# EFFECT OF SURROUNDING TEMPERATURE TO TENSILE STRENGTH OF POLYVINYL ALCOHOL (PVA) NANOFIBERS STRUCTURES

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**BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (REFRIGERATION AND AIR CONDITIONING) WITH HONOURS**

**2023**

# Faculty of Mechanical and Manufacturing Engineering Technology

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**KAARTIK A/L BALU**

**A thesis submitted**
**in fulfillment of the requirements for the degree of**
**Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning system) with Honours**

**Faculty of Mechanical and Manufacturing Engineering Technology**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2023**

## DECLARATION

I declare that this Choose an item. entitled " Effect of surrounding temperature to the tensile strength of Polyvinyl Alcohol (PVA) nanofibers structures" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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| Name | : | *KAARTIK A/L BALU* |
| Date | : | 19/1/2023 |

**APPROVAL**

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning System) with Honours.

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| Signature | : | |
| Supervisor Name | : | *TS. DR. AMIR ABDULLAH BIN MUHAMMAD DAMANHURI* |
| Date | : | 19/1/2023 |

# DEDICATION

To my beloved parents,

Balu A/L Subramaniam and Jayanthy A/P Krishanan.

Thank you for your gentleness in caring for me, supporting, advising, and loving me.

Thank you to my supervisor, Ts. Dr. Amir Abdullah Bin Muhamad Damanhuri, Azmil Arif Bin Mohamad Wazir, and also to the friends for your help.

Thank you to the Faculty of Mechanical Engineering and Faculty of Manufacturing Engineering for providing the opportunity to use machines and equipment to conduct this research.

## ABSTRACT


Electrospinning is a very simple and quick way to produce fibers with nanoscale in diameter from various types of polymers. These nanofibers contains several important characteristics such as superior mechanical properties, volume ratio and high porosity. Application of nanofibers in industry a such as textile, paper industry, air filter industry and food packaging. In this study, tensile strength test were applied on nanofibers in order to identify the strength of nanofibers in air filter. 5 samples were used containing same concentration of 10wt%, distance of 15cm from tip to collector, voltage of 15kV and feed rate of 1.5m L/h.
Meanwhile 5 different temperature 32 ºC, 34 ºC, 36 ºC, 38 ºC and 40 ºC is used. Polyvinyl alcohol (PVA) has been used with distilled water as solvent. Electrospinnig samples size of 60mm by 10 mm were used to study the tensile strength using Universal Testing Machine (UTM). Maximum force, maximum stress, maximum stroke, maximum stroke strain, maximum displacement, maximum strain and maximum time for the sample to fracture was obtained. UTM results shows that the sample for 38 ºC has the highest reading of all. It recorded 0.88908 N for maximum force and stress. 24.3775mm for maximum stroke and maximum displacement. Maximum strain recorded 40.6292%. The time taken to fracture was 731 seconds. These reading are directly influenced by the temperature that operated during electrospinning process. During that process it is recorded that the humidity level was 48%. This means that the air is holding 48% water in it. The relation between temperature and humidity formula are inversely proportional. That means if the temperature increases it will lead to decrease in humidity. So, at 38ºC the air is relatively drier compare to lower temperature. At this temperature the formation of nanofibers were good enough to be able to withstand higher force, stress, stroke, displacement and strain during tensile testing. This is because there were enough time for the nanofibers to travel form the tip to the flat plate collector before it evaporates and dried up. This will strengthen up the each of the fibers during electrospinning. The nanofibers also took relatively the longest time compared to other sample which indicates that the bond between the fibers are strong which makes them harder to fracture. This shows that to create stroger nanofibers, the best temperature for electrospinning is 38ºC.

