

**EFFECT OF SYNTHESIS PARAMETERS OF
POLYPROPYLENE MELT BLOWN NANOFIBERS
FOR OIL SORPTION**



ZYKAMILIA BINTI KAMIN

UMS
UNIVERSITI MALAYSIA SABAH

**FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH
2023**

**EFFECT OF SYNTHESIS PARAMETERS OF
POLYPROPYLENE MELT BLOWN NANOFIBERS
FOR OIL SORPTION**

ZYKAMILIA BINTI KAMIN



**THIS THESIS SUBMITTED IN FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY**

**FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH
2023**

UNIVERSITI MALAYSIA SABAH
BORANG PENGESAHAN STATUS TESIS

JUDUL : **EFFECT OF SYNTHESIS PARAMETERS OF POLYPROPYLENE MELT BLOWN NANOFIBERS FOR OIL SORPTION**

IJAZAH : **DOKTOR FALSAFAH KEJURUTERAAN**

BIDANG : **KEJURUTERAAN KIMIA**

Saya **ZYKAMILIA BINTI KAMIN**, Sesi **2012-2023**, mengaku membenarkan tesis Doktor ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis ini adalah hak milik Universiti Malaysia Sabah
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/):

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA 1972)

/

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

UNIVERSITI MALAYSIA SABAH

Disahkan Oleh,

ZYKAMILIA BINTI KAMIN
PK1211012T

(Tandatangan Pustakawan)

Tarikh : 29 September 2023

(Professor Ir. Dr. Roslam Hj. Sarbatly))
Penyelia Utama

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries, and references, which have been duly acknowledged.

3 November 2022

Zykamilia binti Kamin
PK1211012T



UMS
UNIVERSITI MALAYSIA SABAH

CERTIFICATION

NAME : **ZYKAMILIA BINTI KAMIN**

MATRIC NO. : **PK1211012T**

TITTLE : **EFFECT OF SYNTHESIS PARAMETERS OF
POLYPROPYLENE MELT BLOWN NANOFIBERS FOR OIL
SORPTION**

DEGREE : **DOCTOR OF PHILOSOPHY IN ENGINEERING**

FIELD : **CHEMICAL ENGINEERING**

VIVA DATE : **3 NOVEMBER 2022**



CERTIFIED BY;
UMS
UNIVERSITI MALAYSIA SABAH

Signature

1. MAIN SUPERVISOR
Professor Ir. Dr. Rosalam Hj. Sarbatly

2. CO-SUPERVISOR
Professor Dr. Duduku Krishnaiah

ACKNOWLEDGEMENT

Alhamdulillah, praise God, the Almighty, who has granted me the blessing, knowledge, and opportunity to complete this study. Apart from the effort by me, this thesis is finished with the guidance and encouragement of many others.

I wish to thank my supervisor Professor Ir. Dr. Rosalam Hj. Sarbatly for his guidance. My gratitude also goes to Professor Dr. Awang Bono for his technical advice. I am also grateful to Professor Dr. Duduku Krishnaiah, Professor Dr. Akihiko Tanioka, and Mr. Mitsuhiro Takahashi for their advice on a melt-blowing process.

I thank Zetta Ltd. Japan, for the melt-blowing fabrication rig support in Nanofiber and Membrane Research Laboratory and Universiti Malaysia Sabah for grant SDK007-2018. I thank Associate Professor Dr. Zaleha Abd. Aziz and Dr. Zarina Amin, the Directors of the Centre for Instrumentation and Science Services (PIPS) and the Biotechnology Research Institute (BRI), UMS, and Professor Dr. Jualang Azlan Gansau, Dean of the Faculty of Science and Natural Resources (FSSA), UMS for instrumentation accessibility.

Many thanks to Mr. Abdullah Tarikim and Mr. Zuhair Abdullah for assisting in the Nanofiber; and Gas and Petroleum Laboratories in the Faculty of Engineering. Thank you to Pn. Marlenny of BRI and Pn. Malah of PIPS for the SEM technical assistant. Thank you to Mr. Hardy and Mr. Tan for advice on adsorption study. To my family, friends, and colleagues your continuous support are appreciated.

I am indebted to both of my beloved late parents, Mr. Kamin Kusaran and Mrs. Hasnah Kadong, for their support during the completion of my study. Al-Fatihah. Finally, I wish to express my thanks to all those who have, in one way or another, helped me make my study a success. May Allah bless all of you.

