ENHANCING OILS AND SOLVENTS REMOVAL FROM WATER BY IMMOBILIZING CARBONACEOUS MATERIALS ON POLYURETHANE FOAM

By

KADILI JULIUS ATTAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To my dear wife, Abigail and my beautiful daughter, Eliana.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor Abdul Halim bin Abdullah, PhD
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This study reports the preparation of new polyurethane (PU) composite foams by dip-coating method and evaluates their performances in the oil-water separation process. Oils and organic solvents were chosen as models because of the menace of oil spills during exploration, transportation, and storage and indiscriminate discharge of industrial petrochemical wastes are potential risk factors for human health and the environment. Conventional methods for oil spill cleanup have reached a threshold with various collateral effects. Oils and organic solvents absorption onto solid absorbents, especially hydrophobic polyurethane (PU) foam, is an excellent technique for oil spill cleanup due to high sorption capacity, selectivity, and reusability arising from the synergistic effect of PU foam and carbonaceous fillers. Therefore, this research aimed to produce a flexible hydrophobic/oleophilic polyurethane foam for efficient oil/water separation. The absorbents were prepared by facilely coating PU foam skeletons with graphene oxide (GO), graphite (GT), and hydroxylated multiwalled carbon nanotubes (MWCNTs-OH) using polydimethylsiloxane (PDMS) as an effective adhesive. In this work, 12 different absorbents were prepared at stage one involving four samples each with graphene oxide contents of 3.6, 5.8, 8.0 and 11.1 wt.%; graphite contents of 4.76, 9.09, 13.04, and 15.73 wt.%; and MWCNT contents of 3.61, 6.97, 10.11 and 12.83 wt.% dip-coated for 1 h on PU foam blocks with dimension $1.5 \times 1.5 \times 1.5$ cm^3. A pristine PU foam was included as a reference in each group of samples. The absorption performance of each foam sample (PU, PU/GO, PU/GT, PU/CNT) was tested in engine oil, and the optimum sample for each carbon material was selected for further treatment. At stage two, PU composite foams with optimal carbon contents were treated with 1.5, 2.5, 5.0, 10.0, and 20.0 mg/mL PDMS prepolymer (Sylgard 184A) and curing agent (Sylgard 184B) at a weight ratio of 10:1. From these, the absorbents-PU/GO-PDMS; PU/GT-PDMS and PU/CNT-PDMS with optimal PDMS content of 5.49, 8.91 and 6.52 wt.% respectively were chosen for absorption performance test in oils (engine oil, cooking oil) and organic solvents (chloroform, acetone, cyclohexane), followed by reusability test in engine oil only. For application in oil/water separation, the hybrid foams were used in the separation of engine oil from water under stable (no external force) and dynamic (under magnetic stirring) systems with separation efficiency >90%. Furthermore, an attempt was made to mimic a continuous oil spill cleanup process. The absorbent was fitted into one pipe end and immersed into a beaker containing a mixture of cyclohexane (stained with Sudan III red) and water, with the other end connected to a vacuum pump via a suction flask. The pump was used to create a pressure difference, which selectively removed the colored organic solvent into the suction flask, leaving the water in the beaker. The kinetic experiments were carried out in engine oil, cooking oil, acetone, and cyclohexane using the PU foam hybrids. The kinetic data for each absorbent suggests that three major factors, including oil-sorbent affinity resulting from hydrophobicity, surface morphological characteristics of the sorbents, and physical properties of the test oil, determine the sorption performance of carbon-modified PU foams. The physicochemical properties of both pristine and modified PU foams were studied using water contact angle (WCA), FTIR, FESEM-EDX, and compression tests. The influence of carbonaceous fillers and polydimethylsiloxane on PU foam's wettability and absorption performance was studied. The modified PU foam absorbents possessed superhydrophobicity, with optimal water contact angles of 151.95°, 150.76° and 153.59° for PU/GO-PDMS, PU/GT-PDMS, and PU/CNT-PDMS, respectively, and were found to be stable (greater than 150°) over a broad range of pH (2-12), confirming their superhydrophobic stability in corrosive environments. The FESEM results show highly interconnected spherical pore structures of the hybrid foams with microscale holes, capable of absorbing oil from an oil/water mixture with high absorption capacity and selectivity. The influence of different carbon loading and PDMS concentrations on the oil absorption performance of the hybrid foams was also studied. The results suggest 5.8, 13.04, and 6.97 wt.% as the optimal contents of GO, GT, and MWCNTs, respectively, and 5.49, 8.91, and 6.52 wt.% PDMS reveals remarkable improvement in the absorption performances of the materials, with absorption capacity ranging from 29.63 to 68.30 g/g in engine oil, cooking oil, chloroform, acetone, and cyclohexane. The recyclability test showed that the hybrid foams retained at least 90% of their initial oil absorption capacity after 10 absorption-desorption cycles. The PU/GO-PDMS, PU/GT-PDMS, and PU/CNT-PDMS hybrid foams, which are low-cost, highly reusable, and durable hybrid materials, exhibit excellent absorption characteristics, confirming their potential as suitable candidates for efficiently removing oil and organic solvents from water.

