Faculty of Mechanical Engineering

FUNCTIONAL ELECTROSPUN NANOFIBRES FOR HEAT DISSIPATION APPLICATIONS

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Master of Mechanical Engineering (Energy Engineering)

2021

FUNCTIONAL ELECTROSPUN NANOFIBRES FOR HEAT DISSIPATION APPLICATIONS

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A thesis submitted in fulfillment of the requirement for the degree of Master of Mechanical Engineering (Energy Engineering)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this report entitled "Functional Electrospun Nanofibres for Heat Dissipation Applications" is the result of my own work except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

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Date : 31 AUGUST 2021

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of the scope and quality as a partial fulfillment of Master of Mechanical Engineering (Energy Engineering)

Signature : ……………………………………………………

Supervisor's Name : Nurfaizey Bin Abdul Hamid

Date : 31 August 2021

DEDICATION

I would like to dedicate this project to my esteemed parents Mr. Sharif bin Othman and Mrs. Jamaliah Binti Long, my sagacious and unwavering supervisors Dr. Nurfaizey bin Abdul Hamid and Dr. Mohd Zaid bin Akop, passionate family members, lecturers, faculty members, and friends who gave me never-ending support, love, encouragement, ideas and pray of day and night throughout this Master Project.

ABSTRACT

With the rapid growth in electronic power density, effective heat dissipation has been the primary issue to be addressed in the continuous development of industrial electronics, which aims to minimize size while increasing performance. This has resulted in experts working hard to create innovative and effective ways to deal with the problem of heat dissipation at high temperatures, in order to improve the heat transfer rate between hot surfaces and the environment by increasing the heat transfer coefficients or expanding the heat transfer area. Nanofiber was discovered to be one of the potential alternative materials that could serve the purpose in heat dissipation application due to its large Surface Area to Volume Ratio (SAVR). Most of the time, the nanofiber is fabricated by means of bicomponent extrusion, phase separation, template synthesis, drawing, melt blowing, centrifugal spinning, and electrospinning. As for this study, electrospinning is utilized by using Polyacrylonitrile-Dimethylformamide (PAN-DMF) solution to produce PAN nanofibers. Two samples were prepared with different tip-to-collector distances; Sample I = 10cm and Sample II = 20cm, to establish the minimum and maximum size of PAN nanofibers that could be produced under the limitation imposed by the currently available electrospinning machine in the Advanced Materials Characterization Laboratory (AMCHAL) in UTeM, Melaka. Both of the samples were characterized on their respective morphology and fiber diameter to be used as a reference in Computational Fluid Dynamics (CFD) simulation in ANSYS Fluent. The simulations of the fibers were conducted as steady-state thermal analysis with the Turbulence Model of Realizable k-epsilon with enhanced wall treatment. The morphology of the fiber resembles a somewhat smooth cylindrical solid with a continuous, and randomly oriented pattern while the diameter of the fiber produced was 1.24μm and 717nm, respectively. From the simulation, the total Heat Flux dissipated with regard to SAVR constant volume were 104.35992×10^3 W for Nanofiber Model and 104.35989 W for Microfiber Model. Due to the value of SAVR in nanofiber was discovered to be inversely related to the diameter of the nanofiber, nanofiber with smaller diameter will dissipate heat better than nanofiber with greater diameter, particularly when heat dissipation is required in very tiny areas.