Zykamilia Kamin

3 November 2022

ABSTRACT

Nanofiber is an effective oil sorbent for hydrocarbon crude oil spill clean-up operations. However, techniques to mass-produce nanofibers using melt blowing technique have not yet been fully developed to produce nanofibers with high oil sorption capacity. Subsequently, it needs a detailed study on the correlation between production, structures, properties, and applications. Hence, this study focuses on nanofibers synthesis using polypropylene by varying melt blowing variables, i.e., melt flow rate, air pressure, and die-to-collector distance, with ranges of 1 - 5 Hz, 0.25 - 0.50 Mpa and 0.15 - 0.45 m respectively. This work studied the interaction between process variables and nanofibers' physical properties (average fiber diameter, specific surface area, pore volume, and average pore diameter) and the interaction between the nanofibers' physical properties and oil sorption capacity. The SEM and BET characterize the fiber's physical properties, and a standard method was used to quantify oil sorption capacity. The response surface methodology was used to analyze the interactions. In addition, selectivity studies over water were conducted using Pseudo Ideal Monolayer theory on heavy metals Pb^{2+} . The results obtained for physical properties for average fiber diameter, specific surface area, pore volume, and average pore diameter were in the ranges of 370.84 - 1885.00 nm, 1.3669 - 4.3188 m^2/g , 0.002143 - 0.08283 cm^3/g , and 61.93 - 93.00 \AA , respectively. The finding shows that the most significant factor for all responses is melt flow rate except for average pore diameter, where melt flow rate and die collector distance interaction are the most significant factors. The oil sorption capacity was in the range of 11.37 - 36 g/g, with which the highest value was obtained at 1 Hz, 0.45 m, and 0.5 Mpa due to voids among fibers by fiber entanglement induced by the die-to-collector distance. At a low solute concentration, the maximum preference for the Pb^{2+} was at a 9.0×10^{-5} mole fraction, and the adsorption capacity, N_s , was 5.0758×10^{-5} mg/g. These indicate that the selectivity towards Pb^{2+} is high, despite a low adsorption capacity, making the nanofibers effective for oil-water separation for an oil spill clean-up operation. This knowledge contribution provides an avenue for future research in adsorption studies for hydrocarbons, oil and heavy metals.

ABSTRAK

KESAN PARAMETER SINTESIS TIUPAN CECAIR GENTIAN NANO POLIPROPILENA UNTUK SERAPAN MINYAK

Gentian nano adalah penyerap minyak berkesan membersihkan tumpahan minyak. Namun, teknik penghasilan gentian nano berskala besar secara teknik tiupan cair untuk menghasilkan gentian nano penyerapan minyak berkapasiti tinggi belum dibangunkan sepenuhnya. Hubungan antara fabrikasi, struktur, sifat dan aplikasi memerlukan kajian. Kajian ini berfokus kepada sintesis gentian nano menggunakan polipropilen dengan pembolehubah tiupan cecair, berkadar aliran, tekanan angin dan jarak berjulat 1-5 Hz, 0.25-0.5 Mpa dan 0.15-0.45 m. Kajian menjelaskan interaksi antara pembolehubah dan sifat fizikal gentian nano (purata diameter gentian, luas permukaan spesifik, isipadu liang dan purata diameter liang), dan interaksi antara sifat fizikal gentian nano dan kapasiti serap minyak. Kajian selektiviti logam berat Pb^{2+} ke atas air dijalankan menggunakan teori Pseudo Ideal Monolayer. SEM dan BET mencirikan sifat fizikal gentian nano dan kaedah standard digunakan untuk mengukur kapasiti serapan minyak. Response Surface Methodology digunakan untuk menganalisis interaksi ini. Keputusan purata diameter gentian, luas permukaan spesifik, isipadu liang dan purata diameter liang, adalah berjulat 370.84 - 1885.00 nm, 1.3669 - 4.3188 m^2/g 0.002143 - 0.08283 cm^3/g , dan 61.93 - 93.00 Å. Didapati, kadar aliran cair adalah faktor yang paling penting untuk semua respon, kecuali purata diameter liang, di mana kadar aliran cecair dan jarak alat tekan ke pengumpul adalah faktor terpenting. Kapasiti minyak berjulat 11.37 - 36 g/g, yang mana serapan minyak tertinggi diperolehi pada 1 Hz, 0.45 M, dan 0.5 Mpa. Serapan minyak tinggi disebabkan ruang di antara gentian oleh keterikatan gentian, akibat jarak ke pengumpul. Pada larutan yang cair, selectivity maksimum Pb^{2+} adalah pada pecahan mol 9.0×10^{-5} . Kapasiti penyerapan, N_s ialah 5.0758×10^{-5} mg/g. Ini menunjukkan walaupun kapasiti penyerapan rendah, selektiviti ke arah Pb^{2+} adalah tinggi. Sumbangan pengetahuan ini memberi panduan untuk penyelidikan masa depan dalam kajian penyerapan untuk hidrokarbon, minyak, dan logam berat.