## *ABSTRAK*

Electrospinning adalah cara yang sangat mudah dan cepat untuk menghasilkan gentian dengan diameter nano daripada pelbagai jenis polimer. Nanofibers ini mengandungi beberapa ciri penting seperti sifat mekanikal yang unggul, nisbah isipadu dan keliangan yang tinggi. Penggunaan gentian nano dalam industri a seperti tekstil, industri kertas, industri penapis udara dan pembungkusan makanan. Dalam kajian ini, ujian kekuatan tegangan telah digunakan pada gentian nano untuk mengenal pasti kekuatan gentian nano dalam penapis udara. 5 sampel telah digunakan yang mengandungi kepekatan yang sama iaitu 10wt%, jarak 15cm dari hujung ke pengumpul, voltan 15kV dan kadar suapan 1.5m L/j. Manakala 5 suhu berbeza 32 ºC, 34 ºC, 36 ºC, 38 ºC dan 40 ºC digunakan. Polivinil alkohol (PVA) telah digunakan dengan air suling sebagai pelarut. Saiz sampel Electrospinnig 60mm kali 10 mm digunakan untuk mengkaji kekuatan tegangan menggunakan Mesin Ujian Sejagat (UTM). Daya maksimum, tegasan maksimum, strok maksimum, regangan strok maksimum, anjakan maksimum, regangan maksimum dan masa maksimum untuk sampel untuk patah telah diperolehi. Keputusan UTM menunjukkan bahawa sampel untuk 38 ºC mempunyai bacaan tertinggi. Ia mencatatkan 0.88908 N untuk daya dan tegasan maksimum. 24.3775mm untuk lejang maksimum dan anjakan maksimum. Regangan maksimum dicatatkan 40.6292%. Masa yang diambil untuk patah ialah 731 saat. Bacaan ini secara langsung dipengaruhi oleh suhu yang beroperasi semasa proses electrospinning. Semasa proses itu direkodkan bahawa tahap kelembapan adalah 48%. Ini bermakna udara menahan 48% air di dalamnya. Hubungan antara formula suhu dan kelembapan adalah berkadar songsang. Ini bermakna jika suhu meningkat ia akan membawa kepada penurunan kelembapan. Jadi, pada 38ºC udara agak kering berbanding dengan suhu yang lebih rendah. Pada suhu ini pembentukan nanofibers cukup baik untuk dapat menahan daya yang lebih tinggi, tegasan, strok, anjakan dan terikan semasa ujian tegangan. Ini kerana terdapat masa yang cukup untuk gentian nano bergerak dari hujung ke pengumpul plat rata sebelum ia sejat dan kering. Ini akan menguatkan setiap gentian semasa electrospinning. Nanofibers juga mengambil masa yang agak lama berbanding sampel lain yang menunjukkan bahawa ikatan antara gentian adalah kuat yang menjadikannya lebih sukar untuk patah. Ini menunjukkan bahawa untuk mencipta gentian nano yang lebih kuat, suhu terbaik untuk pemutaran elektro ialah 38ºC.

## ACKNOWLEDGEMENTS

First and foremost, I want to express my gratitude and praise to Almighty God for everything that has been given to me since the beginning of my life. I'd like to express my gratitude to the Universiti Teknikal Malaysia Melaka (UTeM) for providing me with a research environment. Thank you also for the financial assistance provided by the Malaysian Ministry of Higher Education (MOHE).

I'd like to take this opportunity to thanks my supervisor, Ts. Dr. Amir Abdullah Bin Muhamad Damanhuri, is not only my lecturer but also my mentor and coach at the Faculty of Mechanical and Manufacturing Engineering Technology (FTKMP). As I worked on this thesis, he provided me with supervision, support, and encouragement. Thanks also to Azmil Arif Bin Mohamad Wazir from the Faculty of Mechanical Engineering (FKM) for guidance and advice throughout the conduct of this research.

I would like to express my deepest appreciation to the Faculty of Mechanical Engineering (FKM), Faculty of Manufacturing Engineering (FKP), parents, siblings, and close friends for their moral support in helping me complete this degree. Finally, I would like to record my thanks to all who have contributed in some way in realizing this project, either directly or indirectly.