NANOFIBER ELEKTROSPUN BERFUNGSI UNTUK APLIKASI PEMBUANGAN HABA

ABSTRAK

Dengan pertumbuhan pesat dalam ketumpatan kuasa elektronik, pelesapan haba yang berkesan telah menjadi masalah utama yang harus ditangani dalam pengembangan industri elektronik yang berterusan, yang bertujuan untuk meminimumkan dimensi sambil meningkatkan prestasi. Ini telah menyebabkan para pakar bertungkus lumus untuk menghasilkan kaedah yang inovatif dan berkesan untuk menangani masalah pelesapan haba pada suhu tinggi, untuk meningkatkan kadar pemindahan haba antara permukaan panas dan persekitaran dengan meningkatkan pekali pemindahan haba atau memperluas kawasan pemindahan haba. Nanofiber didapati sebagai salah satu bahan alternatif yang berpotensi untuk memenuhi tujuan dalam aplikasi pelesapan haba kerana Nisbah Kawasan Permukaan kepada Isipadu yang besar (SAVR). Selalunya, nanofiber dibuat dengan cara penyemperitan bicomponen, pemisahan fasa, sintesis templat, lukisan, tiupan lebur, pemintalan sentrifugal, dan elektrospinning. Bagi kajian ini, elektrospinning digunakan dengan menggunakan larutan Polyacrylonitrile-Dimethylformamide (PAN-DMF) untuk menghasilkan nanofiber PAN. Dua sampel disediakan dengan jarak tip-ke-pengumpul yang berbeza; Sampel I = 10cm dan Sampel II = 20cm, untuk menentukan ukuran minimum dan maksimum nanofiber PAN yang dapat dihasilkan di bawah batasan yang dikenakan oleh mesin elektrospinning yand sedia ada di Makmal Pencirian Bahan Lanjutan (AMCHAL) di UteM, Melaka. Kedua-dua sampel tersebut dicirikan pada morfologi dan diameter serat masing-masing untuk digunakan sebagai rujukan dalam simulasi Pengiraan Dinamik Bendalir (CFD) dalam ANSYS Fluent. Simulasi serat dilakukan sebagai analisis termal keadaan stabil dengan Model Turbulensi k-epsilon berserta Realizable dengan rawatan dinding yang dipertingkatkan. Morfologi serat menyerupai pepejal silinder yang agak halus dengan corak berterusan, dan berorientasi rawak sementara diameter serat yang dihasilkan masing-masing adalah 1.24μm dan 717nm. Dari simulasi, jumlah Heat Flux yang dibuang oleh sistem terhad kepada isipadau tetap SAVR adalah 104.35992×10^3 W untuk Model Nanofiber dan 104.35989 W untuk Model Microfiber. Oleh kerana nilai SAVR dalam nanofiber didapati berkadar songsang dengan diameter nanofiber, nanofiber dengan diameter yang lebih kecil akan menghilangkan haba lebih baik daripada nanofiber dengan diameter yang lebih besar, terutama ketika pelesapan haba diperlukan di kawasan yang sangat kecil.

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to Allah S.W.T for giving me a chance and opportunity to finish this project. I would also like to express my appreciation to my supervisors, Dr. Nurfaizey bin Abdul Hamid, and Dr. Mohd Zaid bin Akop for their incredible guidance in terms of practical, psychological support, critical comments, and passion along with this project duration. Without their valuable helping hand, this work would have not progressed smoothly let alone be completed within the time constraint. Particularly, I would like to express my deepest gratitude to my father Sharif bin Othman and my mother Jamaliah binti Long for their moral support on this project. Finally, I would like to give thanks to my fellow seniors and colleagues who provided experienced insight on this project and to my fellow classmates which gave important comments and constructive criticisms on the project.

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LIST OF ABBREVIATION

PAN	Polyacrylonitrile
PAN/DMF	Polyacrylonitrile/Dimethylformamide
SVAR	Surface Area to Volume Ratio
CFD	Computational Fluid Dynamics
AMCHAL	Advanced Materials Characterization Laboratory
SEM	Scanning Electron Microscope
RMS	Residual Monitors

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Most of the applications or equipment of the 21st century have scaled down in terms of size and increase in intelligence over the last few decades. With the rapid rise in electronic power density, efficient heat removal has become a major challenge, especially for flexible electronic devices (Chen et al., 2018). According to Timbs *et al.*, (2021), heat dissipation has been the main problem to be tackled in the ongoing development of industrial electronics which seeks to reduce the size and increase performance. However, overheating was claimed to be the cause of 55% of environmentally caused failures for electronic equipment, with a cost of $163 million per year.