LIST OF CONTENTS

	Page
TITLE	i
DECLARATION	ii
CERTIFICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
<i>ABSTRAK</i>	vi
LIST OF CONTENTS	vii
LIST OF TABLES	xv
LIST OF FIGURES	xvii
LIST OF ABBREVIATIONS	xxiii
LIST OF APPENDICES	xxiv
CHAPTER 1: INTRODUCTION	1
1.1 Overview	1
1.2 Oil Fate In Marine Environment	2
1.3 Oil Spill Cleaning Methods	3
1.4 Nanofibers for Oil Sorbent	6
1.5 Melt Blowing Technique to Produce Nanofibers	7
1.6 Materials for Melt Blowing Technique to Produce Nanofibers	9
1.7 Melt Blown Polypropylene Fiber Application In Oil and Heavy Metal Sorption	10
1.8 Problem Statement	11
1.9 Research Questions	13
1.10 Objectives	14
1.11 Research Scope	14
1.12 Hypotheses	15

1.13	Significant of Study	15
1.14	Thesis Statement	18
1.15	Summary	19
CHAPTER 2: LITERATURE REVIEW		20
2.1	Overview	20
2.2	Nanofiber Definition	20
2.3	Methods to Produce Nanofibers	22
	2.3.1 Electrospinning Technique	22
	2.3.2 Centrifugal Spinning Technique	23
	2.3.3 Solution Blowing Technique	24
	2.3.4 Melt Blowing Technique	25
2.4	Nanofiber Fabrication Technique: Advantages and Limitation	26
2.5	Importance of Structure-Property-Performance Relationship Study for Pristine Polymer	27
2.6	Correlation Between Processing Parameters-Structure- Properties	29
2.7	Correlation Between Operating Conditions, Physical Characteristic and Oil Sorption and Heavy Metal Selectivity Performances	30
	2.7.1 Electrospinning	35
	2.7.2 Centrifugal Spinning	41
	2.7.3 Solution blow Spinning	41
	2.7.4 Melt Blowing	45
2.8	Application of Nanofiber for Oil-Water Separation	49
	2.8.1 Crude Oil Component and Effect To Environment	52
	2.8.2 Bulk Crude Oil and Trace Elements	53
	2.8.3 Crude Oil Solubility in Water	54
2.9	The Properties of Nanofiber Required As Oil Sorbent	55
	2.9.1 Surface Morphology	55
	2.9.2 Voids Among Fibers	56
	2.9.3 Porosity of The Fibers	56

2.9.4	Diameter of The Fibers	59
2.9.5	Specific Surface Area of The Fibers	60
2.9.6	Surface Tension	60
2.10	Factors Effecting Oil Sorption of Nanofibers	60
2.10.1	Oil Viscosity	60
2.10.2	Surface Tension of The Oil	61
2.10.3	Fiber Physical Characteristic	62
2.10.4	Buoyancy	62
2.10.5	Oil Retention	63
2.10.6	Wettability	64
2.11	Previous Study on Oil Spill Cleaning Using Nanofiber	64
2.12	Gap Based on The Usage Nanofiber Sorbent In Oil Spill	67
2.13	Melt Blowing Process to Produce Nanofibers	69
2.13.1	Melt Blowing Process	69
2.13.2	Physio-Chemistry of Fiber Development From Polymer Melt at The Air Flow Field Between Die and Collector	70
2.14	Processing Parameters Influencing Nanofiber Physical Properties On Oil-Water Separation Properties Of Nanofibers	72
2.14.1	Fibers Diameter and Fiber Diameter Distribution	72
2.14.2	Porosity of The Fibers	75
2.14.3	Voids Among Fibers	78
2.15	Response Surface Methodology	81
2.16	Response Surface Methodology Related Work	82
2.17	Oil Sorption Mechanism Using Nanofibers	82
2.18	Oil Sorption Environment of Sorbent in Oil/Water Mixture	83
2.18.1	Static System	84
2.18.2	Dynamic System	84
2.19	Metal Ion Adsorption	84
2.20	Mechanism for Adsorption	86
2.21	Excess Adsorption Isotherms	87
2.22	Basis of polymer selection	92

