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UNIVERSITI PUTRA MALAYSIA  
BERILMU BERBAKTI

**ABSORPTION AND ADSORPTION OF BENZENE, TOLUENE, AND  
XYLENE FROM WATER USING A HYDROPHOBIC  
POLYDIMETHYLSILOXANE FOAM**

By

**ALATAWI LILA SALEEM E**

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

**January 2024**

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## DEDICATION

This thesis is dedicated to my family.  
For their endless love, support, and encouragement.



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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**January 2024**

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**Faculty : Science**

Due to untreated wastewater disposal from a growing population and industry, biological and chemical pollutants have accumulated in the environment. Benzene, toluene, and xylene (BTX) are among the most common pollutants in industrial wastewater. Due to their toxic and carcinogenic nature, BTX-containing industrial wastewater requires proper treatment prior to discharge to open water. The low adsorption capacity and low recyclability of the current sorbents have motivated the search for more efficient sorbent for BTX removal. In this study, polydimethylsiloxane (PDMS) foam was prepared and used to remove BTX from water. A facile and green synthesis was developed for the preparation of PDMS foam. Using the gas foaming method, PDMS was polymerized with the addition of  $\text{NaHCO}_3$  as a blowing agent and acetic acid as the catalyst. The prepared PDMS foams were characterised by their density, morphology (FESEM), hydrophobicity (water contact angle), and mechanical properties. By changing the  $\text{NaHCO}_3$ : acetic acid ratios and the curing temperature, foams with varying properties were obtained. The PDMS foam produced at a 1: 2

NaHCO<sub>3</sub>: acetic acid ratio and cured at 100°C (1:2(100) foam) has the highest hydrophobicity of all the PDMS foams. All PDMS foams can be compressed to a maximum strain of 95% and retained their original size, showing excellent mechanical properties. With increasing curing temperatures, the porosity of the foams increases while their density, elastic modulus, and compressive strength decrease. However, the PDMS characteristics does not depend on the NaHCO<sub>3</sub>: acetic acid ratio, as no clear trend in feature change is observed with the changing of the NaHCO<sub>3</sub>: acetic acid ratio. The potential of the synthesised PDMS foams as sorbents to remove BTX from water was evaluated. The absorption of BTX by PDMS foams was studied at high BTX concentrations (higher than the solubility of BTX compounds in water). In contrast, the adsorption study was applied to remove low- concentration BTX when these organic compounds are dissolved in water. In the absorption method, the 1:2(100) PDMS foam exhibited the highest absorption capacity with 7.5 g/g, with 95% uptake occurring within the first minute, attributed to its higher hydrophobicity and medium porosity. The absorption capacity of PDMS foam followed the order: X>T>B. The PDMS foam retained its high absorption capacity for B, T, and X even after 10 absorption-desorption cycles, indicating its excellent stability and reusability. For the adsorption study, batch experiments were carried out for B, T, and X uptake from aqueous solution onto PDMS foam in mono-component systems at varied operating conditions. 1:2(100) PDMS foam was found to have the highest adsorption capacity with 4.2 mg/g at 50 mg/L of benzene concentration. BTX adsorption also increased with increasing concentration. The adsorption data were well-fitted with Freundlich isotherms and a pseudo-second-order kinetic model. The adsorption capacity of PDMS foam followed the order X>T>B. Based on experimental findings, PDMS foam is a promising sorbent with high stability and reusability for BTX removal from water.

**Keyword:** Adsorption Isotherm, Adsorption Kinetic, BTX Removal, Gas Foaming Process, PDMS Foam

**SDG:** GOAL 6: Clean Water and Sanitation, GOAL 14: Life Below Water.



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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENYERAPAN DAN PENJERAPAN BENZENA, TOLUENA, DAN XILENA  
DARIPADA AIR MENGGUNAKAN BUSA HIDROFOBIAK  
POLIDIMETILSILOKSANA**

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Oleh kerana pembuangan air sisa yang tidak dirawat daripada populasi manusia dan industri yang semakin meningkat, bahan pencemar biologi dan kimia telah terkumpul di alam sekitar. Benzena, toluena, dan xilena (BTX) adalah antara bahan pencemar yang paling biasa dalam air sisa industri. Disebabkan sifat toksik dan karsinogeniknya, air sisa industri yang mengandungi BTX memerlukan rawatan yang betul sebelum dibuang ke air terbuka. Kapasiti penyerapan dan kebolehkitar semula yang rendah bagi sorben semasa telah mendorong pencarian sorben yang lebih cekap untuk penyingkiran BTX. Dalam kajian ini, busa polidimetilsiloksana (PDMS) telah disediakan dan digunakan untuk menyingkirkan BTX daripada air. Sintesis yang ringkas dan mesra alam telah digunakan untuk penyediaan busa PDMS. Menggunakan kaedah pembusaan gas, PDMS telah dipolimerkan dengan penambahan  $\text{NaHCO}_3$  sebagai agen perongga dan asid asetik sebagai pemangkin. Busa PDMS yang disediakan telah dicirikan dengan ketumpatan, morfologi (FESEM), keterhidrofobiikan (sudut sentuhan air), dan sifat mekanikal. Dengan mengubah

nisbah  $\text{NaHCO}_3$ : asid asetik dan suhu rawatan, busa dengan sifat yang berbeza-beza telah diperolehi. Busa PDMS yang dihasilkan pada nisbah 1:2  $\text{NaHCO}_3$ : asid asetik dan dirawat pada  $100^\circ\text{C}$  (busa 1:2(100)) mempunyai keterhidrofobikan tertinggi antara semua busa PDMS. Semua busa PDMS boleh dimampatkan kepada kemampatan maksimum 95% dan mengekalkan saiz asalnya, menunjukkan sifat mekanikal yang sangat baik. Dengan peningkatan suhu rawatan, liang rongga meningkat manakala ketumpatan, modulus keanjalan, dan kekuatan mampatannya berkurangan. Walau bagaimanapun, ciri PDMS tidak bergantung pada nisbah  $\text{NaHCO}_3$ : asid asetik, kerana tiada trend yang jelas dalam perubahan ciri diperhatikan dengan perubahan nisbah  $\text{NaHCO}_3$ : asid asetik. Potensi busa PDMS yang disintesis sebagai penyerap untuk menyingkirkan BTX daripada air telah dikaji. Penyerapan BTX oleh busa PDMS dikaji pada kepekatan BTX yang tinggi (lebih tinggi daripada keterlarutan sebatian BTX dalam air). Sebaliknya, kajian penjerapan digunakan untuk menyingkirkan BTX berkepekatan rendah di mana sebatian organik ini dilarutkan dalam air. Dalam kaedah penyerapan, busa PDMS 1:2(100) menunjukkan kapasiti penyerapan tertinggi dengan nilai 7.5 g/g, dengan 95% penyerapan berlaku dalam minit pertama, yang dikaitkan dengan keterhidrofobikan dan liang rongga sederhana yang lebih tinggi. Kapasiti penyerapan busa PDMS mengikut susunan:  $X > T > B$ . Busa PDMS mengekalkan kapasiti penyerapan yang tinggi untuk B, T, dan X walaupun selepas 10 kitaran penyerapan-penyahserapan, menunjukkan kestabilan dan kebolehgunaan semula yang sangat baik. Untuk kajian penjerapan, eksperimen secara kelompok telah dijalankan untuk penyingkiran B, T, dan X daripada larutan bercampur air menggunakan busa PDMS dalam sistem monokomponen pada keadaan operasi yang berbeza-beza. Busa 1:2(100) PDMS didapati mempunyai kapasiti penjerapan tertinggi dengan 4.2 mg/g pada 50 mg/L kepekatan benzena. Penjerapan BTX juga meningkat apabila kepekatan

meningkat. Data penjerapan menunjukkan kesesuaian yang baik dengan isoterma Freundlich dan model kinetik tertib pseudo kedua. Kapasiti penjerapan busa PDMS mengikut urutan  $X>T>B$ . Berdasarkan penemuan eksperimen, busa PDMS adalah penyerap yang menjanjikan kestabilan dan kebolehgunaan semula yang tinggi untuk penyingkiran BTX daripada air.

**Kata kunci:** Busa PDMS, Isoterma Jerapan, Kinetik Jerapan, Penyingkiran BTX Proses Pembusaan Gas.

**SDG:** MATLAMAT 6: Kebersihan Air dan Sanitasi, MATLAMAT 14: Kehidupan di dalam Air

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## LIST OF SYMBOLS

$q_e$	Adsorption capacities at equilibrium	mg/g
$q_t$	Adsorption capacities at time $t$ (min)	mg/g
$K_1$	Pseudo-first-order kinetic model rate constants	L/min
$K_2$	Pseudo-second-order model rate constants	g/mg.min
$K_{dif}$	Intraparticle diffusion model rate constants	mg/g.min <sup>1/2</sup>
$C$	Boundary layer thickness effect	mg/g
$C_e$	Equilibrium concentration of the adsorbate	mg L <sup>-1</sup>
$q_{max}$	Maximum adsorption capacity	mg/g
$K_L$	Adsorption equilibrium Langmuir constant	L/mg
$R_L$	Separation factor	-
$K_F$	Freundlich constant	(mg/g)(L/mg) <sup>1/n</sup>
$n$	Surface heterogeneity	-
$K_T$	Temkin isotherm equilibrium binding constant	L/g
$B_1$	Temkin constant related to heat of sorption	J/mol
$T$	Absolute temperature	K
$\rho$	The density	g/cm <sup>3</sup>
$\rho_{PDMS}$	The density of cured PDMS	g/cm <sup>3</sup>
$P$	The porosity of the foam	%
$W_0$	Foam weights before absorption	g
$W_1$	Foam weights after absorption	g
$W_2$	Weigh of the recovered absorbate	g
$\lambda_{max}$	maximum wavelength	nm
$C_0$	Initial BTX concentrations	mg/L
$V$	Volume of the BTX solution	mg/L

m	Mass of adsorbent	g
$q_e(\text{cal})$	Calculated adsorption capacity	mg/g
$q_e(\text{exp})$	Experimental adsorption capacity	mg/g
$R^2$	Correlation coefficient	-
t	Time	Min