This means that the standard air-cooling approach has been unable to satisfy the need for high-density heat dissipation. Computer consumers favor personal computers with fast microprocessors. Thus, thermal design optimization is needed where the heat sinks reduce in terms of size and weight while improving the heat removal and, as a result, boosting the speed of electronic devices (Ahmed *et al.*, 2018). Moreover, the frequent requirement for adequate heat dissipation methods has proved to become a major problem. As a result, experts have been working hard to create innovative and effective ways for dealing with the problem of high temperatures. The improvement in heat transfer is focused on improving the heat transfer rate between the hot surfaces and the surrounding by increasing the coefficients of heat transfer or by expanding the heat transfer area (Dhaiban and Hussein, 2020).

To elaborate, according to You *et al.*, (2021), as the need for improvement of efficient heat dissipation of electronics grows, a number of heat sinks with various fin architectures, such as flat-plate fin, pin fin, interrupted fin, slotted fins, etc. have been reported. There have been several efforts to optimize the heat sink structure, for example, breadth, height, fin distribution, and fin form where heat dissipation is required in relatively tiny areas (Fugmann *et al.*, 2018). Another option is to alter the heat sink's material, including the fins and substrate. Porous materials like micro tubes, sintered metal, and metal foam are widely popular in research, as they have a very large surface area where heat dissipation in relatively small spaces is required (You *et al.*, 2021).

In terms of surface area, electrospun nanofibers are promising and frequently utilized materials in a wide range of industries due to their large surface area and porous structure (Mousavi *et al.*, 2019). The benefit of having polymer-based nanofibrous material production technologies are most compelling in multiple areas. For example, chemical and materials engineering in which nanoporous materials with large surface-area-to-volume ratios, high porosity, and good internal connectivity are used for filtrations, protective garments, etc. (Ramakrishna *et al.*, 2006). Taking advantage of the aforementioned benefits, PE/PA nonwovens were successfully designed and prepared by electrospinning Nylon-6 (PA) nanofibers onto polyethylene (PE) melt-blown nonwovens, resulting in excellent filtration and radiative heat dissipation (Xu *et al.*, 2021).

Various methods for producing polymeric nanofibers are presently available. For example, bicomponent extrusion, phase separation, template synthesis, drawing, melt blowing, centrifugal spinning, and electrospinning (Almetwally *et al.*, 2017). However, with all the feasible techniques that are available, electrospinning appears to be the feasible way of generating nanofibers. Electrospinning is usually categorized as solution electrospinning and melt electrospinning by determining if nanofibers are electrospinned from solutions or melt materials (Wang and Nakane, 2020).

The applicability of electrospun Polyacrylonitrile (PAN) nanofibers for heat dissipation will be investigated in this study. The fabrication of PAN nanofiber will be achieved through means of electrospinning technique where Polyacrylonitrile-Dimethylformamide (PAN-DMF) solution is used. The morphology and fiber diameter of the electrospun PAN nanofibers will be investigated using Scanning Electron Microscopy (SEM) and ImageJ software. The simulations of PAN fiber will be executed via steady-state thermal analysis in ANSYS Fluent. The heat dissipated by simulated PAN fiber with the largest surface area per volume ratio would be the highest. Thus, the utilization of PAN nanofiber in heat dissipation application would be feasible despite the modest thermal conductivity value.

1.2 Problem Statement

Heat dissipation has been a major issue that must be addressed in the ongoing development of industrial devices with the goal of reducing the size and improving the performance. In the efforts to overcome such a challenge, various designs have been investigated in order to achieve optimal heat sink fin geometry. Geometrical modifications such as interruption, slots, and perforation have been used to improve the thermal performance of fins or to reduce their weight or cost (Dhaiban and Hussein, 2020). However, electronic devices will become more miniaturized, with higher power, performance, and temperature as microelectronic techniques advance. The thermal limit of forced air convection, the traditional heat transfer method, had already been reached (Ahmed *et al.*, 2018).

Despite the success in recent research in conceiving PE/PA nonwovens with a favorable filtration and radiative heat dissipation as claimed by Xu *et al.*, (2021), the assessment of using nanofibers based on the high value of Surface Area to Volume Ratio (SAVR) as a means to dissipate heat is in no way had been fully explored by the preceding researchers. The appeal of utilizing nanofibers as a candidate material for heat dissipation was literally non existing due to the thermal conductivities of polymers are too modest, to begin with. According to Guo *et al.*, (2020), the inherent relatively low thermal conductivity values of polymers and polymer composites severely limit their wider applicability in sectors that need high thermal conductivity values and rapid heat dissipation.

