Faculty of Mechanical Engineering

DEVELOPMENT OF NANOFIBER-COATED CABIN AIR FILTER FOR ENHANCING FILTRATION PERFORMANCE

Ahmad Shahizam Bin Abd Rahim

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DEVELOPMENT OF NANOFIBER-COATED CABIN AIR FILTER FOR ENHANCING FILTRATION PERFORMANCE

AHMAD SHAHIZAM BIN ABD RAHIM

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DECLARATION

lare that this report entitled "Development of Nanofiber-Coated Cabin Air Filt
ıcing Filtration Performance" is the results of my own research except as cited
:nces. The report has not been accepted for any degree and is not concur
itted in candidature of any other degree.

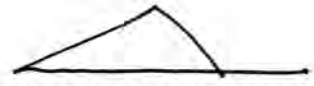
Signature : .....

Name : Ahmad Shahizam bin Abd. Rahim

Date : 22/11/2016

APPROVAL

:by declare that I have read this report and in my opinion this report is suffici
of scope and quality as a partial fulfillment of Master of Mechanical Engin
motive).

Signature : 

Supervisor Name : Dr. Nurfaizey bin Abdul Hamid

Date : 24/11/2016

DEDICATION

I dedicate this thesis to my beloved wife *Rafidah binti Mohamad Zaham*

My sons and daughters,

Ahmad Azfar Sufi, Ahmad Azhar Yusof, Afifah Zahidah and Aina Maisarah

My father and mother,

Haji Abd Rahim bin Yeop Said and *Hajjah Zaleha binti Abdullah*

My siblings,

Ahmad Shahrunizar, Ahmad Shahril Azwan, Ahmad Shazri, Ahmad Shukri,

Ahmad Zharif and Amira

For your endless love, support and encouragement

You have successfully made me the person I am becoming.

ABSTRACT

ıdays, the quality of vehicle's cabin air has become one of the health concerns a
ımers. Typical air filters used in an air conditioning system of a vehicle are ma
ıfiber materials such as fiberglass and polymeric materials. Nanofibers have a
tial to be used as high efficient filter materials due to their nanoscale diameters.
facturers claim that filters made of nanofibers can trap dusts or particles with
% efficiency. However, there is limited information available on the effectiven
ospun nanofiber filter media in filtering submicron particulates. Therefore, this
ned at developing and studying the performance of nanofiber-coated filte
ng submicron particles. The filters were incorporated with electrospun ny
ibers at 10kV of applied voltage and 10 cm spinning distance. The coated filters
ıced at varying collection times ranging from 1 to 10 minutes. The filter samples
using a dedicated test rig to simulate an actual air conditioning system. Parti
r (PM) measurement technique was used in measuring air particle concent
n^3) across the filter. The morphology of the nanofiber coated filters was ana
on Scanning Electron Microscope (SEM) micrographs. It was observed th
ospun nanofibers have diameters ranging from 104 nm to 117 nm. The nanc
d filters showed a significant improvement of around 33% in efficiency whe
ospinning collection time was 10 minutes compared to control samples. The
evealed that a longer electrospinning collection time produced a thicker lay
ibers producing filters with higher filtration efficiency for capturing fine parti
rs.

