

Springer Proceedings in Complexity

Samsul Ariffin Abdul Karim ·
Mohd Fadhlullah Abd Shukur ·
Chong Fai Kait · Hassan Soleimani ·
Hamzah Sakidin *Editors*

Proceedings of the 6th International Conference on Fundamental and Applied Sciences

ICFAS 2020

 Springer

Springer Proceedings in Complexity

Springer Proceedings in Complexity publishes proceedings from scholarly meetings on all topics relating to the interdisciplinary studies of complex systems science. Springer welcomes book ideas from authors. The series is indexed in Scopus.

Proposals must include the following:

- name, place and date of the scientific meeting
- a link to the committees (local organization, international advisors etc.)
- scientific description of the meeting
- list of invited/plenary speakers
- an estimate of the planned proceedings book parameters (number of pages/articles, requested number of bulk copies, submission deadline)

Submit your proposals to: Hisako.Niko@springer.com

More information about this series at <https://link.springer.com/bookseries/11637>


Samsul Ariffin Abdul Karim ·
Mohd Fadhlullah Abd Shukur · Chong Fai Kait ·
Hassan Soleimani · Hamzah Sakidin
Editors

Proceedings of the 6th International Conference on Fundamental and Applied Sciences

ICFAS 2020

 Springer

Editors

Samsul Ariffin Abdul Karim 
Fundamental and Applied Sciences
Universiti Teknologi PETRONAS
Seri Iskandar, Perak, Malaysia

Mohd Fadhlullah Abd Shukur
Fundamental and Applied Sciences
Universiti Teknologi PETRONAS
Seri Iskandar, Perak, Malaysia

Chong Fai Kait
Universiti Teknologi PETRONAS
Seri Iskandar, Perak, Malaysia

Hassan Soleimani
Universiti Teknologi PETRONAS
Seri Iskandar, Perak, Malaysia

Hamzah Sakidin
Universiti Teknologi PETRONAS
Seri Iskandar, Perak, Malaysia

ISSN 2213-8684

ISSN 2213-8692 (electronic)

Springer Proceedings in Complexity

ISBN 978-981-16-4512-9

ISBN 978-981-16-4513-6 (eBook)

<https://doi.org/10.1007/978-981-16-4513-6>

© Institute of Technology PETRONAS Sdn. Bhd. 2021

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Organization

The 6th International Conference on Fundamental and Applied Sciences (ICFAS 2020), 13–15 July 2021

Virtual Event

Organizing Committee

Chairman

Assoc. Prof. Dr. Hanita Daud

Co-chairman

Assoc. Prof. Dr. Maizatul Shima Shaharun

Assoc. Prof. Dr. Vijanth Sagayan

Secretary

Dr. Nooraini Zainuddin

Treasury

Dr. Mohana Sundaram Muthuvalu

Assoc. Prof. Dr. Ibrahima Faye

Technical

Dr. Khairulazhar Jumbri

Assoc. Prof. Dr. Balbir Singh Mahinder Singh

Assoc. Prof. Dr. Chong Fai Kait

Dr. A'fza Shafie

Assoc. Prof. Dr. Hassan Soleimani

Dr. Hayyiratul Fatimah Mohd Zaid

Dr. Hamzah Sakidin
Dr. Lee Kean Chuan
Dr. Lim Jun Wei
Dr. Zulkifli Merican Aljunid Merican

Publication

Dr. Samsul Ariffin Abdul Karim
Assoc. Prof. Dr. Anita Ramli
Assoc. Prof. Dr. Cecilia Devi Wilfred
Assoc. Prof. Dr. Mahmud Othman
Dr. Beh Hoe Guan
Dr. Khe Cheng Seong
Dr. Mohd Fadhlullah Abd Shukur
Dr. Normawati Mohamad Yunus

Sponsorship

Assoc. Prof. Dr. Noor Asmawati Mohd Zabidi
Prof. Dr. Norani Muti Mohamed

Publicity and Protocol

Dr. Dennis Ling Chuan Ching

Event

Dr. Noraini Abd Ghani
Noor Akmal Mohamad Saleh

Logistic

Mohd Faisal Taha

IT and Media

Muhammad Hanif Zahari
Dr. Rajalingam A/L Sokkalingam

Preface

The Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, is honoured to host the Virtual Event of 6th International Conference on Fundamental and Applied Sciences (ICFAS 2020) from 13 to 15 July 2021. It is our pleasure to welcome delegates from Malaysia, Indonesia, Kazakhstan, Nigeria, Vietnam, Pakistan, Ghana, New Zealand and Brunei to share and exchange ideas on the latest advancement in mathematics, chemistry and physics with the theme of “Innovative Science towards Sustainability and Industrial Revolution 4.0”. This conference has certainly provided a platform for sharing and discussion on recent advances in sustainable chemistry, nano and sustainable technology, and mathematical and analytical methods in science and technology. The conference topics include green materials, molecular modelling, catalysis, nanodevices and nanosystems, smart materials applications, solar cell technology, computational mathematics, data analysis and visualization, but not limited to numerical analysis. It is our hope that the contents of this book will benefit researchers, postgraduate students and industrial practitioners in the areas of mathematics, physics and chemistry as most of the topics are in line with IR 4.0. On behalf of the sponsors and the Conference Committees, we would like to gratefully acknowledge all the keynote and invited speakers, presenters and participants in contributing to the success of ICFAS 2020. Special appreciation and thank you to all the reviewers for providing their expertise in improving the quality of the papers, without which this book will not be possible. Finally, thank you to Springer for publishing our conference in Springer Proceedings in Complexity.

Seri Iskandar, Malaysia

Samsul Ariffin Abdul Karim
Mohd Fadhlullah Abd Shukur
Chong Fai Kait
Hassan Soleimani
Hamzah Sakidin

Contents

Sustainable Chemistry

Acoustic Performance of Mixing EFB and OPF Low-Density Fibreboards in Different Thickness	3
Mageswaran Ravi Chandran, Ewe Lay Sheng, Mohammad Nazhan Nasir, Yew Weng Kean, and Zawawi Ibrahim	
Modified Alginate Adsorbent Using Ionic Liquid for Manganese Removal from Aqueous Solution	15
Noor A.'in A. Rahman, Gowri Selvaraj, and Cecilia Devi Wilfred	
Synthesis and Modification of Pour Point Depressant (PPD) Based on Copolymers of α-Olefins and Maleic Anhydride for Waxy Crude Oil	27
Kozhabekov Serik Samsalykovich, Zhubanov Amin Abdirasululy, Donenov Beisen Kainarbaevich, Makhmetova Aliya Ruslanovna, and Abayev Talgat Bakytuly	
Effects of NPK Fertilizers on the Growth, Yield and Chemical Content of Tomato (<i>Lycopersicon esculentum</i> L. Mill)	37
Lyazzat Bekbayeva, Zuraini Zakaria, Tatyana Karpenyuk, Alla Goncharova, El-Sayed Negim, and Kozhanova Kaldanay	
Production of Greener Biodiesel from a Low-Cost CaO Catalysts of Waste Freshwater Shells	51
Nazrizawati Ahmad Tajuddin, Nurul Natasha Shahrom, and Noraini Hamzah	
CO₂ Hydrogenation to Methanol: Effects of Reaction Temperatures and Pellet Crushing on the Catalytic Performance	61
Nor Hafizah Berahim, Noor Asmawati Mohd Zabidi, Nadia Syazana Abd Halim, Akbar Abu Seman, and Nor Hafizah Yasin	