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## LIST OF ABBREVIATIONS

1:1(100)	PDMS foam synthesised at 100°C in a 1:1 NaHCO <sub>3</sub> to acetic acid ratio
1:2(100)	PDMS foam synthesised at 100°C in a 1:2 NaHCO <sub>3</sub> to acetic acid ratio
1:2(120)	PDMS foam synthesised at 120°C in a 1:2 NaHCO <sub>3</sub> to acetic acid ratio
1:2(80)	PDMS foam synthesised at 80°C in a 1:2 NaHCO <sub>3</sub> to acetic acid ratio
2:1(100)	PDMS foam synthesised at 100°C in a 2:1 NaHCO <sub>3</sub> to acetic acid ratio
BTX	Benzene, Toluene, And Xylene
CNT	Carbon nanotube
EDC	(3-Dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride
FESEM	Field emission scanning electron microscopy
FTIR	Fourier transform infrared
IPA	Isopropyl Alcohol
NHS	N-hydroxysuccinimide
PDA	Polydopamine
PDMS	Polydimethylsiloxane
PVA	Polyvinyl Alcohol
Sylgard 184A	Sylgard 184 silicone elastomer pre-polymer
Sylgard 184B	Thermal curing agent
UATR	Universal Attenuated Total Reflectance
VOCs	Volatile Organic Compounds
ZIFs	Zeolitic imidazolate frameworks

# CHAPTER 1

## INTRODUCTION

### 1.1 Research Background

Fresh water is vital for the survival of both humans and wildlife on the planet. However, sea water constitutes about 97.5% of the total water resources on Earth, and human beings are still confronted by a significant freshwater shortage. The availability of safe drinking water is critical to living a healthier life. As a result of the rapidly growing population and industrial activity, biological and chemical pollutants have accumulated in the environment due to the disposal of untreated wastewater (Sajid et al., 2018; Wang et al., 2020a). Industries such as plastics, resins, detergents, paints, inks, adhesives, and the pharmaceutical industry are significant contributors that enhance the concentration of contaminants present in wastewater. The disposable wastes of these industries contain volatile organic compounds such as benzene, toluene, and xylene (BTX), as they are used as starting compounds. (Fayemiwo et al., 2017; Tursi et al., 2020). BTX has harmful effects on human health, even at low concentrations, due to its highly toxic and carcinogenic properties. Moreover, exposure to BTX can lead to irritation of the skin, eyes, and mucous membranes, fatal nervous system deficiencies, and leukemia (Kuppusamy et al., 2020; Tursi et al., 2020). Thus, removing such harmful pollutants from wastewater is a critical global concern.

The two main types of techniques applied to control BTX are destruction and recovery. Catalytic and thermal oxidation and biodegradation are examples of destruction techniques, while absorption, adsorption, and membrane separation are examples of recovery techniques (Lima et al., 2017; Nourmoradi et al., 2012). The sorption process (absorption and adsorption) is proven to be a technically and economically efficient method for organic compound removal from water. Different sorbents, such as commercial organoclay (Lima et al., 2017), activated sludge (Ramteke & Gogate, 2016), activated carbon (Saha et al., 2018), and periodic mesoporous organosilica (Moura et al., 2011), have been used for BTX removal from water. However, there are some difficulties in using these sorbents, such as complex preparation, low working capacity, and low recyclability. Moreover, removing sorbents from the solution requires pre-treatment processes such as filtration or centrifugation, which limits large-scale application. In addition, some of these sorbents produce toxic by-product that cause secondary contamination. Therefore, there is a strict need to develop low-cost, non-toxic, and eco-friendly materials.

Porous polymeric materials such as polydimethylsiloxane (PDMS) have recently attracted significant attention due to their excellent characteristics. PDMS foam has many applications in different fields because of its hydrophobicity, simple fabrication, low cost, remarkable reusability, large surface area, high flexibility, elasticity, and thermal stability. Some of its applications involve sensors, microfluidics, adsorbents, absorbents, and oil/water separation (Michel et al., 2019; Zhao et al., 2014; Zhu et al., 2017).

Many approaches have been applied to prepare PDMS foams, such as porogen leaching (the template method), emulsion templating, and gas foaming. In the porogen leaching method, a porogen like salt, sugar cubes, ZnO powders, Ni foam, or polymer particles is added to the PDMS mixture before it cures. Once cured, the porogen is removed by leaching, leaving a porous structure behind (Choi et al., 2011; Jiang et al., 2023; Sosnin et al., 2020; Turco et al., 2019; Vadalà et al., 2023; Wang et al., 2023a). Although porogen leaching methods have been utilised in numerous studies, they are time-consuming and cannot be used for large-scale synthesis.

The emulsion templating method involves the formation of an emulsion of two immiscible liquids, where one liquid is a continuous phase and the other is a dispersed phase. After polymerization, the dispersed phase is removed, resulting in the formation of a porous structure. Typically, PDMS foams are produced from prepolymer-water emulsions. Several variables, including emulsifier type, polymerization circumstances, and processing parameters, have a substantial impact on the form and properties of the PDMS foams that result (Dong et al., 2022; Juchniewicz et al., 2007; Kovalenko et al., 2016; Kwak et al., 2021; Timusk et al., 2022; Turco et al., 2017; Zhang et al., 2019). However, the emulsion method is also time-consuming and requires hazardous solvents, and the surfactants used in the emulsion method affect the foam's properties and need to be removed.

In the gas foaming technique, a foaming agent is introduced into the processes to produce an inert gas that generates pores with various structures. The gas foaming technique can be physical or chemical (Chen et al., 2016; Tebboth et al., 2015; Wang et al., 2020a). The reported studies that used the gas foaming method to prepare the

PDMS foam were either combined with other methods or used additional harmful solvents, making it complicated and time-consuming. Pore structures and absorption capacity of PDMS foam can be controlled by using different diluent ratios due to their effect on generating gas in the gas foaming technique.

In this work, the PDMS foam was prepared using a new, simple, effective, and time-saving method. In this method, PDMS was polymerized with the addition of  $\text{NaHCO}_3$  as a blowing agent and acetic acid as the catalyst. This method is suitable for large-scale production. A synthesised PDMS foam was tested as an absorbent and adsorbent to remove BTX from water. The sorption capacity of BTX was investigated. To the best of my knowledge, no previous attempts have been reported on the same method of preparation of the PDMS foams as a facile and green synthesis.

## **1.2 Problem statement**

The rapid development in the petrochemical industries has led to water pollution with volatile organic compounds such as BTX components that are threatening humans and the environment. BTX is considered one of the most common contaminants present in surface and groundwater. Because of its severe hazardous and carcinogenic properties, BTX has negative impacts on human health, even at low concentrations. In addition, BTX exposure can cause skin, eye, and mucous membrane irritation, as well as catastrophic nervous system deficits and leukaemia. Therefore, BTX-containing industrial wastewater requires proper treatment prior to discharge to open water.

The sorption process is proven to be a technically and economically efficient method for organic compound removal from water. Different sorbents have been used for BTX removal, such as commercial organoclay, activated sludge, activated carbon, and periodic mesoporous organosilica. However, there are some difficulties in using these sorbents, such as complex preparation, low working capacity, and low recyclability. Recyclability of the sorbents and BTX recovery are significant factors because they permit a decrease in both the cost of waste-water remediation and uncontrolled toxic waste generation. Moreover, removing sorbents from the solution requires pre-treatment processes such as filtration or centrifugation, which limits large-scale application. Hence, The low adsorption capacity and low recyclability of the current sorbents have motivated the search for more efficient sorbent for BTX removal

PDMS foam as a porous polymeric material has many excellent properties, such as its hydrophobicity, simple fabrication, low cost, remarkable reusability, high flexibility, elasticity, and thermal stability. Different techniques have been used to fabricate PDMS foams, including porogen leaching, gaseous blowing agents, and emulsion techniques. However, the porogen leaching technique is time-consuming and requires hazardous solvents, while the surfactants used in the emulsion method affect the foam's properties and need to be removed. Additionally, the reported studies that used the gas foaming method to prepare the PDMS foam were either combined with other methods or used additional harmful solvents, making it a complicated, time-consuming, and non-eco-friendly method. Therefore, there is a strict need to develop non-toxic and eco-friendly materials using low-cost, simple, fast, and green synthesis methods.

### 1.3 Significance of the research

There is tremendous stress on global environments and natural resources due to the growing population and rapid industrial development. The use of these resources must be efficient and economically viable in order to achieve sustainable development. The use of these resources must be efficient and economically viable in order to achieve sustainable development. Therefore, it is important to monitor and manage human activities in terms of potential environmental impacts and apply cost-effective and efficient remediation techniques. This study involves the use of PDMS foam to improve water quality by effectively removing BTX, which can be harmful to both human health and the environment, even at low concentrations. The foam is made from eco-friendly components, no toxic ingredients are used, and no waste materials result from the preparation process, which promotes green chemistry. The outstanding reusability of the PDMS foam makes it a practical and sustainable choice for clean-up tasks. Additionally, the foam has excellent selectivity, ensuring that it only absorbs the desired contaminants, leaving the surrounding water or environment relatively unaffected and helping in the recovery of spilled oils and organic compounds. The findings of this research will be useful in developing effective methods of water treatment instead of the conventional methods that require more effort to remove sorbent materials from the treated water, making them suitable for large-scale applications and easy to handle. The results can be used to optimise the foam synthesis process and tailor the material properties to meet the specific requirements of applications. Additionally, the sorption of BTX by PDMS foam can be applied both in situ and ex situ to achieve economical treatment efficiencies.