ABSTRAK

masa kini, kualiti udara kabin kenderaan telah menjadi salah satu kebimb
ıtan di kalangan pengguna. Penapis udara biasa digunakan dalam sistem peng
ı kenderaan yang diperbuat dari bahan mikrofiber seperti gentian kaca dan b
ı polimer. Serat nano mempunyai potensi yang besar untuk digunakan sebagai l
ıis bercekapan tinggi kerana ia mempunyai diameter berskala nano. Peng
ıis mendakwa bahawa penapis diperbuat daripada serat nano boleh memera
: atau zarah dengan kecekapan sehingga 99.99%. Walau bagaimanapun, mak
sedia ada amat terhad mengenai keberkesanan media penapis semburan serat
ı menapis zarah submikron. Oleh itu, kajian ini bertujuan untuk membangunka
kaji prestasi penapis bersalut serat nano untuk menapis zarah submikron. Pe
disembur dengan larutan nylon 6 pada bekalan voltan 10kV dan jarak sem
10 cm. Penapis bersalut tersebut dihasilkan berdasarkan masa k
ospinning antara 1 hingga 10 minit. Sampel penapis telah diuji menggu
tar ujian khusus untuk mensimulasikan sistem pengudaraan kabin. 1
ıkuran Particulate Matter (PM) telah digunakan bagi mengukur kepekatan
ı (mg/m^3) yang melalui penapis. Morfologi penapis bersalut serat nano dia
gunakan mikrograf Mikroskop Imbasan Elektron (SEM). Adalah diperh
va penapis serat nano mempunyai diameter di antara 104 nm hingga 11
ıis bersalut serat nano menunjukkan peningkatan kecekapan yang ketara
yak 33% apabila masa koleksi electrospinning adalah 10 minit berbanding s
'an. Kajian ini juga mendedahkan bahawa masa koleksi electrospinning yang
menghasilkan lapisan serat nano yang tebal menjadikan penapis memp
apan penapisan yang lebih tinggi untuk memerangkap zarah halus.

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LIST OF ABBREVIATIONS

EDS	-	Energy Dispersive Spectroscopy
HEPA	-	High Efficiency Particulate Arrestance
HVAC	-	Heating Ventilation Air Conditioning
LAS	-	Laser Aerosol Spectrometer
MPP	-	Most Penetrating Particle
NIH	-	National Institutes of Health
OPC	-	Optical Particle Counters
PE	-	Polyethylene
PM	-	Particulate Matter
ppm	-	parts per million
PVC	-	Polyvinyl Chloride
QCM	-	Quartz Crystal Microbalance
SEM	-	Scanning Electron Microscope
TEOM	-	Tapered Element Oscillation Microbalance
UFP	-	Ultra Fine Particle
USB	-	Universal Serial Bus

LIST OF SYMBOLS

Au	-	Gold
PM_{10}	-	Particulate Matter 10 μm
$PM_{2.5}$	-	Particulate Matter 2.5 μm
$PM_{0.1}$	-	Particulate Matter 0.1 μm
R	-	Range
ΔX	-	Uncertainty in measurement
ΔX_{avg}	-	Uncertainty in average
X_{max}	-	Data value maximum
X_{min}	-	Data value minimum

CHAPTER 1

INTRODUCTION

1.1 Project Background

The need for air cleaning and better air filter media are becoming a huge concern nowadays due to air pollution. This includes providing cleaner air for equipment, component, personal protection aid for respirations, interior comfort environment such as vehicle cabin and building. The main function of an air filter is to collect dust, dirt and contaminants. It prevents air contaminants from reaching the equipment that can lead to higher maintenance cost as well as preventing eliminate unpleasant smells, harmful particles and dangerous gas pollutants to human.

The demand for better filter media has created new challenges towards producing high performance filters. Conventionally, filter medias are made of micro-sized cellulose, cellulose / synthetic, spunbond, or melt blown fibers. However, recent development in nanotechnology has opened up new opportunities to take advantage of nano-sized fibers for its smaller interfiber spaces or pores, offers better capability to capture more submicron particles, having high dust holding capacity, promoting lower restriction and prolong the filter life.

A cabin air filter is a vital part of a vehicle's passenger compartment heating, ventilation and air conditioning systems. The filter task is to filter out the impurities and pollutants that flow in from the ambient surrounding. As a result, high air quality, better breathable atmosphere in the cabin and apparently protecting air conditioning system components from dust.