Catalytic Conversion of CO₂ into Alcohols: Comparison of Supports	71
Nur Insyirah Zulkifli and Noor Asmawati Mohd Zabidi	
Raman Spectroscopy of TiO₂ Nanoparticles Synthesized by Hydrolysis of TiCl₄: Effect of Sulfate Ions Concentration	85
Kar Mun Lee, Chong Fai Kait, Jun Wei Lim, and Geok Bee Teh	
Growth of <i>Lactobacillus casei</i> and <i>Propionibacterium jensenii</i> in Different Glucose Concentration and Incubation Temperature	97
S. M. Mohamed Esivan, R. Rashid, A. Jati, and N. A. Zaharudin	
A Comparison of Two Methods for the Development of Low-Cost Carbonaceous Adsorbent from Rubber-Seed Shell (RSS)	107
Syeda Saba Fatima, Azry Borhan, and Muhammad Faheem	
Adsorptive Removal of Bisphenol A Using Zeolitic Imidazolate Framework (ZIF-8)	117
Afzan Mahmad, Maizatul Shima Shaharun, Zakariyya Uba Zango, Teh Ubaidah Noh, and Bahrudin Saad	
Inclusion Complexes of β-Cyclodextrin/Pioglitazone and β-Cyclodextrin-Ionic Liquid/Pioglitazone: Spectroscopic Methods Combined with Molecular Docking Studies	131
Nurul Yani Rahim, Nur Najihah Md Zuki, Khairulazhar Jumbri, Sharifah Mohamad, Ninie Suhana Abdul Manan, Nadiyah Sidek, Yih Hui Boon, and Muggundha Raoov Ramachandran	
Mechanism of Alkaline Surfactant Polymer in Oil-Water Interface: Physicochemical of Fluid Rheology, Interfacial Tension and Molecular Dynamics Simulation	147
Mohd Sofi Numin, Khairulazhar Jumbri, Anita Ramli, and Noorazlenawati Borhan	
Free Energy Calculation of CO₂ in Cholinium-Based Amino Acid Ionic Liquids	157
Fitri Norizatie Salehin, Khairulazhar Jumbri, Anita Ramli, Mohd Azlan Kassim, and Mohd Faisal Taha	
Microwave-Assisted Solvothermal Liquefaction of Kenaf Stalks for Bio-oil Production	175
Anita Ramli, Lai Weng Kin, Nur Akila Syakida Idayu Khairul Anuar, Normawati M. Yunus, and Nurul Jannah Abd Rahman	
Interaction of TFSI-Imidazole and TFSI-Pyridinium ILs with MOFs from Molecular Docking Simulation	185
Nor Ain Fathihah Abdullah, Khairulazhar Jumbri, and Nurul Yani Rahim	

Impact of Photoperiod on the Carbon Metabolic Pathways of <i>Chlorella Vulgaris</i> for Biomass Production and Nutrient Removal in Treating Nutrient-Rich Wastewater	195
Nur Afiqah Mohamad Saman, Wai Hong Leong, Hemamalini Rawindran, Mardawani Mohamad, Muslim Abdurrahman, and Jun Wei Lim	
Effect of Anodization Voltage on TiO₂ Nanotubes for Photodegradation of Formaldehyde	203
Nurul Tasnim Sahrin, Chong Fai Kait, Lee Siew Ling, and Mohd Dzul Hakim Wirzal	
Molecular Dynamics Simulation of H₂S Solubility in Protic Ionic Liquids	213
Sorfina Amran, Mohamad Amirul Ashraf Mohd Razip, Khairulazhar Jumbri, and Mohd Faisal Taha	
Synthesis and Characterization of Nickel–Magnesium Catalyst Supported on Reduced Graphene Oxide	225
Nur Diyan Mohd Ridzuan, Maizatul Shima Shaharun, Israf Ud Din, and Poppy Puspitasari	
UiO-66 and ZIF-8 Metal-organic Frameworks for Acenaphthene Adsorption	239
Zakariyya Uba Zango, Anita Ramli, Khairulazhar Jumbri, and Muslim Abdurrahman	
The Simplex Lattice Design of Experiments: Formulation of Low-IFT Foam Surfactant for EOR Application	255
Nur Fatin Syazwanie Zahari, Anita Ramli, Norhidayah Ahmad Wazir, Wasan Saphanuchart, and Khaled Abdalla Elraies	
Effects of Metal Ratio and Promoter on Physicochemical Properties of CuFe Catalyst	271
Nor Hafizah Berahim, Nabilah Saafie, Onn Chiew Mey, Nur Amirah Suhaimi, Nur Insyirah Zulkifli, and Noor Asmawati Mohd Zabidi	
Ultrasonication Assisted Extraction of Lipids from <i>Chlorella vulgaris</i> with [Bmim][MeSO₄] as an Additive	281
Ninna Sakina Binti Azman, Noraini Abd Ghani, and Lam Man Kee	
Nano and Sustainable Technology	
Role of Surface Modification in Synthesis of Structurally Well-Defined Silica Nanoparticles for Oil and Gas Applications	293
Hasnah Mohd Zaid, Muhammad Adil, and Mohd Arif Agam	

Sensitivity of Nickel Oxide Nanoflakes Layer on Extend Gate Field Effect Transistor for pH Sensor 303
Dauda Abubakar, Naser M. Ahmed, and Zakariyya Uba Zango

Synthesis and Characterization of Nickel–Cobalt Oxide (NiCo₂O₄) for Promising Supercapacitor Material 315
Poppy Puspitasari, Mahdalena Julia, Avita Ayu Permanasari, Maizatul Shima Shaharun, Timotius Pasang, and Muhamad Fatikul Arif

Microwave Absorption of Coconut Wasted Derived Activated Carbon 327
Hassan Soleimani, Jemilat Yetunde Yusuf, Noorhana Yahya, Amir Reza Sadrolhosseini, Maziyar Sabet, and Lawal Adebayo Lanre

Assessment of In-Depth Transport and Retention of Zinc Oxide Nanoparticles Using a Coreflood Approach 337
Mohammed Falalu Hamza, Hassan Soleimani, Abdelazim Abbas Ahmed, and Hassan Ali

Application of ANN Model in Sandstone Reservoir Using Electromagnetic Parameters for Predicting Recovery Factor 347
Surajudeen Sikiru, Hassan Soleimani, and Noorhana Yahya

Design and FEA Analysis of MEMS Acoustic Sensors for High Voltage Applications 357
Farooq Ahmad, Ayesha Rafique, and Syed Muhammad Arslan Gilani

Hubbard’s Modified Density Functional Theory Calculations for the Electronic Structure and Optical Properties of Carbon Doped Anatase TiO₂ 371
Norani Muti Mohamed, Farman Ullah, Robabeh Bashiri, Chong Fai Kait, Mohamed Shuaib Mohamed Saheed, and Muhammad Umair Shahid

Temperature-Conductivity Relationship of Solid Polymer Electrolyte Membrane Based on PVA-K₂CO₃ 383
Bashir Abubakar Abdulkadir, John Ojur Dennis, Mohd Fadhllullah Abd Shukur, Mohamed Mahmoud Elsayed Nasef, and Fahad Usman

Simulation and Experimental Study for Electromagnetic Absorption in Sandstone with SrFeO₃ Nanofluid 393
Hassan Ali, Hassan Soleimani, Noorhana Yahya, and Mohammed Falalu Hamza