#### **1.4 Research Goal and Objectives**

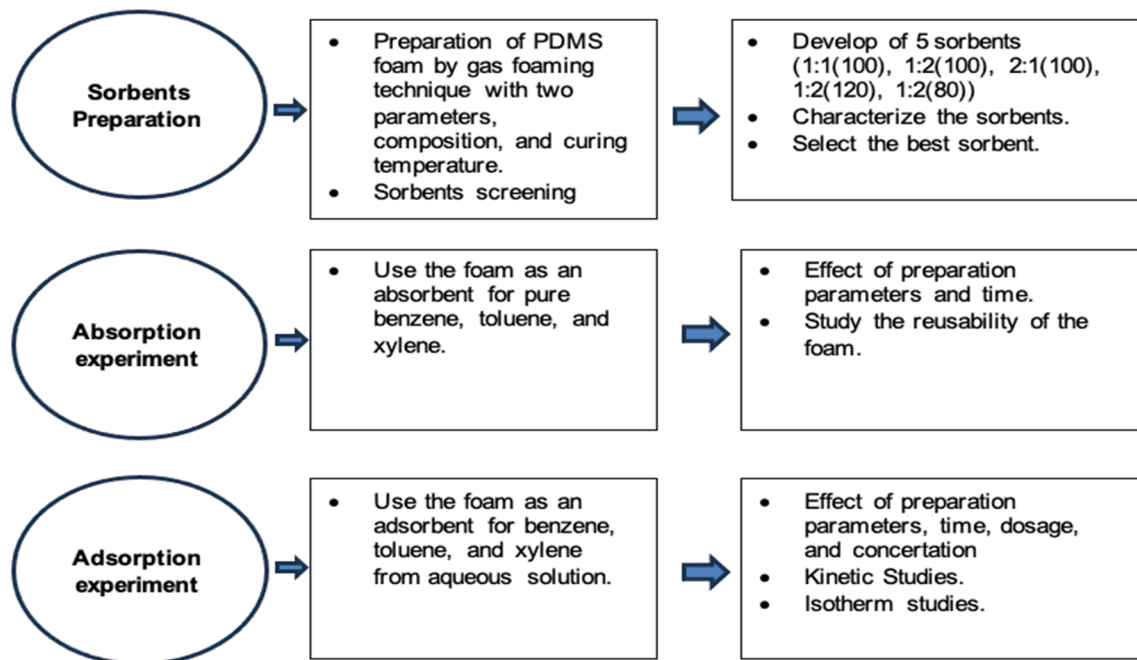
The main goal of this project is to fabricate an efficient PDMS foam, via green method, for removing BTX from water. These goals would be achieved through the following objectives:

- i. To determine the best formulation and reaction conditions for the preparation of the PDMS foam by gas foaming method.
- ii. To characterise PDMS foams and evaluate the effect of preparation conditions on the mechanical and physical properties of the PDMS foam.
- iii. To evaluate the absorption and reusability of PDMS foam for BTX absorption.
- iv. To evaluate the efficiency of PDMS foams to remove BTX from water by adsorption technique.

#### **1.5 Scope of the Study**

This research focused on the preparation and application of PDMS foam as a non-toxic and eco-friendly sorbent to remove BTX from water. Sorption is a general term that includes both absorption and adsorption. At low concentrations, the process of adsorption occurs, while at high concentrations (higher than the solubility of BTX compounds in water), the absorption process dominates. Both cases were studied for the removal of BTX from water by PDMS foam, depending on the conditions of the experiment. In the absorption experiment, the ability of PDMS foam to absorb pure BTX as well as absorb it from the water surface. In addition, the reusability of the PDMS foam for the absorption process of BTX would be studied. In the adsorption experiment, the effect of several operating parameters, such as preparation condition, initial BTX concentration, contact time, and sorbent dosage, on the BTX removal

efficiency of the PDMS foam would be investigated. Figure 1.1 schematically illustrates the main scope of this research.



**Figure 1.1: The main scope of the research work**

## 1.6 Novelty of the Research

This work introduces a new method for the preparation of PDMS foam, which involves green materials and processes with minimal environmental impact. PDMS foam was prepared using sodium bicarbonate as the chemical blowing agent, and acetic acid acted as a catalyst. The gas foaming method is an established method to produce foam. Based on a literature search, there is limited work reported on the formation of PDMS foam by this method. HCl and HNO<sub>3</sub> (strong acid) are the most commonly used catalysts for the gas foaming method. This is the first work to report the use of acetic acid, a weak acid, as a catalyst in the gas foaming method to produce PDMS foam. Acetic acid promotes the chemical decomposition of sodium bicarbonate to produce carbon dioxide gases that form the

foam structure. Using sodium bicarbonate and acetic acid can be considered more environmentally friendly than traditional methods using different types of hazardous solvents. These materials are non-toxic, eco-friendly, and can be easily removed from the foam after foaming, leaving no residues and reducing the environmental impact. This method is extremely facile, low cost, fast, and green.



## REFERENCES

- Abdel-Aziz, M. A., Younis, S. A., Moustafa, Y. M., & Khalil, M. M. H. (2019). Synthesis of recyclable carbon/lignin biocomposite sorbent for in-situ uptake of BTX contaminants from wastewater. *Journal of environmental management*, 233, 459-470.
- Adebajo, M. O., Frost, R. L., Klopogge, J. T., Carmody, O., & Kokot, S. (2003). Porous materials for oil spill cleanup: a review of synthesis and absorbing properties. *Journal of Porous materials*, 10, 159-170.
- Aivalioti, M., Pothoulaki, D., Papoulias, P., & Gidarakos, E. (2012). Removal of BTEX, MTBE and TAME from aqueous solutions by adsorption onto raw and thermally treated lignite. *Journal of Hazardous Materials*, 207–208, 136–146. <https://doi.org/10.1016/j.jhazmat.2011.04.084>
- Ajmal, M., Demirci, S., Uzun, Y., Siddiq, M., Aktas, N., & Sahiner, N. (2016). Introduction of double amidoxime group by double post surface modification on poly(vinylbenzyl chloride) beads for higher amounts of organic dyes, As (V) and Cr (VI) removal. *Journal of Colloid and Interface Science*, 470, 39–46. <https://doi.org/10.1016/j.jcis.2016.02.040>
- Al-Lami, H. S., Abdulwahid, A. A., & Mizhir, A. A. (2022). Adsorption process for removing hazardous Congo red dye from aqueous solutions: isotherm, kinetic, and thermodynamic studies. *Desalination and Water Treatment*, 280, 177–187. <https://doi.org/10.5004/dwt.2022.29114>
- Alshameri, A., Yan, C., Al-Ani, Y., Dawood, A. S., Ibrahim, A., Zhou, C., & Wang, H. (2014). An investigation into the adsorption removal of ammonium by salt activated Chinese (Hulaodu) natural zeolite: Kinetics, isotherms, and thermodynamics. *Journal of the Taiwan Institute of Chemical Engineers*, 45(2), 554–564. <https://doi.org/10.1016/j.jtice.2013.05.008>
- Amelio, M., & Morrone, P. (2007). Numerical evaluation of the energetic performances of structured and random packed beds in regenerative thermal oxidizers. *Applied Thermal Engineering*, 27(4), 762–770. <https://doi.org/10.1016/j.applthermaleng.2006.10.016>
- Ayawei, N., Ebelegi, A. N., & Wankasi, D. (2017). Modelling and interpretation of adsorption isotherms. *Journal of chemistry*, 2017. <https://doi.org/10.1155/2017/3039817>
- Aziz, A., Kim, M., Kim, S., & Kim, K. S. (2017). adsorption and kinetic studies of volatile organic compounds (vocs) on seed assisted template free zsm-5 zeolite in air. *Journal of Nanotechnology & Advanced Materials*, 5(1), 1. <https://doi.org/10.18576/jnam/050101>

- Balzer, R., Drago, V., Schreiner, W. H., & Probst, L. F. D. (2014). Synthesis and structure-activity relationship of a WO<sub>3</sub> catalyst for the total oxidation of BTX. *Journal of the Brazilian Chemical Society*, 25(11), 2026–2031. <https://doi.org/10.5935/0103-5053.20140187>
- Bandura, L., Kołodyńska, D., & Franus, W. (2017). Adsorption of BTX from aqueous solutions by Na-P1 zeolite obtained from fly ash. *Process Safety and Environmental Protection*, 109, 214–223. <https://doi.org/10.1016/j.psep.2017.03.036>
- Belessi, V., Romanos, G., Boukos, N., Lambropoulou, D., & Trapalis, C. (2009). Removal of Reactive Red 195 from aqueous solutions by adsorption on the surface of TiO<sub>2</sub> nanoparticles. *Journal of Hazardous Materials*, 170(2–3), 836–844. <https://doi.org/10.1016/j.jhazmat.2009.05.045>
- Boscaini, E., Alexander, M. L., Prazeller, P., & Märk, T. D. (2004). Investigation of fundamental physical properties of a polydimethylsiloxane (PDMS) membrane using a proton transfer reaction mass spectrometer (PTRMS). *International Journal of Mass Spectrometry*, 239(2–3), 179–186. <https://doi.org/10.1016/j.ijms.2004.08.011>
- Buckley, T., Xu, X., Rudolph, V., Firouzi, M., & Shukla, P. (2022). Review of foam fractionation as a water treatment technology. *Separation Science and Technology*, 57(6), 929–958. <https://doi.org/10.1080/01496395.2021.1946698>
- Carvalho, M. N., da Motta, M., Benachour, M., Sales, D. C. S., & Abreu, C. A. M. (2012). Evaluation of BTEX and phenol removal from aqueous solution by multi-solute adsorption onto smectite organoclay. *Journal of Hazardous Materials*, 239–240, 95–101. <https://doi.org/10.1016/j.jhazmat.2012.07.057>
- Ceylan, D., Dogu, S., Karacik, B., Yakan, S. D., Okay, O. S., & Okay, O. (2009). Evaluation of butyl rubber as sorbent material for the removal of oil and polycyclic aromatic hydrocarbons from seawater. *Environmental Science and Technology*, 43(10), 3846–3852. <https://doi.org/10.1021/es900166v>
- Chang, Q. (2016). Emulsion, foam, and gel. *Colloid and Interface Chemistry for Water Quality Control*, Elsevier, 227–245. <https://doi.org/10.1016/b978-0-12-809315-3.00011-6>
- Chavan, A. A., Li, H., Scarpellini, A., Marras, S., Manna, L., Athanassiou, A., & Fragouli, D. (2015). Elastomeric nanocomposite foams for the removal of heavy metal ions from water. *ACS Applied Materials and Interfaces*, 7(27), 14778–14784. <https://doi.org/10.1021/acsami.5b03003>
- Chen, S., Zhuo, B., & Guo, X. (2016). Large area one-step facile processing of microstructured elastomeric dielectric film for high sensitivity and durable sensing over wide pressure range. *ACS Applied Materials and Interfaces*, 8(31), 20364–20370. <https://doi.org/10.1021/acsami.6b05177>