2.22.1	Polymer processing of injection molding	92
2.22.2	Air-blowing mechanism	94
2.22.3	Polymer flowability characterization	96
2.22.4	Polypropylene structure	99
2.22.5	Polypropylene crystalline structure relation with oil sorption capability	104
2.23	Summary of Method of Analysis	110
2.24	Summary	112
CHAPTER 3: MATERIALS AND METHODS		114
3.1	Overview	114
3.2	Materials	115
3.2.1	Input Material for Nanofiber Production	115
3.2.2	Material and Analytical Chemicals for Nanofiber Characterization	116
3.2.3	Material for Nanofiber Adsorption Performance Study	116
3.3	Flowchart of Procedure	116
3.4	Nanofibers Fabrication Methodology	118
3.5	Preparation of Input Material for Melt Blowing Technique	122
3.5.1	Characterization of Flow Ability as Input Material into the Melt Blowing Machine	122
3.5.2	Characterization of Thermal Profile and Purity of Polymer as Input Material into the Melt Blowing Machine	122
3.6	Physical Properties Characterization of Melt Blown Nanofibers	122
3.6.1	Morphology And Diameter of Nanofiber	122
3.6.2	Contact Angle Measurement	123
3.6.3	Surface Area, Pore Volume, Average Pore Diameter and Average Pore Width of Nanofibers	124
3.7	Performance of Nanofibers on Oil Sorption Capacity of Bulk Oil	125

3.7.1	Oil Sorption Capacity of Pure Bulk Crude Oil for Static System	125
3.7.2	Oil Sorption Capacity Of Crude Oil/Water and Hexane/Water for a Dynamic System	126
3.7.3	Observation of Nanofiber-Oil Interaction Behavior	126
3.8	Study of The Effect of Production Process Parameters on Physical Properties and Sorption Performance of Melt Blown Nanofibers	127
3.9	Performance of Nanofibers on Pb/Water Selectivity of Pb-Water Mixture	129
3.10	Summary	131
CHAPTER 4: RESULTS AND DISCUSSION – STUDY ON CORRELATION BETWEEN OPERATING PARAMETERS AND NANOFIBERS PHYSICAL PROPERTIES		132
4.1	Overview	132
4.2	Raw Material Properties	132
4.2.1	Flow Ability of Polymer as Input Material	132
4.2.2	Thermal Profile and Purity of Polymer as Input Material	134
4.3	Physical Properties of Melt Blown Nanofibers	135
4.3.1	Average Diameter and Fiber Diameter Distribution	135
4.3.2	Contact Angle Measurement	153
4.3.3	Specific Surface Area, Pore Volume, Average Pore Diameter of Nanofibers	154
4.3.4	Effect of Diameter on Nanofiber Specific Surface Area, Pore Volume, and Average Pore Diameter	157
4.4	Study on The Correlation Between Operating Parameter and Nanofiber Physical Properties	158
4.4.1	Effect of Processing Variables on Average Fiber Diameter	160