Flexible Photoelectrode Based on Binder-Free Paste for Dye-Sensitized Solar Cell	403
Norani Muti Mohamed, Muhammad Umair Shahid, Kamilah Ramly, Balbir Singh Mahinder Singh, Chong Fai Kait, Siti Noor Azella Zaine, and Farman Ullah	
Ni-Doped TiO₂ Nanotubes for Low Concentration H₂ Sensing	413
Summaira Abbasi, Norani Muti Mohamed, Balbir Singh Mahinder Singh, and Mohamed Shuaib Mohamed Saheed	
Effect of Nickel Doping on the Optical and Morphological Properties of Titanium Dioxide Nanotubes	423
Summaira Abbasi, Norani Muti Mohamed, Balbir Singh Mahinder Singh, Asad Mumtaz, and Mohamed Shuaib Mohamed Saheed	
Performance of Organic Polymer Electrolyte Based on Extracted Aloe Vera Polysaccharide Compared with Mannose, Agarose and Carboxymethyl-Cellulose (CMC) for DSCs Application	431
N. A. S. Yuharmon, Norani Muti Mohamed, Chong Fai Kait, and K. Y. Cheong	
Effect on Addition of Low Loading of Graphene Oxide to the Physical Characterization of Electrospun Polystyrene Fiber Mat	441
Kamilah Ramly, Norani Muti Mohamed, and Chong Fai Kait	
Cellulose Nanofibers from Palm Bio-waste as Separator Membrane for EDLC	453
Khairul Anuar Jamaluddin, John Ojur Dennis, Mohd Fadhlullah Abd Shukur, Hisyam Jusoh, Bashir Abubakar Abdulkadir, Irwan Othman, and Imtias Amir	
Study the Impact of Shading on Series-Connected PV Modules	463
Easter Joseph and Balbir Singh Mahinder Singh	
Mathematical and Analytical Methods in Science and Technology	
CFD Simulation of Petcoke Gasification in an Updraft Gasifier	479
Dennis Ling Chuan Ching and Iman Eslami Afrooz	
Multivariate Gaussian Process Regression for Evaluating Electromagnetic Profile in Screening Process of Seabed Logging Application	487
Muhammad Naeim Mohd Aris, Hanita Daud, Khairul Arifin Mohd Noh, and Sarat Chandra Dass	

On the Optimal Control of the Thermal Exchange on a Two-Phase Boundary Layer 503
 Zh. Zhanabekov, G. Abduakhitova, and U. Kusherbayeva

Surface Reconstruction Using Rational Quartic Triangular Spline 513
 Nur Nabilah Che Draman, Samsul Ariffin Abdul Karim, Ishak Hashim, and Yeo Wee Ping

Positivity Preserving Using C^2 Rational Quartic Spline Interpolation 529
 Noor Adilla Harim and Samsul Ariffin Abdul Karim

K-means Clustering Analysis for EEG Features of Situational Interest Detection in Classroom Learning 541
 Ernee Sazlinayati Othman, Ibrahima Faye, Areej Babiker, and Aarij Mahmood Hussaan

Modelling the Disease Severity of Cocoa Black Pod Rot Disease 551
 Albert Ling Sheng Chang, Suhaida Salleh, Ahmad Kamil Mohd Jaaffar, and Haya Ramba

Monotonicity Preserving Interpolation Using Rational Quartic Said-Ball Function 565
 Samsul Ariffin Abdul Karim and Van Thien Nguyen

Some Inequalities for σ -Convex Functions 575
 Ibrahima Faye and Van Thien Nguyen

On the Space of m -subharmonic Functions 587
 Samsul Ariffin Abdul Karim and Van Thien Nguyen

Unsteady Nanofluid Flow Over Exponentially Stretching Sheet with Vertical Throughflow 595
 Abdullah Al-Yaari, Hamzah Sakidin, Nooraini Zainuddin, and Ishak Hashim

Pitt's Inequality Associated with Fractional Wavelet Transform 611
 Mawardi Bahri and Samsul Ariffin Abdul Karim

A Comparison Study on Developed FSWGARCH, SWGARCH and GARCH Models in Time Series Forecasting: An Application to Airline Passenger Volume 623
 Amiratul Liyana Mohamad Hanapi, Mahmod Othman, Rajalingam Sokkalingam, and Hamzah Sakidin

Optimization of PV/T Solar Collector Performance with Fuzzy If-Then Rules Generation 637
 Noran Nur Wahida Khalili, Mahmod Othman, Hamzah Sakidin, Mohd Nazari Abu Bakar, and Lazim Abdullah

Predicting Household Income Due to Fuel Price Fluctuations 645
 Norhana Abd. Rahim and Yumn Suhaylah Yusoff

Review on Cardiovascular Disease Risk Factors Among Selected Countries in Asia 655
 Yumn Suhaylah Yusoff, Norhana Abd. Rahim, and Muhammad Hariz Hasmi

Forecasting Petroleum Fuel Price in Malaysia by ARIMA Model 671
 Rajalingam Sokkalingam, Richard M. N. Y. Sarpong-Streeter, Mahmood Othman, Hanita Daud, and Derrick Asamoah Owusu

ARIMAX Modelling of Ron97 Price with Crude Oil Price as an Exogenous Variable in Malaysian 679
 Richard M. N. Y. Sarpong-Streeter, Rajalingam Sokkalingam, Mahmood Othman, Hanita Daud, and Derrick Asamoah Owusu

Application of Newton-GS Iterative Method with Second-Order Quadrature Scheme in Solving Nonlinear Fredholm Integral Equations 693
 Labiyana Hanif Ali, Jumat Sulaiman, Azali Saudi, and Xu Ming Ming

Gauss-Newton and L-BFGS Methods in Full Waveform Inversion (FWI) 705
 Samsul Ariffin Abdul Karim, Mudassar Iqbal, Afza Shafie, and Muhammad Izzatullah

Removing the Blurring from X-Ray Image Using BM3D Technique 715
 Ariful Islam, Nooraini Zainuddin, and Samsul Ariffin Bin Abdul Karim

Empirical Formulation of (n, p) Nuclear Cross-Section at 14–15 meV 723
 Mohamad Amin Bin Hamid, Beh Hoe Guan, Xiao Yan Chew, and Saba Ayub

Outlier Detection in Subsurface Modeling of 2D Electrical Resistivity Imaging by Using Boxplot 729
 Siti Nur Athirah Mazlan, Hanita Daud, Khairul Ariffin Mohd Noh, and Muhammad Naeim Mohd Aris

Numerical Investigations of Nano-fluid Flow in Square Porous Cavity: Buongiorno’s Mathematical Model 739
 Mudasar Zafar, Hamzah Sakidin, Iskandar Dzulkarnain, and Farkhanda Afzal

Forecasting Electricity Consumption in Malaysia by Hybrid ARIMA-ANN 749
 Nur Ezzati Mohd Izudin, Rajalingam Sokkalingam, Hanita Daud, Hermiza Mardesci, and Abdullah Husin

**Fractional Model for the Flow of Casson Nanofluid using
the Generalized Fourier’s Law for Heat Transfer** 761
Nadeem Ahmad Sheikh, Dennis Ling Chuan Ching, Hamzah Sakidin,
and Ilyas Khan

Author Index 771

Subject Index 775

Editors and Contributors

About the Editors



Samsul Ariffin Abdul Karim is Senior Lecturer at Universiti Teknologi PETRONAS (UTP), Malaysia. He has published more than 140 papers in journals and conferences including three edited conference volumes and 40 chapters. He was the recipient of Effective Education Delivery Award and Publication Award (Journal and Conference Paper), UTP Quality Day 2010, 2011 and 2012, respectively. He was Certified WOLFRAM Technology Associate, Mathematica Student Level. He also has published nine books with Springer Publishing including five books with Studies in Systems, Decision and Control (SSDC) series.