Keyword: Absorption, Composite, Polyurethane, Reusability, Superhydrophobic

SDG: GOAL 6: Clean Water and Sanitation, GOAL 11: Sustainable Cities and Communities, GOAL 13: Climate Action

Abstrak tesis yang dibentangkan kepada Senat Universiti Putra Malaysia bagi memenuhi keperluan untuk ijazah Doktor Falsafah

MENINGKATKAN PENYINGKIRAN MINYAK DAN PELARUT DARIPADA AIR OLEH BAHAN KARBON TERSEKAT-GERAK PADA BUSA POLIURETANA

Oleh

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Kajian ini melaporkan penyediaan busa komposit poliuretana (PU) baharu dengan kaedah salutan celup dan menilai prestasinya dalam proses pengasingan minyak-air. Minyak dan pelarut organik dipilih sebagai model kerana ancaman tumpahan minyak semasa penerokaan, pengangkutan, dan penyimpanan serta pelepasan industri secara sembarangan. Sisa petrokimia merupakan faktor risiko yang berpotensi untuk kesihatan manusia dan alam sekitar. Kaedah konvensional untuk pembersihan tumpahan minyak telah mencapai hadnya dengan pelbagai kesan sampingan. Penyerapan minyak dan pelarut organik pada penyerap pepejal, terutamanya buih poliuretana hidrofobik (PU), adalah teknik yang sangat baik untuk pembersihan tumpahan minyak kerana kapasiti penyerapan yang tinggi, selektiviti dan kebolehgunaan semula yang timbul daripada kesan sinergistik busa PU dan bahan pengisi berasaskan karbon. Oleh itu, penyelidikan ini bertujuan untuk menghasilkan busa poliuretana hidrofobik/oleofilik yang fleksibel untuk pengasingan minyak/air yang cekap. Penyerap disediakan dengan menyalut rangka busa PU dengan grafin oksida (GO), grafit (GT), dan nanotiub karbon bertembok berbilang terhidroksilasi (MWCNTs-OH) menggunakan polidimetilsiloksana (PDMS) sebagai pelekat yang berkesan. Dalam kajian ini, 12 penyerap berbeza telah disediakan pada peringkat pertama melibatkan empat sampel setiap satu dengan kandungan grafin oksida 3.6, 5.8, 8.0 dan 11.1 wt.%; kandungan grafit 4.76, 9.09, 13.04, dan 15.73 wt.%; dan kandungan MWCNT 3.61, 6.97, 10.11 dan 12.83 wt.% bersalut celup selama 1 jam pada blok busa PU dengan dimensi $1.5\,x\,1.5\,x\,1.5$ cm^3. Busa PU asal dimasukkan sebagai rujukan dalam setiap kumpulan sampel. Prestasi penyerapan setiap sampel busa (PU, PU/GO, PU/GT, PU/CNT) telah diuji dalam minyak enjin, dan sampel optimum bagi setiap bahan karbon telah dipilih untuk rawatan selanjutnya. Pada peringkat kedua, busa komposit PU dengan kandungan karbon optimum dirawat dengan 1.5, 2.5, 5.0, 10.0, dan 20.0 mg/mL prapolimer PDMS (Sylgard 184A) dan agen pengawetan (Sylgard 184B) pada nisbah berat 10:1. Daripada ini, penyerap PU/GO-PDMS; PU/GT-PDMS dan PU/CNT-PDMS dengan kandungan PDMS optimum masing-masing 5.49, 8.91 dan 6.52 wt.