4.4.2	Interaction of Variables and Response on Average Fiber Diameter	164
4.4.3	Effect of Processing Variables on Specific Surface Area	169
4.4.4	Interaction of Variables and Response on Specific Surface Area	174
4.4.5	Effect of Processing Variables on Pore Volume	179
4.4.6	Interaction of Variables and Response on Pore Volume	184
4.4.7	Effect of Processing Variables on Average Pore Diameter	189
4.4.8	Interaction of Variables and Response on Average Pore Diameter	193
4.5	Summary	199
CHAPTER 5: RESULTS AND DISCUSSION – STUDY ON CORRELATION BETWEEN NANOFIBER PHYSICAL PROPERTIES AND OIL SORPTION PERFORMANCE		202
5.1	Overview	202
5.2	Performance of Nanofibers on Oil Sorption Capacity of Bulk Oil	202
5.3	Oil Sorption Capacity of Crude Oil/Water and Hexane/Water for a Dynamic System	204
5.4	Sorbent Buoyancy Observation	207
5.5	Crude Oil Retention Behavior Observation	209
5.6	Adsorption Process Behavior Observation	210
5.7	Study on The Effect of Contact Time on Adsorption Speed Behavior	211
5.8	Effect of Fiber Physical Properties on Oil Sorption Properties	212
	5.8.1 Effect of Average Fiber Diameter on Oil Sorption Capacity	213
	5.8.2 Effect of Specific Surface Area on Oil Sorption Capacity	213
	5.8.3 Effect of Pore Volume on Oil Sorption Capacity	214
	5.8.4 Effect of Average Pore Diameter on Oil Sorption Capacity	215
5.9	Interaction of Variables And Response on Sorption Capacity	216
5.10	Summary	223

CHAPTER 6: RESULTS AND DISCUSSION – STUDY ON NANOFIBERS ON PB SELECTIVITY ON PB – WATER MIXTURE	232
6.1 Overview	224
6.2 Performance of Nanofibers on Pb/Water Selectivity of Pb- Water Mixture	224
6.3 Excess Adsorption Isotherm of Pb ²⁺ onto Nanofiber At 30 ° C	225
6.4 Pseudo Ideal Monolayer Linear Regression Analysis for Non-Competitive Adsorption of Pb ²⁺ onto Nanofiber At 30 ° C	226
6.5 Individual Adsorption Isotherms of Pb ²⁺ onto Nanofiber At 30 ° C	227
6.6 Selectivity of Pb ²⁺ onto Nanofiber At 30°C	228
6.7 Summary	229
 CHAPTER 7: CONCLUSION AND RECOMMENDATIONS	 230
7.1 Conclusion	230
7.2 Recommendations for Future Work	231
REFERENCES	233
APPENDICES	251



UMS
 UNIVERSITI MALAYSIA SABAH

LIST OF TABLES

	Page
Table 1.1 : List of Clean-Up Methods for Oil Spills	4
Table 2.1 : Comparison of Various Technique	28
Table 2.2 : Influence of Processing Parameters of Different Spinning Method on Fiber Characteristic	31
Table 2.3 : Selected Previous Study on Process–Structure– Physical Property-Performance for Electrospinning	37
Table 2.4 : Selected Previous Study on Process–Structure– Physical Property- Performance for Centrifugal Spinning	42
Table 2.5 : Selected Previous Study on Process–Structure– Physical Property- Performance for Solution Blow Spinning	47
Table 2.6 : Selected Previous Study on Process–Structure– Physical Property- Performance for Melt Blowing	50
Table 2.7 : Example of Crude Oil Composition (Exxonmobil)	52
Table 2.8 : Status of Nanofiber Applications For Oil Spill Clean-Up	68
Table 2.9 : Previous Work That Influence Melt Blowing Processing Parameter on Physical Characteristic Of Nanofibers For Oil Spill	70
Table 2.10 : Material Balance of Liquid Phase Adsorption	89
Table 3.1 : The Proposed 20 Experiment by RSM Showing Factors and Responses	128
Table 3.2 : Condition for The Lead (II) Ion (Pb^{2+}) Preparation	130
Table 4.1 : Results of MFI Test For PP Powder	133
Table 4.2 : Summary of Data Obtained From The Fiber Diameter Distribution Data	151
Table 4.3 : Fiber Diameter Distribution At Peak Range For A3, B4, B10 And C3	152
Table 4.4 : The Surface Area, Pore Volumes and Average Pore Diameters of Selected Samples of The Nanofiber	157
Table 4.5 : Summary of Results for The Factors and Response	159

Table 4.6	: ANOVA for Response of Average Fiber Diameter of Surface Linear Model	165
Table 4.7	: ANOVA for Response of Specific Surface Area of Surface Linear Model	174
Table 4.8	: ANOVA for Response of Pore Volume of Surface Linear Model	184
Table 4.9	: ANOVA for Response of Average Pore Diameter of Surface Cubic Model	194
Table 5.1	: Crude Oil Sorption Capacity for Selected Sample A1, B10 And C5	203
Table 5.2	: ANOVA for Response Surface of Oil Sorption Capacity of Cubic Model	217
Table 6.1	: Equilibrium Constant, K and Adsorption Capacity, N_s of Nanofiber Toward Pb^{2+}	227