Mohd Fadhlullah Abd Shukur is Senior Lecturer at the Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS (UTP). His research interest is in the field of ionic conductor including the development and characterization of polymer electrolytes for application in various energy storage devices. He has received several research grants, acting as the head researcher or co-researcher for such grants. He has been invited as reviewer for various journals and has published 41 articles in ISI/Scopus Indexed Journals. Currently, his H-index is 21 with 1347 citations in Google Scholar Citations.



Chong Fai Kait is Associate Professor at Universiti Teknologi PETRONAS. She graduated with B.Sc. (Hons) in Industrial Chemistry from Universiti Putra Malaysia in 1993. In 1998, she received her Ph.D. from University of Dundee, Scotland, in the area of heterogeneous catalysis for naphtha reforming process. She has more than 20 years of academic and research experience, and her main research interests are in photocatalysis and its integration with ionic liquids or other techniques for sustainable environmental applications.



Hassan Soleimani is Associate Professor at Universiti Teknologi PETRONAS, Malaysia. He has obtained a Ph.D. in wave propagation from Universiti Putra Malaysia. He has published more than 120 research articles in peer-reviewed international. He is Committee Member and Organizer of international conference of Diffusion in Solid and Liquids (DSL) since 2011 in Europe. He has been Visiting Scientist at many universities including University of Cambridge, UK; Wright State University, USA; University of Patras, Greece; and School of Engineering and Griffith University, Australia.



Hamzah Sakidin is Senior Lecturer at Universiti Teknologi PETRONAS (UTP), Seri Iskandar, Perak, since September 2013. His research interest is in the field of applied mathematics and mathematical modelling. He has received several research grants, acting as the head researcher or co-researcher for some research grants. He is also Author of several mathematics books for tertiary level of education. He has more than 20 years of experience teaching in secondary and tertiary level of education.

Contributors

Summaira Abbasi Centre of Innovative Nanostructures and Nanodevices (COINN), Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Nadia Syazana Abd Halim Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Zhubanov Amin Abdirasululy Kazakh-British Technical University, Almaty, Kazakhstan

G. Abduakhitova Al-Farabi Kazakh National University, Almaty, Kazakhstan

Samsul Ariffin Abdul Karim Fundamental and Applied Sciences Department and Centre for Systems Engineering (CSE), Institute of Autonomous System, Universiti Teknologi PETRONAS (UTP), Seri Iskandar, Perak Darul Ridzuan, Malaysia

Ninie Suhana Abdul Manan Department of Chemistry, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia

Bashir Abubakar Abdulkadir Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Lazim Abdullah School of Informatics and Applied Mathematics, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia

Nor Ain Fathihah Abdullah Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Muslim Abdurrahman Department of Petroleum Engineering, Universitas Islam Riau, Pekanbaru, Indonesia

Akbar Abu Seman PETRONAS Research Sdn.Bhd, Kajang, Selangor, Malaysia

Dauda Abubakar Department of Physics, Bauchi State University Gadau, Bauchi, Nigeria

Muhammad Adil Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Iman Eslami Afrooz Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Farkhanda Afzal MCS, National University of Science and Technology (NUST), Islamabad, Pakistan

Mohd Arif Agam Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia, UTHM Pagoh Campus, Muar, Johor, Malaysia

Farooq Ahmad Department of Electrical Engineering, University of Engineering and Technology, Lahore, Pakistan

Abdelazim Abbas Ahmed Institute of Hydrocarbon Recovery, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Naser M. Ahmed School of Physics, Universiti Sains Malaysia, Pulau Pinang, Malaysia

Abdullah Al-Yaari Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Hassan Ali Fundamental and Applied Science Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia;
Department of Physics, University of Narowal, Narowal, Pakistan

Labiyana Hanif Ali Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Sabah, Malaysia

Imtias Amir Centralized Analytical Laboratory, Universiti Teknologi PETRONAS Seri Iskandar, Perak, Malaysia

Sorfina Amran Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nur Akila Syakida Idayu Khairul Anuar Fundamental and Applied Sciences Department, HICoE Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Muhamad Fatikul Arif Institut Teknologi Sumatera, Lampung, Indonesia

Muhammad Naeim Mohd Aris Department of Fundamental & Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Saba Ayub Research Center for Dielectric and Advanced Matter Physics, Pusan National University, Busan, Republic of Korea

Ninna Sakina Binti Azman Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Centre of Research in Ionic Liquids, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Areej Babiker Electronic Engineering Department, Future University, Khartoum, Sudan

Mawardi Bahri Department of Mathematics, Hasanuddin University, Makassar, Indonesia

Mohd Nazari Abu Bakar Faculty of Applied Sciences, Universiti Teknologi MARA Perlis, Arau, Perlis, Malaysia

Abayev Talgat Bakytuly Kazakh-British Technical University, Almaty, Kazakhstan

Robabeh Bashiri Centre of Innovative Nanostructure and Nanodevices (COINN), Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, Malaysia;
Department of Fundamental & Applied Sciences, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, Malaysia

Lyazzat Bekbayeva Department of Engineering Disciplines, Asfendiyarov Kazakh National Medical University, Almaty, Kazakhstan;
Biology Program, School of Distance Education, Universiti Sains Malaysia, Minden, Penang, Malaysia

Nor Hafizah Berahim Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Petronas Research Sdn Bhd, Kajang, Selangor, Malaysia

Yih Hui Boon Department of Chemistry, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia;
Integrative Medicine Cluster, Advanced Medical and Dental Institute, Universiti Sains Malaysia, Pulau Pinang, Malaysia

Azry Borhan Department of Chemical Engineering, HICoE, Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Noorazlenawati Borhan Hydrocarbon Recovery Technology, PETRONAS Research Sdn Bhd, Bandar Baru Bangi, Selangor, Malaysia

Mageswaran Ravi Chandran College of Engineering, Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia

Albert Ling Sheng Chang Malaysian Cocoa Board, Kota Kinabalu, Sabah, Malaysia

K. Y. Cheong School of Material and Mineral Resources, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia

Xiao Yan Chew Department of Physics Education, Pusan National University, Busan, Republic of Korea

Dennis Ling Chuan Ching Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, Malaysia

Chong Fai Kait Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Centre of Innovative Nanostructures and Nanodevices (COINN), Institute of Autonomous System (IAS), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Sarat Chandra Dass Heriot-Watt University Malaysia, Putrajaya, Malaysia

Hanita Daud Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskander, Perak, Malaysia

John Ojur Dennis Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Fundamental of Applied Science, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Israaf Ud Din Department of Chemistry, College of Science and Humanity, Prince Sattam bin Abdulaziz University, Al-kharj, Saudi Arabia

Nur Nabilah Che Draman Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS (UTP), Seri Iskandar, Perak, Malaysia

Iskandar Dzulkarnain Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Khaled Abdalla Elraies Petroleum Engineering Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Muhammad Faheem Department of Chemical Engineering, University of Engineering and Technology, Lahore, Pakistan

Syeda Saba Fatima Department of Chemical Engineering, HICoE, Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Ibrahima Faye Centre for Intelligent Signal and Imaging Research (CISIR), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Fundamental and Applied Science Department, Universiti Teknologi PETRONAS (UTP), Seri Iskandar, Perak, Malaysia

Noraini Abd Ghani Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Centre of Research in Ionic Liquids, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Syed Muhammad Arslan Gilani Department of Electrical Engineering, University of Engineering and Technology, Lahore, Pakistan

Alla Goncharova Department of Biotechnology, Faculty of Biochemistry, Al-Farabi, Kazakh National University, Almaty, Kazakhstan