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| | | |
|---|---|---|
| UTM | - | Universal Testing Machine |
| PVA | - | PolyVinyl Alcohol |
| HEPA | - | High-Efficiency Particulate Air |
| Nm | - | Newton meter |
| % | - | Percentage |
| °C | - | Degree Celcius |
| mL | - | Milliliter |
| mL/h | - | Milliliter per hour |
| W | - | Wattt |
| wt% | - | Percentage by weight |

**LIST OF APPENDICES**

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Electrospinning is a simple and versatile technique that relies on the electrostatic repulsion between surface charges to continuously draw nanofibers from a viscoelastic fluid. It has been applied to successfully produce nanofibers, with diameters ranging from 1 nanometer to 1000 nanometers from a rich variety of materials, including polymers either natural or synthetic polymers, ceramics, small molecules, and their combinations. Each of the combination creates different type of nanofibers with different strength. In addition to solid nanofibers with a smooth surface, electrospinning has also been adapted to generate nanofibers. The surface of such nanofibers can be further functionalized with nanoparticles during or after an electrospinning process. In addition, electro spun nanofibers can be assembled into ordered arrays or hierarchical structures by manipulation of their alignment, stacking and folding. All these attributes make electro spun nanofibers well-suited for a broad spectrum of applications, including those related to air filtration, water purification, heterogeneous catalysis, environmental protection, smart textiles, surface coating, tissue engineering, and regenerative medicine.

Polyvinyl Alcohol (PVA) was chosen as the solution because it is a water-soluble synthetic polymer. PVA has excellent chemical properties with a semi-crystalline and heat-stable hydrophilic polymer. It is also odourless, non-toxic and resistant to oils and greases, and it is often used in filtering the air. Its unique physical properties, such as strength, flexibility, and ability to function in a high-oxygen environment, have made it the best choice for use.

Due to these properties, PVA is gradually being used in medical, cosmetic, food, pharmaceutical, and packaging applications (Qin & Wang, 2006). There are two types of PVA available in the market, namely powder and pellets. In this study, PVA-type pellets were used. During the process of making this PVA solution, tap water has been mixed with PVA. It can be used only for 2 days after the process of making PVA is completed.

Due to simple instrumentation, continuous processing, lower cost compared to other available methods, and ability to make fiber diameters from a few nm to a few microns, electrospinning is the most widely used method in the industry (Kumbar et al., 2008). Depending on the jet formation produced, electrospinning methods can be classified into several different types of categories. There are two ways nanofibers can be made through 4 electrospinning techniques namely needleless and needle based. In this study, the needlebased electrospinning process was used because it is a continuous and cost-effective process, its diameter can be controlled from a few nm to a few microns, has a programmable needle pump, and the ability to monitor the pump as well as the injection rate.



## 1.2 Problem Statement

High-efficiency air filtration combined with low-pressure dips are the key to air purification. To guarantee that air filtration is clean, safe to use, and ecologically beneficial, the effects of many parameters must be investigated. This is exacerbated by the fact that the globe now possesses a deadly infectious disease such as coronavirus or covid19. This virus is causing a growing number of deaths, and there appears to be no way to stop it. As a result, the only way to stop and slow the spread of this disease are efficient air filtration.

The goal of this work was to determine how to employ appropriate parameters without affecting the morphological structure. However, some research has been done to discover the factors that will affect morphology, such as solution parameters, processing parameters, and environmental factors. When the viscosity of the bead formation is low, there is a large increase in fiber diameter as well as bead loss. High conductivity will result in a reduction in fiber diameter. In the meanwhile, using a polymer with a high molecular weight will reduce the quantity of beads and droplets. The diameter of the fiber will rise when the polymer content is increased. Furthermore, surface tension has no effect on the shape of the fiber, whereas high surface tension does (Tribuzi Morais, 2011).

The application of voltage is a processing parameter that affects morphology, setting a high voltage causes a decrease in fiber diameter. Changes in the applied voltage will alter the shape of the initial fall and cause structural and morphological changes in the fibers. In order to achieve fiber homogeneity, a minimum distance between the tip and the collector is required. When the gap is too close or too far apart, beads will form. The feed rate or flow rate must be set correctly, as a drop-in flow rate will result in a decrease in fiber diameter. The creation of beads will be affected if the flow rate is too high. The charge density will decrease as the solution flow rate increases (Shi et al., 2015).