- Choi, S. J., Kwon, T. H., Im, H., Moon, D. Il, Baek, D. J., Seol, M. L., Duarte, J. P., & Choi, Y. K. (2011). A polydimethylsiloxane (PDMS) sponge for the selective absorption of oil from water. *ACS Applied Materials and Interfaces*, 3(12), 4552–4556. <https://doi.org/10.1021/am201352w>
- Chuang, K. T., Cheng, S., & Tong, S. (1992). Removal and destruction of benzene, toluene, and xylene from wastewater by air stripping and catalytic oxidation. *Industrial and Engineering Chemistry Research*, 31(11), 2466–2472. <https://doi.org/10.1021/ie00011a010>
- Colosi, C., Costantini, M., Barbetta, A., Pecci, R., Bedini, R., & Dentini, M. (2013). Morphological comparison of PVA scaffolds obtained by gas foaming and microfluidic foaming techniques. *Langmuir*, 29(1), 82–91. <https://doi.org/10.1021/la303788z>
- Cossu, R., Ehrig, H. J., & Muntoni, A. (2019). Physical-chemical leachate treatment. In *Solid Waste Landfilling. Concepts, Processes, Technologies* (pp. 575-632). Elsevier.
- da Costa, J. S., Bertizzolo, E. G., Bianchini, D., & Fajardo, A. R. (2021). Adsorption of benzene and toluene from aqueous solution using a composite hydrogel of alginate-grafted with mesoporous silica. *Journal of Hazardous Materials*, 418. <https://doi.org/10.1016/j.jhazmat.2021.126405>
- da Luz, C., de Arruda Guelli Ulson de Souza, S. M., Ulson de Souza, A. A., Dervanoski, A., de Oliveira Samel Moraes, A., & Wood, B. D. (2018). A multiscale model for carbon adsorption of BTX compounds: Comparison of volume averaging theory and experimental measurements. *Chemical Engineering Science*, 184, 285–308. <https://doi.org/10.1016/j.ces.2018.02.047>
- Dardouri, M., Ammari, F., BelHadj Amor, A., & Meganem, F. (2018). Adsorption of cadmium (II), zinc (II) and iron (III) from water by new cross-linked reusable polystyrene adsorbents. *Materials Chemistry and Physics*, 216, 435–445. <https://doi.org/10.1016/j.matchemphys.2018.06.002>
- Dean, B. J. (1978). Genetic toxicology of benzene, toluene, xylenes and phenols. *Mutation Research/Reviews in Genetic Toxicology*, 47(2), 75-97.
- Denkov, N., Tcholakova, S., & Politova-Brinkova, N. (2020). Physicochemical control of foam properties. *Current Opinion in Colloid and Interface Science*, 50, 101376. <https://doi.org/10.1016/j.cocis.2020.08.001>
- Doğan, M., Alkan, M., Demirbaş, Ö., Özdemir, Y., & Özmetin, C. (2006). Adsorption kinetics of maxilon blue GRL onto sepiolite from aqueous solutions. *Chemical Engineering Journal*, 124(1–3), 89–101. <https://doi.org/10.1016/j.cej.2006.08.016>
- Dong, Y., Wang, L., Xia, N., Yang, Z., Zhang, C., Pan, C., ... & Zhang, L. (2022). Untethered small-scale magnetic soft robot with programmable magnetization and integrated multifunctional modules. *Science advances*, 8(25), eabn8932. <https://doi.org/10.1126/sciadv.abn8932>

- Du, Z., Deng, S., Bei, Y., Huang, Q., Wang, B., Huang, J., & Yu, G. (2014). Adsorption behavior and mechanism of perfluorinated compounds on various adsorbents—A review. *Journal of hazardous materials*, 274, 443-454. Elsevier. <https://doi.org/10.1016/j.jhazmat.2014.04.038>
- Duan, S., Yang, K., Wang, Z., Chen, M., Zhang, L., Zhang, H., & Li, C. (2016). fabrication of highly stretchable conductors based on 3d printed porous poly(dimethylsiloxane) and conductive carbon nanotubes/graphene network. *ACS Applied Materials and Interfaces*, 8(3), 2187–2192. <https://doi.org/10.1021/acsami.5b10791>
- El-Naas, M. H., Acio, J. A., & El Telib, A. E. (2014). Aerobic biodegradation of BTEX: Progresses and Prospects. *Journal of Environmental Chemical Engineering*, 2(2), 1104–1122. <https://doi.org/10.1016/j.jece.2014.04.009>
- Fayemiwo, O. M., Daramola, M. O., & Moothi, K. (2017). Btex compounds in water – future trends and directions for water treatment. *Water SA*, 43(4), 602–613. <https://doi.org/10.4314/wsa.v43i4.08>
- Fechtman, M. C. (2013). *Development of a Novel Process to Fabricate Hierarchical Microporous Open-Cell Polymer Foam, Thesis, Rutgers, The State University of New Jersey, USA.*
- Foo, K. Y., & Hameed, B. H. (2010). Insights into the modeling of adsorption isotherm systems. *Chemical engineering journal*, 156(1), 2-10. <https://doi.org/10.1016/j.cej.2009.09.013>
- Fytianos, K., Voudrias, E., & Kokkalis, E. (2000). Sorption–desorption behaviour of 2, 4-dichlorophenol by marine sediments. *Chemosphere*, 40(1), 3-6.
- Ge, J. C., & Choi, N. J. (2019). Performance of electrospun nanofibrous membranes for trapping of BTX aromatic hydrocarbons and heavy metal ions: Mechanisms, isotherms and kinetics. *Journal of Cleaner Production*, 217, 388–397. <https://doi.org/10.1016/j.jclepro.2019.01.196>
- Ghosal, P. S., & Gupta, A. K. (2017). Determination of thermodynamic parameters from Langmuir isotherm constant-revisited. *Journal of Molecular Liquids*, 225, 137–146. <https://doi.org/10.1016/j.molliq.2016.11.058>
- González-Rivera, J., Iglío, R., Barillaro, G., Duce, C., & Tinè, M. R. (2018). Structural and thermoanalytical characterization of 3D porous PDMS foam materials: The effect of impurities derived from a sugar templating process. *Polymers*, 10(6), 616. <https://doi.org/10.3390/polym10060616>
- Grissom, T. G., Sharp, C. H., Usov, P. M., Troya, D., Morris, A. J., & Morris, J. R. (2018). Benzene, toluene, and xylene transport through uio-66: diffusion rates, energetics, and the role of hydrogen bonding. *Journal of Physical Chemistry C*, 122(28), 16060–16069. <https://doi.org/10.1021/acs.jpcc.8b03356>
- Guan, Y., Cheng, F., & Pan, Z. (2019). Superwetting polymeric three dimensional (3d) porous materials for oil/water separation: A review. *Polymers*, 11(5), 806. <https://doi.org/10.3390/polym11050806>

- Guelli Ulson De Souza, S. M., Da Luz, A. D., Da Silva, A., & Ulson De Souza, A. A. (2012). Removal of mono- and multicomponent BTX compounds from effluents using activated carbon from coconut shell as the adsorbent. *Industrial and Engineering Chemistry Research*, 51(18), 6461–6469. <https://doi.org/10.1021/ie2026772>
- Guo, J., Wang, J., Wang, W., Bai, Z., Zhang, Z., Zhang, Y., & Zhang, S. (2019). The fabrication of 3D porous PDMS sponge for Oil and organic solvent absorption. *Environmental Progress and Sustainable Energy*, 38(s1), S86–S92. <https://doi.org/10.1002/ep.12924>
- Guo, M., Liang, H., Luo, Z., Chen, Q., & Wei, W. (2016). Study on melt-blown processing, web structure of polypropylene nonwovens and its BTX adsorption. *Fibers and Polymers*, 17(2), 257–265. <https://doi.org/10.1007/s12221-016-5592-y>
- Gupta, R., & Kulkarni, G. U. (2011). Removal of organic compounds from water by using a gold nanoparticle-poly(dimethylsiloxane) nanocomposite foam. *ChemSusChem*, 4(6), 737–743. <https://doi.org/10.1002/cssc.201000410>
- He, C., Cheng, J., Zhang, X., Douthwaite, M., Pattisson, S., & Hao, Z. (2019). Recent advances in the catalytic oxidation of volatile organic compounds: a review based on pollutant sorts and sources. *Chemical reviews*, 119(7), 4471–4568. <https://doi.org/10.1021/acs.chemrev.8b00408>
- He, X., Lin, S., Feng, X., & Pan, Q. (2021). Synthesis and modification of polyurethane foam doped with multi-walled carbon nanotubes for cleaning up spilled oil from water. *Journal of Polymers and the Environment*, 29(4), 1271–1286. <https://doi.org/10.1007/s10924-020-01942-1>
- He, Y., Lu, X., Wu, D., Zhou, M., He, G., Zhang, J., Zhang, L., Liu, H., & Liu, C. (2023). CNT/PDMS conductive foam-based piezoresistive sensors with low detection limits, excellent durability, and multifunctional sensing capability. *Sensors and Actuators A: Physical*, 114408. <https://doi.org/10.1016/j.sna.2023.114408>
- Herren, B., Webster, V., Davidson, E., Saha, M. C., Altan, M. C., & Liu, Y. (2021). Pdms sponges with embedded carbon nanotubes as piezoresistive sensors for human motion detection. *Nanomaterials*, 11(7). <https://doi.org/10.3390/nano11071740>
- Hickman, R., Walker, E., & Chowdhury, S. (2018). TiO<sub>2</sub>-PDMS composite sponge for adsorption and solar mediated photodegradation of dye pollutants. *Journal of water process engineering*, 24, 74–82. <https://doi.org/10.1016/j.jwpe.2018.05.015>
- Ho, Y.-S. (2004). Citation review of Lagergren kinetic rate equation on adsorption reactions. *Scientometrics*, 59(1), 171–177.
- Hou, L., Li, X., Xie, D., & Wang, H. (2018). Effects of BTEX on the removal of acetone in a coaxial non-thermal plasma reactor: Role analysis of the methyl group. *Molecules*, 23(4). <https://doi.org/10.3390/molecules23040890>