% telah dipilih untuk ujian prestasi penyerapan dalam minyak (minyak enjin, minyak masak) dan pelarut organik (kloroform, aseton, sikloheksana) , diikuti dengan ujian kebolehgunaan semula dalam minyak enjin sahaja. Untuk aplikasi dalam pengasingan minyak/air, busa hibrid digunakan dalam pengasingan minyak enjin daripada air di bawah sistem stabil (tiada daya luaran) dan dinamik (di bawah kacau magnet) dengan kecekapan pemisahan >90%. Tambahan pula, percubaan telah dibuat untuk meniru proses pembersihan tumpahan minyak yang berterusan. Penyerap dipasang pada satu hujung paip dan direndam ke dalam bikar yang mengandungi campuran sikloheksana (diwarnai dengan perwarna Sudan III merah) dan air, dengan hujung satu lagi disambungkan ke pam vakum melalui kelalang sedutan. Pam digunakan untuk mencipta perbezaan tekanan, yang secara selektif mengeluarkan pelarut organik berwarna ke dalam kelalang sedutan, meninggalkan air di dalam bikar. Eksperimen kinetik telah dijalankan dalam minyak enjin, minyak masak, aseton, dan sikloheksana menggunakan busa hibrid PU. Data kinetik bagi setiap penyerap menunjukkan bahawa tiga faktor utama, termasuk pertalian penyerap minyak yang terhasil daripada hidrofobisiti, ciri morfologi permukaan penyerap, dan sifat fizikal minyak ujian, menentukan prestasi penyerapan busa PU yang diubah suai dengan karbon. Sifat fizikokimia kedua-dua busa PU tulen dan diubah suai telah dikaji menggunakan sudut sentuhan air (WCA), FTIR, FESEM-EDX, dan ujian mampatan. Pengaruh pengisi berkarbon dan polidimetilsiloksana terhadap kebolehbasahan dan prestasi penyerapan busa PU telah dikaji. Penyerap busa PU yang diubah suai mempunyai sifat hidrofobik yang tinggi, dengan sudut sentuhan air optimum masing-masing 151.95°, 150.76° dan 153.59° untuk PU/GO-PDMS, PU/GT-PDMS dan PU/CNT-PDMS, dan didapati stabil. (lebih daripada 150°) pada julat pH yang luas (2-12), mengesahkan kestabilan sifat hidrofobiknya dalam persekitaran yang menghakis. Keputusan FESEM menunjukkan struktur liang sfera yang sangat saling berkait bagi busa hibrid dengan liang mikro, mampu menyerap minyak daripada campuran minyak/air dengan kapasiti penyerapan dan selektiviti yang tinggi. Pengaruh pemuatan karbon yang berbeza dan kepekatan PDMS terhadap prestasi penyerapan minyak busa hibrid juga telah dikaji. Keputusan menunjukkan bahawa 5.8, 13.04, dan 6.97 wt.% sebagai kandungan optimum GO, GT, dan MWCNTs, masing-masing, dan 5.49, 8.91, dan 6.52 wt.% PDMS mendedahkan peningkatan yang luar biasa dalam prestasi penyerapan bahan, dengan penyerapan kapasiti antara 29.63 hingga 68.30 g/g dalam minyak enjin, minyak masak, kloroform, aseton dan sikloheksana. Ujian kebolehkitar semula menunjukkan bahawa busa hibrid mengekalkan sekurang-kurangnya 90% daripada kapasiti penyerapan minyak awalnya selepas 10 kitaran penyerapan-penyahserapan. Busa hibrid PU/GO-PDMS, PU/GT-PDMS dan PU/CNT-PDMS, yang merupakan bahan hibrid yang kos rendah, sangat boleh digunakan semula dan tahan lama, mempamerkan ciri penyerapan yang sangat baik, mengesahkan potensinya sebagai calon yang sesuai untuk menyingkirkan minyak dan pelarut organik daripada air dengan cekap.

