NANOFIBRE INCOPRATED FACE MASK FOR HAZE PROTECTION APPLICATIONS

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Report

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SUPERVISOR'S DECLARATION

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ABSTRACT

Face masks will be used when the haze season arrived but the wearer still faced cough and dizzy after inhale the dirty air. This is due to a larger pore in the filter that allows fine particles past the conventional filter. So the purposed of this study is to develop an efficient face mask that can filter a fine particle using a nanofiber filter. Firstly, the test rig for filtration test using a PVC pipe and aluminum clamp to fit the filter were fabricated. Then, polyvinyl alcohol (PVA) mixed with distilled water was prepared for used in electrospinning process. For electrospinning process, the distance from spinneret and collector was constant which is 10 meter but the time collection of nanofibers was different which is from 2 minutes to 10 minutes. This is because to study the electrospinning collection time and effectiveness of the filtration. Next, the measurement of mass particle concentration was taken by using DustTrakII Aerosol Monitor Model 8530 EP. The average of the inlet measurement is 56 ppm while the lowest at outlet is 35 ppm. For the filtration effectiveness it can be seen an increased trend from t=0 minute to t=10 minutes. The longer electrospinning collection time the more effectiveness filtration of filter. Finally, Scanning Electron Morphology (SEM) was used to determine the morphology of PVA fiber and trapped particles. The average nanofiber diameter were from 209 nm to 305 nm (t=2 till t=10 minutes). Increasing the electrospinning collection time, produced thicker layer of nanofibers web, decrease the filter media porosity, increase the rate of fine particle stranded on the fiber and offer better capture effectiveness of particle on face mask.

ABSTRAK

Topeng muka akan digunakan apabila musim jerebu tiba tetapi pemakainya masih menghadapi batuk dan pening selepas menyedut udara kotor. Ini disebabkan liang yang lebih besar dalam penapis yang membolehkan zarah halus lalu penapis konvensional. Jadi tujuan kajian ini adalah untuk membangunkan sebuah topeng muka yang berkesan yang boleh menapis zarah halus menggunakan penapis nanofiber. Pertama, pelantar ujian telah direka untuk ujian penapisan menggunakan paip PVC dan pengapit aluminium untuk dimasukkan penapis. Kemudian, polyvinyl alcohol (PVA) dicampur dengan air suling telah disediakan untuk digunakan dalam proses electrospinning. Untuk proses electrospinning, jarak dari spinneret dan pemungut adalah tetap iaitu 10 meter tetapi koleksi masa bagi nanofibers berbeza iaitu dari 2 minit hingga 10 minit. Ini adalah kerana untuk mengkaji masa koleksi electrospinning dan keberkesanan penapisan. Seterusnya, pengukuran kepekatan jisim zarah telah diambil dengan menggunakan DustTrakII Aerosol Monitor Digital 8530 EP. Purata ukuran salur masuk adalah 56 ppm manakala yang terendah pada salur keluar adalah 35 ppm. Untuk keberkesanan penapisan ia boleh dilihat arah aliran yang meningkat daripada t = 0 minit hingga t = 10 minit. Semakin lama koleksi masa electrospinning semakin berkesan penapisan penapis. Akhir sekali, Scanning Electron Morfologi (SEM) telah digunakan untuk menentukan morfologi gentian PVA dan zarah terperangkap. Purata diameter nanofiber adalah dari 209 nm hingga 305 nm (t = 2 hingga t = 10 minit). Meningkatkan koleksi masa electrospinning, menghasilkan lapisan tebal nanofibers, mengurangkan keliangan media penapis, meningkatkan kadar zarah halus terdampar di gentian dan menawarkan keberkesanan dengan lebih baik bagi zarah topeng muka.

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LIST OF ABBEREVATIONS

API - Air Pollutant Index

PSI - Pollutant Standard Index

USEPA - United States Environmental Protection Agency

HEPA - High Efficiency Particulate Air

SEM - Scanning Electron Microscope

PM - Particulate Matter

HVAC - Heating Ventilation Air Conditioning

ULPA - Ultra-Low Penetration Air

SULPA - Super Ultra-Low Penetration Air

PP - Polypropylene

PVC - Polyvinyl Chloride

PE - Polyethylene

PVA - Polyvinyl Alcohol

MPP - Most Penetrating Particle

NIH - National Institute of Health

BFE - Bacteria Filtration Efficiency

PFE - Particle Filtration Efficiency

CHAPTER 1

INTRODUCTION

1.1 Background

Haze phenomenon due to accumulated dust and smoke particles in air often occurs in Malaysia (Rahman, 2013). In recent years, many countries in the Southeast Asia including Malaysia, Brunei, Indonesia, Singapore and Thailand have been significantly affected by this problem. One of the worst haze episodes happened in 2013. The Air Pollution Index (API) hit 172 on 19^{th} June 2013. On 20^{th}June, the haze in Malaysia worsened where Johor and Malacca remained the worst-affected states. In Johor for example, Muar recorded hazardous API reading of (383), which was one of the worst recorded API values in Malaysia (Rahman, 2013).

Open burning forest and agricultural wastes from the neighbouring countries caused a haze in our country (Fires, Pollution, & Asia, 2000). Other than open burning, there are problems that could cause haze such as industrial and vehicle emissions. The accumulated dusk and smoke particles in air produces poor air quality which could lead to serious health problems. The riskiest persons are those who have respiratory issues such as asthma and, pneumonia, older people, young children, pregnant women and cancer patients.

Dirtied air can specifically experience the lung alveolar to bring about numerous sicknesses including asthma. As of late, numerous Malaysian urban areas are secured by murkiness air. Figure 1.1 demonstrated the contaminated air at

Malaysia during 2014. The overwhelming metals followed on particles may even prompt serious constant wellbeing issues, for example, growth after long haul introduction under the particles contained environment. The majority of those covers are made of non-woven fabric, actuated carbon, or cotton which has fibre breadth of a few micro meters. They have noteworthy weakness of poor air dismissal and low air porousness.

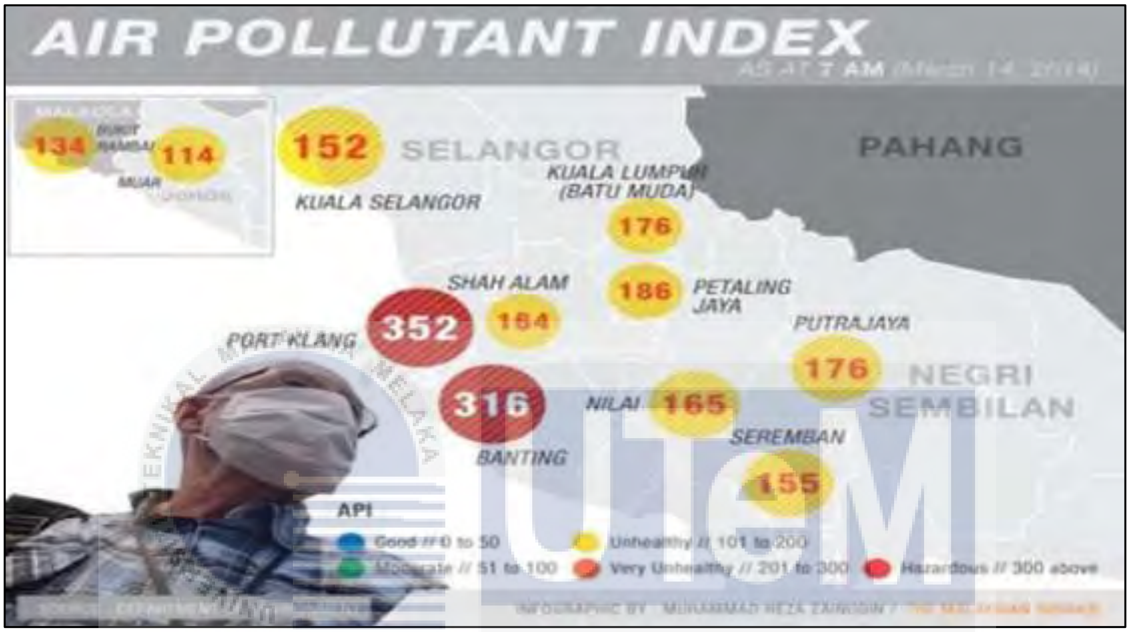


Figure 1.1: The sub-micron surgical face mask used in medical industry(Abdullah, Samah, & Tham, 2012)

Air pollutant index (API) is to show the condition of the air per daily in Malaysia. Air pollutant index (API) is a pointer for the air quality status at a specific area. This API system closely follows the Pollutant Standard Index (PSI) of the United States Environmental Protection Agency (USEPA) and is mainly based on five major pollutants (PM10, SO2, NO2, CO, and O3) in the ambient air (Abdullah et al., 2012). Table 1.1 shows the air pollution index that usually make as a reference.

Table 1.1: Air Pollution Index References (Control, Poor, Sharma, Aditya, & Engineer, 2014).

Percentage	Condition	Description
Below 50	Good	Low contamination with no awful impact on wellbeing
51-100	Moderate	Moderate contamination that does not represent any awful impact on wellbeing
101-200	Unhealthy	Exacerbate the wellbeing state of high hazard individuals who is the general population with heart and lung confusions
201-300	Very Unhealthy	Exacerbate the wellbeing condition and low resilience of physical activities to individuals with heart and lung intricacies. Influence general wellbeing
More than 300	Hazardous	Unsafe to high hazard individuals and general wellbeing.

Given the issues of air contamination and defilement is one thing that often happens, attention must be focused and must address this issue with a fast time period. In this age of advanced technology, various ways to produce equipment for the production of clean environment. Filtration innovation is one of such progressed approaches for making a more advantageous and cleaner environment. The standard bandage used to forestall breathing in the fine particles. Those filters are not ready to sift through the expansive porosity of the veil materials. Some cover is avoided because it has severe breathing capacity, which increased the danger of another well fare.

During the haze, the citizen will provided a surgical face mask by ministry of health. There are three types of fabrics forming technology which is woven, non-woven and knitted. Nowadays, non-woven is used to make up the surgical face masks. The typical material using spun bond technology with 20 gsm of polypropylene and 25 gsm polypropylene non-woven sheet by using melt blown technology to manufacture surgical face masks (Chellamani, Veerasubramanian, & Vignesh Balaji, 2013). Face mask, 1 μ in size, filter the material with two filters and made up of three or four layers. Moreover, the more effective surgical face masks to prevent the spread of fine particle entering the mouth required 85% or even 99% protection.

Polymeric nanofiber have been used in air filtration applications over the last 20 years, and hold promise in an expanding field of filtration applications as it have a technical benefits (Graham et al., 2002). Nanofibers are one of the novel materials which have one request of size littler than traditional filaments. The high surface-to-volume proportion, low resistance and upgraded filtration execution make nanofiber an alluring material for some applications, for example, medicinal services, vitality and air filtration. Activated carbon is used to remove toxic chemicals through adsorption process, whereas High Efficiency Particulate Air (HEPA) filters are used to filter particles such as lint and other debris from the air (Sundarrajan, Tan, Lim, & Ramakrishna, 2014).

Figure 1.2 is a Scanning Electron Microscope (SEM) of electrospun nanofiber. The fibres are approximately 250 nano meters in diameter. As the fibres themselves have a small diameter, the thickness of the nano web can likewise be quite small, with a thickness of four nanofiber diameters approaching only one micron (Graham et al., 2002).

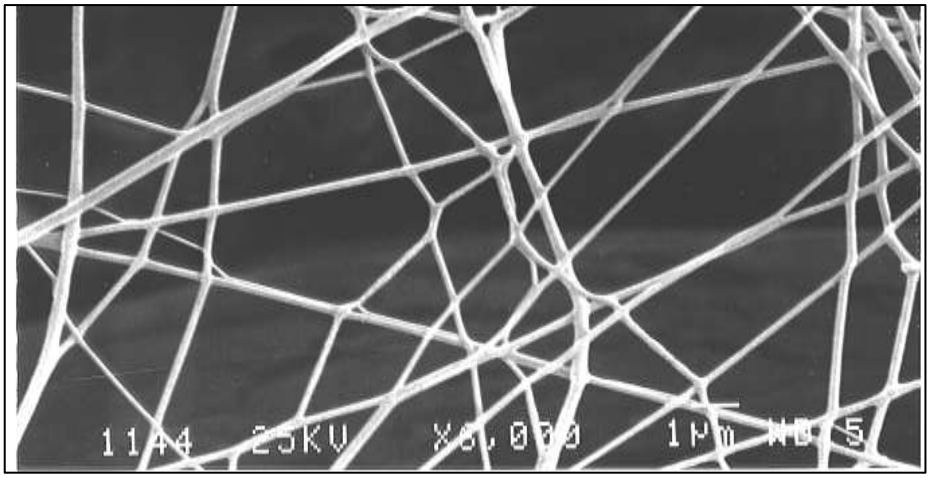


Figure 1.1: A typical Scanning Electron Micrograph of electrospun nanofiber (Graham et al., 2002).

