparticles technology [2]. Wet spinning also imparts microporosity and drug release properties to the polymeric matrix.

The machine also used to create precise and uniform fiber structures that can serve as a scaffold for cellular growth. The resulting tissue-engineered products can be used to repair or replace damaged or diseased tissue in the body, helping to restore normal function. Wet spinning machines can also be used to produce fibers with specific mechanical, chemical, and biological properties, making them well suited for a wide range of biomedical applications [2].

Figure 1: Wet spinning machine [1][3]

Fibers produced by wet-spinning have potential application in numerous fields owing to their lightweight, high surface area, and high porosity. Various chemical fibermaterials including long and short fibers such as alginate fiber, polyester, polypropylene, polyacrylonitrile (PAN), vinylon, aramid fiber, acrylic fiber, polyvinylchloride fiber, common viscose fiber, Lyocell, chitosan fiber, soybean protein fiber and milk protein fiber. Even though it is thermoplastic, it does not melt under typical circumstances. It deteriorates prior to melting. It is a very versatile polymer that is used to create a wide range of goods,including ultrafiltration membranes [4].

2. Methodology

In this project, a development an easily reconfigurable rotary collector of fibers for the wet-spinning machine. The main advantage is that with wet spinning there is no thermal degradation, and a smaller fiber diameter can be achieved. A mechatronic system was designed and programmed using an Arduino Uno microcontroller to control the speed of the stepper motor. This chapter describes the method and steps to achieve the objectives of the project. The process and stages during the design and implementation of the project will be described thoroughly.

2.1 Schematic diagram

The schematic diagram shown in Figure 2 is the input pins (A+, A-, B+ and B-) of the stepper motor wereidentified and connected to the same alphabet pins at the stepper driver. The positive pins of direction (DIR+) connected to the digital pin number 17, enable (ENA+) connected to the switch 1 and pulse (PUL+) were connected to the digital pin number 16. DIR-, ENA-, PUL- was connected to the ground. Pin from rotary encoder SW connect to digital pin 15, DT connect to digital pin 14, CLK connect to digital pin 13. Furthermore, OLED pin from SCL and SDA is connected to analog pin 23 and 24. The LEDs were on digital pins 25, 27 and 29. There were three analogue pins, which were A2, A3 and A4, from the Arduino microcontroller connected to the switches during an initial active state.