Kata kunci: Penyerapan, Komposit, Poliuretana, Kebolehgunaan Semula, Superhidrofobik

SDG: MATLAMAT 6: Air Bersih dan Sanitasi, MATLAMAT 11: Bandar dan Komuniti Mampan, MATLAMAT 13: Tindakan Iklim

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LIST OF ABBREVIATIONS

CNT	Carbon Nanotubes
EDX	Energy Dispersive X-ray
FESEM	Field Emission Scanning Electron Microscopy
FTIR	Fourier Transform Infrared
GO	Graphene Oxide
GT	Graphite
h	Hour
mg	Milligram
min	Minute
mL	Milliliter
m_o	Mass of sorbed oil
m_w	Mass of sorbed water
MWCNTs	Multiwalled Carbon Nanotubes
MWCNTs-OH	Hydroxylated Multiwalled Carbon Nanotubes
OAE	Oil Absorption Efficiency
PDMS	Polydimethyl Siloxane
PU	Polyurethane
PU/C	Polyurethane/Carbon (GO, GT, CNT) composite
PU/CNT	Polyurethane/ Carbon Nanotubes
PU/CNT-PDMS	Polyurethane/ Carbon Nanotubes- polydimethyl siloxane hybrid
PU/C-PDMS	Polyurethane/Carbon (GO, GT, CNT) -polydimethyl siloxane
PU/GO	Polyurethane /graphene oxide composite
PU/GO-PDMS	Polyurethane/ graphene oxide-polydimethyl siloxane hybrid
PU/GT	Polyurethane/graphite composite

PU/GT-PDMS	Polyurethane/graphite- polydimethyl siloxane hybrid
qe_o	Oil sorption capacity
qe_w	Water sorption capacity
SI	Selectivity index
V_f	Foam Porosity
WCA	Water Contact Angle
wt.%	Weight percent
ρ_f	Foam density
ρ_{oil}	Density of oil
ρ_s	Density of solid polyurethane
Q_{exp}	Experimental absorption capacity
Q_{max}	Maximum absorption capacity
S_0	Weight of sample before absorption
S_T	Weight of sample after absorption