1.2 Problem Statement

Particulate Matter (PM) is a complex mixture of extremely small particles and liquid droplets. On the basis of the particle size, PM is categorized by $PM_{2.5}$ which have a particle sizes below 2.5 µm and PM_{10} have a particle sizes below 10 µm respectively (Liu et al., 2015). There are two types of air filters. There is a porous membrane filter is made by creating pores on solid substrate and it is usually has very small pore size to filter out the larger sizes. The efficiency is high and the pressure drop is large. Next, there is fibrous air filter which filter the particles by the combination of thick physical boundaries and adhesion. This is made of numerous layers of thick fibers of various diameters across from a few microns to many microns. Normally, thick filter is to have a high efficiency. The inadequacy of the second kind of filter is the massiveness, not transparency and the tolerance between air flow and efficiency. So, the two types of filters which are not have a high filtering efficiency, high resistance and not light. Besides that, when the fibre diameter is larger, the particle-capture possibility is decreased a lot which are not effective to capture the small particle.

1.3 Objectives

The objectives of this project are as follows:

1) To developed a high efficient face mask.
2) To understand the relationship between the amounts of nanofibers and filter efficiency.

1.4 Scope of Project

The scopes of this project are:

1) Production of electrospun nanofibers by using an electrospinning process.
2) To evaluate the performance of the filtration membrane by using DuskTrakII Aerosol Monitor 8530.
3) Analysing the nanofibers morphology using scanning electron microscopy (SEM).

CHAPTER 2

LITERATURE REVIEW

2.1 The Air Pollution

These days, the worldwide mindfulness in diminishing contamination has risen fundamentally. Individuals over the world requests better arrangement in controlling the Particulate Matter (PM) contamination created in the environment. The visibility diminished incredibly and the air quality was poor due to a great degree elevated amounts of PM amid hazy days. The combustion from a carbon compound or water will deform on filter surfaces and require more grounded binding amid the way toward attaching to the filter. The soft PM tends to be more difficult to capture rigid inorganic PM with larger amounts of carbon and water content, since the same material are made to capture efficiencies of fibrous filters are lower in soft PM (Liu et al., 2015). Considering the fact by Hinds that to get a better filtration efficiency the fibre diameter must be less, the utilization of electrospun fibres for air filtration applications is a practical range (Matulevicius, Kliucininkas, Prasauskas, Buivydiene, & Martuzevicius, 2016). Air filtration studies indicated that electrospinning of nanofibers by air blowing method was carried out and air flow tests been conducted can be conceivably applied for air filtration applications (Sundarrajan et al., 2014). The need of high performance of filtration on face mask to filter the exterior air pollution from entering the mask which certainly provide better air quality, a good breathability by controlling the efficiency of filtration. The discomforts condition by human are due to have a cough, harmful particles and hazardous air pollution are main problem due to fine particle sizes. The electrospinning of nanofiber is to traps bacteria or fine particle which is widely used in medical masks applications (Chellamani et al., 2013).

2.1.1 Particle Classification

Particulate Matter (PM) is a mixture of microscopic solid and liquid droplets suspended in the air, consisting of various segments, as example acids, organic chemicals, metals, solids or tidy particles, and allergens (Bai & Sun, 2016). The airborne particulates contains of mass concentration and size distribution. Surrounding levels of mass fixation are measured in micrograms per cubic (µg/m^3). The size properties are normally measured as aerodynamic diameter across of the tidy of the particulates as far as microns.

The aerodynamic diameter often recognized into three categorizations as thoracic, fine and ultrafine particles. The size of thoracic particle PM_{10} is the biggest which is below than 10 µm diameter while fine particle $PM_{2.5}$ is below than 2.5 µm diameter. Next, the ultrafine $PM_{0.1}$ is the smallest which is below than 0.1 µm in diameter particles (Bai & Sun, 2016). Particles fine $PM_{2.5}$ and PM_{10} are most expected to cause bad health effects. Particulate matter is the most harmful air pollutants to human health especially in excessive PM circumstances. This specific size molecule raised real worries because of its ethicalness of their size, they can be effortlessly breathed in and travel deep into human lung indirectly causing breathing problem. People who have been presented to PM will increment of cardio-respiratory sickness and dreariness, and a reduction life expectancy that been accounted for by public health (Kwon, Jeong, Park, Kim, & Cho, 2015). For further understanding of the particle sizes, Figure 2.1 represents the comparison of PM_{10} and $PM_{2.5}$ particles between human air and beach sand.

Furthermore, ($PM_{2.5}$) is an essential particles which is created amid burning process that specifically discharged into the air. Conversely, coarse particle (PM_{10}) is the secondary particles is made by mechanical or compound responses in the atmosphere (Liu et al., 2015).

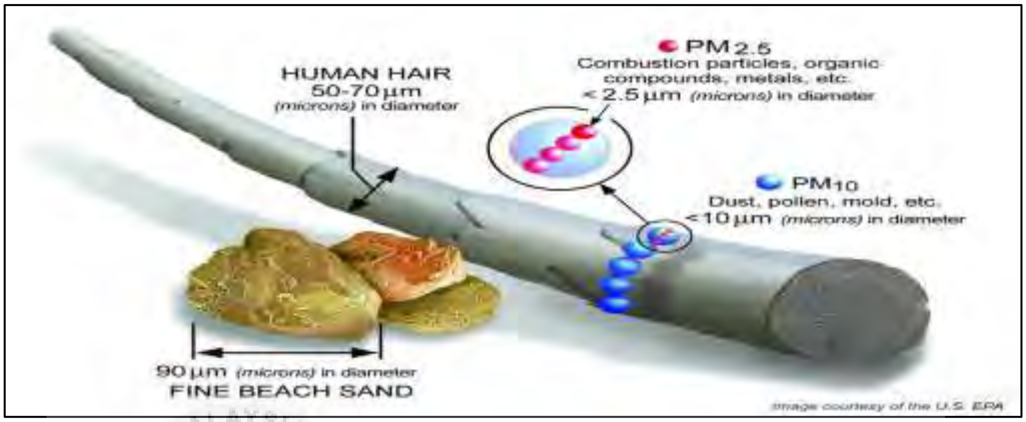


Figure 2.1: A comparison of PM with human air and beach sand (Kim, Kabir, & Kabir, 2015).

The size fine beach sand is the biggest among others which have 90 µm followed by human hair which have 50-70 µm in diameter respectively. Physically, human hairs have a small diameter compared to sand, but for $\boldsymbol{PM_{10}}$ and $\boldsymbol{PM_{2.5}}$ are smallest between human hairs. $\boldsymbol{PM_{10}}$ is a coarse particle which the size are less than 10 µm of diameter which normally for dust, pollen and mold. Then, $\boldsymbol{PM_{2.5}}$ is the smallest particles which have less than 2.5 µm in size and it exist in $\boldsymbol{PM_{10}}$ particle. For example of the particle are from combustion, organic compounds and metals.

2.1.2 Basic Filtration Mechanism

Basically, filtration is the premise by which components for filtration and detachment of particulate matter are created. Filtration and detachment theory is more worried with the components, recorded beneath, for molecule detachment after the molecule enters the surface of the medium. There are four basic mechanisms which are inertial impaction filtration mechanisms, interception, diffusion and electrostatic attraction. When the molecule inertia is so high the inertial impaction is happens that it has adequate force to split far from air streamlines and impact the fibre (Hutten & Hutten, 2016). This component is in charge of collecting bigger particles. Next, the interception is happens when a molecule does not have adequate inertia to break far from the streamline. It may approaches enough to the fibre so that common strengths forces will attach the molecule to the fibre. Again, this component is also in charge of collecting bigger particles.

The diffusion is a very small particle which is below than 0.5 μm based on the Brownian (zigzag) motion. This unpredictable and probabilistic development from the streamline and possibly interface with a fibre surface will bring about a molecule to differ (Hutten & Hutten, 2016). Lastly, the electrostatic is used as an electric charge to shift the particle from the streamline and attracted to fibre. Particles can be captured through the mechanisms depicted in Figure 2.2 as inertial impaction, interception, diffusion, electrostatic, gravity.

Figure 2.2: Aerosol filtration mechanism illustration (Chuanfang, 2012).

2.2 Face Mask Filtration

Face mask filter widely used in the event of air pollution because it is used to filter the mouth and nose from entering the small particles, protect from virus, bacteria, biological substances and particles in the air. Typically, the face mask filter that used is given from a medical industry as shown in Figure 2.3. It is represents the cross sectional filter area in the mask if it cut the surface. The masks have a three layer which is to embodiment the invention and to filter the small particles.

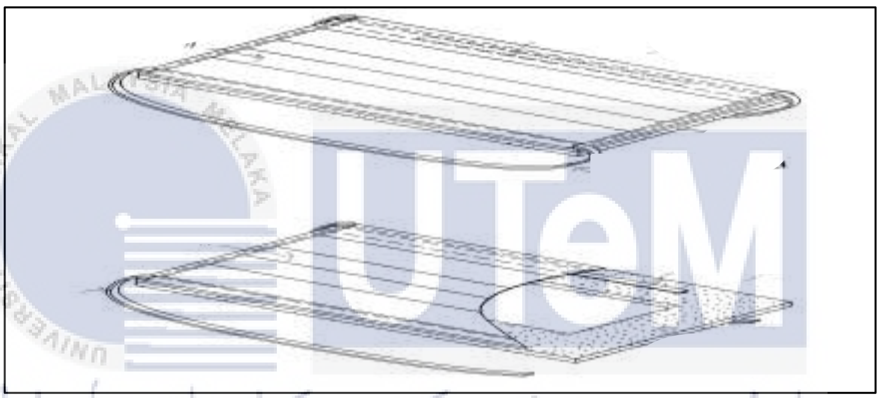


Figure 2.3: An illustration of face mask filtration(Tutor, 2002)

Protect the user from liquids and particles are also other function of face mask. Mostly viruses are small particles which is smaller than 1 micron. So, for the filtration of infection classic masks are not satisfy the criteria (Akalin, Usta, Kocak, & Ozen, 2010). The properties of the filter medium determine how the filter performs to evacuate the particles in the slurry and figure out if the particles shape a cake, are caught in the profundity of the filter, or go through the filter. The structure of materials framing the media is the most direct approach to describe the different sorts of media. The main categories include woven media, non-woven media and membranes. In comparison with woven texture filter, nonwovens offer numerous technical specialized qualities, including more prominent porousness, more specific particular surface range, and controllable pore measure dissemination, and little pore size.

2.2.1 Non- Woven Media

Non-woven fibre media are widely used type of media in industry. Non-woven fibres are widely utilized as a part of the medical field and in protection (Ajmeri & Joshi Ajmeri, 2011). Non- woven fibre are easy to fabricate and inexpensive. In addition, the surface has great filtration properties. It can filter up to very small particle particularly below than 1 micron. Membranes that are produced by directly coating onto the carrier material's surface are based on non-woven fabrics which are additionally backup support and mechanical strength to the nearly thin and fragile polymer (Hutten, 2016). The fabric can be particularly built to give the exact porosity and stream rate required for the specific filtering application. Non-woven is to enhance the effectiveness of filter media while upgrading the removal capacity of both particulate and chemical contaminant.

Non-woven filter have different applications in numerous segments in air, gas, and fluid filtrations. Higher efficiency is the fundamental point for the filter media and enhancing the effectiveness is a consistent improvement in future. Approximately 65-70% of the non-woven filtration media usually for air and gas while for the liquid filtration remaining 30-35%. Heating Ventilation Air Conditioning (HVAC) applications in residential, air and water filtrations in power stations, intake and exhaust air are the examples of their bulk applications which is from air and water filtration. The viruses are the smallest of the contaminants and only can just effectively be evacuated with High Efficiency Particulate Air (HEPA) filtration. Minimum efficiency of a filter that can be called HEPA is 99.97% retention of 0.3-μm particles. ULPA (Ultralow Particulate Air) is a filter that can have an efficiencies of 99.999% , while filters with 99.9999% are called SULPA (Super Ultra-Low Penetration Air) (Hutten, 2016).

Furthermore, fibre size and fibre geometries impact filter pore sizes, as well as straightforwardly decide filtration effectiveness and pressure drops. Fibres of more prominent straight thickness and circular cross areas could lead to more large porosity and porousness, in this way having a decreased pressure drop. Thus, filtration efficiency and pressure drop could influence by combination of fibre sizes and fibre geometries. Efficiency ratio and contains particle size, filtrated air quantity and using time are used to determine the filter efficiency.

Polypropylene (PP) fibre is used because of its non-absorber properties for the basic face masks (Akalin et al., 2010; Mao, 2016). PP has a high electrical resistance to retain the stability of E-charges, to achieve lower pressure drops. The electret filters are widely used in (HVAC) filters, respiratory masks, cabin air filters, vacuum filters, (HEPA)/ (ULPA) filters, dust removals, and engine intake air filters (Mao, 2016). Particulate filters from nanofiber coating by electrospinning process has the ability to filter out the fine particles, dust, pollutants and other air bones contaminants effectively compared than the others. Figure 2.4 show the face mask that usually used in medical industry.

Figure 2.4: The sub-micron surgical face mask used in medical industry

Face mask that usually used in medical industry was manufactured to meet and exceed International Standard of ASTM F2100. The capabilities of mask filtration can be determined by a size of the pores and the filtration efficiency (Molinari, Ph, Nelson, & Barrier, 2014). There are 4 criteria that should be aware on ASTM of medical face mask which is fluid resistance, bacteria filtration efficiency (BFE), particulate filtration efficiency (PFE) and flame spread. Firstly, for the fluid resistance, face mask resistance to penetration by synthetic blood. It also measures capacity of masks development to minimize fluids from going through the material and conceivably corning into contact with the wearer. The protection will get a better if the filtration of the fluid is higher.