High charge densities can result in electrospun jets experiencing secondary bending instability, which will contribute to the formation of fibers with smaller diameters (Son et al., 2004). In addition, ambient parameters also influence the morphology which when setting high humidity will result in pores on the fibers. If using high temperatures will result in a reduction in fiber diameter (McKee et al., 2004). Thus, it can be concluded that high consumption on conductivity, voltage, and temperature will result in a decrease in fiber diameter (Bhardwaj & Kundu, 2010).

Therefore, this study was made to replace the existing polymer application filters in the market with better ones and at the same time study the tensile strength on nanofiber membranes. It covers the study of suitable temperature for electrospinning process and effective polymer for air filtration. However, parameters such as collector rod speed and relative humidity were not thoroughly studied in this study. The use of the electrospinning method has been carried out because it is capable of producing nanofibers with unmatched small sizes and high surface zone (Khude, 2017).

## 1.3 Research Objective

The main goal of this study was to find out the effect of temperature to the electrospinning PVA nanofibers structures and to investigate the tensile strength of the samples. Specifically, the objectives are as follows:

a) To develop nanofibers using 15 cm of distance, 1.5ml/h feed rate, 10 wt% and 15 kV by using different temperature.

b) To investigate the tensile strength nanofiber membranes based on different temperature.

## 1.4 Scope of Research



The scope of this research are as follows:

a) The use of constant polymer concentration namely 10wt%.

b) The use of constant power supply voltage of 15kV for the electrospinning process.

c) Use constant distance of 15cm between the tip of the pipette to the collector plate.

d) Use of feed rate between 1.5mL/h for solution release from the syringe.

e) Use of needle based electrospinning machine with different range of temperature 32 ºC,34 ºC,36 ºC,38 ºC and 40 ºC.

f) Tensile strength of PVA nanofibers.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In the air filtration industry, the use of activated carbon and fiberglass can be seen clearly. This is because it has its own potential and its undeniable advantages. The use of activated carbon is used to remove toxic chemicals that go through the adsorption process, while High- Efficiency Particulate Air (HEPA) filters are used aimed at filtering particles such as fibres and other debris from the air. Among nanotechnology products, nanofiber is one of the unique materials that have been studied or combined with other materials such as textiles and fiberglass (Ramaseshan et al., 2007). Nanotechnology has recently made a big and high influence in a variety of disciplines, including healthcare, energy, and the environment. The field of nanotechnology has progressed at a rapid pace. Nanofiber is a oneof-a-kind material that is thousands of times smaller than normal fibres (Sundarrajan et al., 2014).



In this study, the electrospinning process was carried out without electrode contact to the spinneret. Instead, use an electric field method that will collect enough charge to extend the droplets of solution to the plate collector (Chung, 2008). In addition, with the voltage adjustment will affect the process of electro rotation applied to the solution. A large volume of solution will be removed from the tip of the needle if using a high voltage. This is so because, referring to previous studies, by increasing the voltage is able to speed up the process on electrospinning jets (Liu et al., 2019). The use of high voltage will also cause the fibers to become thinner (Buchko et al., 1999). Figure 1.1 shows the effect in terms of voltage increase for the electrospinning process and fiber diameter (Liu et al., 2019).