- Hristovski, K. D., & Markovski, J. (2017). Engineering metal (hydr)oxide sorbents for removal of arsenate and similar weak-acid oxyanion contaminants: A critical review with emphasis on factors governing sorption processes. *Science of the Total Environment*, 598, 258–271. <https://doi.org/10.1016/j.scitotenv.2017.04.108>
- Hu, H., & Xu, K. (2019). Physicochemical technologies for HRP and risk control. In *High-Risk Pollutants in Wastewater* (pp. 169–207). Elsevier. <https://doi.org/10.1016/B978-0-12-816448-8.00008-3>
- Hubbe, M. A., Park, J., & Park, S. (2014). Cellulosic substrates for removal of pollutants from aqueous systems: a review. part 4. dissolved petrochemical compounds. *BioResources*, 4(9), 7782–7925.
- Inagaki, M., Qiu, J., & Guo, Q. (2015). Carbon foam: Preparation and application. *Carbon*, 87, 128–152. Elsevier Ltd. <https://doi.org/10.1016/j.carbon.2015.02.021>
- Islam, M., & Patel, R. K. (2007). Evaluation of removal efficiency of fluoride from aqueous solution using quick lime. *Journal of Hazardous Materials*, 143(1–2), 303–310. <https://doi.org/10.1016/j.jhazmat.2006.09.030>
- Jang, Y., Bang, J., Seon, Y. S., You, D. W., Oh, J. S., & Jung, K. W. (2020). Carbon nanotube sponges as an enrichment material for aromatic volatile organic compounds. *Journal of Chromatography A*, 1617. <https://doi.org/10.1016/j.chroma.2019.460840>
- Jiang, H., Zhu, Y., Zhao, G., Tian, A., Li, H., Li, J., Zhao, S., Zhang, G., Gao, A., Cui, J., & Yan, Y. (2023). Preparation and optimization of conductive PDMS composite foams with absorption-dominated electromagnetic interference shielding performance via silvered aramid microfibers. *European Polymer Journal*, 191, 112029. <https://doi.org/10.1016/j.eurpolymj.2023.112029>
- Jodeh, S., Ahmad, R., Suleiman, M., Radi, S., Emran, K. M., Salghi, R., Warad, I., & Hadda, T. Ben. (2015). Kinetics, thermodynamics and adsorption of btx removal from aqueous solution via date-palm pits carbonization using SPME/GC-MS. *Journal of Materials and Environmental Science*, 6(10), 2853–2870.
- Juchniewicz, M., Stadnik, D., Biesiada, K., Olszyna, A., Chudy, M., Brzózka, Z., & Dybko, A. (2007). Porous crosslinked PDMS-microchannels coatings. *Sensors and Actuators, B: Chemical*, 126(1), 68–72. <https://doi.org/10.1016/j.snb.2006.10.041>
- Jung, H. S., Koh, E. H., Mun, C. W., Min, J., Sohng, W., Chung, H., Yang, J. Y., Lee, S., Kim, H. J., Park, S. G., Lee, M. Y., & Kim, D. H. (2019). Hydrophobic hBN-coated surface-enhanced Raman scattering sponge sensor for simultaneous separation and detection of organic pollutants. *Journal of Materials Chemistry C*, 7(42), 13059–13069. <https://doi.org/10.1039/c9tc04299g>
- Kausar, A. (2020). Polydimethylsiloxane-based nanocomposite: present research scenario and emergent future trends. *Polymer-Plastics Technology and Materials*, 59(11), 1148–1166. <https://doi.org/10.1080/25740881.2020.1719149>

- Kim, S. H., Park, J. H., Hong, Y., & Lee, C. Y. (2014). Removal of BTX using granular octyl-functionalized mesoporous silica nanoparticle. *International Biodeterioration and Biodegradation*, 95(PA), 219–224. <https://doi.org/10.1016/j.ibiod.2014.04.016>
- Klomkliang, N., Do, D. D., & Nicholson, D. (2012). Affinity and packing of benzene, toluene, and p-xylene adsorption on a graphitic surface and in pores. *Industrial and Engineering Chemistry Research*, 51(14), 5320–5329. <https://doi.org/10.1021/ie300121p>
- Kong, L., Li, Y., Qiu, F., Zhang, T., Guo, Q., Zhang, X., Yang, D., Xu, J., & Xue, M. (2018). Fabrication of hydrophobic and oleophilic polyurethane foam sponge modified with hydrophobic Al<sub>2</sub>O<sub>3</sub> for oil/water separation. *Journal of Industrial and Engineering Chemistry*, 58, 369–375. <https://doi.org/10.1016/j.jiec.2017.09.050>
- Konggidinata, M. I., Chao, B., Lian, Q., Subramaniam, R., Zappi, M., & Gang, D. D. (2017). Equilibrium, kinetic and thermodynamic studies for adsorption of BTEX onto Ordered Mesoporous Carbon (OMC). *Journal of Hazardous Materials*, 336, 249–259. <https://doi.org/10.1016/j.jhazmat.2017.04.073>
- Kovalenko, A., Zimny, K., Mascaro, B., Brunet, T., & Mondain-Monval, O. (2016). Tailoring of the porous structure of soft emulsion-templated polymer materials. *Soft Matter*, 12(23), 5154–5163. <https://doi.org/10.1039/c6sm00461j>
- Kumar, K. V., & Sivanesan, S. (2006). Pseudo second order kinetics and pseudo isotherms for malachite green onto activated carbon: Comparison of linear and non-linear regression methods. *Journal of Hazardous Materials*, 136(3), 721–726. <https://doi.org/10.1016/j.jhazmat.2006.01.003>
- Kunin, R. (1976). The use of macroreticular polymeric adsorbents for the treatment of waste effluents. *Soc. Plast. Eng*, 22, 248-250.
- Kuppusamy, S., Maddela, N. R., Megharaj, M., & Venkateswarlu, K. (2020). Total Petroleum Hydrocarbons: Environmental Fate, Toxicity, and Remediation. In *Total Petroleum Hydrocarbons: Environmental Fate, Toxicity, and Remediation*. Total Petroleum Hydrocarbons. <https://doi.org/10.1007/978-3-030-24035-6>
- Kwak, Y., Kang, Y., Park, W., Jo, E., & Kim, J. (2021). Fabrication of fine-pored polydimethylsiloxane using an isopropyl alcohol and water mixture for adjustable mechanical, optical, and thermal properties. *RSC Advances*, 11(29), 18061–18067. <https://doi.org/10.1039/d1ra02466c>
- Labouriau, A., Cox, J. D., Schoonover, J. R., Patterson, B. M., Havrilla, G. J., Stephens, T., & Taylor, D. (2007). Mössbauer, NMR and ATR-FTIR spectroscopic investigation of degradation in RTV siloxane foams. *Polymer Degradation and Stability*, 92(3), 414–424. <https://doi.org/10.1016/j.polymdegradstab.2006.11.017>

- Lee, J. N., Park, C., & Whitesides, G. M. (2003). Solvent compatibility of poly(dimethylsiloxane)-based microfluidic devices. *Analytical Chemistry*, 75(23), 6544–6554. <https://doi.org/10.1021/ac0346712>
- Li, X., Zhang, L., Yang, Z., He, Z., Wang, P., Yan, Y., & Ran, J. (2020). Hydrophobic modified activated carbon using PDMS for the adsorption of VOCs in humid condition. *Separation and Purification Technology*, 239(December 2019), 116517. <https://doi.org/10.1016/j.seppur.2020.116517>
- Li, Z., Zhang, Y., Niu, J., Tao, T., Zhao, R., Li, Z., Ye, C., Li, D., & Fan, L. (2019). A porous aromatic framework as a versatile fiber coating for solid-phase microextraction of polar and nonpolar aromatic organic compounds. *Microchimica Acta*, 186(8), 1–8. <https://doi.org/10.1007/s00604-019-3669-1>
- Liang, S., Li, Y., Yang, J., Zhang, J., He, C., Liu, Y., & Zhou, X. (2016). 3D stretchable, compressible, and highly conductive metal-coated polydimethylsiloxane sponges. *Advanced Materials Technologies*, 1(7). <https://doi.org/10.1002/admt.201600117>
- Lima, L. F., De Andrade, J. R., Da Silva, M. G. C., & Vieira, M. G. A. (2017). Fixed bed adsorption of benzene, toluene, and xylene (btx) contaminants from monocomponent and multicomponent solutions using a commercial organoclay. *Industrial and Engineering Chemistry Research*, 56(21), 6326–6336. <https://doi.org/10.1021/acs.iecr.7b00173>
- Liu, L., Chen, J., Zhang, W., Fan, M., Gong, Z., & Zhang, J. (2020a). Graphene oxide/polydimethylsiloxane composite sponge for removing Pb(ii) from water. *RSC Advances*, 10(38), 22492–22499. <https://doi.org/10.1039/d0ra03057k>
- Liu, M., Yu, L., Vudayagiri, S., & Skov, A. L. (2020b). Incorporation of liquid fillers into silicone foams to enhance the electro-mechanical properties. *International Journal of Smart and Nano Materials*, 11(1), 11–23. <https://doi.org/10.1080/19475411.2020.1727061>
- Liu, P., Zhang, Y., Liu, S., Zhang, Y., Du, Z., & Qu, L. (2019). Bio-inspired fabrication of fire-retarding, magnetic-responsive, superhydrophobic sponges for oil and organics collection. *Applied Clay Science*, 172, 19–27. <https://doi.org/10.1016/j.clay.2019.02.015>
- Liyanage, D., & Walpita, J. (2019). Organic pollutants from E-waste and their electrokinetic remediation. In *Handbook of Electronic Waste Management: International Best Practices and Case Studies* (pp. 171–189). Elsevier. <https://doi.org/10.1016/B978-0-12-817030-4.00006-1>
- Lu, T., Zhang, C., Du, F., Zhang, C., Zhang, R., Liu, P., & Li, J. (2023). Mutual inhibition effects on the synchronous conversion of benzene, toluene, and xylene over MnOx catalysts. *Journal of Colloid and Interface Science*, 641, 791–802. <https://doi.org/10.1016/j.jcis.2023.03.103>