Particulate Matter or PM is a term use to describe the combination between fine liquid and solid particles available in the environment. Certain particles can be originated straightly from a particular source and others through complex chemical reactions in the atmosphere. The particles with size less than or equal to 10 micrometers is known as PM_{10}. It has the capability to travel into the deepest parts of the lung when being inhaled. This can possibly lead to serious health problem involving respiratory system. Generally, PM_{10} is a main element of air pollution which negatively affecting both our health and our environment.

Previous studies showed that the PM conc entrations in vehicle's cabin can be higher compared to other outdoor or indoor micro-environments (Geiss O. et al, 2009) and surpassed the outdoor concentration numbers by three to five times (Praml G. and Schierl R., 2000). Although initially a filter can perform its function effectively, one must not ignored the fact that as time goes by, the filter media becomes saturated with dust and particles, resulting in restricted and blockage airflow. It even worsens the situations if the passengers tend to keep the windows rolled up, consequently increasing the particle concentration, trapping further harmful fumes and particles inside the cabin. This can be a health issue concern when it affects our respiratory system especially for those who spend many hours of their time driving to work and other destinations (Lyons G. et al, 2008). Therefore, it is significance to conduct a preliminary study on the effectiveness of nanofiber integrated cabin air filter for reducing air particles.

In this study, nylon nanofibers electrospun are produced from nylon 6 in formic acid solution using electrospinning technique. Test filter medias are modified from commercially-available cabin air filter (cellulose type). Nylon nanofibers are directly being electrospun to one of the filter's surfaces. The coated filters are fabricated into several samples and classified according to their electrospinning collection time. The filters are tested at room temperature using a dedicated test jig. The amount of the air particle mass concentration across of each filter is measured using a dust monitor device.

1.2 Problem Statement

The common air filters were normally produced from material such as fiberglass and polymeric compositions such as micro-sized cellulose, cellulose / synthetic, spunbond, or melt blown fibers. It has the ability to traps airborne dust, the largest soot, and other air particles. Filters with small pore sizes are good in filtering submicron particles. Nanofibers are potentially suitable to be used as filter media or coating due to their fine diameters of several hundred of nanometers providing enormous surface area per unit mass, higher porosities and distinctive nanometers scale structures. It also offers a higher permeability to air filtration over conventional materials.

However, there is limited information available on the effectiveness of electrospun nanofiber filter media in filtering submicron particulates PM_{10}. A preliminary study need to be carried out to investigate the filtration performance of nanofiber filter medias coating on conventional filter. Consequently, by comparing the findings from of the nanofiber-coated filter with conventional filter will enable us to determine whether the coating idea is effective in promoting better reduction of submicron particles concentration of PM_{10} particles in air filtration applications.

1.3 Objectives

Based on the problem statements mentioned above, the present study is to achieve the following objective:

a. To develop nanofiber-coated cabin air filter through nanofiber depositions based on electrospinning collection time in electrospinning process.

b. To determine the performance of nylon 6 nanofiber-coated cabin air filters effectiveness in trapping PM_{10} particles during filtration process by means of PM measurement method.

1.4 Scope of Work

In order to achieve the above mentioned objectives, the subsequent scopes of study have been emphasized are as follows:

a. Fabricate a filtration test rig to allow airflow travel through the filters.

b. Fabricate nanofiber-coated cabin air filter by nanofiber depositions based on electrospinning time collection which the filter originated from the commercial cabin air filter available in the market.

c. Conduct the performance test of the filter using the filtration test rig to measure the filtered particle mass concentration using dust monitor with PM_{10} filter element.

d. Characterize the filters sample using Scanning Electron Microscope (SEM) imaging and ImageJ software to evaluate the sample's morphology.

1.5 Significance of Study

The significances of this research will be based on the followings as to fulfil the objectives mentioned earlier:

a. The development of high efficient filters by integrated nanofiber mats into commercially-available cabin air filter from electrospinning process.

b. The results should support further studies and open up new opportunities in application of other nanofiber material for air filters which enhance air filter performance and its efficiency.