Aside from thermal conductivity, heat dissipation of material had other aspects that influence its efficiency, to name a few, specific heat capacity and also the SAVR value. Thermal conductivities and specific heat capacity could only be change by changing the material itself. Meanwhile, SAVR depends on the geometry of the materials instead. An increment in SAVR value denotes a higher amount of exposed area of the materials which allows a higher heat transfer rate (Mehrali *et al.*, 2015). According to Kattan, (2016), suppose if a nanofiber has a shape of a cylinder with a diameter of 10nm and a height equal to 100 nm, the SAVR of said nanofiber would be 220,000,000 which clearly is a large number. Thus, this project aims to fabricate nanofiber made of Polyacrylonitrile polymer, to study the morphological of the nanofiber produced, and to simulate the fiber in Computational Fluid Dynamics for better comprehension towards the heat dissipation application in the constraint of the total surface area of nanofiber.

1.3 Research Objectives

Based on the issue outlined in the problem statement, the main objectives of this study are:

i. To obtain the average diameter of Polyacrylonitrile (PAN) nanofibers produced through the electrospun technique.
ii. To characterize the morphology of PAN nanofibers.
iii. To investigate the heat dissipation applications behavior of electrospun fiber using Computational Fluid Dynamics (CFD).

1.4 Research Scope

i. Using the solution electrospinning method to produce nanofibers from Polyacrylonitrile (PAN).
ii. Using a Scanning Electron Microscope (SEM) to characterize the morphology of nanofibers.
iii. Using ANSYS CFD simulation software to investigate the heat dissipation applications of PAN nanofibers membrane.

iv. Using ANSYS SpaceClaim software to design the Model of the Fibre.

v. Using Fluent to solve CFD steady-state thermal simulations.

vi. Using Realizable k-epsilon Model with Standard Wall Functions as the Turbulence Model.

1.5 Thesis Outline

There are five chapters in this thesis. Namely, the Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion and Recommendation, respectively. Chapter 1 describes the background of the selected research title along with the problem statement, objectives, and scope of the project. Meanwhile, Chapter 2 covers the literature review of current development on nanofibers, methods of producing nanofibers, the Electrospinning process, the Surface Area to Volume Ratio (SAVR) of nanofibers, Polyacrylonitrile (PAN) nanofiber, and the thermo-physical properties of PAN nanofiber in heat dissipation study. Chapter 3 specifies the methodology for nanofibers fabrication, simulation, and morphological diagnosis. Meanwhile, in Chapter 4, the results, and the analysis of nanofibers fabrication, simulation, and the morphological diagnosis along with their justification according to the literature review conducted, are discussed. Lastly, Chapter 5, concludes the findings of the project and the proposition for future endeavor.

CHAPTER 2

LITERATURE REVIEW

2.1 Nanofiber Research

With the advent of nanotechnology, researchers have grown more interested in investigating the unique characteristics of nanoscale materials (Bhardwaj and Kundu, 2010). Since 2014, electrospun nanofibers have accounted for about 1000 of all yearly nanotechnology papers (Badmus *et al.*, 2021). This interest stems in part from the interesting morphologies displayed by self-assembled electrospun nanofibers, which has led to its application in processes such as medication delivery, filtration, and energy storage (Ramakrishna *et al.*, 2006). They have extended continuous fibers with a high aspect ratio and a high degree of fiber orientation (Sarwar *et al.*, 2019). Other methods for producing nanofibers include template synthesis, phase separation, melt blowing, and bicomponent extrusion. These methods may produce fibers ranging from one-dimensional (1D) to three-dimensional (3D).

However, among the methods developed, electrospinning which dates back to 1900 and was formerly known as electrospraying in the 1890s, is one of the easiest, cheapest, and quickest techniques for converting solutions, melts, and suspensions into nanoscale diameter continuous fibers. (Badmus *et al.*, 2021). The electrospinning method is also a well-known technology for producing continuous polymeric fibers using the influence of an electric field