- Łuczak, J., Jungnickel, C., Markiewicz, M., & Hupka, J. (2013). Solubilization of benzene, toluene, and xylene (BTX) in aqueous micellar solutions of amphiphilic imidazolium ionic liquids. *Journal of Physical Chemistry B*, 117(18), 5653–5658. <https://doi.org/10.1021/jp3112205>
- Luz, A. D., Guelli Ulson De Souza, S. M. D. A., Da Luz, C., Rezende, R. V. D. P., & Ulson De Souza, A. A. (2013). Multicomponent adsorption and desorption of BTX compounds using coconut shell activated carbon: Experiments, mathematical modeling, and numerical simulation. *Industrial and Engineering Chemistry Research*, 52(23), 7896–7911. <https://doi.org/10.1021/ie302849j>
- Ma, K., Lontas, R., Conn, C. A., Hirasaki, G. J., & Biswal, S. L. (2012). Visualization of improved sweep with foam in heterogeneous porous media using microfluidics. *Soft Matter*, 8(41), 10669–10675. <https://doi.org/10.1039/c2sm25833a>
- Madsen, F. B., Dimitrov, I., Daugaard, A. E., Hvilsted, S., & Skov, A. L. (2013). Novel cross-linkers for PDMS networks for controlled and well distributed grafting of functionalities by click chemistry. *Polymer Chemistry*, 4(5), 1700–1707. <https://doi.org/10.1039/c2py20966g>
- Mamaghanifar, Z., Heydarinasab, A., Ghadi, A., & Binaeian, E. (2020). BTX Removal from Aqueous Solution Using Copper- and Nickel-Modified Zeolite 4A: Kinetic, Thermodynamic, and Equilibrium Studies. *Water Conservation Science and Engineering*, 5(1–2), 1–13. <https://doi.org/10.1007/s41101-019-00079-0>
- Mark, J. E. (2004). Some interesting things about polysiloxanes. *Accounts of Chemical Research*, 37(12), 946–953. <https://doi.org/10.1021/ar030279z>
- Masihi, S., Panahi, M., Maddipatla, D., Hanson, A. J., Bose, A. K., Hajian, S., Palaniappan, V., Narakathu, B. B., Bazuin, B. J., & Atashbar, M. Z. (2021). Highly sensitive porous PDMS-based capacitive pressure sensors fabricated on fabric platform for wearable applications. *ACS Sensors*, 6(3), 938–949. <https://doi.org/10.1021/acssensors.0c02122>
- Mello, J. M. M., Brandão, H. L., Valério, A., de Souza, A. A. U., de Oliveira, D., da Silva, A., & de Souza, S. M. A. G. U. (2019). Biodegradation of BTEX compounds from petrochemical wastewater: Kinetic and toxicity. *Journal of Water Process Engineering*, 32. <https://doi.org/10.1016/j.jwpe.2019.100914>
- Mi, H. Y., Jing, X., Politowicz, A. L., Chen, E., Huang, H. X., & Turng, L. S. (2018). Highly compressible ultra-light anisotropic cellulose/graphene aerogel fabricated by bidirectional freeze drying for selective oil absorption. *Carbon*, 132, 199–209. <https://doi.org/10.1016/j.carbon.2018.02.033>
- Michel, T. R., Capasso, M. J., Cavusoglu, M. E., Decker, J., Zeppilli, D., Zhu, C., Bakrania, S., Kadlowec, J. A., & Xue, W. (2020). Evaluation of porous polydimethylsiloxane/carbon nanotubes (PDMS/CNTs) nanocomposites as piezoresistive sensor materials. *Microsystem Technologies*, 26, 1101–1112. <https://doi.org/10.1007/s00542-019-04636-4>

- Mitra, S., & Roy, P. (2011). BTEX: a serious ground-water contaminant. *research journal of environmental sciences*, 5(5), 394–398. <https://doi.org/10.3923/rjes.2011.394.398>
- Mo, S., Mei, J., Liang, Q., & Li, Z. (2021). Repeatable oil-water separation with a highly-elastic and tough amino-terminated polydimethylsiloxane-based sponge synthesized using a self-foaming method. *Chemosphere*, 271, 129827. <https://doi.org/10.1016/j.chemosphere.2021.129827>
- Moghaddas, M. (2019). Removal of volatile organic compounds (VOCs) by photocatalytic oxidation –A review. *International Journal of Pharmaceutical Research*, 11(1), 518–529. <https://doi.org/10.31838/ijpr/2019.11.01.069>
- Moura, C. P., Vidal, C. B., Barros, A. L., Costa, L. S., Vasconcellos, L. C. G., Dias, F. S., & Nascimento, R. F. (2011). Adsorption of BTX (benzene, toluene, o-xylene, and p-xylene) from aqueous solutions by modified periodic mesoporous organosilica. *Journal of Colloid and Interface Science*, 363(2), 626–634. <https://doi.org/10.1016/j.jcis.2011.07.054>
- Mourabet, M., El Boujaady, H., El Rhilassi, A., Ramdane, H., Bennani-Ziatni, M., El Hamri, R., & Taitai, A. (2011). Defluoridation of water using brushite: equilibrium, kinetic and thermodynamic studies. *Desalination*, 278(1–3), 1–9. <https://doi.org/10.1016/j.desal.2011.05.068>
- Mustafa, S. K., Al-Aoh, H. A., Bani-Atta, S. A., Alrawashdeh, L. R., Aljohani, M. M. H., Alsharif, M. A., Darwish, A. A. A., Al-Shehri, H. S., Ahmad, M. A., Al-Tweher, J. N., & Alfaidi, M. A. (2021). Enhance the adsorption behavior of methylene blue from wastewater by using zncl<sub>2</sub> modified neem (*Azadirachta indica*) leaves powder. *Desalination and Water Treatment*, 209, 367–378. <https://doi.org/10.5004/dwt.2021.26494>
- Nagaraju, P., Vijayakumar, Y., & Ramana Reddy, M. V. (2019). Room-temperature BTEX sensing characterization of nanostructured ZnO thin films. *Journal of Asian Ceramic Societies*, 7(2), 141–146. <https://doi.org/10.1080/21870764.2019.1579401>
- Najib, N. N., Ariff, Z. M., Bakar, A. A., & Sipaut, C. S. (2011). Correlation between the acoustic and dynamic mechanical properties of natural rubber foam: Effect of foaming temperature. *Materials and Design*, 32(2), 505–511. <https://doi.org/10.1016/j.matdes.2010.08.030>
- Nakajima, A., Abe, K., Hashimoto, K., & Watanabe, T. (2000). Preparation of hard super-hydrophobic films with visible light transmission. *Thin Solid Films*, 376(1-2), 140-143.
- Norfatriah, A., Ahmad Syamaizar, A. S., & Zuruzy, A. S. (2018). Application of Porous Polydimethylsiloxane (PDMS) in oil absorption. *IOP Conference Series: Materials Science and Engineering*, 342(1). <https://doi.org/10.1088/1757-899X/342/1/012050>

- Nourmoradi, H., Nikaeen, M., & Khiadani, H. H. (2012). Removal of benzene, toluene, ethylbenzene and xylene (BTEX) from aqueous solutions by montmorillonite modified with nonionic surfactant: Equilibrium, kinetic and thermodynamic study. *Chemical Engineering Journal*, 191, 341–348. <https://doi.org/10.1016/j.cej.2012.03.029>
- Pan, Y., Wang, W., Peng, C., Shi, K., Luo, Y., & Ji, X. (2014). Novel hydrophobic polyvinyl alcohol-formaldehyde foams for organic solvents absorption and effective separation. *RSC Advances*, 4(2), 660–669. <https://doi.org/10.1039/c3ra43907k>
- Pan, Z., Guan, Y., Liu, Y., & Cheng, F. (2021). Facile fabrication of hydrophobic and underwater superoleophilic elastic and mechanical robust graphene/PDMS sponge for oil/water separation. *Separation and Purification Technology*, 261(December 2020), 118273. <https://doi.org/10.1016/j.seppur.2020.118273>
- Pandey, K., Bindra, H. S., Jain, S., & Nayak, R. (2022). Sustainable lotus leaf wax nanocuticles integrated polydimethylsiloxane sorbent for instant removal of oily waste from water. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 634(October 2021), 127937. <https://doi.org/10.1016/j.colsurfa.2021.127937>
- Park, J., Wang, S., Li, M., Ahn, C., Hyun, J. K., Kim, D. S., Kim, D. K., Rogers, J. A., Huang, Y., & Jeon, S. (2012). Three-dimensional nanonetworks for giant stretchability in dielectrics and conductors. *Nature Communications*, 3. <https://doi.org/10.1038/ncomms1929>
- Pasquali 2007. (n.d.).
- Pei, J., & Zhang, J. S. (2011). Critical review of catalytic oxidization and chemisorption methods for indoor formaldehyde removal. *Hvac&R Research*, 17(4), 476-503. <https://doi.org/10.1080/10789669.2011.587587>
- Pinto, J., Athanassiou, A., & Fragouli, D. (2018). Surface modification of polymeric foams for oil spills remediation. *Journal of environmental management*, 206, 872-889. <https://doi.org/10.1016/j.jenvman.2017.11.060>
- Pitois, O. (2012). *Foam Ripening 4.1 Introduction*.
- Pu, Y., Xie, Z., Ye, H., & Shi, W. (2021). Amidation modified waste polystyrene foam as an efficient recyclable adsorbent for organic dyes removal. *Water Science and Technology*, 83(9), 2192–2206. <https://doi.org/10.2166/wst.2021.129>
- Qian, C., Guo, Q., Xu, M., Yuan, Y., & Yao, J. (2015). Improving the SERS detection sensitivity of aromatic molecules by a PDMS-coated Au nanoparticle monolayer film. *RSC Advances*, 5(66), 53306–53312. <https://doi.org/10.1039/c5ra07324c>
- Qiu, S., Bi, H., Hu, X., Wu, M., Li, Y., & Sun, L. (2017). Moldable clay-like unit for synthesis of highly elastic polydimethylsiloxane sponge with nanofiller modification. *RSC Advances*, 7(17), 10479–10486. <https://doi.org/10.1039/C6RA26701G>