Next, the BFE is to measure the productivity of bacteria pass through with using a face mask filtration. It is represents percentage of bacteria or dusk filtered through at pore size 1-5 microns. On the other side, the PFE is slightly lower which is it represents percentage of particles that have been filtered through at pore size of 0.1 to 1.0 microns. It is critical if the particles that have been filtered are captured because the ranges of the size are already lowest. The PFE is to measure the productivity of the particles pass through with using a face mask filtration. Lastly, the mask material must be measures by using a flame spread. Table 2.1 shows the material requirements by performance level.

Table 1.1: Material Requirements by Performance Level (Molinari et al., 2014).

	ASTM Level 1	ASTM Level 2	ASTM Level 3
Fluid Resistance, mmHg	80	120	160
BFE	Below or equal than 95%	Below or equal than 98%	Below or equal than 98%
PFE for 0.1 micron	Below or equal than 95%	Below than 98%	Below than 98%
Flame Spread	Class 1	Class 1	Class 1

2.3 Nanofiber Production Methods

Nanofibers are commonly produced by using two processes, i.e. electrospinning and melt blown process. These methods have gotten to be accessible to the non-woven and filtration industries and the items have been utilized for a wide scope of filtration applications.

2.3.1 Electrospinning

Electrospinning is a polymer solution to produce a polymer fibre on the sub-micron scale (Call, 2008). Electrospinning is a process by which a voltage is applied to the polymer solution (Graham et al., 2002) which competent of producing nanofiber with diameter less than 1000 nm (Qin & Wang, 2006). Electrospinning was performed in barometrical conditions, and a computerized thermometer was utilized to monitor the temperature and moistness of the ambient environment. The volume of liquid polymer solution in a syringe is between 1-10 mL/h is emitted using a fine nozzle at a voltage with range 0 to 30 kV. The outer diameter of syringe between 0.62-0.64 mm and an inner diameter syringe of 0.32-0.34 mm. The distance between the needle tip and the collector located between 10 -15 cm.

The electrospinning set up consists of a high voltage power supply, a needle tip of small diameter act as nozzle, a collector, and a syringe pump for polymer solution as shown in Figure 2.5. The polymer solution in syringe pump is ejected to forms droplet which can produce a Taylor cone as presented in Figure 2.6 at the tip of nozzle due to high voltage potential of the polymer solution. During testing it was vital to maintain steady flow conditions; this was finished by ensuring that none of the arrangement incorporated up with expansive beads on the needle and fall from the tip. The resulting in continuous nanofiber is drawn out from the polymer solution.

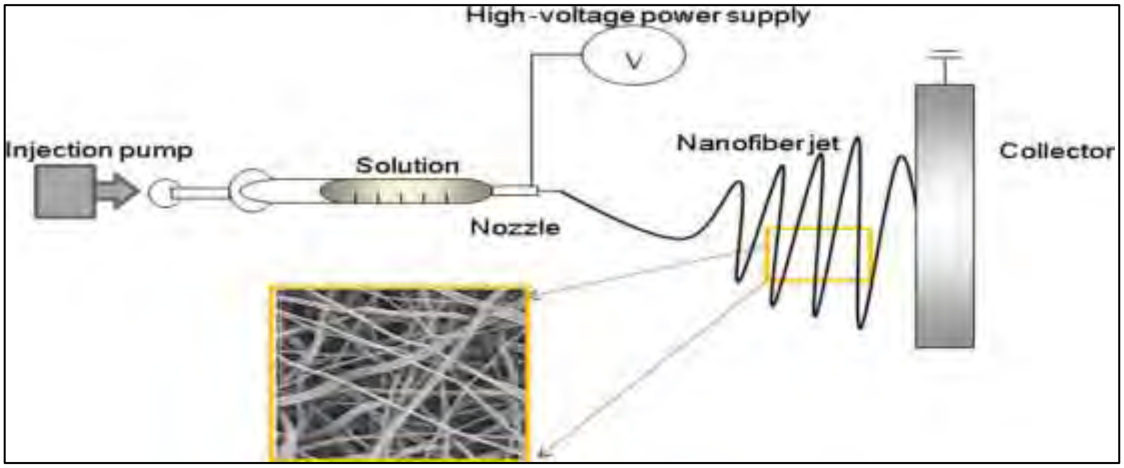


Figure 2.5: Schematic view of electrospinning setup(Shin, Purevdorj, Castano, Planell, & Kim, 2012).

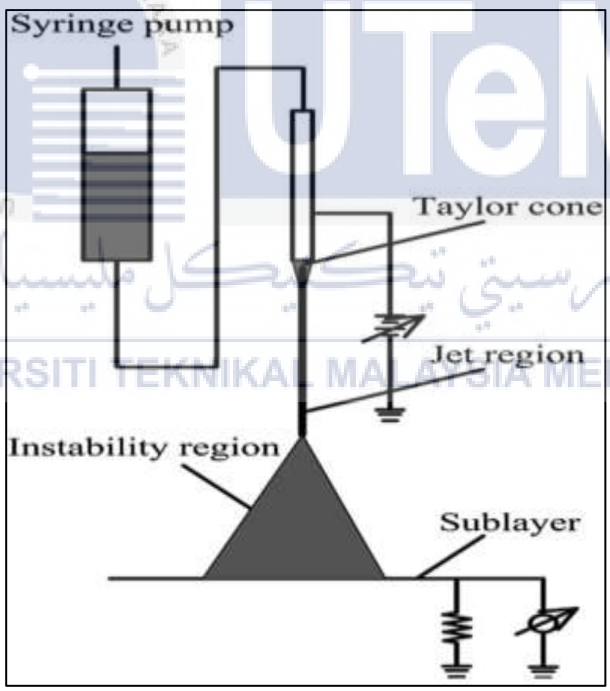


Figure 2.6: The forming of Taylor cone from electrospinning (Qin & Wang, 2006).

2.3.2 Melt Blown

Melt Blown is a process by injecting molten polymer streams into high velocity air jets used to produce microfibers that form a self-bonded web when collected on a moving surface (Hassan, Yeom, Wilkie, Pourdeyhimi, & Khan, 2013). The same air streams deliver the fibre onto a collector. With the development of the filaments to the collector, the fibre itself are extinguished, at the same time shaping entrapments and bonded to each other to frame a reliable non-woven web. High-velocity air jets impinge upon the polymer as it emerges from the spinneret is a process of melt blown that illustrate in Figure 2.7. The drag force brought about by the air attenuates the fibre rapidly and diminishes its diameter by as much as hundred times from that of the nozzle diameter.

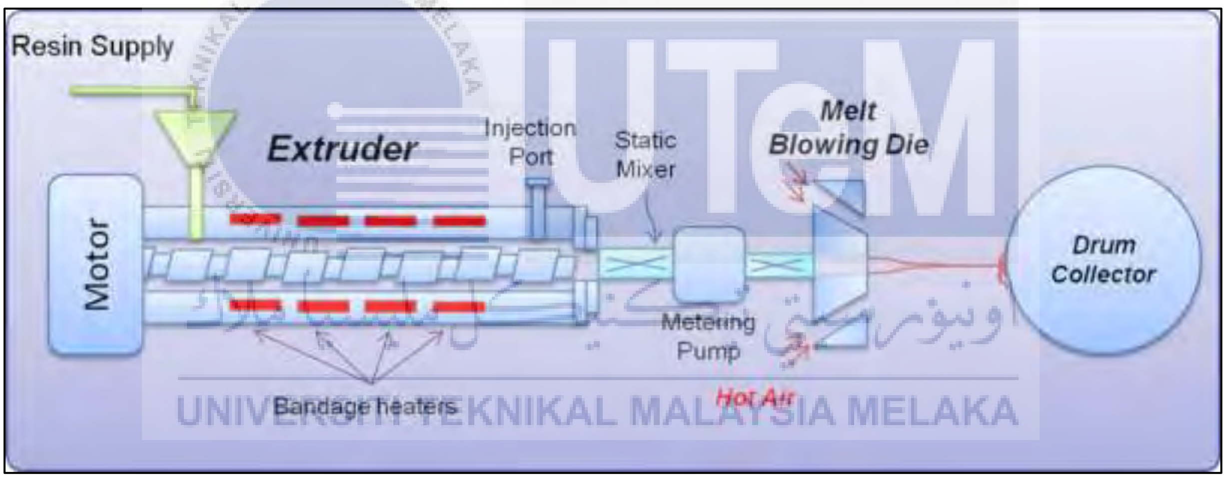


Figure 2.7: Schematic drawing of the melt blown process (Hassan et al., 2013).

Melt blown process membranes have an average diameter of 1-2 µm with fibre sizes running from 0.5 to 10 µm. This process has a high surface area per unit weight, high protection esteem, and high barrier properties. Melt blowing has the potential to compete positively with electrospinning if the melt blowing process could be utilized to create materials in the nanofiber range; melt blowing would provide a much speedier, easier, and less expensive compared to the electrospinning system.

Table 1.2: Advantages and Limitations of Electrospinning and Melt Blown method

Type	Advantages	Limitations
Electrospinning	▪ Cost effective ▪ Long continuous nanofibers ▪ The fibre diameters can be as low as 50 nm ▪ Various type of polymers can be use ▪ Similar fibre diameters	▪ Low production rate ▪ Complexity of device scale up ▪ High production cost ▪ Jet instability ▪ Fairly weak and damageable ▪ Two step process ▪ Fibres only in layers
Melt Blown	▪ High productivity ▪ Solvent free ▪ Single step process ▪ Finer fibre diameters ▪ Fit for various polymers	▪ Normal operation: fibre diameters of only 1-2 microns ▪ Only suitable for thermoplastic polymers.

From Table 2.2 as shown above, it be can summarize that electrospinning process is the best way to use for filtration process. This is because it is simplest, cost effective and preferable choice for producing nanofibers.

2.4 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) is successful way in estimating the nanofibers diameter and size of particles in an air stream caught by nanofibers. Furthermore, nanofibre SEM has the ability to determine diameters, porosity and surface area of nanofiber. There are benefits and limitations for SEM which is for the advantages; it can be used for almost all kinds of samples, conducting and non-conducting, has a very large depth of focus, direct examination and it imaging at all directions through x-y-z (3D) rotation of sample. While the limitations of SEM are generally required surface stain-coating with metals for electron conducting and it has a low resolution.

Some industries used SEM as their instruments because of its ability to image materials moreover, structures with submicron determination (Inkson, 2016). The resolution is determined by beam of electrons to form an image of an example permitting imaging and evaluation of surface topographic components. SEM is like an optical microscope but uses electrons instead of light. Figure 2.8 shows illustration of SEM using an electron. SEM has been proved to be suitable tools for imaging of almost any material with a high resolution (Utah, 2009).

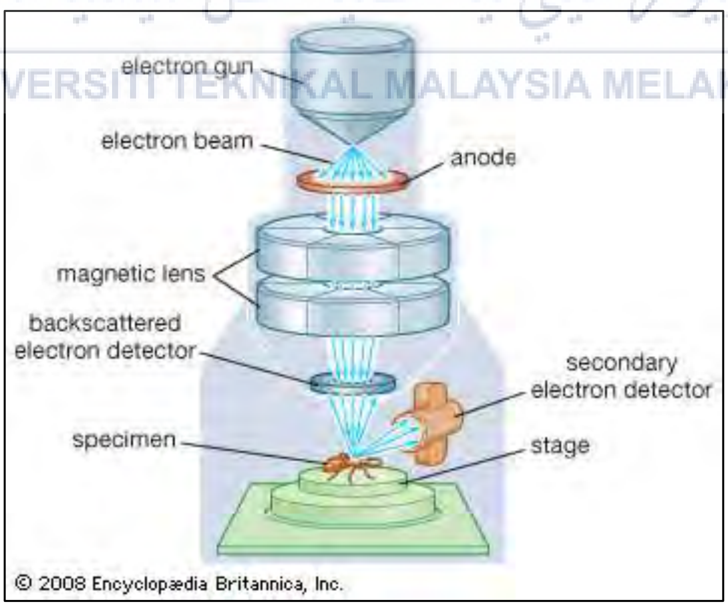


Figure 2.8: Illustration of SEM (Inkson, 2016).

2.4.1 Development in Nanofibrous Filtration Technologies

Nanofiber are generally having fine diameter but they lack of mechanical quality to remain solitary. Applying the nanofiber webs onto substrates is necessary to endure most applications of air filters. Figure 2.9 shows the observation of nanofiber webs and substrates under several thousand magnification image using SEM. The substrates provide the essential mechanical properties of maintaining the structural of the filter. The nanofiber web ensures to improve the filtration execution to trap the submicron particles if it is remain intact. Leung and Hung indicates that mixture of filters by microfiber and nanofiber through coating of nanofibers onto microfiber substrates have Most Penetrating Particle (MPP) less than conventional microfiber (Sundarrajan et al., 2014).