Beh Hoe Guan Centre of Innovative Nanostructure and Nanodevices, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Department of Fundamental & Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Mohamad Amin Bin Hamid Centre of Innovative Nanostructure and Nanodevices, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Mohammed Falalu Hamza Department of Pure and Industrial Chemistry, Bayero University Kano, Kano, Nigeria

Noraini Hamzah School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia

Amiratul Liyana Mohamad Hanapi Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Noor Adilla Harim Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS (UTP), Seri Iskandar, Perak, Malaysia

Ishak Hashim Department of Mathematical Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia;
School of Mathematical Sciences, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

Muhammad Hariz Hasmi Faculty of Science and Technology, Universiti Sains Islam Malaysia, Nilai, Negeri Sembilan, Malaysia

Abdullah Husin Program Studi Sistem Informasi, Universitas Islam Indragiri, Riau, Indonesia

Aarij Mahmood Hussaan Computer Science Department, IQRA University, Karachi, Pakistan

Zawawi Ibrahim Engineering and Processing Division, Malaysian Palm Oil Board (MPOB), Kajang, Selangor, Malaysia

Mudassar Iqbal Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia;
Department of Mathematical Sciences, Balochistan University of Information Technology, Engineering and Management Sciences (BUIITEMS), Quetta, Pakistan

Ariful Islam Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Nur Ezzati Mohd Izudin Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Perak, Malaysia

Muhammad Izzatullah Seismic Modeling and Inversion Group (SMI), King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

Ahmad Kamil Mohd Jaaffar Malaysian Cocoa Board, Kota Kinabalu, Sabah, Malaysia

Khairul Anuar Jamaluddin Fundamental of Applied Science, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

A. Jati Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor DT, Malaysia

Easter Joseph Department of Fundamental and Applied Sciences (FASD), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Mahdalena Julia Universitas Negeri Malang, East Java, Indonesia

Khairulazhar Jumbri Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Centre of Research in Ionic Liquids (CORIL), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Hisyam Jusoh Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Donenov Beisen Kainarbaevich Kazakh-British Technical University, Almaty, Kazakhstan

Kozhanova Kaldanay Department of Engineering Disciplines, Asfendiyarov Kazakh National Medical University, Almaty, Kazakhstan

Samsul Ariffin Bin Abdul Karim Department of Fundamental and Applied Sciences and Centre for Systems Engineering (CSE), Institute of Autonomous System, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Tatyana Karpenyuk Department of Biotechnology, Faculty of Biochemistry, Al-Farabi, Kazakh National University, Almaty, Kazakhstan

Mohd Azlan Kassim School of Science and Technology, Sunway University, Bandar Sunway, Selangor, Malaysia

Yew Weng Kean School of Engineering and Physical Science, Heriot-Watt University Malaysia, Putrajaya, Malaysia

Lam Man Kee Department of Chemical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Noran Nur Wahida Khalili Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Ilyas Khan Department of Mathematics, Majmaah University, Majmaah, Saudi Arabia

Lai Weng Kin Fundamental and Applied Sciences Department, HICoE Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

U. Kuserbayeva Al-Farabi Kazakh National University, Almaty, Kazakhstan

Lawal Adebayo Lanre Fundamental and Applied Science Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Kar Mun Lee Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Wai Hong Leong Department of Fundamental and Applied Sciences, HICoE—Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Jun Wei Lim Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Department of Fundamental and Applied Sciences, HICoE—Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Lee Siew Ling Center for Sustainable Nanomaterials, Ibnu Sina Institute for Scientific and Industrial Research, Universiti Teknologi Malaysia, Johor Bahru, Malaysia;
Chemistry Department, Faculty of Science, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Afzan Mahmud Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Laboratory Department, Royal College of Medicine Perak, Universiti Kuala Lumpur, Perak, Malaysia

Hermiza Mardesci Fakultas Pertanian, Universitas Islam Indragiri, Riau, Indonesia

Siti Nur Athirah Mazlan Department of Fundamental & Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nur Najihah Md Zuki School of Chemical Sciences, Universiti Sains Malaysia, Pulau Pinang, Malaysia

Onn Chiew Mey Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Xu Ming Ming Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Sabah, Malaysia

Mardawani Mohamad Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Jeli Campus, Jeli, Kelantan, Malaysia

Sharifah Mohamad Department of Chemistry, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia

Norani Muti Mohamed Centre of Innovative Nanostructure and Nanodevices, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

S. M. Mohamed Esivan Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor DT, Malaysia

Muhammad Naeim Mohd Aris Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Khairul Arifin Mohd Noh Department of Geosciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nur Diyan Mohd Ridzuan Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Noor Asmawati Mohd Zabidi Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Asad Mumtaz Centre of Innovative Nanostructures and Nanodevices (COINN), Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia;
Center of Contaminant Control and Utilization (CenCoU), Institute of Contaminant Management for Oil and Gas, Universiti Teknologi PETRONAS, Perak, Malaysia

Mohamed Mahmoud Elsayed Nasef Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

Mohammad Nazhan Nasir College of Engineering, Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia

El-Sayed Negim Laboratory of Advanced Materials and Technology, Kazakh-British Technical University, Almaty, Kazakhstan

Van Thien Nguyen Department of Mathematics, FPT University, Education Zone, Hanoi, Vietnam

Khairul Ariffin Mohd Noh Department of Geosciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Teh Ubaidah Noh Institute of Bioproduct Development (IBD), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia

Mohd Sofi Numin Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Ernee Sazlinayati Othman Department of Fundamental and Applied Sciences, Centre for Intelligent Signal and Imaging Research (CISIR), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Irwan Othman Centralized Analytical Laboratory, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Mahmod Othman Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Derrick Asamoah Owusu Mathematics Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Timotius Pasang Oregon Institute of Technology, Klamath Falls, USA

Avita Ayu Permanasari Universitas Negeri Malang, East Java, Indonesia

Yeo Wee Ping Faculty of Science, Universiti Brunei Darussalam, Bandar Seri Begawan, Brunei Darussalam

Poppy Puspitasari Mechanical Engineering Department, State University of Malang, Malang, East Java, Indonesia;
Universitas Negeri Malang, East Java, Indonesia

Ayesha Rafique Department of Electrical Engineering, University of Engineering and Technology, Lahore, Pakistan

Norhana Abd. Rahim Faculty of Science and Technology, Universiti Sains Islam Malaysia, Nilai, Malaysia

Nurul Yani Rahim School of Chemical Sciences, Universiti Sains Malaysia, Pulau Pinang, Malaysia

Noor A.'in A. Rahman Electrical and Electronics Engineering Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nurul Jannah Abd Rahman Fundamental and Applied Sciences Department, HICoE Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Muggundha Raov Ramachandran Department of Chemistry, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia

Haya Ramba Cocoa Research and Development Center, Kota Samarahan, Sarawak, Malaysia

Anita Ramli Fundamental and Applied Sciences Department, HICoE Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
School of Science and Technology, Sunway University, Bandar Sunway, Selangor, Malaysia

Kamilah Ramly Fundamental and Applied Sciences Department, Centre of Innovative Nanostructure and Nanodevices (COINN), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

R. Rashid Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor DT, Malaysia

Hemamalini Rawindran Department of Fundamental and Applied Sciences, HICoE—Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Mohamad Amirul Ashraf Mohd Razip Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Makhmetova Aliya Ruslanovna Kazakh-British Technical University, Almaty, Kazakhstan

Bahrudin Saad Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nabilah Saafie Universiti Teknologi PETRONAS, Perak, Malaysia

Maziyar Sabet Department of Petroleum and Chemical Engineering, Jalan Tungku Link, Gadong, Universiti Teknologi Brunei (UTB), Darussalam, Brunei