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Marine oil spills and petrochemical industrial wastewater emission are of serious environmental and ecological concerns, and most of these occurrences are a consequence of upsurge in petroleum and chemical industries as well as marine transport (Dhumal *et al*., 2021; Kulal *et al*., 2019; Piperopoulos *et al.*, 2020). For example, the explosion of BP's Deepwater Horizon in 2010 was reported to have released about 210 million gallons of oil in the Gulf of Mexico (Li and Boufadel, 2010). Similarly, Fingas (2013) reported that daily oil spills in the United States navigable waters is about 15 incidences. Water pollution due to oil and toxic organic solvents spills have raised very serious environmental concern globally (Dhumal *et al*., 2021; He *et al*., 2021; Kulal *et al*., 2019). The release of these pollutants can occur in the process of extraction, transportation, storage as well as disposal (Rahmani *et al*., 2017). After accumulating in fish and other edible marine organisms, the pollutants are eventually consumed by humans, thereby posing severe risk to human health (Carpenter *et al*., 2019; Jamaly *et al*., 2015). This scenario has therefore, heightened the demand for effective method of oil and organic solvents removal from water. Moreover, provision of clean water and environment for all by the year 2030 is part of the 17th United Nation's sustainable development goals.
There are several methods of oil spill remediation such as enhancing the natural biodegradation by breaking up the oil molecules with the application of biological agents, mechanical cleaning, in-situ combustion, and chemical sedimentation (Doshi *et al*., 2018; Evans *et al*., 2001; Zahed *et al*, 2010). Another method of oil spill remediation is by absorption, in which absorbent materials such as mats, pads, and socks are used for oil spill clean-up (Piperopoulos *et al*., 2018; Yu *et al*., 2017). Among the various technologies available for water treatment, an emerging route considered as one of the most effective approach to oil spill clean-up is absorption. This method is widely accepted because of its low cost, high selectivity towards oil, easy fabrication, environmental harmlessness, and recyclability (He *et al*., 2021). Compared to many porous natural sorbents, such as sawdust, wool fiber, activated carbon, bentonite, and zeolite (Annunciado *et al*, 2005; Wang *et al*, 2013) and synthetic sorbents such as fibrous polypropylene and cellulose materials (Paul *et al*., 2016; Liu *et al*., 2017a), polyurethane (PU), a member of the 3D absorbents has been widely investigated and reported as an ideal sorbent material for oil-water separation (Guo *et al*., 2017; Zhang *et al*., 2017a). This is because, despite the high surface area and porous structures exhibited by most natural sorbents, most of them present low sorption capacities, poor selectivity, and no recyclability. On the other hand, the application of synthesized materials, although with good selectivity and high sorption capacity, is not only limited by expensive raw materials but also constrained by complex synthesis procedures. (Shamsijazeyi *et al*, 2014). High oil sorption capacity, oil-water selectivity, recyclability, and low cost which are important parameters required of a suitable absorbent material for large scale oil spill clean-up have been reported for polyurethane foam by several researchers (Wang *et al*., 2013; Zhu and Pan, 2014; Shi *et al*., 2014). These enhanced sorption performances characteristics of the polyurethane sorbents were achieved by means of chemical modification of their surface properties to make them hydrophobic and oleophilic.

Furthermore, the combination of nanotechnology with membrane separation technology has been recently considered as viable and effective approach in the enhancement of membrane performance (Pendergast and Hoek, 2011). Nanomaterials, including single-walled carbon nanotubes (SWMWCNTs) and multi-walled carbon nanotubes (MWCNTs), graphene and its derivatives among others, have been considered materials of choice by researchers in the fields of material science and engineering for the fabrication and design of new composite membranes for water treatment application. This is due to their high specific surface area, high mechanical strength, excellent chemical inertness, and outstanding water-transport property (Goh *et al*, 2016; Lee *et al*, 2016). Recently, nanocomposite membrane which is a combination of polymeric and nanomaterials has highly attracted the attention of researchers and has been employed for water treatment. Based on existing results from the literature, this seems to be a promising solution to the challenges of conventional membrane separation. Incorporating nanomaterials into conventional polymeric membrane enhances structural tunability and physicochemical properties such as hydrophobicity, porosity, thermal, and mechanical stability of membranes.

This study is therefore, aimed at facilely fabricating robust and reusable nanocomposite materials, highly hydrophobic and oleophilic, which exhibits high oil sorption capacity, oil-water selectivity and enhanced mechanical resistance using commercially available polyurethane foam as substrate and carbonaceous materials such as graphene oxide, graphite as well as MWCNTs as fillers. The sorption performances of the prepared composite foams were investigated for different oils (engine oil, cooking oil) and organic solvents including chloroform, acetone, and cyclohexane. Various methods were employed to characterize the fabricated materials to identify and verify the presence of surface functional groups, surface wettability, morphology, mechanical strength using Fourier transform infra-red spectroscopy, water contact angle, Field emission scanning electron microscopy and compressive modulus respectively.