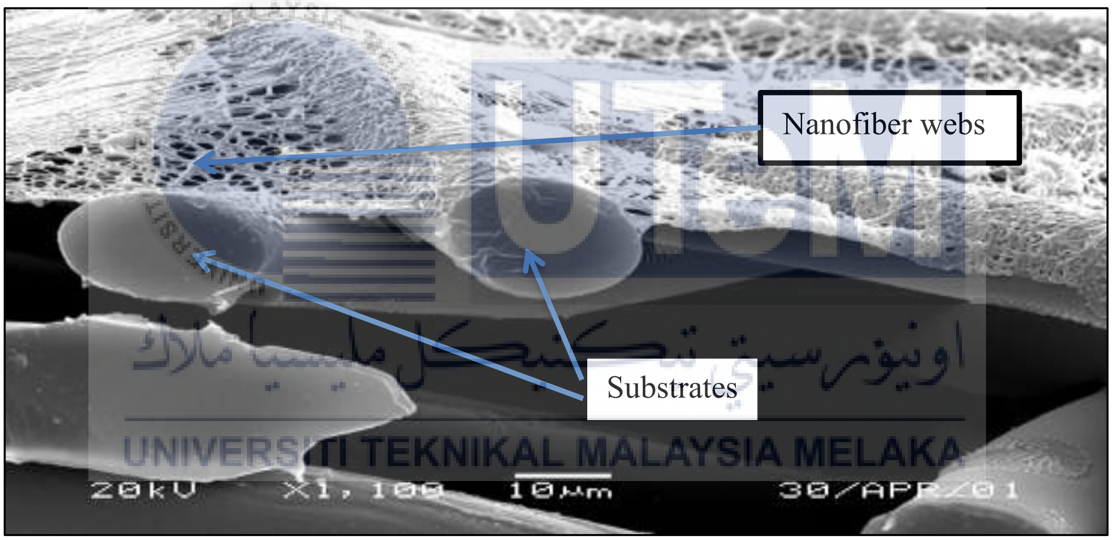


Figure 2.9: Example of SEM image for substrates air filter layered by nanofibres coating (Sundarrajan et al., 2014).

:

In order to examine the fibre morphology, samples were sputter coated with a thin layer of gold and analysed with SEM and ImageJ processing program its precision, faster and reliable. National Institute of Health (NIH) was developed a public domain Java image processing and analysis program which called as ImageJ (T. Ferreira, 2012). This program can calculate the area of user-defined selections, measure distances and angles and create density histograms. This program also can be zoomed up a small particle. It is an open source and supports any number of images simultaneously as shown in Figure 2.10.

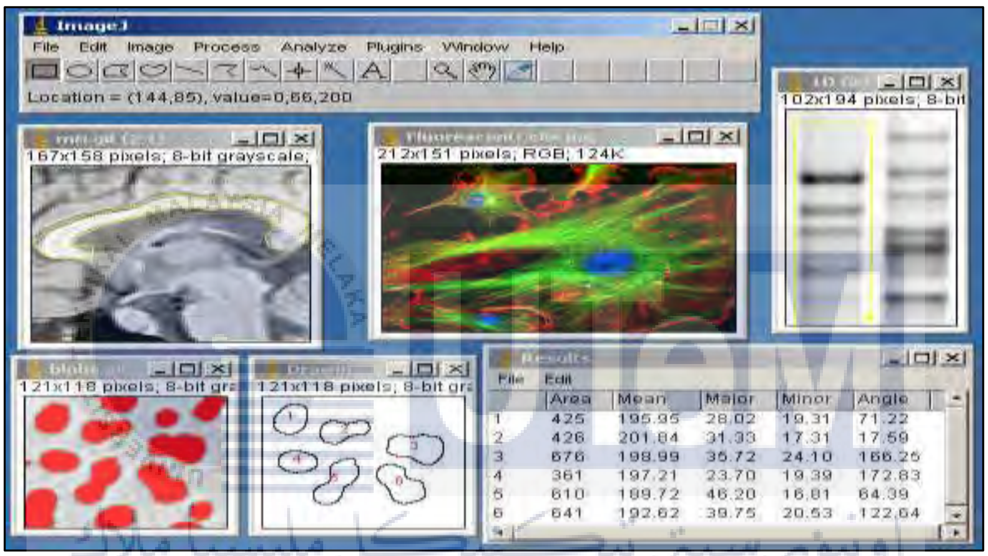


Figure 2.10: The ImageJ window consists of a menu bar with the images, histogram, results (S.Imagej, 2012)

CHAPTER 3

METHODOLOGY

3.1 Overview of the experiment

In this study, an experiment on nanofiber coated of face mask air filter and its performance was carried out. The nanofiber filter was manufactured by incorporating the industrially accessible face mask air filter and electrospun nanofiber through electrospinning procedure. A filtration test rig for the experimental purpose was been designed and fabricated to filter the stream of air flow across the filter. Inside the test filter there were fixed the sample filters and the mass concentration of particle was measured before and after the filter. Dusk monitor was used to measure the filters performance regarding of reducing mass concentration of particle. Scanning Electron Microscope (SEM) imaging was utilized to describe the sample's morphology.

3.1.1 Experimental Work Flow Chart

The experimental work began with literature review of nanofiber applications in air filtration as shown on Figure 3.1. Next step was a fabrication of face mask filter using nanofibre by electrospinning and filtration test rig. Then, the setup ready, control test was conducted for both experiments. The deposition of nanofiber electrospinning on the sample was carried out after get uniform coating during the control test while measurement of mass concentration was performed when the ambient air particle concentration remain stable.

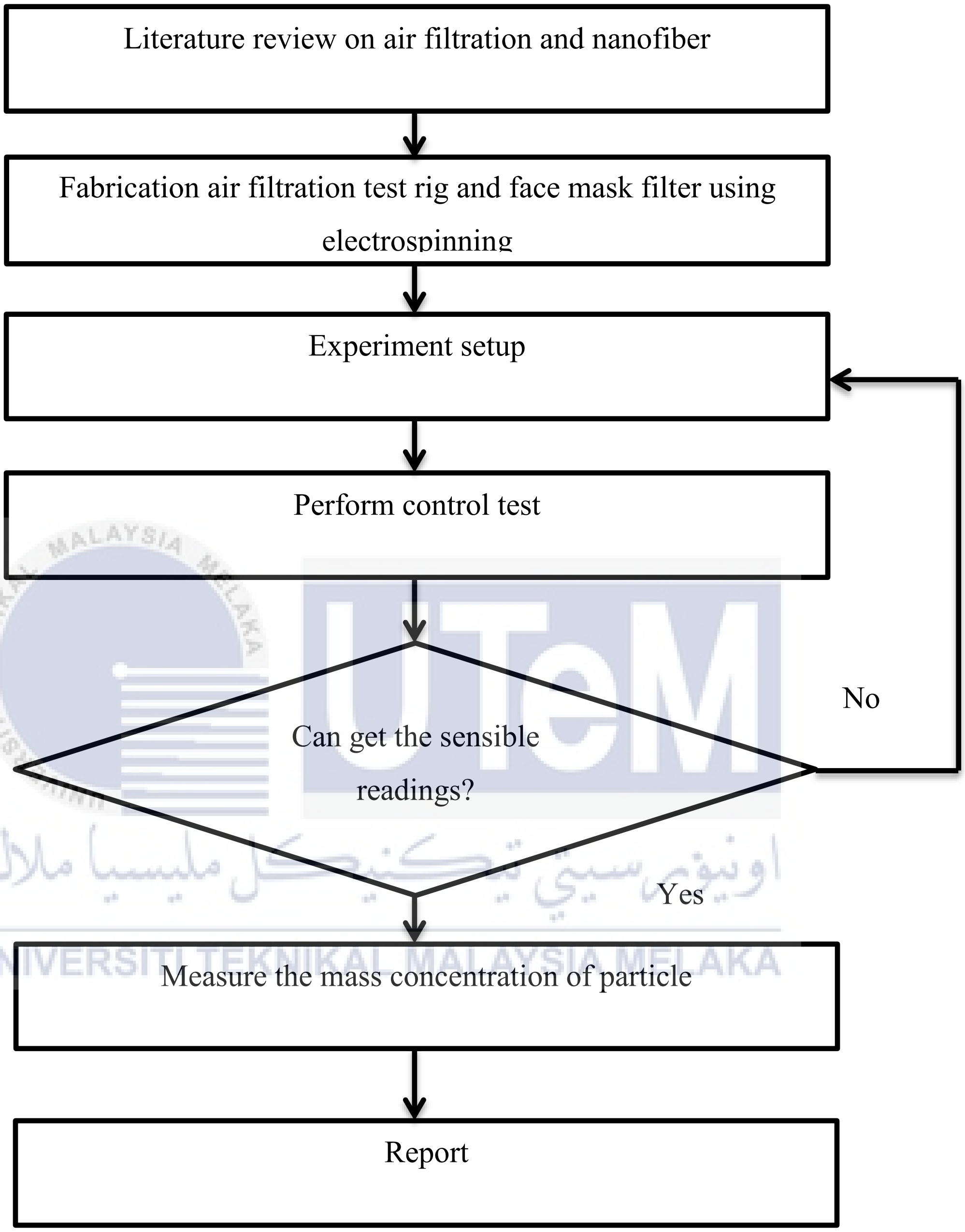


Figure 3.1: Flow chart of experimental work

3.1.2 Experimental Work Gantt Charts

Table 3.1 and Table 3.2 below represent the Gantt chart for PSM 1 and PSM 2:

Table 3.1: Gantt chart PSM 1

Gantt Chart for PSM 1	2016													
Project Activity	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Briefing	Supervisor Briefing							Mid Term Break						
Identify Objective and Scope of Journal														
Identify Method														
Journal Research														
Summary of Journal														
Design Finalization														
Material Finalization														
Fabrication														
Result and Discussion														
Progress Report Submission														
Report writing														
Submission FYP 1														
Presentation FYP 1														

Table 3.2: Gantt chart PSM 2

Gantt Chart for PSM 2	2017													
Project Activity	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Planning	Supervisor Briefing	■						Mid Term Break						
Material Selection			■											
Polymer Preparation			■	■										
Electrospinning					■	■	■							
Sample Collection									■					
SEM Analysis										■				
Concentration Analysis											■			
Results and Discussion												■	■	
Progress Report Submission							■							
Report writing						■	■		■	■	■	■	■	
Submission FYP 2														■
Presentation FYP 2														■

3.2 Electrospinning Setup

The electrospinning experiment was held at the laboratory of Universiti Teknikal Malaysia Melaka (UTeM). The machine that used for producing polypropylene electrospun fibres is Electrospinz Model ES1a. The electrospinning apparatus are presented in Figure 3.2 and Table 3.3. A high voltage is used in the electrospinning process to create an electrically charged stream of polymer solution. It is linked with the polymer solution which is filled up in the glass. Then, the solution is spun through a capillary. The collector plate is grounded as to produce voltage slope in order to induce polymer traversing. Taylor cone is formed at the tip of capillary due to high voltage electric field between the tip of capillary and a grounded collector. It is to producing sub-micron in diameter fibres. The polymer will be projected towards the oppositely charged collector and formations of solid nanofibers will appear on the collector plate when the electric field overcomes the surface tension.

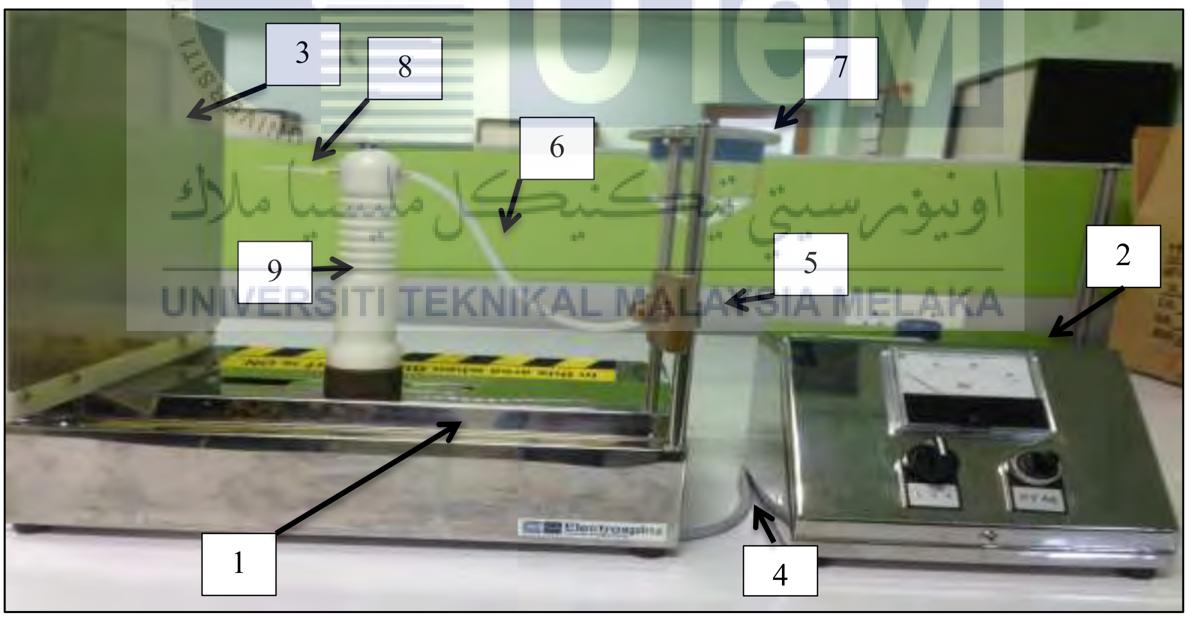


Figure 3.2: Electrospinz Model ES1a machine.

Table 3.3: Specifications of Electrospinz Model ES1a.