LIST OF FIGURES

		Page
Figure 1.1	: Physical, Chemical And Biological Processes Changing Properties of Oil Slicks	2
Figure 1.2	: A Chemical Structure of a Repeating Unit of Polypropylene.	10
Figure 1.3	: Research On Nanofiber In Scopus Database From 1992-2021	16
Figure 1.4	: Number of Publications In Scopus Database Based on Article Title For Electrospinning, Centrifugal Spinning Solution Blow Spinning and Melt Blowing Spinning From 1999-2021	17
Figure 1.5	: Development of Publication Activity About Nanofibers, Nonwovens, and Melt Blown as of June 2019	18
Figure 2.1	: This Figure Show (A) Definition of Nanofibers And (B) Thickness of Nano-Sized Fiber	21
Figure 2.2	: Schematic of Electrospinning Setup	23
Figure 2.3	: Schematic of Centrifugal Spinning System	24
Figure 2.4	: Schematic of Solution Blow System	25
Figure 2.5	: Schematic of Melt Blowing Process	26
Figure 2.6	: Mechanism of Oil – Water Separation Using Nanofiber (A) Capillary Action (B) Absorption And (C) Adsorption	49
Figure 2.7	: Chromatogram of a Light Crude	53
Figure 2.8	: Type Of Oleophilic Skimmers	55
Figure 2.9	: FE-SEM images of PS fibers formed at relative humidity (RH) of (a) 45 % and (b) 20 %	58
Figure 2.10	: Adsorption Scenario of Adsorbate onto Sorbent	85
Figure 2.11	: An Example of Metal Ion Adsorption To Polymer Based Sorbent	86
Figure 2.12	: Classification of Excess Adsorption Isotherms According to Schay And Nagy	89
Figure 2.13	: Schematic diagram of injection molding machine	93

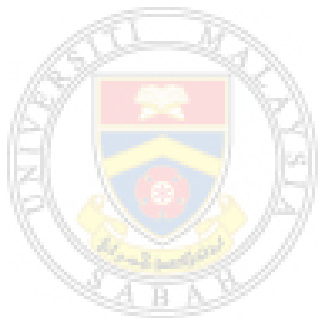
Figure 2.14	: Schematic of typical melt blowing system and illustration of the melt blowing fiber formation at the die	94
Figure 2.15	: Detailed schematic of the melt-blowing die: (a) sectional and (b) end-on-view of the two-piece	95
Figure 2.16	: The GPC result for: (a) PP; (b) LDPE and (c) HDPE	98
Figure 2.17	: The structure for PP and PE – LDPE and HDPE	98
Figure 2.18	: The multiple molecular structure for PP	100
Figure 2.19	: (a) Electron micrograph of a polyethylene single crystal. 20,000 \times . (b) The chain-folded structure for a plate-shaped polymer crystalline	102
Figure 2.20	: (a) Schematic representation of the detailed structure of a spherulite (b) Interspherulitic boundary	103
Figure 2.21	: A transmission photomicrograph (using cross- polarized light) showing the spherulite structure of polyethylene. Linear boundaries form between adjacent spherulites, and within each spherulite appears a Maltese cross 525 \times .	104
Figure 2.22	: Phase diagram of iPP showing the region of stability of the different polymorphic forms as a function of strain and stereoregularity	105
Figure 3.1	: The Experimental Research Flowchart	117
Figure 3.2	: Schematic Diagram of The Multi-Nozzle, Melt-Blown Spinning Machine	118
Figure 3.3	: Schematic Diagram Of The Patented Machine [202: Nanofiber Generation Device, 204: Cylinder, 206: Hopper, 208: Screw Shaft, 210: Ejector Nozzle, 212: Air Nozzle, 214: Guide Box, 214A: N/A, 216: Nozzle Head, 218: Connection Pipe, US20170016146A1	120
Figure 3.4	: Melt Blowing Machine Used In This Study (A) With Detail Information (B) Real Picture At Laboratory	121
Figure 3.5	: Sampling to determine average of fiber diameter	123
Figure 3.6	: Contact Angle Measurement	124
Figure 3.7	: Diagram of The Oil Sorption Procedure	125
Figure 3.8	: Diagram of The Adsorption Procedure	137