1.2 Problem Statement and Justification

Methods such as in situ burning (Aurell and Gullett, 2010), skimming (Broje and Keller, 2007; Al-Majed *et al*., 2012), chemical dispersants (Kujawinski *et al*., 2011) have been previously employed in oil spill clean-up. However, these methods are not only expensive, ineffective and difficult to operate, but also associated with secondary pollution in which the end products of the absorbents after use, constitute wastes and contaminate the environment if not properly disposed (Abuhasel *et al*., 2021; Perez-Calderon *et al*., 2018).

Absorption method is considered the most effective approach to oil-water separation (Wu *et al*., 2014; Cao *et al*., 2017). This is because of the low cost, easy preparation, simplicity of operation and environmental harmlessness of absorbent materials (Liu *et al*., 2021). For example, natural sorbents, such as vegetable fiber, sawdust, cotton fiber and zeolite have been widely investigated for oil clean up purposes. This is due to their high surface area and porous structure. However, they present low sorption capacities, poor selectivity, poor handling and no recyclability (Piperopoulos *et al*, 2020). Similarly, some synthesized materials, though possess excellent sorption performance and good selectivity, are limited by expensive raw materials and complex synthesis procedures (Shamsijazeyi *et al*, 2014).

Furthermore, carbon materials such as nanotubes, graphite and graphene oxide have demonstrated successful applicability in various fields including water remediation; however, individual application of these materials for oil absorption purposes has been faced with various limitations. Their major setbacks which limit their application include difficulty in structure control, poor handling, poor processability, no recyclability. Moreover, some of these materials are expensive, their application may also lead to secondary pollution since they are not recyclable.

On the other hand, 3D absorbent materials such as polyurethane foam composites are inexpensive and possess high porosity, large specific surface area, high sorption capacity, recyclability as well as good oil/water selectivity (Ma *et al*., 2016; Wu *et al*., 2019; Jamsaz and Goharshadi, 2020). However, polyurethane foams in their pristine state have very poor oil/water selectivity. This is because of the presence of hydrophilic groups on their surfaces. Hence, the need for surface modification to make polyurethane foams suitable for oil/water separation (Liu *et al*., 2013a). Therefore, combination of nanotechnology and membrane separation techniques as employed in this work can be a breakthrough in overcoming the challenges. This is achieved by formation of composites using bulk carbon nanomaterials and polymer foam to improve their practical applications. In this regard, the desired properties such as hydrophobicity, good mechanical properties are provided by the carbon materials while others such as high flexibility, improved handling, low cost, easy fabrication as well as reusability are contributed by the polymer. The synergistic effect of these materials results in a composite which overcomes the stated challenges and exploitable for oil-water separation. Moreover, the promising materials must possess both hydrophobic and oleophilic behavior to selectively absorb oil while repelling water.

Polyurethane (PU) foams are a member of the family of polymer foams with a variety of applications in everyday life due to their unique properties and ability to be modified. PU foam modification for oil-water separation has been the center of many research, making it of great interest for oil-water separation. This is probably due to the simplicity of its fabrication method, coupled with its outstanding stability, cyclic lifetime, and separation capacity. Hence, was chosen for this research work. Similarly, MWCNTs, graphite and graphene oxide were chosen as polyurethane foam surface modifiers due to their versatility and unique features. Because of their stronger chemical and physical interactions, rapid equilibrium, high sorbent capacity, excellent mechanical strength, and tailored surface chemistry, they are considered as superior materials for the remediation of a wide range of organic and inorganic contaminants compared with conventional sorbents such as clay, zeolite, and activated carbon.

Therefore, combining the highly exotic properties of these materials with those of polyurethane foam as demonstrated in this study, a superhydrophobic/oleophilic absorbent can be fabricated for oil/water separation.