No	Components	Specifications
1	Spinning platform	Stainless steel
2	Power supply	Stainless steel, 0 to + or – 33, 000 VDC, Single phase 100 to 240 VAC, 1 amp maximum
3	Collector plate	300mm x 350mm x 10mm polyethylene (PE)
4	Power cable	Fittings are made of brass
5	Constant head system	Adjustable
6	Hose	Silicone rubber
7	Glass header tank	Borosilicate glass
8	Spinning tip	High density polypropylene
9	Retractable spinning post	0 to 150 mm

There are three layers of the face mask that are usually used in medical industry. For this project, the first layers of face mask are chosen due to the microstructure of the mask and it is more grounded than second and third layer. Furthermore, the first layers can filters more sub-particles other than other layers. In addition, the spinning movement is going straight attached to the mask due to the negative charged of first layers are greater than others and it also have thinner layer. In contrast, the spinning movement of second and third layers goes around the mask which is the plate are more grounded. The web that attached on the masks is not balanced and scattered. When it comes to first layers, the fiber straightly focused or attach to the middle of the mask. From that, the morphology of web are balanced and not scattered.

Variable high voltage control supply was utilized for the electrospinning. It was used to produce voltage between 0 to 33 kV, and the voltage that was used for this experiment was 10 kV. The capillary tip is 1 mm diameter are attach to glass header tank that filled up by PVA. While the distance between capillary tip and collector plate are remained unchanged, where 10 cm. Figure 3.3 is shows the fiber is injected by using an electrospinning process. The web can be seen at the center of the mask which is the spinning movement are straight forward.

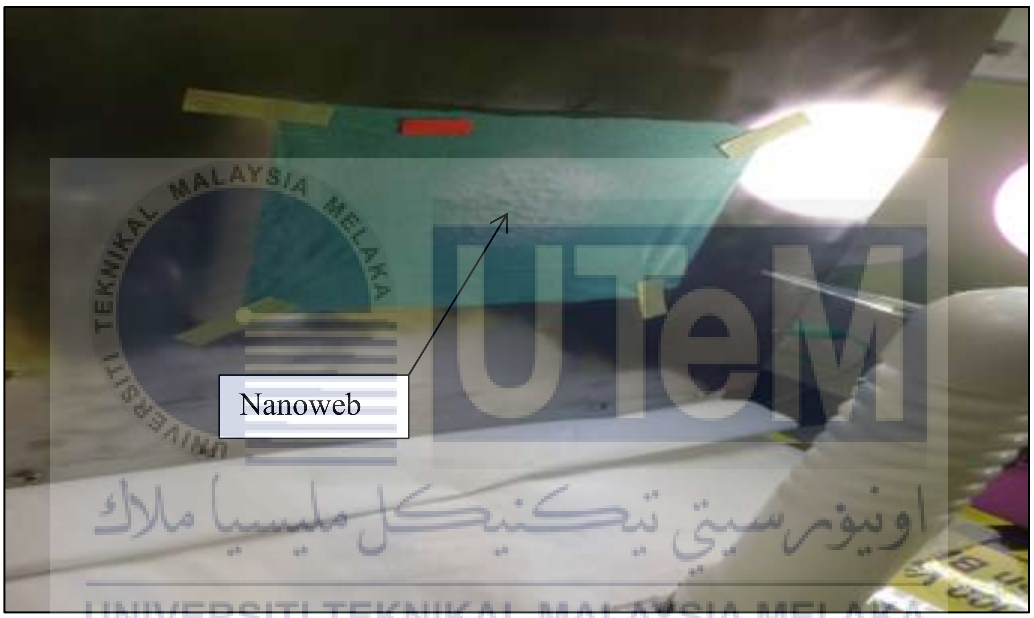


Figure 3.1: Producing fibre by using electrospinning process.

3.3 Material

For this experiment, Polyvinyl Alcohol (PVA) is used as the molten solution that to fabricate nanofibers. PVA is a semi-crystalline, hydrophilic polymer with good chemical and thermal stability (Qin & Wang, 2006). The PVA was selected due to its highly biocompatible, nontoxic, water-soluble polymer and can form gels from various types of solvents. PVA is odourless and tasteless that appropriate to form a nanofibers on a face mask. Figure 3.4 shows the molecular bonding of polyvinyl alcohol.

Figure 3.3: Molecular bonding of Poly vinyl alcohol (Assessment, 2004).

3.3.1 Polymer Preparation

Polyvinyl Alcohol in the form of pellets and water as solvent were used in this experiment as shown in Figure 3.5. The polymer solution is prepared by dissolving PVA in water at least one night at room temperature by using a magnetic stirrer. In order to get the 8 wt % of PVA concentration, the PVA and water were measured using a four figure balance to get the exact mass fraction. The concentration was based on weight for 50 ml. The polymer solution is prepared through 4 grams of PVA and 46 grams of water to get a concentration of 8 wt % PVA.

The polymer preparation was held at Chemical laboratory, Universiti Teknikal Malaysia Melaka (UTeM). For this experiment, 50 ml of solution was produced by using a PVA as solute and distilled water as a solvent. 4 grams of PVA and 42 ml of distilled water were measured by digital analytical balance. The reading that been taken by digital analytical balance was précised. Then, magnetic stirrer was used to stir the solution inside the beaker by putting the magnet as in Figure 3.6. So, the heat was us to 25 Celsius while the stirrer was up to 2.5 rpm. The polymer preparation was done by stirred for 1 hour and 30 minutes.

Figure 3.4: Polyvinyl Alcohol sample.

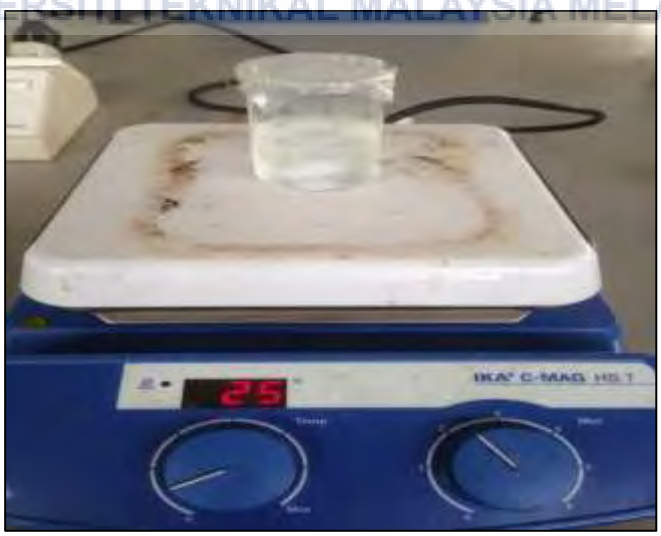


Figure 3.5: Magnetic stirrer process of PVA and H_2O solution

3.4 Air Filtration Setup

Before the experiment can be carried out, the fabrication of the filtration test jig was been done at Heating Ventilation Air Conditioning (HVAC) laboratory, Universiti Teknikal Malaysia Melaka (UTeM).

3.4.1 Test Rig Apparatus

The test rig apparatus of filtration consists of PVC elbow connector, Tee- PVC connector, PVC cone connector, PVC tubes, PVC ball valves, aluminium filter, speed controller, inlet container, desktop computer fan and mounting jig. The size of this air filter apparatus is 90 cm in length and width is 25 cm. It has two supporting stands in the middle of rig with both height are 22 cm. The schematic diagram of the test rig is shown in Figure 3.7 and the components used to filter the contaminants in the air are listed in Table 3.4.

Filtered air (exit)

Non-filtered air (in)

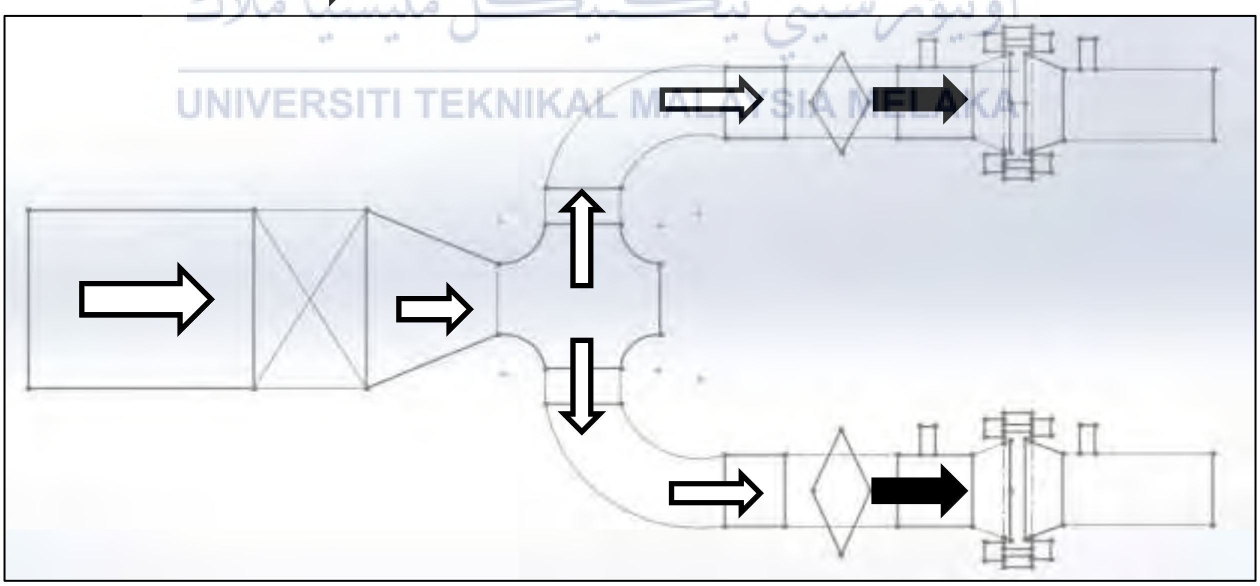


Figure 3.6: Schematic diagram of the filtration test rig.

Table 3.4: Components and specifications of the filtration test rig.

Components	Specifications
PVC Connector	90° Elbow type 25 mm in diameter, Tee- type 25 mm in diameter
PVC Ball valves	25 mm in diameter
PVC Tube	25 mm in diameter
Filter sample clamp	Aluminium connectors 28 mm in diameter
Desktop computer fan	240/12V
Speed regulator	0-15 V
Inlet Housing	Plastic container 140 cm in diameter
PVC Cone Connector	100 mm x 50 mm and 50 mm x 25 mm

The function of speed controller in Figure 3.8 is to control the speed of the desktop fan in Figure 3.9. The speed controller is connected with a power supply (12V) and a fan. The fan was placed inside the inlet container to generate air flow inside the PVC tube in Figure 3.10. The test rig split into two ways flow which the air flow can be block using PVC ball valves. One way pass through the normal filter while the other one with a nanofiber filter.

Figure 3.7: Speed controller 0-15 V.

Figure 3.8: Desktop computer fan 240/12V.

Figure 3.9: The fabricated filtration test rig and its components.

Design of Test Rig using CATIA Software

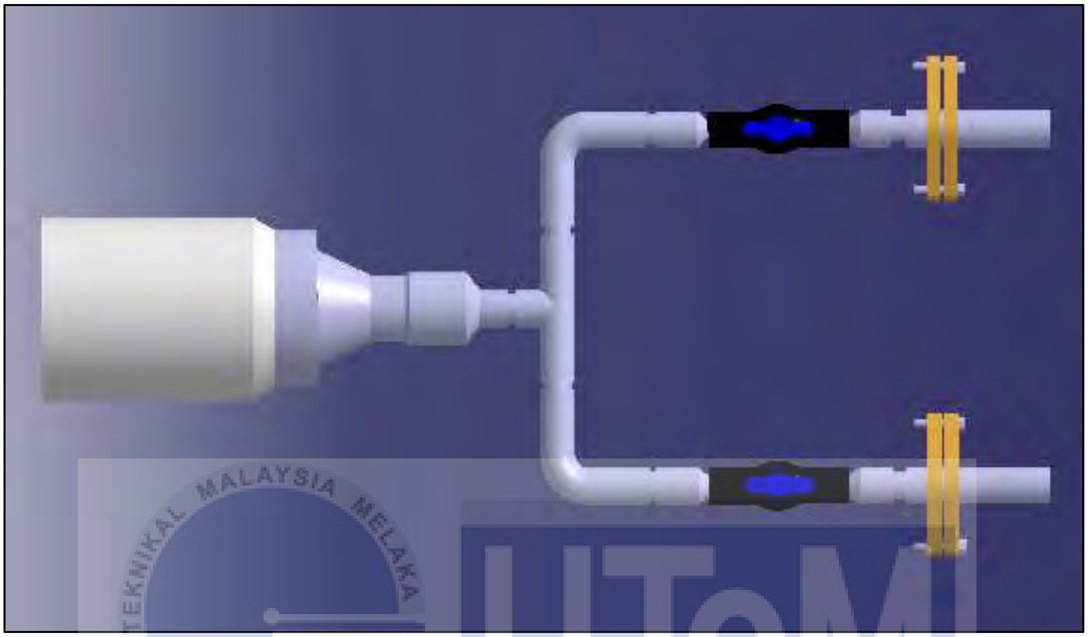


Figure 3.10: Design of Test Rig.

Figure 3.11: The Aluminium Clamp and Ball Valve.

3.5 Particle Concentration Measurement

The experiment led in accordance to PM measurement method to determine the amount of the mass particle concentration. DustTrakII Aerosol Monitor Model 85330 EP in Figure 3.12, the dusk monitor device is a single channel basic photometric instrument used to determine the mass particle concentration in real time. Table 3.5 shows the specifications of DustTrakII Aerosol Monitor Model 85330 EP.

Figure 3.12: DustTrakII Aerosol Monitor Model 8530 EP.