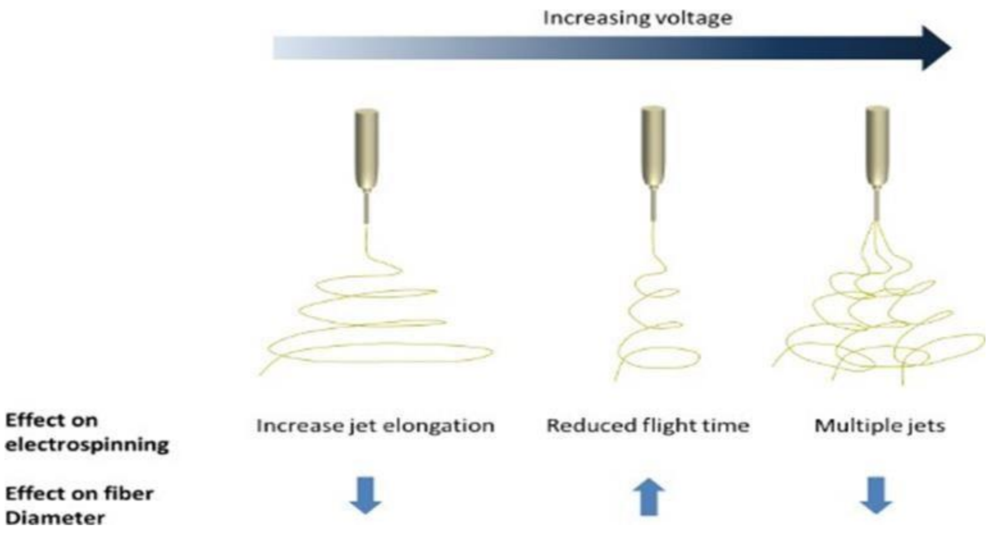


Figure 2.1 The effect in terms of voltage increase for the electrospinning process and fiber diameter (Liu et al., 2019).

Other than that, polymer concentration also plays an important role in the electrospinning process. According to previous studies, the higher concentration of polymer used, the larger of diameter electrospinning fibers (Hossain et al., 2016). The control of the polymer concentration is also the most important factor in controlling the morphological structure of any defects. For the use of too low a concentration, bead formation will occur while using too high a concentration the beads will become elongated (Sreekumar, 2020). Furthermore, the higher of polymer concentration used the higher of diameter nanofiber fibers. Figure 2.1 shows four types of electrospinning defects namely beads, fiber bonding, fiber bundles, or multiple defects.

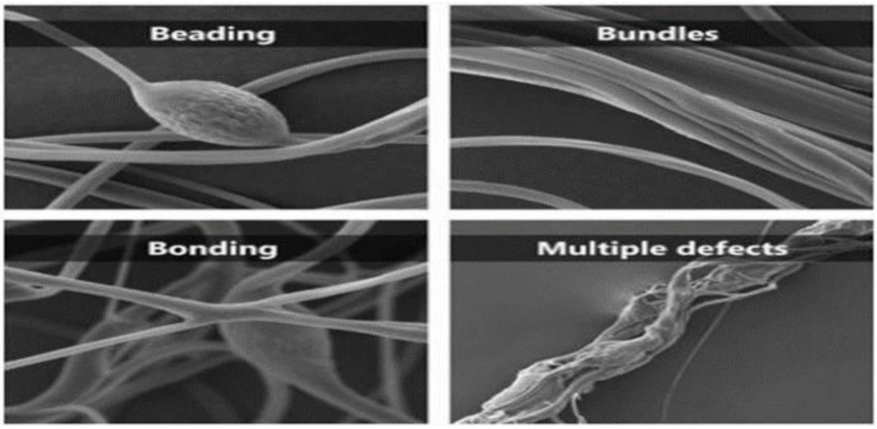


Figure 2.2 Four types of defects specific to electrospinning (Chaparro, 2021)

To produce a uniform and smooth morphological structure, the use of distance should be in the correct range. When too close a distance is used then wet and thick fibers will result because the time to evaporate is too short (Nurfaizey & Munajat, 2020). Meanwhile, the use of too far a distance will also result in the electrospinning process becoming unstable because too long a distance will weaken the strength of the electric field to carry the solvent to the collector. In addition, the use of a fixed feed rate will also cause the Taylor cone to be too small and give an instability effect to the electrospinning process (Zong et al., 2002).



Currently, there are two common methods for producing nanofiber utilizing high voltage needle electrospinning and needleless electrospinning. The first method is the one that has been employed by laboratory researchers the most. The polymer solution can be turned more simply and simultaneously controlled utilizing the needle electrospinning technique to get the desired output. The electric field caused a Taylor cone to form at the hollow needle's tip. Figure 2.3 shows Taylor cone formation.