Amir Reza Sadrolhosseini Department of Physics, Faculty of Science, University Putra Malaysia, Selangor, Malaysia

Mohamed Shuaib Mohamed Saheed Centre of Innovative Nanostructure and Nanodevices (COINN), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Department of Fundamental & Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nurul Tasnim Sahrin Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Hamzah Sakidin Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Fitri Norizatit Salehin Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Suhaida Salleh Cocoa Research and Development Center, Jengka, Pahang, Malaysia

Nur Afiqah Mohamad Saman Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Kozhabekov Serik Samsalykovich Kazakh-British Technical University, Almaty, Kazakhstan

Wasan Saphanuchart PETRONAS Research Sdn. Bhd, Bangi, Malaysia

Richard M. N. Y. Sarpong-Streeter Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Azali Saudi Faculty of Computing and Informatics, Universiti Malaysia Sabah, Sabah, Malaysia

Gowri Selvaraj Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Afza Shafie Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Maizatul Shima Shaharun Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Muhammad Umair Shahid Department of Fundamental and Applied Sciences, Centre of Innovative Nanostructure and Nanodevices (COINN), Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, Malaysia;
Department of Materials Science and Engineering, Institute of Space Technology, Islamabad, Pakistan

Nurul Natasha Shahrom School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia

Nadeem Ahmad Sheikh Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Ewe Lay Sheng College of Engineering, Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia

Mohd Fadhlullah Abd Shukur Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia

Nadiah Sidek Department of Chemistry, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia

Surajudeen Sikiru Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Balbir Singh Mahinder Singh Department of Fundamental and Applied Sciences, Centre of Innovative Nanostructure and Nanodevices (COINN), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Centre for Foundation Studies, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Rajalingam Sokkalingam Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Hassan Soleimani Fundamental and Applied Science Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Institute of Hydrocarbon Recovery, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Nur Amirah Suhaimi Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Jumat Sulaiman Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Sabah, Malaysia

Mohd Faisal Taha Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia;
Centre of Research in Ionic Liquids (CORIL), Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nazrizawati Ahmad Tajuddin School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia

Geok Bee Teh Faculty of Engineering & Information Technology, Southern University College, Skudai, Skudai, Johor DT, Malaysia

Farman Ullah Department of Fundamental and Applied Sciences, Centre of Innovative Nanostructure and Nanodevices (COINN), Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia

Fahad Usman Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Norhidayah Ahmad Wazir PETRONAS Research Sdn. Bhd, Bangi, Malaysia

Cecilia Devi Wilfred Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Mohd Dzul Hakim Wirzal Department of Chemical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Noorhana Yahya Fundamental and Applied Science Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, Malaysia

Nor Hafizah Yasin PETRONAS Research Sdn.Bhd, Kajang, Selangor, Malaysia

N. A. S. Yuharmon Department of Fundamental and Applied Science, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Normawati M. Yunus Fundamental and Applied Sciences Department, Centre for Research in Ionic Liquids, Institute of Contaminant Management, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Yumn Suhaylah Yusoff Faculty of Science and Technology, Universiti Sains Islam Malaysia, Nilai, Negeri Sembilan, Malaysia

Jemilat Yetunde Yusuf Fundamental and Applied Science Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Mudasar Zafar Fundamental and Applied Science Department, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nur Fatin Syazwanie Zahari Fundamental and Applied Sciences Department and Centre for Biofuel and Biochemical Research, Institute of Self- Sustainable Building, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

N. A. Zaharudin Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor DT, Malaysia

Hasnah Mohd Zaid Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Siti Noor Azella Zaine Department of Chemical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Nooraini Zainuddin Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, Seri Iskandar, Perak Darul Ridzuan, Malaysia

Zuraini Zakaria Biology Program, School of Distance Education, Universiti Sains Malaysia, Minden, Penang, Malaysia

Zakariyya Uba Zango Fundamental and Applied Sciences Department, Universiti Teknologi PETRONAS, Perak, Malaysia;
Department of Chemistry, College of Natural and Applied Sciences, Al-Qalam University Katsina, Katsina, Nigeria

Zh. Zhanabekov Al-Farabi Kazakh National University, Almaty, Kazakhstan

Nur Insyirah Zulkifli Center of Contaminant Control and Utilization (CenCoU), Institute of Contaminant Management for Oil and Gas, Universiti Teknologi PETRONAS, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/357595585>

UiO-66 and ZIF-8 Metal-organic Frameworks for Acenaphthene Adsorption

Chapter · January 2021

DOI: 10.1007/978-981-16-4513-6_21

CITATIONS

2

READS

35

4 authors:



Zakariyya Uba Zango
Universiti Teknologi PETRONAS

59 PUBLICATIONS 676 CITATIONS

[SEE PROFILE](#)



Anita Ramli
Universiti Teknologi PETRONAS

163 PUBLICATIONS 2,877 CITATIONS

[SEE PROFILE](#)



Khairulazhar Jumbri
Universiti Putra Malaysia

67 PUBLICATIONS 694 CITATIONS

[SEE PROFILE](#)



Muslim Bin Darbi Abdurrahman
Universitas Islam Riau

65 PUBLICATIONS 248 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Flow Assurance [View project](#)



Development of Modified Si-MCM-41 with Amino Compounds and Studies on its Behaviour for CO₂ Adsorption [View project](#)

UiO-66 and ZIF-8 Metal-organic Frameworks for Acenaphthene Adsorption



Zakariyya Uba Zango, Anita Ramli, Khairulazhar Jumbri, and Muslim Abdurrahman

Abstract Comparative adsorption of acenaphthene onto UiO-66 and ZIF-8 metal-organic frameworks (MOFs) were investigated. Response surface methodology (RSM) was employed for the process optimizations according to the central composite design (CCD) with 5 inputs variables. The adsorption efficiency achieved were 99.7 and 60.7% for the UiO-66 and ZIF-8, respectively according to the RSM optimization conditions. The model was significantly described according to statistical analysis of variance (ANOVA). The adsorption process was well fitted by pseudo-second order kinetic model with R^2 values of 0.9947 and 0.97780 for the UiO-66 and ZIF-8, respectively.

Keywords Acenaphthene · Adsorption · Metal-organic frameworks · Response surface methodology

Z. U. Zango · A. Ramli (✉) · K. Jumbri
Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, 3210 Seri Iskandar, Perak, Malaysia
e-mail: anita_ramli@utp.edu.my

K. Jumbri
e-mail: khairulazharjumbri@utp.edu.my

Z. U. Zango
Department of Chemistry, Al-Qalam University Katsina, Katsina 2137, Nigeria

A. Ramli
HiCOE Centre for Biofuel and Biochemical Research (CBBR), Universiti Teknologi PETRONAS, 3210 Seri Iskandar, Perak, Malaysia

K. Jumbri
Centre of Research in Ionic Liquids (CORIL), Universiti Teknologi PETRONAS, 3210 Seri Iskandar, Perak, Malaysia

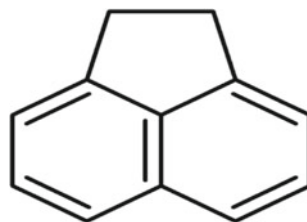
M. Abdurrahman
Department of Petroleum Engineering, Universitas Islam Riau, Jalan Kaharuddin Nasution No. 113, Pekanbaru 28284, Indonesia
e-mail: muslim@eng.uir.ac.id