Table 3.5: DustTrakII Aerosol Monitor Model 8530 EP Specifications (Manual, 2017).

Components	Specifications
Sensor Type	90° light scattering
Range	8530 Desktop 0.001 to 400 mg/m^3
Resolution	$\pm$0.1% of reading of 0.001 mg/m^3, whichever is greater
Zero Stability	$\pm$0.002 mg/m^3 24 hours at 10 sec time constant
Particle Size Range	Approximately 0.1 to 10 µm
Flow Rate	3.0 L/min set at factory 1.4 to 3.0 L/min adjustable
Flow Accuracy	$\pm$5% factory set point Internal flow controlled
Temperature Coefficient	+0.001 mg/m^3 per °C
Operational Temperature	0 to 50 °C
Storage Temperature	-20 to 60 °C
Operational Humidity	0-95% RH, non-condensing
Time Constant Adjustable	1 to 60 seconds
Data Logging	45 days at 1 minute samples
Log Interval	1 seconds to 1 hour
Physical Size (HWD)	Desktop: 5.3 x 8.5 x 8.8 in.
Screen	8630/31: 5.7’’ colour touchscreen
Power-DC	Desktop 24 VDC at 2.5A

3.5.1 Particle Concentration Measurement

All the experiments were carried out at room temperature of about 24.7°C and relative humidity 65% from 12 pm to 5 pm accordingly. The experiment conducted in accordance to PM measurement method to determine the amount of the mass particle concentration. The temperature and humidity is monitored using the Humidity Temperature Meter Model RS – 232 as shown in Figure 3.13.

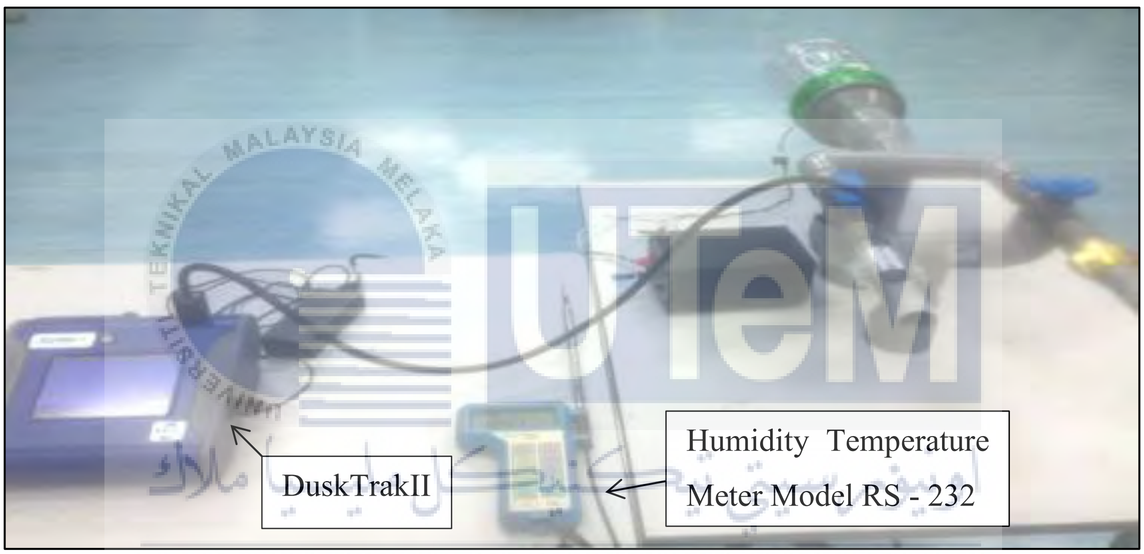


Figure 3.13: Air filter test rig set up.

The experiment started by setting the fan running at maximum speed for 5 minutes to achieve a steady flow. The air was pass through the PVC tubing across the filter with aid of 240/12 V fan. The duct was made of a PVC tube with transparent plastic chamber fixed at the front of the duct. A plastic container with 140 cm diameter was inserted in order to control the ambient particle concentration and confine the air. The filter clamp is using aluminium connectors with diameters of 28 mm. The air particles that flowed inside the test rig without filter was measured for 1 minute at both inlet and outlet point near the filter clamp. The purpose is to obtain the consistency reading inside the test rig.

The non-coated filter sample was inserted in the aluminium clamp and the measurement is record for 1 minute at the inlet point and then repeated for 1 minute at the outlet point. The measurement readings of the experiment will record in Table 3.6 and Table 3.7. The measuring sessions will repeat using similar filters of sample 2 and sample 3. After it done, it will continues with other samples with varies eletrospinning collection time.

Table 3.6: Mass concentration measurement for inlet data.

Electrospinning Collection Time (mins)	Inlet (before filter) Mass Particle Concentration (ppm)			Average (ppm)
	Sample 1	Sample 2	Sample 3	
0				
2				
4				
6				
8				
10				

Table 3.7: Mass particle concentration measurement for outlet data.

Electrospinning Collection Time (mins)	Outlet (after filter) Mass Particle Concentration (ppm)			Average (ppm)
	Sample 1	Sample 2	Sample 3	
0				
2				
4				
6				
8				
10				

3.6 Scanning Electron Microscope (SEM)

The morphology of all the filter samples that been done by electrospinning will be analyse using SEM model. The function of SEM is to determine the sample morphology, the fibre diameter up to micro and nano scale and to trap particles by nanofiber in the filters.

3.6.1 SEM and Sputtering

In Figure 3.14 shows the SEM set up while the specifications in Table 3.6. The model that use for SEM is Hitachi Scanning Electron Microscope Model S-3400N. The testing of the samples was undertaken in a variable pressure SEM (Hitachi S-3400N) using backscatter electron detector at 16 kV. Magnifications of the sample are x9000. The working distance was 8mm.

Figure 3.14: Hitachi Scanning Electron Microscope Model set up (Source: Hitachi S-3400N)

Table 3.8: Specifications of Scanning Electron Microscope Model

Components	Specifications
Resolutions	• 3.0 nm (at 30 kV, SED Image in High Vacuum Mode) • 4.0 nm (at 30 kV, BSED Image in VP Mode)
Magnification	• x 5 to x 300, 000
Accelerating Voltage	• 0.3 to 30 kV
BSE Detector	• Detector with have super thin five- segment solid state
Gun Bias	• Variable voltage supply, Quad-Bias
Image Shift	• +/- 50 µm (W.D = 10 mm)
Power and Safety	• Start quickly • Security interlocks • Auto Transformer

Most of the samples testing were placed on adhesive carbon disc mounted onto aluminium SEM stubs. At another step, selected samples which are zero, two, four, six, eight and ten minutes used to compare the morphology of the fibres. These samples were begins when a substrate is placed in a vacuum chamber containing an inert gas which is usually Argon. Gas will bombard the target by high energy particles and sputters of the material where to deposit. Sputter coated by a platinum alloy to prevent accusing of the electron beam in regular SEM mode (Cartwright, 2012) and it gives the required properties of good electrical conductivity and complete flexibility from atmospheric erosion (Hood, 1976). This process will be carried out for 60 seconds. If this process is carried out in a long time, the substrate will get darker.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Particle Concentration

In this project, the measurements were taken at the same day. The measurement was carried out on afternoon due to get an ambient humidity and temperature. The filtration measurements were conducted in the laboratory with measured condition of temperature and the relative humidity 24.7°C and 65%. These results are being compared and analyzed to verify the capability of nanofibers in enhancing filtration effectiveness. So, all the results were be inserted in tables and tabulated graphically so that it can be analyze and discusses accordingly. The average ambient particle concentration is recorded at 0.060 mg/$m^3$and for better data presentation all of the readings were converted to 60 μg/m^3or 60 part per millions (ppm). The non-coated filters which are three sets of samples have been tested, followed by the rest of the samples with each sample readings will take for one minute time duration.

From the Table 4.1, the average mass particle concentration readings at the inlet were almost constant at 56 ppm indicating that the ambient condition was stable during experiment. At the outlet, the readings shows significant drop of average mass particle concentration from 55 ppm to 35 ppm.

Table 4.1: Measurement of average data in the afternoon.

Electrospinning Collection Time (mins)	Average Mass Particle Concentration (ppm)	
	Inlet	Outlet
0	57	55
2	57	45
4	55	42
6	56	41
8	56	38
10	55	35
Average	**56**	-

The particle concentration readings are in average condition. The average mass particles concentration readings at the inlet were 56 ppm, the readings were fluctuated and unstable throughout the session. This was due to traffic activities in the afternoon which affecting the amount of ambient air particle from exhaust emission. In addition, factor of temperature risen and the relative humidity dropped affected the particle concentration in the environment. Inlet readings were taken before the filter while the outlet readings were taken after the air flow pass through the filter sample on the test rig.

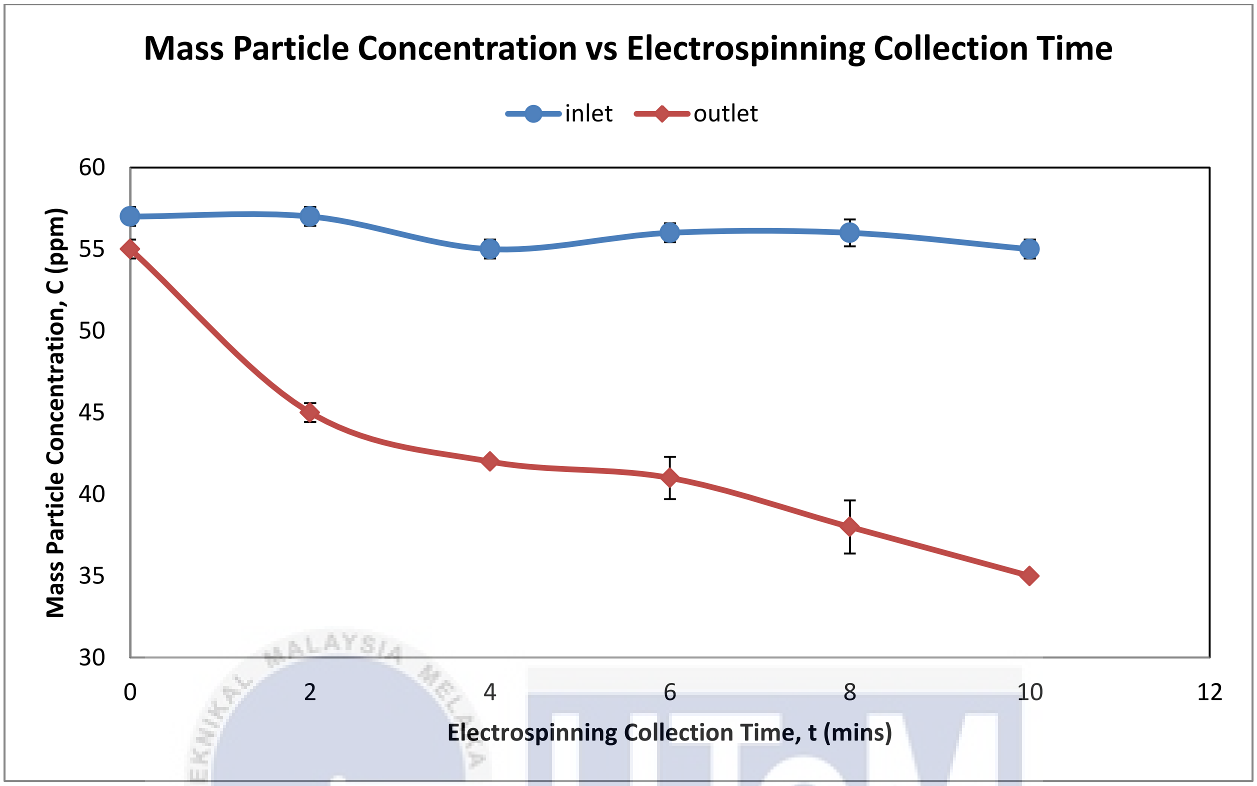


Figure 4.1: Measurement of mass particle concentration between inlet and outlet of the filters.

Figure 4.1 shows the mass particle concentration against electrospinning collection time. For non-coated filter (t=0), the measured mass particle concentration at inlet and outlet are at range around 60 ppm. For the t=2 till t=10 minutes measurements at the inlet shows a slight fluctuation outline in range of 55 ppm to 57 ppm. The reason of the measurements before filter is higher than after the filter could be because of huge pores size of the conventional filter fiber is not able to sifting submicron particle allowed into the filters contrasted with nanofiber filters. From electrospinning time (t=2 to t=10 minutes), the graph projected a dropped pattern of mass particle concentration at outlet as the lowest is 35 ppm. The thickness layer of the nanofiber is increased as the electrospinning collection time became longer. For the coated filters by electrospinning showed that the nanofiber coating able to captured fine air particle and reduced the concentration in the air streamline. The fiber distributed by electrospinning creates more obstacles to the travelling air particle and increased the possibility of the particle to stick with the nanofiber resulting clean air coming out from the filter.