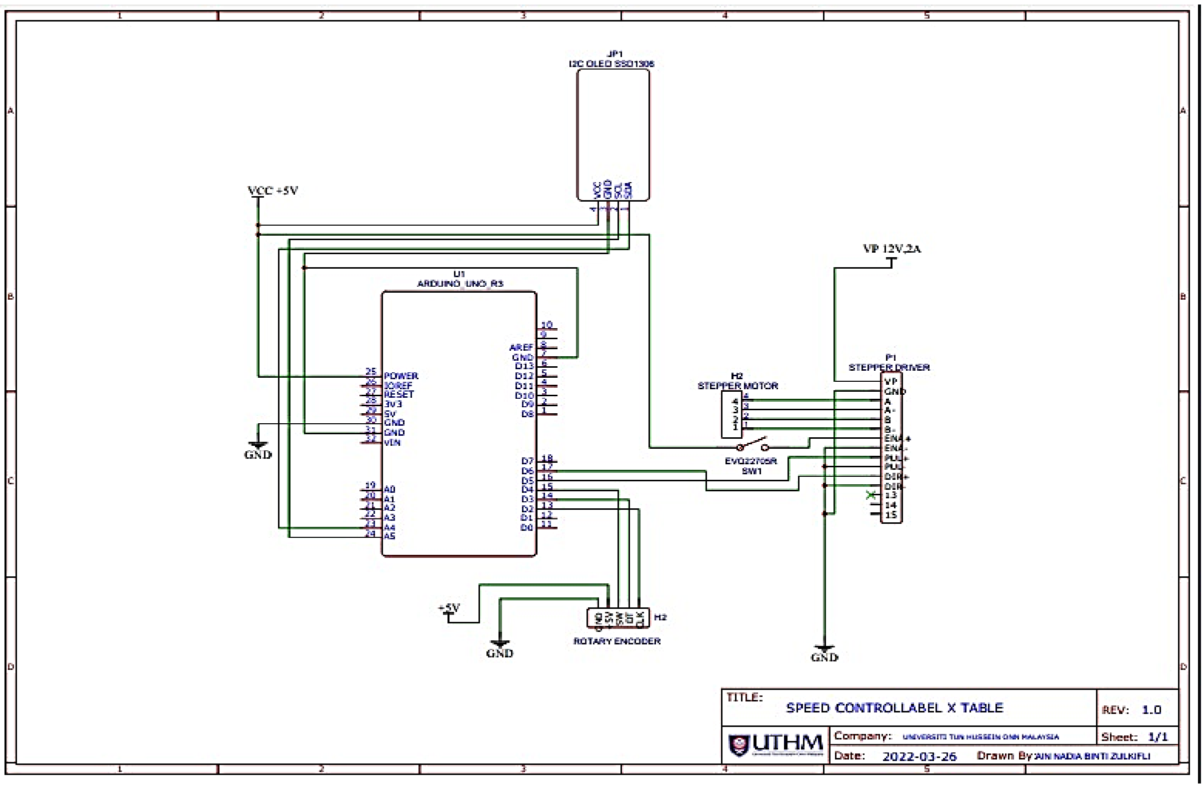


Figure 2: Schematic diagram of rotary collector

2.2 Programming microcontroller flowchart for the rotary collector

The flowchart in Figure 3 shows the programming of the Arduino UNO microcontrollerfor the development of this rotary collector. The Arduino Uno was reprogrammable via the USB connection to a computer. Three libraries were used, which were *wire.h*, *Adafruit_SSD1306.h and Adafruit_GFX.h* libraries. It is important to declare each input, output and data type. Next, when the rotary encoder speed is selected either 0 or 100 or 500 or 1000 or 1200 the motor will be moved if the value selected is more than 0. If the value 0 is selected the coding need to verify back through rotary encoder. Otherwise, the reset button can be used as a command to stop and reboot the Arduino UNO.