1.3 Hypothesis

Pristine polyurethane foams are highly porous and hydrophilic, hence are not suitable for oil-water separation. Since carbon materials are usually hydrophobic, it is hypothesized that the addition of carbon materials such as graphene oxide, graphite or MWCNTs will improve the hydrophobicity/oleophilicity of the foam thus improves the oil-water separation process. The amount of carbon material and PDMS coated on the foam may play key role in the absorption performance of the composite. If the amount of carbon material loaded into the foam is too low, there may be low absorption capacity and poor oil/water selectivity due to inadequate surface roughness and hydrophobicity. On the other hand, if the amount of surface modifiers is too high, there is increased weight of the composite, possible agglomeration, and partial clogging of the polyurethane foam's pore structures. These also lead to poor absorption performance. In addition to hydrophobic character, the surface morphology (porosity, pore size and connectivity) of the PU foam absorbent as well as the intrinsic properties of the sorbate plays significant role in oil absorption performance. Moreover, the presence of carbonaceous filler within the PU foam architectures does not only enhance the sorbent's durability due to increase in mechanical strength, but also its oil retention capacity and sorption capacity. Although the sole aim of PDMS is to act as efficient adhesive between the carbon material and the PU foam skeleton, it is capable of improving the hydrophobicity of the sorbent due to its low surface energy and hydrophobic character.

1.4 Significance of the Research

Increasing human population and urbanization, rapid development of the petroleum industry as well as marine transport has frequently led to oil spills, and petrochemical industrial wastewater emission. These are of serious environmental and ecological concern due to the tremendous pressure on natural resources such as water and their consequences on human health. Therefore, to achieve sustainable development via provision of clean water and environment for all as stated in the United Nation's sustainable development goals, there is need to develop cost-effective, efficient, and durable absorbents for the remediation of oil spill and organic solvent emissions. This is because environmental pollution arising from these sources is almost inevitable. In this regard, the study of alternative method of removing oil pollutants or organic solvents from water is worthwhile. This study involves the surface modification of commercial polyurethane foam using carbonaceous materials and PDMS pre polymer and its application in the remediation of oil spill and organic solvents from water. From the findings of this research, a more efficient, cost-effective, and durable alternative means of water remediation will be developed to replace the conventional methods. In cases of water pollution due to accidental discharge of oil during transport or storage, the application of the techniques described in this research will be useful to environmental protection agencies to selectively remove oil and organic solvents from water. This will prevent the poisoning of aquatic organisms and humans by these hazardous pollutants.
Furthermore, this research is useful to petrochemical industries for environmental clean-up during oil exploration when spillage is almost inevitable. It is also noteworthy that since the polyurethane hybrid foam can be reused, the possibility of secondary pollution from disposal or burning of used absorbent is avoided. This makes this research unique and environmentally friendly compared to other conventional methods. However, a

major limitation of the present study is that the prepared absorbents could only achieve a partial separation of oil-in-water or water-in-oil emulsions. This is because additional modifications required for this application could not be carried out due to limited time and resources.

1.5 Aim and Objectives of Research

The main aim of this research is to produce a flexible hydrophobic/oleophilic polyurethane foam for efficient oil/water separation.

The specific objectives of the work are as follows:

i. to prepare hydrophobic/oleophilic polyurethane foam modified with carbon and PDMS.

ii. to characterize the prepared polyurethane foam absorbents using FTIR, FESEM-EDX, water contact angle, compressive strength

iii. to evaluate the maximum absorption capacity of the polyurethane foam hybrids in oils (engine oil, cooking oil) and organic solvents (acetone, chloroform, cyclohexane)

iv. to investigate the performance of the prepared absorbents in terms of reusability and oil/water selectivity under static and dynamic systems

v. to evaluate the sorption kinetics of the prepared absorbents with respect to the diffusion rates of oils and organic solvents.