4.2 Filtration Effectiveness

The filter performance is expressed in terms of filtration effectiveness percentage defined as the ratio of particle concentration difference between inlet and outlet to the particle concentration at inlet by multiple with 100. The effectiveness of the corresponding filter samples will calculate using Equation (4.1)(Ma, Shen, Shui, Li, & Zhou, 2016) for different electrospinning collection time as presented in Table 4.1.

$$\text{Filtration Effectiveness, } \eta = \left(1 - \frac{Outlet\ Concentration}{Inlet\ Concentration}\right) \text{ x } 100\ \% \qquad \text{Equation (4.1)}$$

In Table 4.2 shows the filtration effectiveness percentage of the three sets of filter samples. From the formula in Equation (4.1), the data can be inserted in the table. It shows that the longer the coating time, the higher the percentage of filtration effectiveness. As can see that, sample (t= 0 minute) has the lowest filtration effective with 2.35 % because of it is non-coated filter which is unable to filter the fine particles. From that, it can be say that this non-coated filter (conventional filter) is incapable of reducing fine particle across such asPM_{10}. In contrast, sample (t = 10 minutes) has the highest filtration effective averagely around 36 %.

Table 4.2: Data for each set of filtration effectiveness percentage

Electrospinning Collection Time, t (mins)	Filtration Effectiveness, %			
	Set 1	Set 2	Set 3	Average
0	1.754	1.786	3.509	2.350
2	21.053	19.643	22.807	21.168
4	23.636	22.222	23.636	23.156
6	25.455	28.671	21.818	25.281
8	27.273	36.842	32.143	32.086
10	36.364	36.364	35.185	35.971

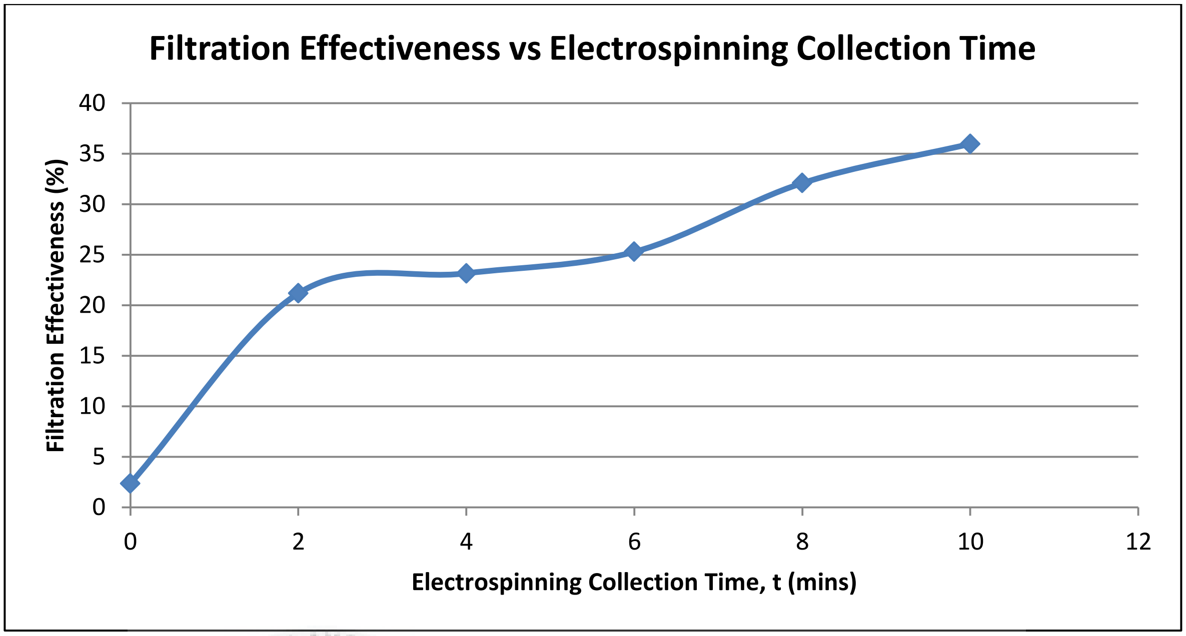


Figure 4.2: The average filtration effectiveness percentage.

This graph in Figure 4.2 represented filtration effectiveness against electrospinning collection time. Generally, increasing electrospinning collection time will increase the effectiveness of the filters capturing fine particles. For uncoated filter (t=0 minute) have a smallest value of effectiveness which is 2.3%. What is interesting when t=2 minutes, it show a risen trend from uncoated filter which up to 21 %. From t=2 minutes till t=10 minutes shows a linear outline but for t=4 minutes and t=6 minutes are slightly increased. There are several reasons due to the case happened:

i. Instability of ambient condition through temperature and humidity.
ii. Nanofiber mats torn finely which grew more pores size.
iii. Insufficient sample for measurement which can't get an good average.

As the electrospinning collection time become longer, the thickness of nanofiber mats increased. The filter will be more effective in capturing particle but at the same time also built up pressure drop in the streamline. For any filtration, the impact of pressure drop must be kept as least as possible for good permeability of air across filter. If pressure drop increased, the less air flow means less particle or dust to be sifted over the filters.

4.3 Statistics Data Analysis

The measurement readings were also analyzed statically using standard deviation and error bars to minimize the discrepancies of the data.

4.3.1 Standard Deviation

Based on the Table 4.3 and Table 4.4, the standard deviation for 1 minute coating of inlet and outlet were calculated and tabulated. In the standard deviation, when the deviations of particle concentrations measurement were averaged, for readings with higher precision, the result would be zero because of high and low values data that would cancel each other. So, the standard deviation for 4 and 10 minutes coating in Table 4.4 gave zero readings which determine better precision. This happened since the filter sets of 4 and 10 minutes have coincidently have same particle concentration value. In order to improve readings, the number of readings must be increase. As sample size increases, the standard deviation become smaller and confidence interval become narrower. This will reduce variability, so that the results become more precise and reduce standard error.

Table 4.3: Data of standard deviation for average measurement at inlet

Electrospinning Collection Time (mins)	Inlet (before filter) Mass Particle Concentration (ppm)			Standard Deviation	Average (ppm)
	Sample 1	Sample 2	Sample 3		
0	57	56	57	0.5774	57
2	57	56	57	0.5774	57
4	55	54	55	0.5774	55
6	55	56	55	0.5774	56
8	55	57	56	0.8165	55
10	55	55	54	0.5774	55

Table 4.4: Data of standard deviation for average measurement at outlet

Electrospinning Collection Time (mins)	Outlet (after filter) Mass Particle Concentration (ppm)			Standard Deviation	Average (ppm)
	Sample 1	Sample 2	Sample 3		
0	56	55	55	0.5774	55
2	45	45	44	0.5774	45
4	42	42	42	0.0000	42
6	41	40	43	1.2910	41
8	40	36	38	1.6330	38
10	35	35	35	0.0000	35

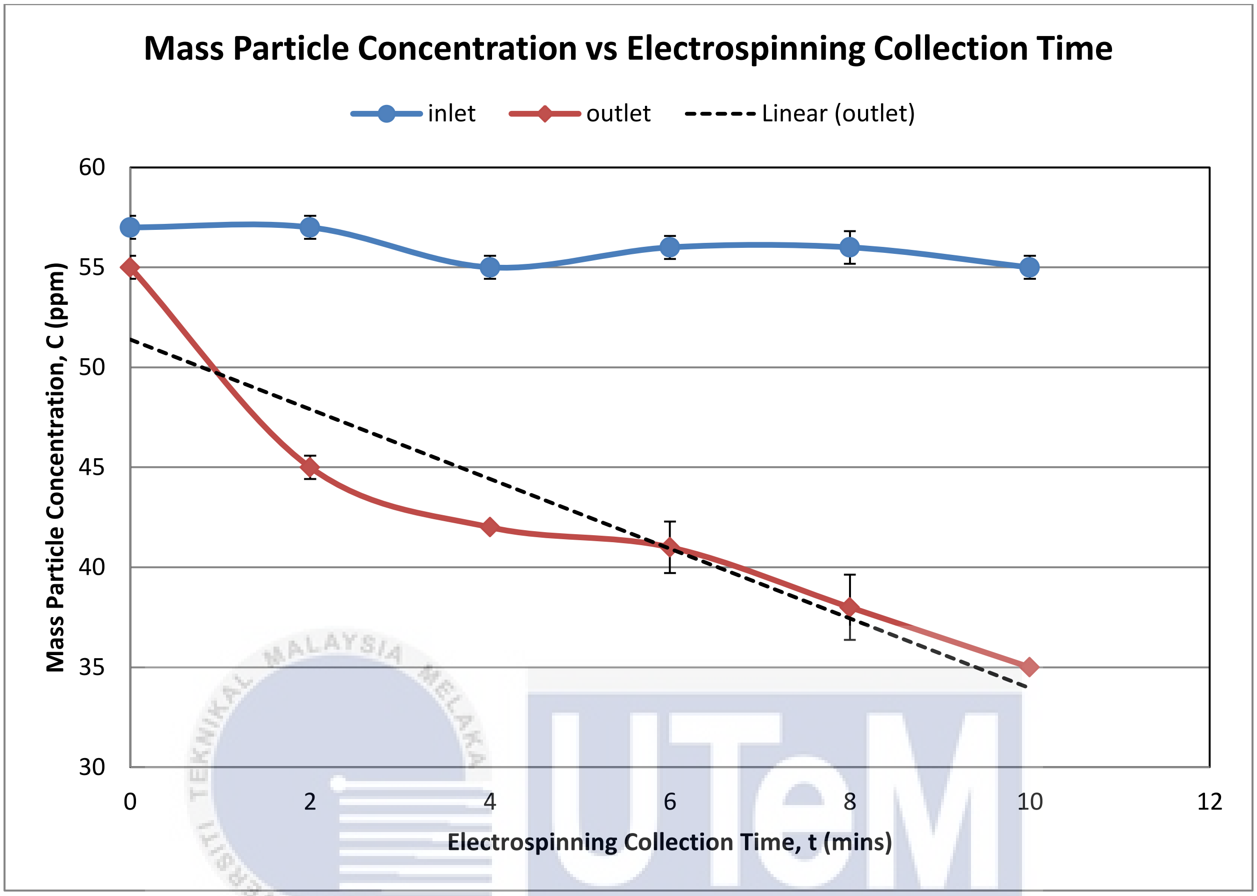


Figure 4.3: Error bars at outlet

The error bars on the graphs correspond to the standard deviation error of the average data collected before and after the filter. The error bars are the lines relating to the size of the error on either side of the data point. Though a plot of the data points in their raw form will not generally lie on a straight line, after all the data can usually be made to fit a straight line by linear regression to form a linear equation. The data points between electrospinning time collection and mass particle concentration forming a decreasing straight line. So, the increase of the nanofiber electrospinning collection time influences the particle concentration in sense that the filtration able to eliminate fine particles.

4.4 SEM Morphology

Scanning Electron Microscope (SEM) was used to examine the nanofiber morphology of the samples. ImageJ analysis was conducted on the SEM images to determine the nanofiber diameter.

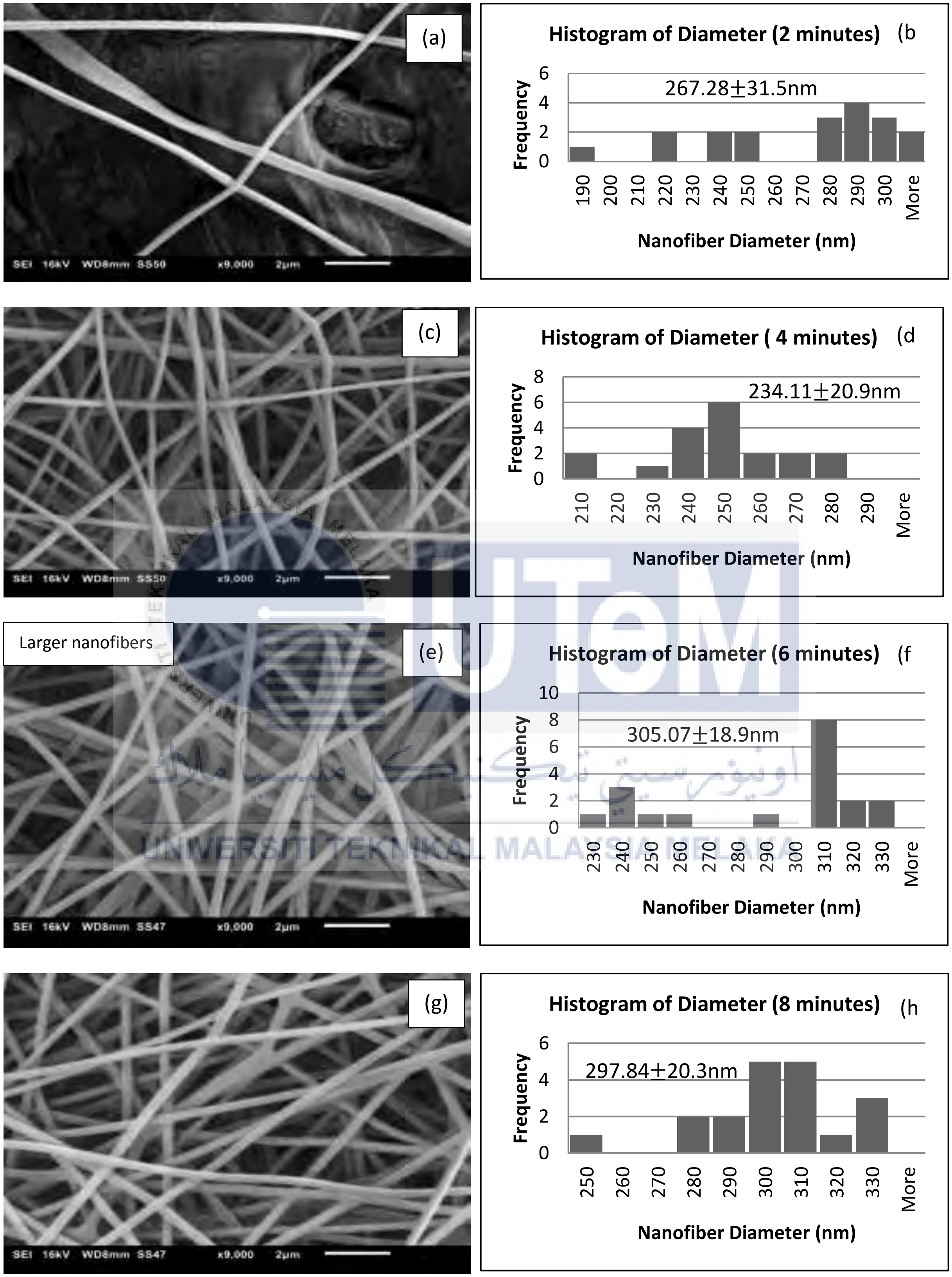
4.4.1 Nanofiber Diameter

Nanofiber diameter distributions of the SEM images for 2 minutes, 4 minutes, 6 minutes, 8 minutes and 10 minutes were obtained respectively. It was done manually by measuring the nanofiber diameter using ImageJ software as shown in Figure 4.4 (a), (c), (e), (g) and (i). The average nanofiber diameter was measured and tabulated in Table 4.5. Range of average for nanofiber diameters using Equation (4.2) was shown below.