- Radhakrishnan, A., Balaganesh, P., Vasudevan, M., Natarajan, N., Chauhan, A., Arora, J., Ranjan, A., Rajput, V. D., Sushkova, S., Minkina, T., Basniwal, R. K., Kapardar, R., & Srivastav, R. (2023). Bioremediation of hydrocarbon pollutants: recent promising sustainable approaches, scope, and challenges. *Sustainability*, *15*(7), 5847. <https://doi.org/10.3390/su15075847>
- Raj, A., & Sinha, S. (2015). Reaction mechanism for the oxidation of aromatic contaminants present in feed gas to claus process. *Physics Procedia*, *66*, 61–64. <https://doi.org/10.1016/j.egypro.2015.02.032>
- Ramteke, L. P., & Gogate, P. R. (2016). Removal of benzene, toluene and xylene (BTX) from wastewater using immobilized modified prepared activated sludge (MPAS). *Journal of Chemical Technology and Biotechnology*, *91*(2), 456–466. <https://doi.org/10.1002/jctb.4599>
- Ren, J., Wu, F., Shang, E., Li, D., & Liu, Y. (2023). 3D printed smart elastomeric foam with force sensing and its integration with robotic gripper. *Sensors and Actuators A: Physical*, *349*. <https://doi.org/10.1016/j.sna.2022.113998>
- Rinaldi, A., Tamburrano, A., Fortunato, M., & Sarto, M. S. (2016). A flexible and highly sensitive pressure sensor based on a PDMS foam coated with graphene nanoplatelets. *Sensors*, *16*(12), 2148. <https://doi.org/10.3390/s16122148>
- Robinson, H. D., Knox, K., Bone, B. D., & Picken, A. (2005). Leachate quality from landfilled MBT waste. *Waste Management*, *25*(4 SPEC. ISS.), 383–391. <https://doi.org/10.1016/j.wasman.2005.02.003>
- Saha, D., Mirando, N., & Levchenko, A. (2018). Liquid and vapor phase adsorption of BTX in lignin derived activated carbon: Equilibrium and kinetics study. *Journal of Cleaner Production*, *182*, 372–378. <https://doi.org/10.1016/j.jclepro.2018.02.076>
- Sahoo, T. R., & Prelot, B. (2020). Adsorption processes for the removal of contaminants from wastewater: The perspective role of nanomaterials and nanotechnology. In *Nanomaterials for the Detection and Removal of Wastewater Pollutants* (pp. 161–222). Elsevier. <https://doi.org/10.1016/B978-0-12-818489-9.00007-4>
- Sajid, M., Nazal, M. K., Ihsanullah, Baig, N., & Osman, A. M. (2018). Removal of heavy metals and organic pollutants from water using dendritic polymers based adsorbents: A critical review. *Separation and Purification Technology*, *191*(June 2017), 400–423. <https://doi.org/10.1016/j.seppur.2017.09.011>
- Salleh, M. A. M., Mahmoud, D. K., Karim, W. A. W. A., & Idris, A. (2011). Cationic and anionic dye adsorption by agricultural solid wastes: a comprehensive review. *Desalination*, *280*(1-3), 1-13. <https://doi.org/10.1016/j.desal.2011.07.019>

- Santiago, F., Lima, S., Pinheiro, T., Silvestre, R. T., Otero, U. B., Tabalipa, M. M., Kosyakova, N., Ornellas, M. H., Liehr, T., & Alves, G. (2017). Benzene poisoning, clinical and blood abnormalities in two Brazilian female gas station attendants: two case reports. *BMC Research Notes*, *10*(1), 1–5. <https://doi.org/10.1186/s13104-016-2369-8>
- Sarma, G. K., Sen Gupta, S., & Bhattacharyya, K. G. (2019). Nanomaterials as versatile adsorbents for heavy metal ions in water: a review. *Environmental Science and Pollution Research*, *26*, 6245–6278. <https://doi.org/10.1007/s11356-018-04093-y>
- Scott, A., Gupta, R., & Kulkarni, G. U. (2010). A simple water-based synthesis of Au nanoparticle/PDMS composites for water purification and targeted drug release. *Macromolecular Chemistry and Physics*, *211*(15), 1640–1647. <https://doi.org/10.1002/macp.201000079>
- Shahbaz, M., Rashid, N., Saleem, J., Mackey, H., McKay, G., & Al-Ansari, T. (2023). A review of waste management approaches to maximise sustainable value of waste from the oil and gas industry and potential for the State of Qatar. *Fuel*, *332*. <https://doi.org/10.1016/j.fuel.2022.126220>
- Shin, J. H., Heo, J. H., Jeon, S., Park, J. H., Kim, S., & Kang, H. W. (2019). Bio-inspired hollow PDMS sponge for enhanced oil–water separation. *Journal of Hazardous Materials*, *365*(October 2018), 494–501. <https://doi.org/10.1016/j.jhazmat.2018.10.078>
- Si, P., Wang, J., Zhao, C., Xu, H., Yang, K., & Wang, W. (2015). Preparation and morphology control of three-dimensional interconnected microporous PDMS for oil sorption. *Polymers for Advanced Technologies*, *26*(9), 1091–1096. <https://doi.org/10.1002/pat.3538>
- Singh, V. P., & Vaish, R. (2019). Candle soot coated polyurethane foam as an adsorbent for removal of organic pollutants from water. *European Physical Journal Plus*, *134*(9). <https://doi.org/10.1140/epjp/i2019-12778-7>
- Sosnin, I. M., Vlassov, S., Akimov, E. G., Agenkov, V. I., & Dorogin, L. M. (2020). Hydrophilic polydimethylsiloxane-based sponges for dewatering applications. *Materials Letters*, *263*, 127278. <https://doi.org/10.1016/j.matlet.2019.127278>
- Su, F., Lu, C., Johnston, K. R., & Hu, S. (2010). Kinetics, thermodynamics, and regeneration of BTEX adsorption in aqueous solutions via NaOCl-Oxidized carbon nanotubes. In *Environanotechnology* (1st ed., Issue X). Elsevier. <https://doi.org/10.1016/B978-0-08-054820-3.00005-8>
- Sun, X., Shi, K., Mo, S., Mei, J., Rong, J., Wang, S., Zheng, X., & Li, Z. (2023). A sustainable reinforced-concrete-structured sponge for highly-recyclable oil adsorption. *Separation and Purification Technology*, *305*. <https://doi.org/10.1016/j.seppur.2022.122483>

- Sun, Y., Li, H., Li, G., Gao, B., Yue, Q., & Li, X. (2016). Characterization and ciprofloxacin adsorption properties of activated carbons prepared from biomass wastes by H<sub>3</sub>PO<sub>4</sub> activation. *Bioresource Technology*, 217, 239–244. <https://doi.org/10.1016/j.biortech.2016.03.047>
- Tamhane, D. U., & Morarka, A. R. (2017). On the attenuation of light by a polydimethylsiloxane (PDMS) foam and its implementation as a weight sensor. *Mapan - Journal of Metrology Society of India*, 32(1), 1–6. <https://doi.org/10.1007/s12647-016-0185-1>
- Tan, H., Tu, S., Zhao, Y., Wang, H., & Du, Q. (2018). A simple and environment-friendly approach for synthesizing macroporous polymers from aqueous foams. *Journal of Colloid and Interface Science*, 509, 209–218. <https://doi.org/10.1016/j.jcis.2017.09.018>
- Tan, K. L., & Hameed, B. H. (2017). Insight into the adsorption kinetics models for the removal of contaminants from aqueous solutions. *Journal of the Taiwan Institute of Chemical Engineers*, 74, 25–48. <https://doi.org/10.1016/j.jtice.2017.01.024>
- Teas, C., Kalligeros, S., Zankos, F., Stournas, S., Lois, E., & Anastopoulos, G. (2001). Investigation of the effectiveness of absorbent materials in oil spills clean up. *Desalination*, 140(3), 259–264.
- Tebboth, M., Jiang, Q., Kogelbauer, A., & Bismarck, A. (2015). Inflatable elastomeric macroporous polymers synthesized from medium internal phase emulsion templates. *ACS Applied Materials and Interfaces*, 7(34), 19243–19250. <https://doi.org/10.1021/acsami.5b05123>
- Timusk, M., Nigol, I. A., Vlassov, S., Oras, S., Kangur, T., Linarts, A., & Šutka, A. (2022). Low-density PDMS foams by controlled destabilization of thixotropic emulsions. *Journal of Colloid and Interface Science*, 626, 265–275. <https://doi.org/10.1016/j.jcis.2022.06.150>
- Torkaman, R., & Kazemian, H. (2010). Removal of BTX compounds from wastewaters using template free mfi zeolitic membrane. In *J. Chem. Chem.* 29 (4), 91-98.
- Tran, D. N. H., Kabiri, S., Sim, T. R., & Losic, D. (2015). Selective adsorption of oil-water mixtures using polydimethylsiloxane (PDMS)-graphene sponges. *Environmental Science: Water Research and Technology*, 1(3), 298–305. <https://doi.org/10.1039/c5ew00035a>
- Turco, A., Pennetta, A., Caroli, A., Mazzotta, E., Monteduro, A. G., Primiceri, E., de Benedetto, G., & Malitesta, C. (2019). Easy fabrication of mussel inspired coated foam and its optimization for the facile removal of copper from aqueous solutions. *Journal of Colloid and Interface Science*, 552, 401–411. <https://doi.org/10.1016/j.jcis.2019.05.059>