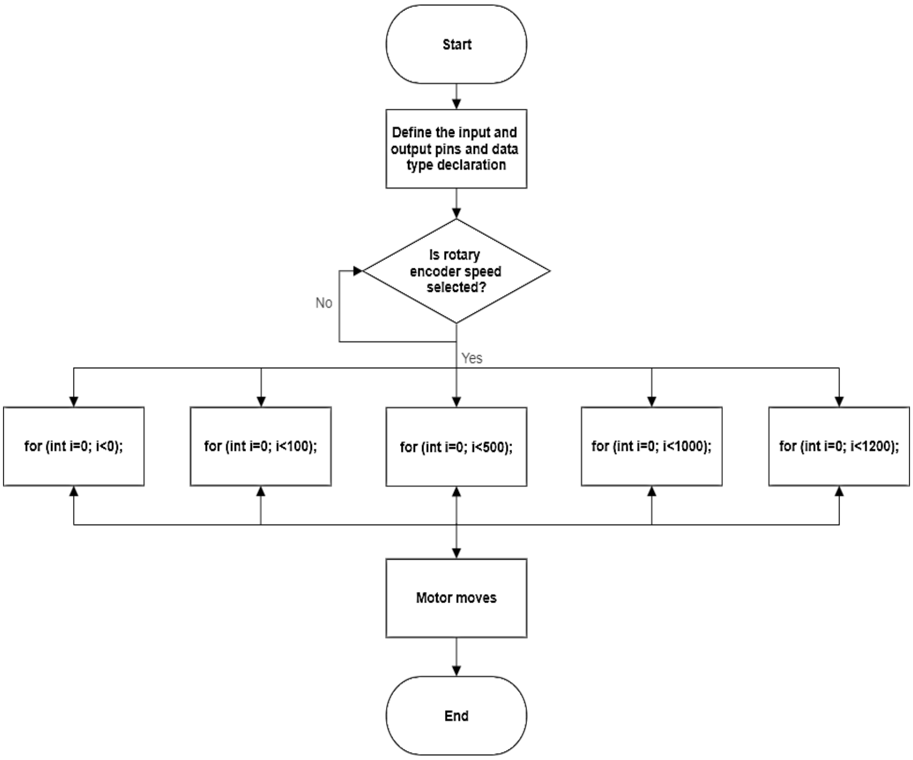


Figure 3: Rotary collector coding flowchart

2.3 Development of rotary collector (hardware)

Figure 4 shows that all the component that usedhas been connected successfully. Concerning to this project, rotary collector produced one axis which moves forward direction with a speed that designated. The program that designs from Arduino Uno microcontroller will control the stepper motor of a rotary collector and the system rotate. A rotary collector controlled by a stepper motor and fixed to the existing extruder machine.It forces fiber to align in a perpendicular orientation to the axis of rotation. Hence, the standard operating procedure (SOP) of this hardware is step one switch on the power adapter, turn on the VCC, side switch and switch 1 that connected to ENA+ and VCC. Step 2 by using the rotary encoder switchchoose the speed that appear on OLED either 100, 200, 300, 400 or 500. Step 3, double clicks the rotary encoder and the result of rotary collector will move clockwise because the PAN fiber will collect so only one axis is needed. Step 4 push the reset button (yellow) to choose other speed.

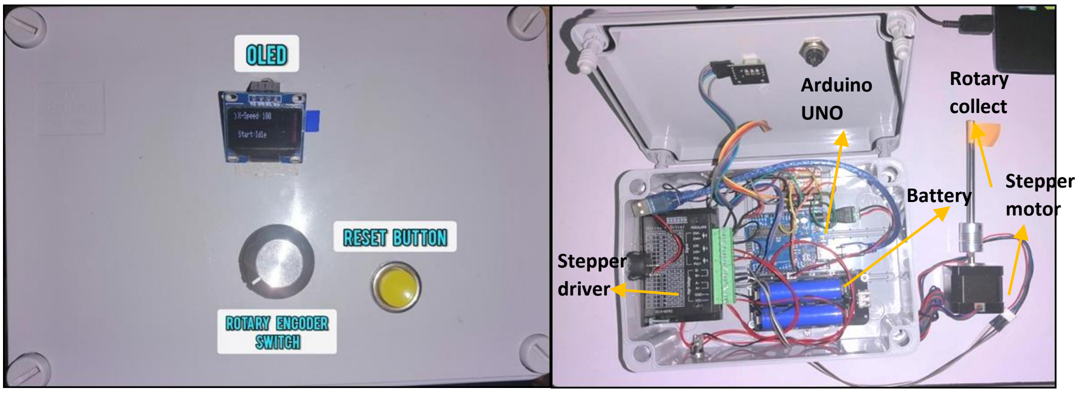


Figure 4: Hardware development of rotary collector

2.4 Existing extruder machine

Figure 5 shows the circuit that controlled the extruder machine to complete the extrusion used in this project. The standard operating procedure (SOP) of this hardware is step one connect the Arduino UNO Universal Serial Bus (USB) to any device or adapter. Step two press the infusion push button to move forward the syringe. After complete press the reverse button to bring the syringe back to its original place.

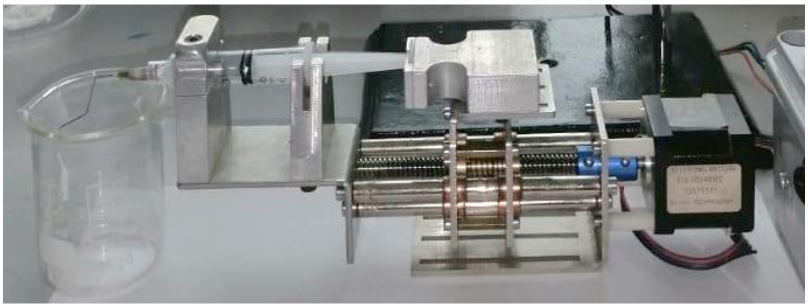


Figure 5: Existing extruder machine

2.5 Hardware combination

As seen in Figure 6, the hardware combination between development of a rotary collector and existing extruder machine. This is for the purpose of collecting data. The retort stand used to secure stepper motors by clamp it and prevent them from falling or coming apart. At extruder machine single needle as spinneret was attached syringe and in front of the syringe located beaker to fill coagulation bath (water) so that the fiber can be produced.