Range, R $= X_{max} - X_{min}$ Equation (4.2)

Table 4.5:The measurement of average nanofiber diameter of coated filters.

Items	2 minutes	4 minutes	6 minutes	8 minutes	10 minutes
No. of measurement, N	10	10	10	10	10
Minimum diameter, X_{min}	213.43 nm	208.80 nm	260.18 nm	245.68 nm	234.90 nm
Maximum diameter, X_{max}	320.15 nm	264.56 nm	329.27 nm	329.62 nm	300.84 nm
Standard Deviation	31.46	20.88	18.87	20.26	56.53
Average Value, X_{avg}	267.28 nm	234.11 nm	305.07 nm	297.84 nm	209.07 nm
Range, R	106.72 nm	55.76 nm	69.09 nm	83.94 nm	65.94 nm
Average Nanofiber Diameters	**267.28±31.5 nm**	**234.11±20.9 nm**	**305.07±18.9 nm**	**297.84±20.3 nm**	**209.07±56.5 nm**


(a)
SEI 16kV WD8mm SS50 x9,000 2µm
Histogram of Diameter (2 minutes) (b
267.28±31.5nm
Frequency
6
4
2
0
190 200 210 220 230 240 250 260 270 280 290 300 More
Nanofiber Diameter (nm)
(c)
SEI 16kV WD8mm SS50 x9,000 2µm
Histogram of Diameter (4 minutes) (d
234.11±20.9nm
Frequency
8
6
4
2
0
210 220 230 240 250 260 270 280 290 More
Nanofiber Diameter (nm)
Larger nanofibers
(e)
SEI 16kV WD8mm SS47 x9,000 2µm
Histogram of Diameter (6 minutes) (f
305.07±18.9nm
Frequency
10
8
6
4
2
0
230 240 250 260 270 280 290 300 310 320 330 More
Nanofiber Diameter (nm)
(g)
SEI 16kV WD8mm SS47 x9,000 2µm
Histogram of Diameter (8 minutes) (h
297.84±20.3nm
Frequency
6
4
2
0
250 260 270 280 290 300 310 320 330 More
Nanofiber Diameter (nm)

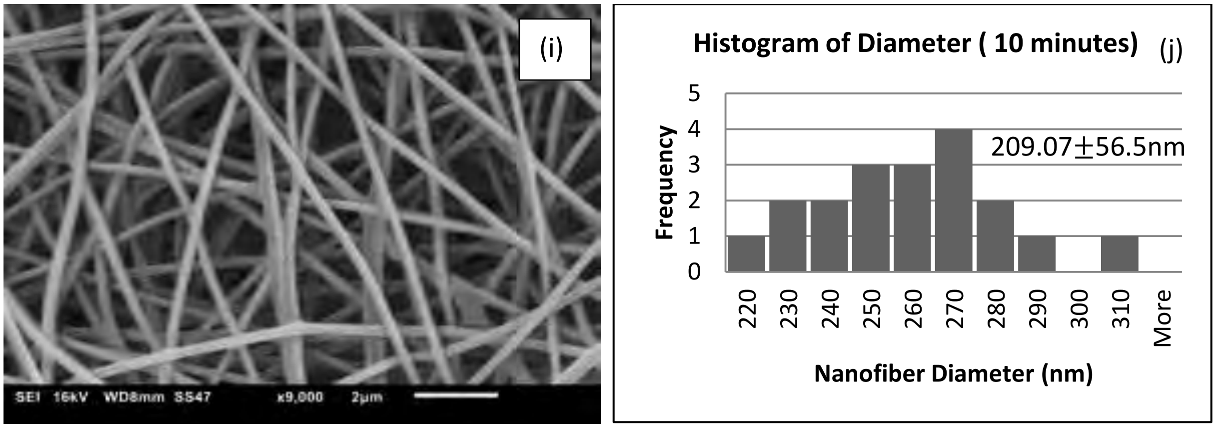


Figure 4.4: SEM image at 9,000x which the nanofiber diameters were manually measured using ImageJ software (a), (c), (e), (g), (i) and its nanofiber diameters distributions (b), (d), (f), (h), (j) for electrospinning collection time of 2 minutes, 4 minutes, 6 minutes, 8 minutes and 10 minutes respectively.

The histogram in Figure 4.4 (b), (d), (f), (h) and (j) shows the distribution of fiber diameters using data in imageJ software. The average diameters in the range 200 – 310 nm indicate that the electrospinning process capable in producing fibers in nano range. From the Figure 4.4 (b), it can be seen that the significant distribution of the nanofiber diameter is at 280 nm to 300 nm region. The average nanofiber diameter is recorded 267.28 ± 31.5 nm. While from the Figure 4.4 (d), it can be seen that the significant distribution of the nanofiber diameter is at the 240 nm to 250 nm region. By the average nanofiber diameter is recorded 234.11 ± 20.9 nm. Then, Figure 4.4 (f), the significant distribution of the nanofiber diameter is at the 310 nm region. The average nanofiber diameter is recorded about 305.07 ± 18.9 nm. Other than that, in Figure 4.4 (h) shows the significant distribution of the nanofiber diameter is at 300 nm to 310 nm region. By the average nanofiber diameter measurement is recorded 297.84 ± 20.3 nm. In Figure 4.4 (j), the significant distribution of the nanofiber diameter is at 250 nm tot 270 nm region. The average nanofiber diameter is recorded 209.07 ± 56.3 nm. The standard deviation being low, indicate high reproducibility of results. Results in Figure 4.4 (f) show higher nanofiber diameter compared to other cause to the existence of several bigger nanofibers.

The difference of uncoated filter and coated filter is the uncoated only has substrates as shown Figure 4.5 while the coated filter have through the electrospinning process which have to increase the effectiveness filtration. There are so many big pores of the uncoated filter compared to coated filters. The fine particles which PM_{10} are able to flow through the substrates and it will affect the health of wearer. In Figure 4.6, it is shown the structure of nanofiber mat of the viscous substrate due to small and the porosity is bigger while for the collection increase a thick nanofiber layer is formed(Faccini, Vaquero, & Amantia, 2012). For this project, morphology of PVA for 2 minutes till 10 minutes can't achieve as Figure 4.6 due to a lacking technique for looking a right morphology.

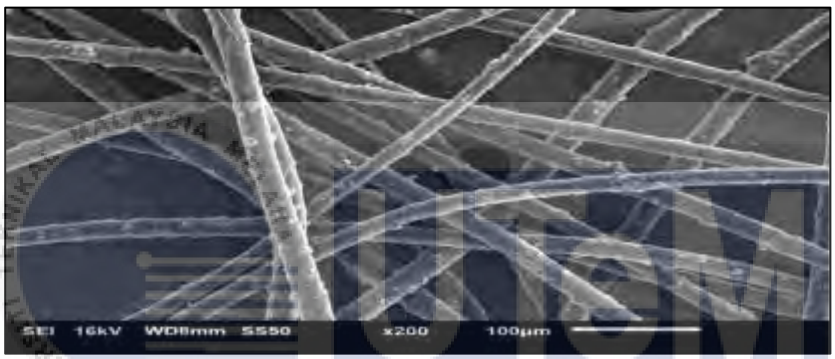


Figure 4.5: Uncoated filter with a 200x magnification.

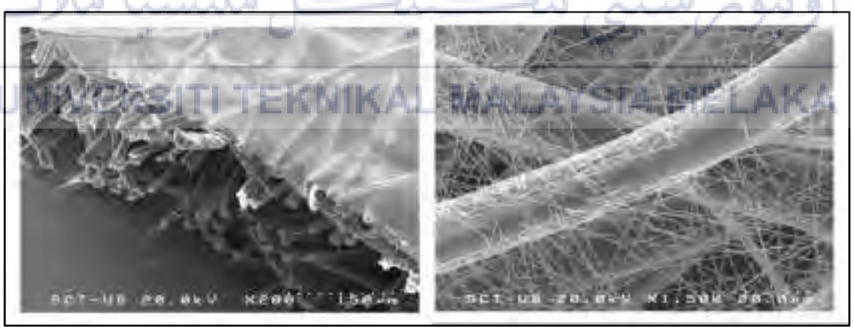


Figure 4.6: SEM images of electrospun membranes thermally bonded onto viscose non-woven (Faccini et al., 2012).

4.4.2 Trapped Particle

In this project, a filters ability to capture particles depends on the particle size passing through its fibers. The filter with longer collection time has bigger thickness of the web and with it consists of many numbers of layers which increase its effectiveness and probability in capturing fine particles. Smaller the pore size of the nanofiber filters is effective in capturing fine particle in air stream. Furthermore, nanofiber filter do provide larger surface of area to volume ratio compare to conventional filter. The fine works of nanofiber layer on top of the microfiber media fundamentally increase the filtration execution in blocking size of airborne particulate. The conventional filters normally are ineffective in sifting sub-micron particulates and can easily become loaded with aggregated coarse particles that restrict air flow. By referring to Figure 4.7 with a large magnification, it can be seen many open spaces or pores. For a better capturing fine particulate, the pores must be smaller.

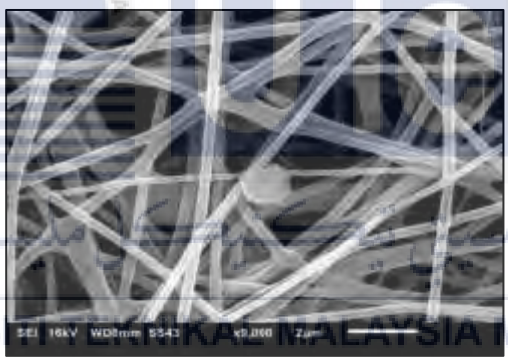


Figure 4.7: Trapped particle for SEM images at 9,000x magnification for electrospinning collection time of 4 minutes respectively.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The purposes of this project to develop high efficient nanofiber-coated face mask filter through electrospinning process and to understand the relationship between the amounts of nanofibers and filter efficiency. Firstly, electrospinning technique was used to produce polyvinyl alcohol nanofibers that have been coated onto medical face mask filter. The process was conducted for each filter concerning electrospinning collection time from 2 minutes till 10 minutes. Then, filtration performance of the filters was tested using a fabricated filtration test rig. From electrospinning time (t=2 to t=10 minutes), it was found that the mass particle concentrations recorded a declined trend graph at outlet measurements as the lowest is averagely 35 ppm. The experimental tests revealed that the uncoated filter or conventional filter at (t=0 minute) unable to filter the fine particles. This recommends that conventional filter is incapable of reducing fine particle across such as PM_{10}. Increasing the electrospinning collection time till 10 minutes of polyvinyl alcohol nanofibers onto face mask filter produced the highest filtration effectiveness averagely 36 % compared to conventional filter which is 2.4 %. This indicated that nanofibers are an excellent filter media to capture particle especially the submicron particles.

The SEM micrographs showed that the average diameter of polyvinyl alcohol fibers were from 209 nm to 305 nm (t=2 till t=10 minutes). The ability of the nanofibers to trap particle can be seen for the filter with 10 minutes coated time which has the ability to capture a variety of small particles. Increasing the electrospinning collection time, produced thicker layer of nanofibers web, decrease the filter media porosity, increase the rate of fine particle stranded on the fiber and offer better capture effectiveness of particle on face mask.

As a conclusion, results from this study show that the application of nanofibers as filter media can additionally upgrade the performance of conventional filter especially in sifting submicron particulates such as the PM_{10} particles. Subsequently, the method of coating nanofiber onto conventional filter is proposed to manufacture nanofiber filter.

5.2 Recommendations

In this study, certain parameters such as pressure drop, airflow rate, permeability factors, etc. were neglected because of absence of proper measurement and techniques. These outcomes the methodologies and procedures received are not standardized. This has constrained the validation of the procedures and has made it hard to analyze results. However, this study can be further improved as follows:

I. The measurement of pressure drop using pressure manometer device can be inserted to study the effect of pressure drop towards the mass particle concentration during filtration.

II. The polymer solution (PVA) can be mix with additional color during the electrospinning process, so a uniform distribution of coating can be identify and control.

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