1 Introduction

Pollution caused by the presence of organic contaminants in environmental waters has been a disturbing phenomenon affecting the peaceful existence of living organisms. Acenaphthene, a member of Polycyclic aromatic carbons (PAHs) heavily found in crude oil and coal [1, 2]. It consisted of naphthalene connected by the ethylene at position 1 and 8 (Fig. 1). It also occurs in small quantity as a result of biomass decay [3]. It has found variety of applications in industrial processing as a precursor and intermediate material for the production of products such as dyes production, plastics, insecticides, fungicides and other manufacturing processes [4, 5]. It is an important component in coal tar for road and highway constructions and as preservative in wood industries [6]. It is among the most prominent organic pollutant ubiquitously found in environmental waters [7]. It is resulted from oil spillage, effluents discharged from petroleum and petrochemical industries, coal conversion process, urban air due to automobile exhaust and cigarette smoke, as well as municipal wastewater due to the soil surface and street asphalt runoff [8, 9]. It is relatively insoluble in water (0.4 mg/100 mL), thus easily transported into the water bodies. Findings have shown the presence of acenaphthene in various ground and surface waters. It is recalcitrant to atmospheric degradation, thus undergoes bioaccumulation in the soil and sediments and subsequently consumed by the plants and aquatic organisms [10]. It was known to cause significant impact to both plants and animals due to its toxic and hazardous effects such as eye and skin irritations, lungs cancer and other respiratory complications [11, 12]. It was listed among the priority PAHs organic pollutant according to USEPA. Thus, essentially required to be eliminated from environmental waters.

Adsorption process have been recognized as an alternative wastewater remediation technology. It is a low-cost and environmental-friendly technique for variety of pollutants removal from the water. The availability of various natural and synthetic adsorbents materials for both organic and inorganic pollutants removal has been capitalized as the way forward compared to other water treatment technologies such as coagulation, reverse osmosis and enzymatic degradation processes [13, 14]. Thus, various adsorbents from natural and sources such as biomass [15], clays, soil and sand particles [16], etc., have been well reported for the acenaphthene adsorption from environmental waters. Despite showing lots of promise in water treatment, most of these adsorbents are not suitable for PAHs removal from water due to the low specific

Fig. 1 Chemical structure of acenaphthene



surface area and pore volumes of the adsorbents [17]. The use of synthetic materials such as activated carbons [18], biochar [19], carbon nanotubes, graphene [20], and silica have also been reported. However, AC is not suitable for organic pollutant removal at low concentrations.

Advancement in materials sciences have paved the way for the invention of new classes of materials with versatile applications. Metal-organic frameworks (MOFs) are among the most advanced materials that attracted the attention of researchers from scientific and engineering fields. They are comprised of coordination sphere made from interaction of metal-ion with organic moieties, forming extensive crystalline frameworks [21, 22]. They acquired unique properties such as exceptionally high porosities, mechanical and thermal strength [23, 24]. Thus, they have found tremendous applications in various fields such as carbon dioxide capture, energy storage, sensors, drug delivery, catalysis and wastewater remediations [25, 26]. They offered promising applications as super adsorbents for both organic and inorganic pollutants removal from water [27–29], due to their ultrahigh porosities and good stabilities.

This work is thus aimed at adsorption of acenaphthene from aqueous medium using UiO-66 and ZIF-8 MOFs. They were chosen due to their high BET surface area and pore volumes as well as their stabilities in both aqueous and organic phases. Response surface methodology (RSM) was used for the experimental design using central composite design (CCD). The kinetics of the adsorption process was evaluated, and the reusability of the MOFs was studied.

2 Materials and Methods

The materials purchased in this work were analytically graded and thus were used as received. Acenaphthene standard (99% purity), ZIF-8 (99% purity) zirconium tetrachloride (99.99% purity), terephthalic acid (97% purity) obtained from Sigma Aldrich (USA), and supplied by Avantis Laboratory, Malaysia.

2.1 *Synthesis and Characterizations of the MOFs*

UiO-66 was synthesized and characterized according to the procedure reported in our previous work [30]. While ZIF-8 was commercially purchased.

2.2 Preparation of the Stock Solution

The acenaphthene stock solution was prepared in acetone by using 10 mg of the standard in 100 ml volumetric flask to make a solution of 100 mg/L. Working solution was prepared from the stock solution in double deionized water using serial dilutions.

2.3 Synthesis of the MOFs

Batch adsorption experiment was designed by the RSM software (Design Expert 11) using full factorial CCD comprises of 5 input variables: contact time (min), dosage (mg), concentration (mg/L), pH and temperature ($^{\circ}\text{C}$) with 5 center points. The adsorption was conducted using 30 mL of the acenaphthene solution in an incubator shaker (Incubator ES 20/60, bioSan) at 200 rpm. The sample was analyzed using UV-visible spectrophotometer (GENESYS 30) analysis at 220 nm. The responses were determined as the percentage adsorption efficiency achieved by the UiO-66 and ZIF-8 MOFs accordingly to the formula:

$$\%R = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

And the amount of the acenaphthene adsorbed onto the MOFs at certain time (q_t) and equilibrium (q_e) were determine from the formula:

$$q_t = \frac{(C_0 - C_t)V}{w} \quad (2)$$

$$q_e = \frac{(C_0 - C_e)V}{w} \quad (3)$$

where C_0 , C_t and C_e are the initial, time and equilibrium concentrations (mg/L), respectively, w is the weight of adsorbent (g), and V is the volume of the solution (L).

3 Results and Discussion

3.1 RSM Optimizations for Acenaphthene Adsorption onto UiO-66 and ZIF-8

The synthesis of UiO-66 was achieved using solvothermal technique described in our previous studies [30], while ZIF-8 was commercially purchased. The BET surface

area of the MOFs were 1421 m²/g and 1299 m²/g, while the pore volumes were 0.91 and 0.60 m³/g for the UiO-66 and ZIF-8, respectively.

The adsorption studies for the removal acenaphthene were thus conducted using both UiO-66 and ZIF-8. The experimental conditions were determined by the CCD consisting of 5 parameters input variables with 47 number of experimental runs as described in Table 1. The adsorption efficiency of the two MOFs were determined according to each set of the experimental conditions given. The adsorption efficiency of UiO-66 was found to be much higher than that of ZIF-8, which was attributed the higher surface area and pore volume of the MOF [31, 32]. Thus, the highest removal efficiency achieved was 99.7% and 60.7% according to the described multi-variate conditions given in Fig. 2a,b for both UiO-66 and ZIF-8, respectively.

The corresponding 2-dimension (2D) and 3-dimension (3D) graphs for the RSM optimizations of the adsorption process. According to the Fig. 2, the adsorption efficiency was shown to increase with increase in the dosage of the MOFs due to the increase in the available number of adsorption sites on the surface of the MOFs. UiO-66 has shown to efficiently adsorbed larger organic molecules such as dyes and pharmaceuticals from aqueous solutions, attributed to its potential breathing capacity [33], high porosity [34], hydrophobicity and extensive stabilities in both organic and aqueous medium [35]. Similarly, the adsorption efficiency was increase with the increasing the contact time for the adsorption due to the increase in the interaction of the acenaphthene with the surface of the MOFs.

The model fittings were described by the analysis of variance (ANOVA) as presented in Table 2 according to the Fischer test (F-test) and p-values (probability > F) with 95% confidence level for the input variables. The overall model p-values were significant (< 0.0500), with F-value of 33.44 and 126.34 for the UiO-66 and ZIF-8, respectively. The significant terms for the adsorption and parameters combination were A, B, C, D, AD, A² and A, B, C, D, AB, BD, A² for the UiO-66 and ZIF-8 respectively. The significance of the model was also described by the reasonable agreements between the adjusted R² (0.9338 and 0.9820 for UiO-66 and ZIF-8, respectively) and predicted R² (0.8733 and 0.9638 for UiO-66 and ZIF-8, respectively) values with less than 20% differences. The lack of fit test for the replicated design points of the residual errors against the pure errors for the model were 0.1915 and 0.5840. The adequate precision of the model was 17.3082 and 32.6708 for the UiO-66 and ZIF-8, respectively, implying that the model can be used to navigate the design space for the adsorption studies. The scatter plots (Fig. 3) have shown significance of the model in terms of good agreement between the experimental and predicted adsorption efficiencies. Thus, RSM model was significant for the design optimizations of acenaphthene adsorption onto UiO-66 and ZIF-8.