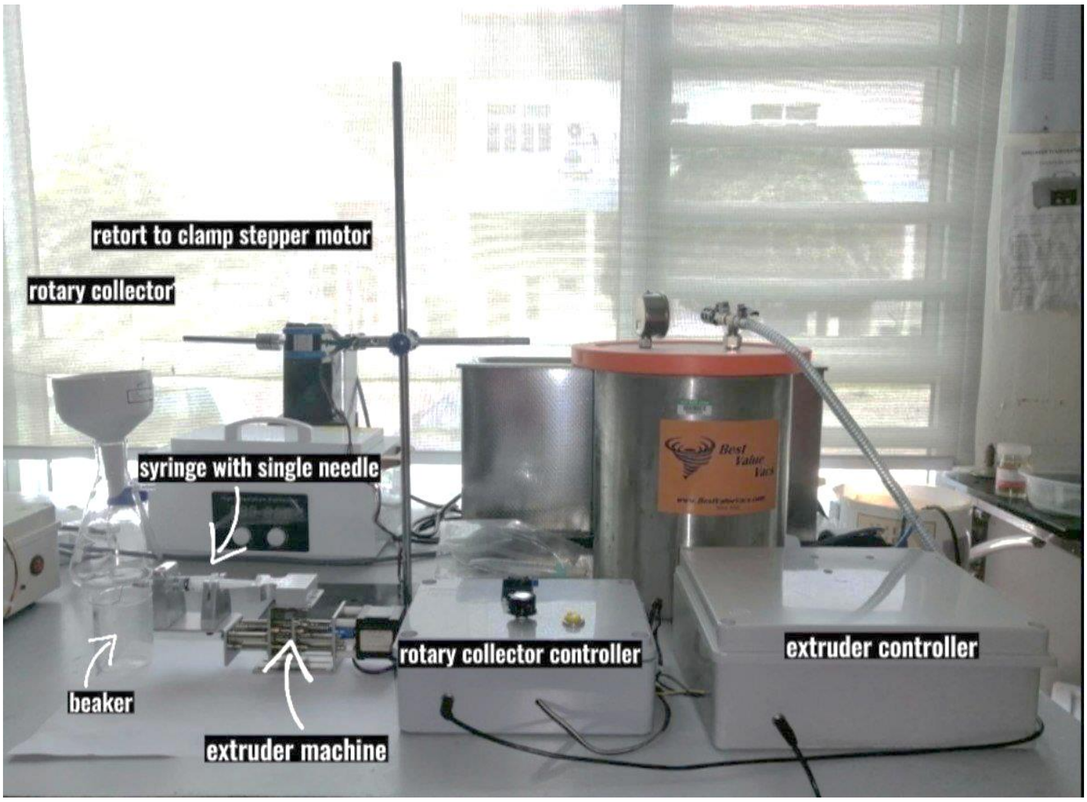


Figure 6: Hardware combination

3. Results and Discussion

3.1 The relationship between size of fiber and stepper motor rotation speed (rpm) before and after dry

The extrusion system was customized with a linear slider that functions as an extruder for the fiber. 11 wt% which it is mixed by 2.2g PAN powder + 20ml of Dimethylformamide (DMF) and stirred by Heidolph MR Hei-End which is magneticstirrer and used in this experiment as shown in Figure 7. To start the motion system, a list of speed of the motor needs to be selected. The rotating collector is controlled by a stepper motor driver. The speed started from 100, 500, 1000 and 1200rpm. The stepper motor was programmed in the Arduino UNO to control the speed. Figure 8 shows how the rotary collector worked on the fiber.