1.6 Overview of Report

This report is structured into 5 chapters accordingly; Chapter 1 discusses the introduction of the report. Project background, problem statements, objectives, project scope and significance are explained in this chapter. Chapter 2 reviews the relevant literatures and findings of the previous works regarding in particular the application of nanofiber in air filtration applications and the techniques to measure the filtration effectiveness. Methodology of fabricating the coated filter and its performance evaluation are shown and demonstrated in Chapter 3. In addition, the coated filter samples are also being evaluated in term of its morphology using Scanning Electron Microscope (SEM) imaging. Chapter 4 discusses the data obtained from the experiment and analyses being made to justify the findings. Lastly, the conclusion and further recommendations for future works are discussed in Chapter 5 as to improve the outcomes of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 The Need of Air Filter

Nowadays, the global awareness in reducing pollution has risen significantly. People across the world demands better solution in controlling the Particulate Matter (PM) pollution generated in the environment. The misconception of air quality in vehicle's cabin is always clean by most people were disputably by Wallace L. and Ott W. (2011) suggested that when involving a confined space usually indoor environment sources are greater than outdoor sources. Since particle concentration in vehicle's cabin can be three to five times higher compared to outside environment, a new type of filter in bringing down these figures is required. In fact, recent studies by Xu B. et a1. (2015), Lee and Zhu (2014) tend towards researching better interior air filtration mechanism to cope out even with the Ultrafine Particles (UFPs) concentrations. The need of superior performance of cabin air filter will filtering the exterior air entering the passenger compartment which certainly provide better interior air quality, breathable atmosphere by controlling particle concentration in cabin and protect air conditioning system components from dust. The discomforts experienced by passengers are due to unpleasant smells, harmful particles and dangerous gas pollutants are the major area of concern when involving PM pollutants according to the main categorization of fine particle sizes for 10 μm and 2.5 μm (Chong L. et al., 2015). The application of ultrafine filter media particularly the nanofiber in cabin air filter is widely being used in automobile filter industry in achieving better interior air quality and comfort in vehicle cabin (Timothy H.G. et al., 2003).

2.1.1 Particle Classification

The physical attributes of airborne particulates consist of mass concentration and size distribution. Ambient levels of mass concentration are measured in micrograms per cubic meter ($\mu g/m^3$). The particulate matter is classified on the basis of their size. The size attributes are usually measured as aerodynamic diameter of the dust particulates in terms of microns.

The airborne particle frequently distinguished into three categorizations as coarse, fine and ultrafine particles. The coarse particles PM_{10} which easily resolve are between 10 μm and 2.5 μm diameter whereas fine particles $PM_{2.5}$ will be between 0.1 μm to 2.5 μm in diameter. The ultrafine is the one with smaller than 0.1 μm in diameter particles (Peters J. et al., 2012). The particles most expected to cause adverse health effects are the fine particulates PM_{10} and $PM_{2.5}$. This particular size particle raised major concerns due to its virtue of their size, they can be easily inhaled and travel deep into the human lung particularly the pulmonary alveolus causing breathing problem (Simone S.A et al., 2015). For further understanding of the particle sizes, Figure 2.1 represent the comparison of PM_{10} and $PM_{2.5}$ particles between human hair and beach sand, and Table 2.1 indicates the listing of common indoor contaminants.

In addition, particles generated during the combustion process are classified as primary particles normally are directly emitted into the atmosphere. This primary particles consists of fine particles, with diameter less than 2.5 μm ($PM_{2.5}$) and the ultrafine particles, with diameters smaller than 0.1 μm ($PM_{0.1}$) indicated by Simone S.A. et al. (2015) as cited in Obaidullah et al. (2012), Wilson et al. (2002), Wark et al. (1998), and Vincent (2007). On the contrary, the secondary particles which are classified as coarse particles, have diameters greater than 2.5 μm or particulate matter smaller than 10 μm in diameter (PM_{10}) is created by mechanical or chemical reactions in the atmosphere.