Figure 4.1	: TGA and DTG Result of PP Resin	134
Figure 4.2	: The SEM Micrograph for Sample (a)-(e) of A1-A5	136
Figure 4.3	: The Fiber Diameter Distribution Based on SEM Micrograph for Sample (a)-(e) of A1-A5	138
Figure 4.4	: The SEM Micrograph for Sample (a)-(e) of B1-B5	149
Figure 4.5	: The Fiber Diameter Distribution Based on SEM Micrograph for Sample (a)-(e) of B1-B5	142
Figure 4.6	: The SEM Micrograph for Sample (a)-(e) of B6-B10	144
Figure 4.7	: The Fiber Diameter Distribution Based on SEM Micrograph for Sample (a)-(e) of Sample B6-B10	146
Figure 4.8	: The SEM Micrograph for Sample (a)-(e) of C1-C5	148
Figure 4.9	: The Fiber Diameter Distribution Based on SEM Micrograph for Sample (a)-(d) of C1-C5	149
Figure 4.10	: Contact Angle Measurement for Sample (a) A1 at 128.61° , (b) B10 at 127.69° and (c) C5 at 119.45°	153
Figure 4.11	: Nitrogen Adsorption/Desorption Isotherm for Sample A1, B10 And C5	156
Figure 4.12	: The Pore Size Distribution for Sample (a)-(c) for A1, B10 And C5	156
Figure 4.13	: Interaction of the average fiber diameter with the effect of a single factor while other factors are fixed (A: Motor speed of polymer melt; B: Die to collector distance; C: Air Pressure)	164
Figure 4.14	: Interaction of Motor Speed and Die-To-Collector Distance on Average Fiber Diameter Response at Fix Pressures (a)0.25 Mpa; (b)0.33 Mpa; (c)0.42 Mpa and (d)0.50 Mpa	166
Figure 4.15	: Interaction of Motor Speed and Pressure on Average Fiber Diameter Response at Fix Die-To-Collector Distance (a)0.15 m; (b)0.25 m; (c)0.35 m and (d)0.45 m	167
Figure 4.16	: Interaction of Die-To-Collector Distance and Pressure on Average Fiber Diameter Response at Fix Motor Speed (a)1.25 Hz; (b)2.5 Hz; (c)3.73 Hz and (d)5 Hz	168

Figure 4.17	: Interaction of The Specific Surface Area With The Effect of A Single Factor While Other Factors Are Fixed (A: Motor Speed Of Polymer Melt; B: Die To Collector Distance; C: Air Pressure)	173
Figure 4.18	: Interaction of Motor Speed and Die-To-Collector Distance on Specific Surface Area Response at Fix Pressures (a)0.25 Mpa; (b)0.33 Mpa; (c)0.42 Mpa and (d)0.50 Mpa	175
Figure 4.19	: Interaction of Motor Speed and Pressure on Specific Surface Area Response at Fix Die-To-Collector Distance (a)0.15 m; (b)0.25 m; (c)0.35 m and (d)0.45 m	177
Figure 4.20	: Interaction of Die-To-Collector Distance and Pressure on Specific Surface Area Response at Fix Motor Speed (a)1.25 Hz; (b)2.5 Hz; (c)3.73 Hz and (d)5 Hz	178
Figure 4.21	: Interaction of The Pore Volume With The Effect of A Single Factor While Other Factors Are Fixed (A: Motor Speed of Polymer Melt; B: Die To Collector Distance; C: Air Pressure)	183
Figure 4.22	: Interaction of Motor Speed and Die-To-Collector Distance on Pore Volume Reponse at Fix Pressures (a)0.25 Mpa; (b)0.33 Mpa; (c)0.42 Mpa and (d)0.50 Mpa	185
Figure 4.23	: Interaction of Motor Speed and Pressure on Pore Volume Response at Fix Die-To-Collector Distance (a)0.15 m; (b)0.25 m; (c)0.35 m and (d)0.45 m	186
Figure 4.24	: Interaction of Die-To-Collector Distance and Pressure on Pore Volume Response at Fix Motor Speed of (a)1.25 Hz; (b)2.5 Hz; (c)3.73 Hz and (d) 5 Hz	187
Figure 4.25	: Interaction of The Average Pore Diameter With The Effect of A Single Factor While Other Factors Are Fixed (A: Motor Speed of Polymer Melt; B: Die To Collector Distance; C: Air Pressure)	193
Figure 4.26	: Interaction of Motor Speed and Die-To-Collector Distance on Average Pore Diameter Response at Fix Pressures (a)0.25 Mpa; (b)0.33 Mpa; (c)0.42 Mpa and (d)0.50 Mpa	195