Figure 7: Polyacrylonitrile

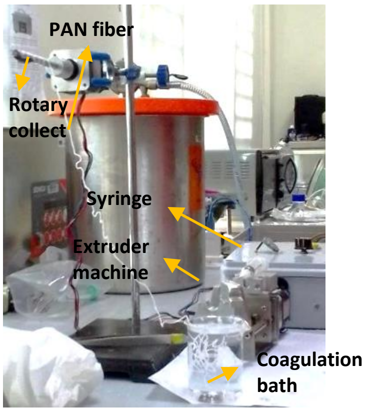


Figure 8: Rotary collector when rotate the fiber

The investigation started with the size of fiber vs rpm before and after dry. As shown in Figure 9, each of the size of fiber represented different number of rotations within 10 seconds. In figure below, the size of fiber is 0.1mm at speed 100 rpm. When the motor rotated at 500 rpm, the size of fiber is 1mm. At 1000rpm, the size of fiber a bit big which is 1.1mm. The size of fiber increase at 1200 rpm which is2mm. There is no difference before and after dry because the size of fiber is not expanded or shrink. Based on this graph, it can be said that the size of this fiber is uncertain, it can be thick and thin. Meanwhile, a greater tensile strength is shown in fibers with lower diameters, indicating that the skin-core structure of the PAN fibers with the lowest diameter is the superior option.

One of the factors that influences when extrude the PAN is fiber size produced.Generally, the size of fiber is also depending on the size of single needle spinneret or with an increase in fiber size, the composite's total strength may decrease in a linearly. In this project Therefore, owing to the concentration of fiber faults or imperfections. The structure of materials determines their performance. Various diameter fiber has different mechanical characteristics, hence there must be variances in the architecturesof different diameter fiber. The fiber extruded from PAN show in Figure 10(a) was extruded at 0.1 mm, while the size of fiber in Figure 10(b) was 1.0 mm. For Figure 10 (c) and Figure 10 (d), the size of fiber were 1.1 mm and 2.0 mm, respectively.