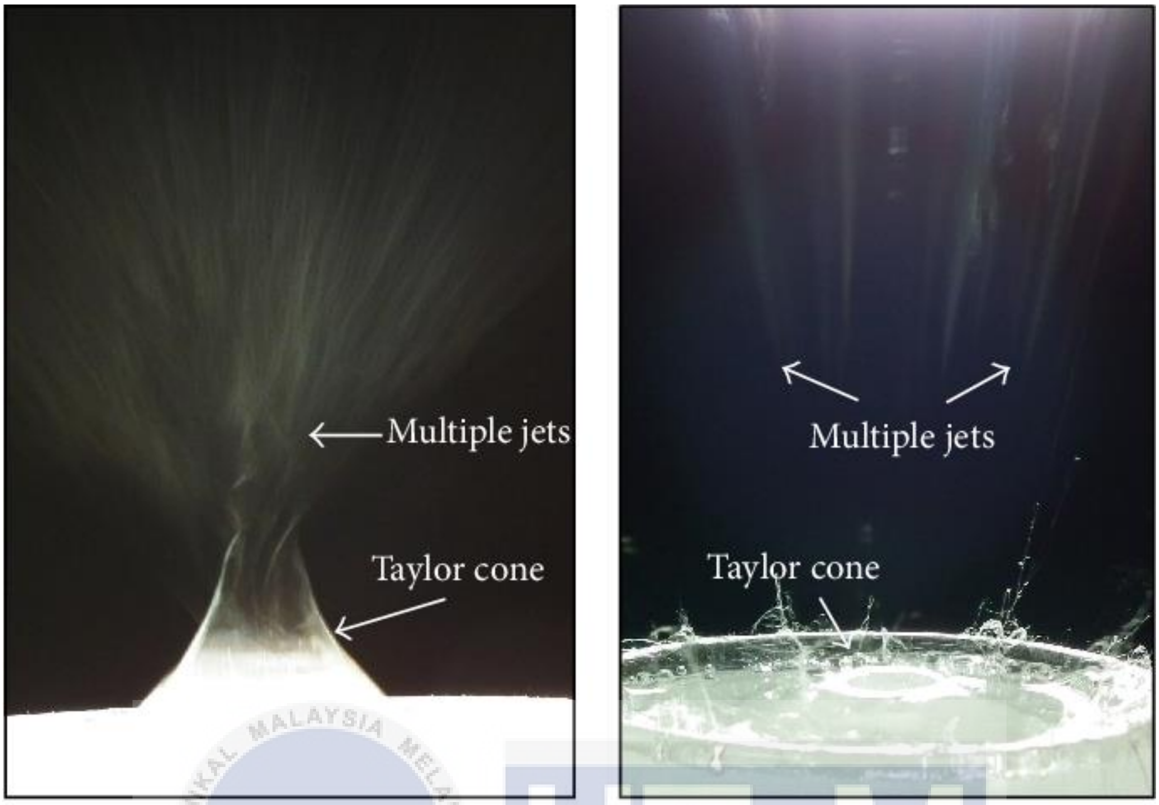


Figure 2.3 Taylor cone formation

Then, from the Taylor cone's end, a jet of polymer emerges, which is finally transformed into submicron fibres. In the second method, numerous Taylor cones are formed concurrently on the surface of the rollers using a sufficiently high voltage, resulting in nanofiber production. In turn, nanofibers gravitate towards collectors (P. J. Brown and K. Stevens, 2007). When compared to needle electrospinning, the effect of external circumstances is more prominent in the needleless electrospinning process (Dao & Jirsak, 2010).

Electrospinning is an active technique for producing biomimetic scaffolds used in tissue engineering. PVA was dissolved in distilled water at concentration 10 wt%. PVA 10wt% solution was prepared as biopolymeric materials for fabricating tissue engineered scaffolds by electrospinning, varying ambient temperature (25, 30, 35, 40, 45 and 50) °C and investigated the ambient temperature effect on tissue nanofibers pore size. Scanning electron