Figure 4.27	: Interaction of Motor Speed and Pressure on Average Pore Diameter Response at Fix Die-To-Collector Distance (a)0.15 m; (b)0.25 m; (c)0.35 m and (d)0.45 m	196
Figure 4.28	: Interaction of Die-To-Collector Distance and Pressure on Average Pore Diameter Response at Fix Motor Speed of (a)1.25 Hz; (b)2.5 Hz; (c)3.73 Hz and (d)5 Hz	197
Figure 5.1	: Oil Sorption Capacity For Crude Oil/Water For A Dynamic System (a)-(c) 10 Minutes And (d)-(f) 47 Minutes	204
Figure 5.2	: Oil Sorption Capacity Of Crude Oil/Water For A Dynamic System	205
Figure 5.3	: Oil Sorption Capacity For Hexane/Water For A Dynamic System (a)-(c) 10 Minutes And (d)-(f) 47 Minutes	206
Figure 5.4	: Oil Sorption Capacity For Hexane/Water For A Dynamic System	207
Figure 5.5	: Observation Of Sorbent Buoyancy	208
Figure 5.6	: Crude Oil Retention Behavior Observation For All Sample A1-5, B1-10 And C1-5	209
Figure 5.7	: Sample For The Crude On The Effect Of Contact Time On Adsorption Speed Behavior For Sample C5	211
Figure 5.8	: Crude Oil Sorption Capacities Of The Sorbent B10 And C5 vs. Contact Time	212
Figure 5.9	: Interaction of The oil Sorption Capacity With The Effect of A Single Factor While Other Factors Are Fixed (A: Motor Speed Of Polymer Melt; B: Die To Collector Distance; C: Air Pressure)	216
Figure 5.10	: Interaction of Motor Speed And Die-To-Collector Distance on Oil Sorption Capacity Response At Fix Pressures (a)0.25 Mpa; (b)0.33 Mpa; (c)0.42 and Mpa (d) 0.50 Mpa	218
Figure 5.11	: Interaction of Motor Speed And Pressure on Oil Sorption Capacity Response At Fix Die-To-Collector Distance (a)0.15 m; (b)0.25 m; (c)0.35 m and (d)0.45 m	219
Figure 5.12	: Interaction of Die-To-Collector Distance And Pressure on Oil Sorption Capacity Response At Fix Motor Speed of (a)1.25 Hz; (b)2.5 Hz; (c)3.73 Hz and (d)5 Hz	221

Figure 6.1	: Excess Adsorption Isotherm Of Pb ²⁺ Onto Nanofiber At 30° C	225
Figure 6.2	: Pseudo Ideal Monolayer Linear Regression Analysis For Non-Competitive Adsorption Of Pb ²⁺ Onto Nanofiber At 30° C	226
Figure 6.3	: Individual Adsorption Isotherms Of Pb ²⁺ Onto Nanofiber At 30° C	228
Figure 6.4	: Selectivity Of Pb ²⁺ Onto Nanofiber At 30° C	229



UMS
UNIVERSITI MALAYSIA SABAH

LIST OF ABBREVIATIONS

BET	-	Brunauer–Emmett-Teller
DCD	-	Die to collector distance
DMF	-	Dimethylformamide
DTA	-	Diethylenetriamine
EDA	-	Ethylenediamine
EG	-	Ethyleneglycol
MWCNT	-	Multi-walled carbon nanotube
PA6	-	Polyamide 6
PAN	-	Polyacrylonitrile
PEI	-	Poly(ethyleneimine)
PES	-	Poly (ether sulfones)
PP	-	Polypropylene
PS	-	Polystyrene
PVDF	-	Polyvinylidene fluoride
SEM	-	Scanning electron microscopy
TGA	-	Thermogravimetry analysis
THF	-	Tetrahydrofuran



UMS
UNIVERSITI MALAYSIA SABAH