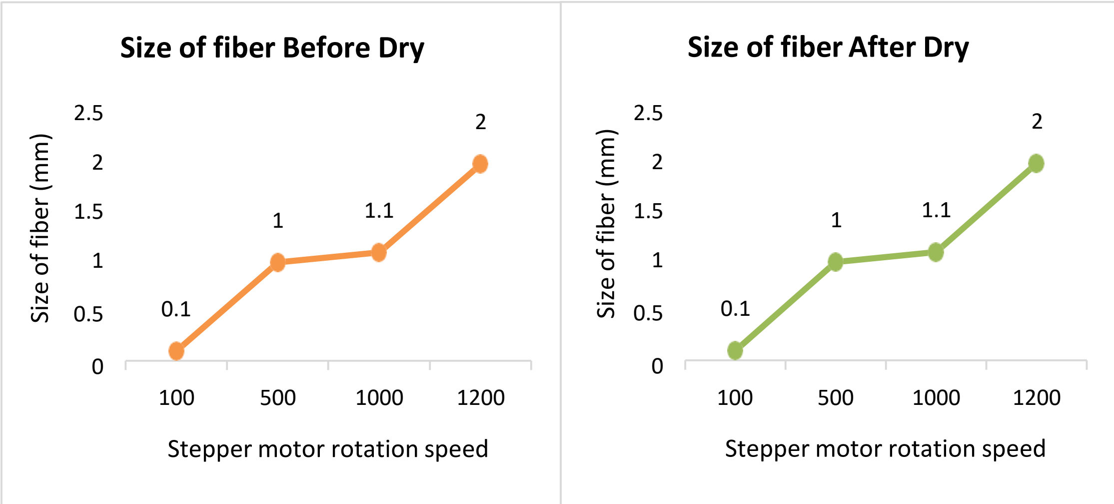


Figure 9: The relationship between size of fiber and rpm before and after dry

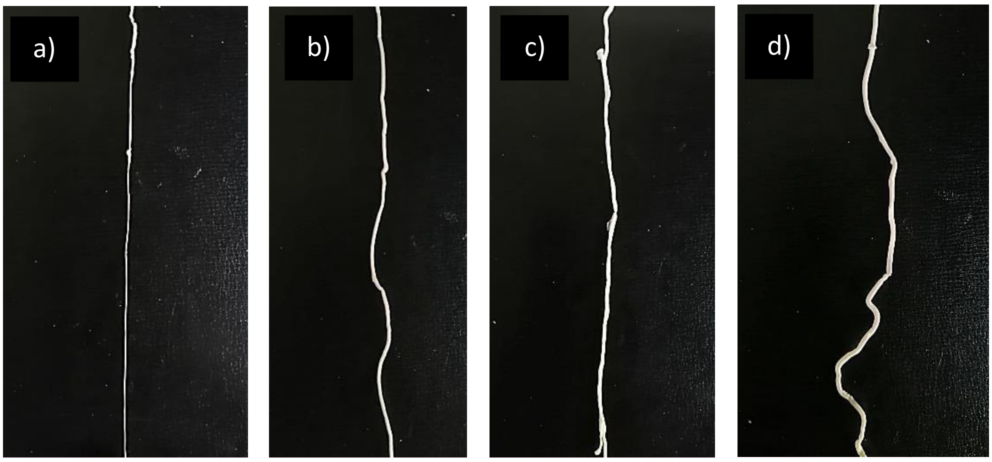


Figure 10: The fiber extruded in different size (a) 0.1 mm (b) 1.0 mm (c) 1.1 mm (d) 2 mm

3.1. The relationship between length of fiber and stepper motor rotation speed (rpm) before and after dry

As shown in Figure 11 and 12, the length of fiber was indicated with linear relationship with the motor speed. The slower the stepper motor, the short the length of the fiber. Each of the flow rates represented different number of rotations within 10 seconds. In Figure 11, the fast movement at 100 rpm and 500 rpm can be observed when the length of fiber was decreased to 45 cm and 40 cm, respectively. The fiber length is 35 cm when the motor rotated at 1000 rpm. The motor rotated at 1200 rpm with fiber length 30 cm. From that it can be conclude the faster the rpm speed of the stepper motor, the longer the fiber produced. The increasing and decreasing speed of the rotating collector can be controlled upon the selection of speed of stepper motor. As can see in both graph below there is no difference measurement before and after dry.

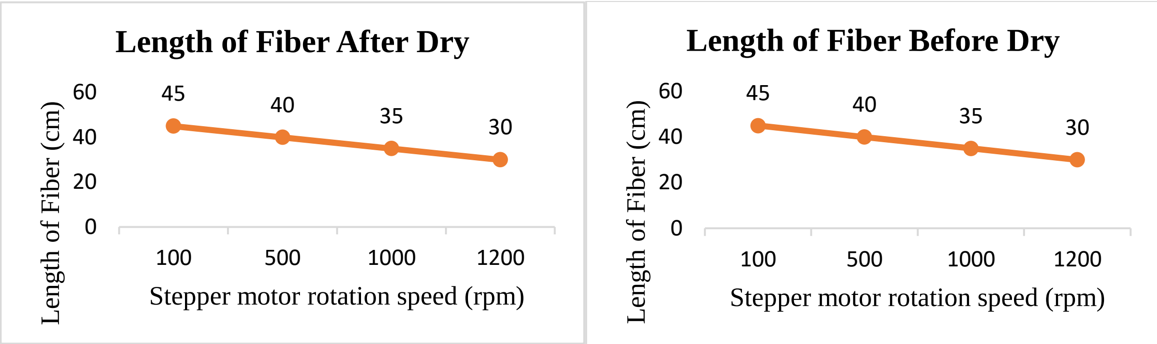
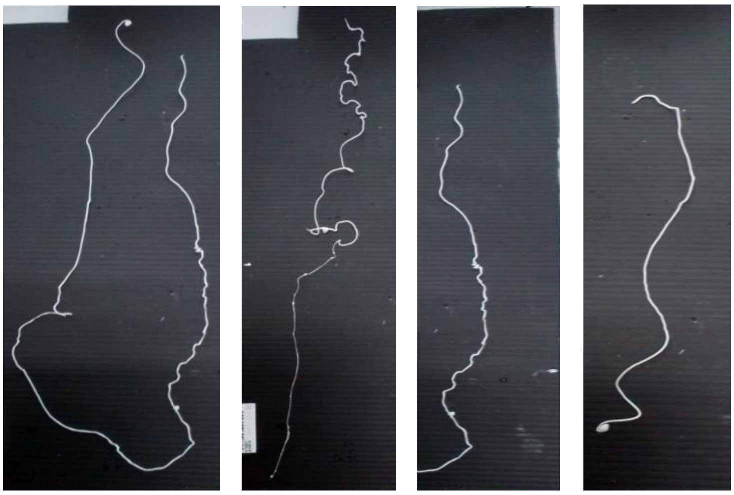