1.6 Scope of the Work

The scope of this work includes the preparation of 12 different absorbents at stage one. This involves four samples for each of graphene oxide (3.6, 5.8, 8.0 and 11.1 wt.%); graphite (4.76, 9.09, 13.04, and 15.73 wt.%); and MWCNTs (3.61, 6.97, 10.11 and 12.83 wt.%) dip-coated on PU foam skeleton, with pristine PU foam sample included in each as reference. The absorption performance of each composite foam was tested in engine oil. The PU composite foams that exhibit the highest oil absorption performance were chosen for further treatments. At stage two, PU composite foams with optimal carbon contents were treated with 1.5, 2.5, 5.0, 10.0 and 20.0 mg/mL PDMS pre polymer and curing agent. From these, the absorbents (PU/GO-PDMS, PU/GT-PDMS and PU/MWCNT-PDMS) with optimal PDMS contents of 5.49, 8.91 and 6.52 wt.% respectively were chosen for absorption performance test in oils (engine oil, cooking oil) and organic solvents (chloroform, acetone, cyclohexane), followed by reusability test in engine oil only. For application in oil/water separation, the hybrid foams were used in the separation of engine oil from tap water under stable (no external force) and dynamic (under magnetic stirring) systems. The kinetic experiments were carried out in engine oil, cooking oil, acetone and cyclohexane using each of PU/GO-PDMS, PU/GT-PDMS and PU/MWCNT-PDMS hybrids. The diffusion rate for each absorbent was determined and related to the surface features and morphologies of the absorbents as well as the properties of the absorbates. The foam density, porosity and pore size distribution were studied. Foam samples were also characterized using various techniques to determine the presence of surface functional groups, surface wettability, morphology and elemental analysis as well as mechanical strength using FT-IR spectroscopy, water contact angle, FESEM-EDX and compressive modulus respectively. The entire task and scope of this research is summarized in Figure 1.1.

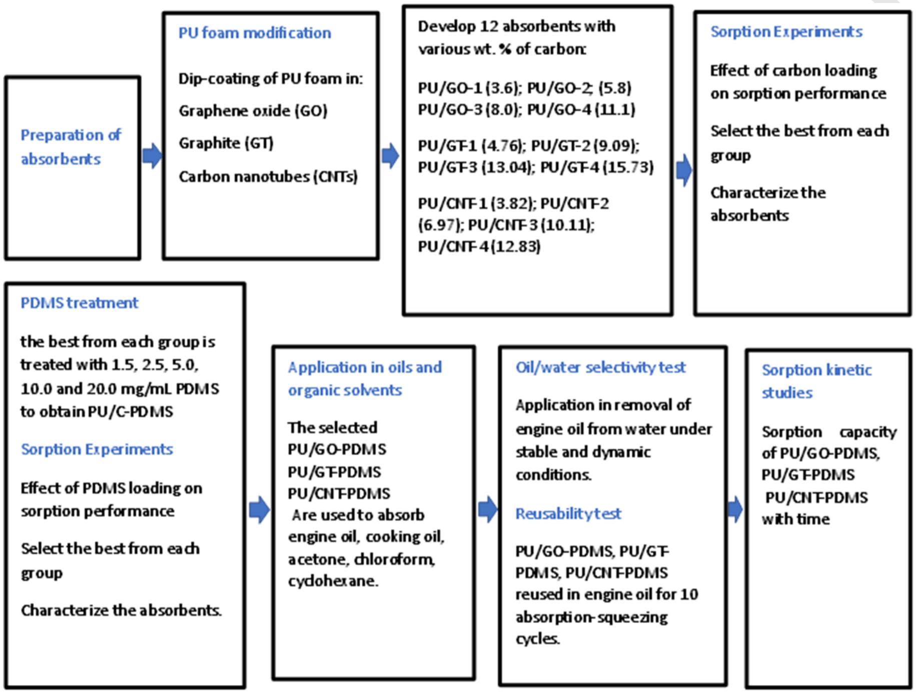

Figure 1.1: The main scope of this research

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