- Turco, A., Primiceri, E., Frigione, M., Maruccio, G., & Malitesta, C. (2017). An innovative, fast and facile soft-template approach for the fabrication of porous PDMS for oil-water separation. *Journal of Materials Chemistry A*, 5(45), 23785–23793. <https://doi.org/10.1039/c7ta06840a>
- Tursi, A., Chidichimo, F., Bagetta, R., & Beneduci, A. (2020). BTX removal from open Aqueous systems by modified cellulose fibers and evaluation of competitive evaporation kinetics. *Water (Switzerland)*, 12(11), 1–20. <https://doi.org/10.3390/w12113154>
- Vadalà, M., Kröll, E., Küppers, M., Lupascu, D. C., & Brunstermann, R. (2023). Hydrogen production via dark fermentation by bacteria colonies on porous PDMS-scaffolds. *International Journal of Hydrogen Energy*. <https://doi.org/10.1016/j.ijhydene.2023.03.285>
- Wan Hamad, W. N. F., Teh, P. L., & Yeoh, C. K. (2013). Effect of Acetic Acid as Catalyst on the Properties of Epoxy Foam. *Polymer - Plastics Technology and Engineering*, 52(8), 754–760. <https://doi.org/10.1080/03602559.2012.762375>
- Wang, H., Zhang, R., Yuan, D., Xu, S., & Wang, L. (2020a). Gas Foaming Guided Fabrication of 3D Porous Plasmonic Nanoplatfom with Broadband Absorption, Tunable Shape, Excellent Stability, and High Photothermal Efficiency for Solar Water Purification. *Advanced Functional Materials*, 30(46), 1–8. <https://doi.org/10.1002/adfm.202003995>
- Wang, J., Nguyen, A. V., & Farrokhpay, S. (2016). Effects of surface rheology and surface potential on foam stability. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 488, 70–81. <https://doi.org/10.1016/j.colsurfa.2015.10.016>
- Wang, J., Wu, Y., Cao, Y., Li, G., & Liao, Y. (2020b). Influence of surface roughness on contact angle hysteresis and spreading work. *Colloid and Polymer Science*, 298(8), 1107–1112. <https://doi.org/10.1007/s00396-020-04680-x>
- Wang, L., Fu, J., Jiang, X., & Li, D. (2023a). Efficient extraction approach based on polydimethylsiloxane/ZIF-derived carbons sponge followed by GC–MS for the determination of volatile compounds in cumin. *Food Chemistry*, 405. <https://doi.org/10.1016/j.foodchem.2022.134775>
- Wang, M., & Phillips, T. D. (2023b). Green-engineered barrier creams with montmorillonite-chlorophyll clays as adsorbents for benzene, toluene, and xylene. *Separations*, 10(4). <https://doi.org/10.3390/separations10040237>
- Wang, Z., Li, K., Fingas, M., Sigouin, L., & Ménard, L. (2002). Characterization and source identification of hydrocarbons in water samples using multiple analytical techniques. *Journal of Chromatography A*, 971(1–2), 173–184. [https://doi.org/10.1016/S0021-9673\(02\)01003-8](https://doi.org/10.1016/S0021-9673(02)01003-8)
- Weelink, S. A., Van Eekert, M. H., & Stams, A. J. (2010). Degradation of BTEX by anaerobic bacteria: physiology and application. *Reviews in Environmental Science and Bio/Technology*, 9, 359–385. <https://doi.org/10.1007/s11157-010-9219-2>

- Wilson, L. P., & Bouwer, E. J. (1997). Biodegradation of aromatic compounds under mixed oxygen/denitrifying conditions: a review. *Journal of Industrial Microbiology and Biotechnology*, *18*, 116-130.
- Wongbunmak, A., Khiawjan, S., Suphantharika, M., & Pongtharangkul, T. (2020). BTEX biodegradation by *Bacillus amyloliquefaciens* subsp. *plantarum* W1 and its proposed BTEX biodegradation pathways. *Scientific Reports*, *10*(1). <https://doi.org/10.1038/s41598-020-74570-3>
- Wu, F. C., Tseng, R. L., Huang, S. C., & Juang, R. S. (2009). Characteristics of pseudo-second-order kinetic model for liquid-phase adsorption: A mini-review. *Chemical Engineering Journal*, *151*(1-3), 1-9. <https://doi.org/10.1016/j.cej.2009.02.024>
- Xu, B., Ye, F., Chen, R., Luo, X., Xue, Z., Li, R., & Chang, G. (2023). A supersensitive wearable sensor constructed with PDMS porous foam and multi-integrated conductive pathways structure. *Ceramics International*, *49*(3), 4641-4649. <https://doi.org/10.1016/j.ceramint.2022.09.351>
- Xu, J., Zhu, S., Liu, P., Gao, W., Li, J., & Mo, L. (2017). Adsorption of Cu(II) ions in aqueous solution by aminated lignin from enzymatic hydrolysis residues. *RSC Advances*, *7*(71), 44751-44758. <https://doi.org/10.1039/c7ra06693g>
- Yoon, S., Seok, M., Kim, M., & Cho, Y. H. (2021). Wearable porous PDMS layer of high moisture permeability for skin trouble reduction. *Scientific Reports*, *11*(1), 1-11. <https://doi.org/10.1038/s41598-020-78580-z>
- Yoro, K. O., Amosa, M. K., Sekoai, P. T., Mulopo, J., & Daramola, M. O. (2020). Diffusion mechanism and effect of mass transfer limitation during the adsorption of CO<sub>2</sub> by polyaspartamide in a packed-bed unit. *International Journal of Sustainable Engineering*, *13*(1), 54-67. <https://doi.org/10.1080/19397038.2019.1592261>
- Yu, B., Yuan, Z., Yu, Z., & Xue-song, F. (2022). BTEX in the environment: An update on sources, fate, distribution, pretreatment, analysis, and removal techniques. *Chemical Engineering Journal*, *435*, 134825. <https://doi.org/10.1016/j.cej.2022.134825>
- Yu, C., Yu, C., Cui, L., Song, Z., Zhao, X., Ma, Y., & Jiang, L. (2017). Facile preparation of the porous pdms oil-absorbent for oil/water separation. *Advanced Materials Interfaces*, *4*(3). <https://doi.org/10.1002/admi.201600862>
- Yuen, P. K., Su, H., Goral, V. N., & Fink, K. A. (2011). Three-dimensional interconnected microporous poly(dimethylsiloxane) microfluidic devices. *Lab on a Chip*, *11*(8), 1541-1544. <https://doi.org/10.1039/c0lc00660b>
- Zargar, R., Nourmohammadi, J., & Amoabediny, G. (2016). Preparation, characterization, and silanization of 3D microporous PDMS structure with properly sized pores for endothelial cell culture. *Biotechnology and Applied Biochemistry*, *63*(2), 190-199. <https://doi.org/10.1002/bab.1371>

- Zepeda, A., Texier, A. C., Razo-Flores, E., & Gomez, J. (2006). Kinetic and metabolic study of benzene, toluene and m-xylene in nitrifying batch cultures. *Water Research*, 40(8), 1643–1649. <https://doi.org/10.1016/j.watres.2006.02.012>
- Zhai, W., Xia, Q., Zhou, K., Yue, X., Ren, M., Zheng, G., Dai, K., Liu, C., & Shen, C. (2019). Multifunctional flexible carbon black/polydimethylsiloxane piezoresistive sensor with ultrahigh linear range, excellent durability and oil/water separation capability. *Chemical Engineering Journal*, 372(January), 373–382. <https://doi.org/10.1016/j.cej.2019.04.142>
- Zhang, A., Chen, M., Du, C., Guo, H., Bai, H., & Li, L. (2013). Poly(dimethylsiloxane) oil absorbent with a three-dimensionally interconnected porous structure and swellable skeleton. *ACS Applied Materials and Interfaces*, 5(20), 10201–10206. <https://doi.org/10.1021/am4029203>
- Zhang, J., Li, H., Xu, T., Wu, J., Zhou, S., Hang, Z. H., Zhang, X., & Yang, Z. (2020). Homogeneous silver nanoparticles decorated 3D carbon nanotube sponges as flexible high-performance electromagnetic shielding composite materials. *Carbon*, 165, 404–411. <https://doi.org/10.1016/j.carbon.2020.04.043>
- Zhang, L., Zhang, Y., Chen, P., Du, W., Feng, X., & Liu, B. F. (2019). Paraffin oil based soft-template approach to fabricate reusable porous pdms sponge for effective oil/water separation. *Langmuir*, 35(34), 11123–11131. <https://doi.org/10.1021/acs.langmuir.9b01861>
- Zhao, W., Fierro, V., Pizzi, A., Du, G., & Celzard, A. (2010). Effect of composition and processing parameters on the characteristics of tannin-based rigid foams. Part II: Physical properties. *Materials Chemistry and Physics*, 123(1), 210–217. <https://doi.org/10.1016/j.matchemphys.2010.03.084>
- Zhao, X., Li, L., Li, B., Zhang, J., & Wang, A. (2014). Durable superhydrophobic/superoleophilic PDMS sponges and their applications in selective oil absorption and in plugging oil leakages. *Journal of Materials Chemistry A*, 2(43), 18281–18287. <https://doi.org/10.1039/c4ta04406a>
- Zheng, X., Ji, B., Jiang, R., Cui, Y., Xu, T., Zhou, M., & Li, Z. (2022). Polydimethylsiloxane/carbonized bacterial cellulose sponge for oil/water separation. *Process Safety and Environmental Protection*, 165, 173–180. <https://doi.org/10.1016/j.psep.2022.07.014>
- Zhou, T., Yang, J., Zhu, D., Zheng, J., Handschuh-Wang, S., Zhou, X., Zhang, J., Liu, Y., Liu, Z., He, C., & Zhou, X. (2017). Hydrophilic sponges for leaf-inspired continuous pumping of liquids. *Advanced Science*, 4(6). <https://doi.org/10.1002/advs.201700028>
- Zhu, D., Handschuh-Wang, S., & Zhou, X. (2017). Recent progress in fabrication and application of polydimethylsiloxane sponges. *Journal of Materials Chemistry A*, 5(32), 16467–16497. <https://doi.org/10.1039/c7ta04577h>