Figure 11: The relationship between length of fiber and rpm before and after dry



a) b) c) d)

Figure 12: The fiber in different length (a) 45 mm (b) 40 mm (c) 35 mm (d) 30 mm and (e) 25 mm

3.2. The relationship between length of fiber and stepper motor rotation speed (rpm) before and after dry

Figure 13 depicts about time constraint observation of fiber extruded from spinneret. It takes 15 seconds from PAN to be extruded into fiber on the support of the extruder machine and syringe. The fiber will be left to soak for a few seconds inside the coagulation bath so that the texture of fiber become a bit strong.

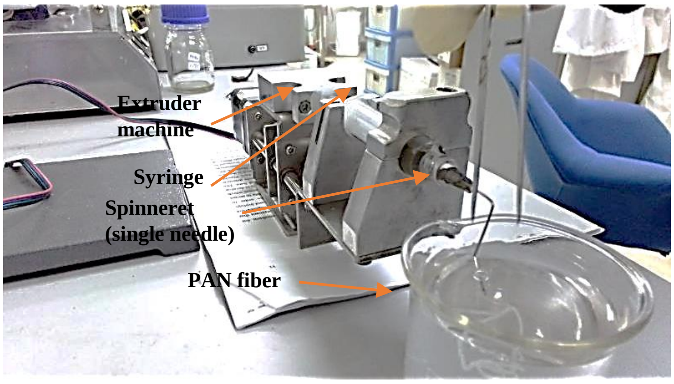


Figure 13: Time constraint observation of fiber extruded from spinneret

4. Conclusion

This project is aiming to help the laboratory workers especially in wet-spinning process. This is because, majority of workers used old method of wet-spinning processes, which acknowledged to have various flaws. The issue is that personnel must manually the must maintain the position during the process of the extrusion of materials when it free to flow in the aqueous solution and italso needs to be removed by using hand manually and repeat every hour to ensure that the fiber does not let so long or accumulate inside the coagulation bath. Thus, we create thisproject to improve wet spinning machine especially in collecting fiber.

As a result, the machine will require less monitoring and decreasing labor in the wet-spinning process. It will become more efficient, and the quality of produce fiber will improve as well. In terms of hardware, the project uses Arduino Uno acts as the brain of the system based on developed codes. Conclusively, wet spinning is a somewhat cost-effective manufacturing technology. Low spinning speeds have lately been abolished as a disadvantage. Furthermore, this project will demonstrate that wet-spun fibers have a wide range of applications in biomedical engineering.

5. Recommendation for future work

There are several recommendations that could improve future works in improving the project outcome. The ideas are based on the research and experience indeveloping this project and the intention to make this project more successful.

i. There are still more things that can be optimised and upgraded into the systemsuch as by adding the time display to collect fibers. So that we can set the timefor the fiber length we want.
ii. Recommendation to use various chemical fiber materials and make comparisons.

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