3.2 Contact Time and Kinetics Study

The uptake of acenaphthene by the UiO-66 and ZIF-8 MOFs were studied. Adsorption experiment was studied using the optimized RSM data. Figure 4 highlighted the

Table 1 RSM optimizations for acenaphthene adsorption onto UiO-66 and ZIF-8 MOFs

Name		Units	Low	High	– Alpha	+ Alpha		
A: Time		min	5	25	0	35		
B: Dosage		mg	3	5	2	6		
C: Concentration		mg/L	1	3	0	4		
D: pH			2	6	0	8		
E: Temperature		°C	25	35	20	40		
Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Response 1	Response 2
		Time	Dosage	Concentration	pH	Temperature	UiO-66 (%R)	ZIF-8 (%R)
		min	mg	mg/L		°C		
1	1	5	3	1	2	25	67.3	30.2
3	2	5	5	1	2	25	77.1	33.5
22	3	25	3	3	2	35	84.2	50.2
24	4	25	5	3	2	35	97.5	53.6
14	5	25	3	3	6	25	96.1	51.2
16	6	25	5	3	6	25	98.4	55.2
36	7	15	6	2	4	30	87.4	45.7
45	8	15	4	2	4	30	85.2	44.3
35	9	15	2	2	4	30	72.2	42.1
5	10	5	3	3	2	25	58.5	29.6
17	11	5	3	1	2	35	63.2	31.5
20	12	25	5	1	2	35	98.5	57.4
42	13	15	4	2	4	40	79.3	44.4
7	14	5	5	3	2	25	58.6	33.8
46	15	15	4	2	4	30	79.1	43.6
31	16	5	5	3	6	35	56.3	32.4
33	17	5	4	2	4	30	54.2	32.1
26	18	25	3	1	6	35	95.5	56.3
28	19	25	5	1	6	35	97.1	57.2
32	20	25	5	3	6	35	92.4	55.4
43	21	15	4	2	4	30	77.3	43.7
39	22	15	4	2	10	30	76.2	44.2
18	23	25	3	1	2	35	94.3	56.3
25	24	5	3	1	6	35	55.7	33.5
34	25	35	4	2	4	30	99.7	60.7
2	26	25	3	1	2	25	94.1	56.4
41	27	15	4	2	4	20	76.5	44.5

(continued)

Table 1 (continued)

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Response 1	Response 2
		Time	Dosage	Concentration	pH	Temperature	UiO-66 (%R)	ZIF-8 (%R)
		min	mg	mg/L		°C		
10	28	25	3	1	6	25	98.5	56.7
27	29	5	5	1	6	35	57.2	34.8
4	30	25	5	1	2	25	99.1	57.5
8	31	25	5	3	2	25	97.8	55.4
11	32	5	5	1	6	25	59.5	35.1
29	33	5	3	3	6	35	56.4	32.5
15	34	5	5	3	6	25	58.3	33.3
47	35	15	4	2	4	30	77.7	44.2
30	36	25	3	3	6	35	92.6	54.6
21	37	5	3	3	2	35	56.4	32.3
23	38	5	5	3	2	35	58.4	33.6
38	39	15	4	4	4	30	75.5	43.6
44	40	15	4	2	4	30	77.3	45.2
6	41	25	3	3	2	25	91.5	53.7
12	42	25	5	1	6	25	98.5	55.2
9	43	5	3	1	6	25	55.4	33.5
40	44	15	4	2	8	30	77.3	46.3
19	45	5	5	1	2	35	56.4	35.2
13	46	5	3	3	6	25	55.4	33.4
37	47	15	4	5	4	30	75.2	43.2

effect of contact time for the adsorption process. Sudden adsorption of the acenaphthene was observed at the onset of the experiment, attributed to the higher BET surface area of the MOFs [36]. The equilibrium of the adsorption was attained within 30 min with the MOFs achieving equilibrium adsorption capacities of 23.814 mg/g and 14.627 mg/g for UiO-66 and ZIF-8, respectively. The adsorption efficiency achieved at equilibrium was 99.23% and 60.95% for UiO-66 and ZIF-8, respectively, confirming the superior adsorption capacity of UiO-66 and its higher porosities as previously reported in our studies [37].

To understand the mechanism and the rate controlling step for the process, the adsorption data for the UiO-66 and ZIF-8 effect of contact time was kinetics models was treated by the kinetics models of pseudo-first order (Eq. 4), pseudo-second order (Eq. 5), intra-particle diffusion (Eq. 6) and Elovich (Eq. 7) models linearly expressed as.

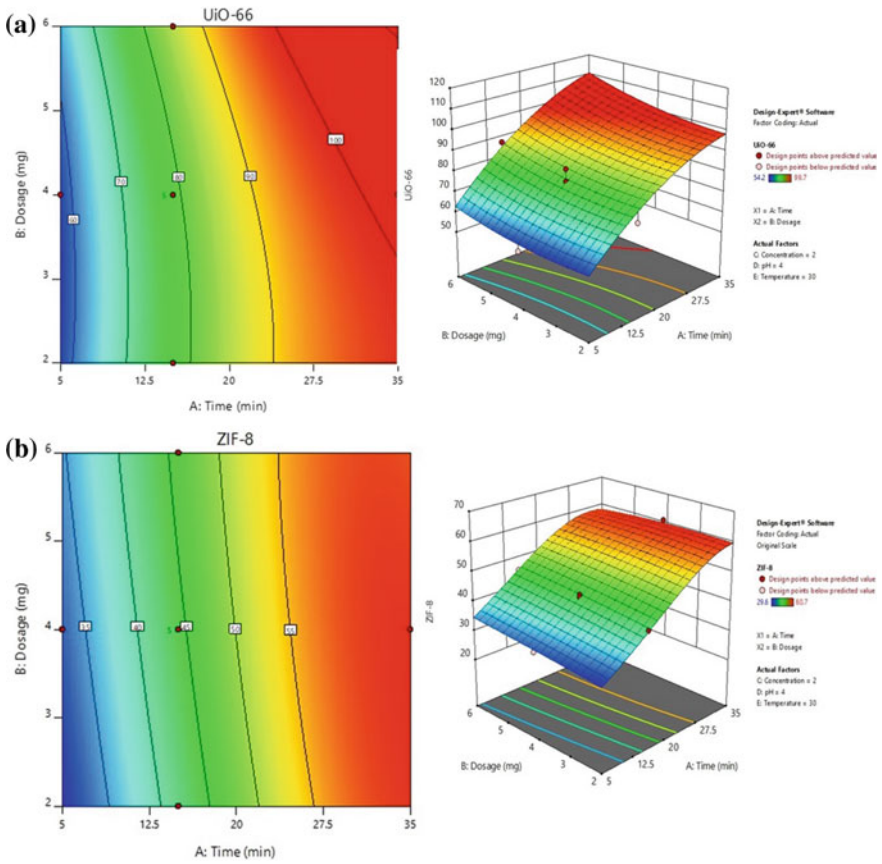


Fig. 2 2D and 3D RSM plots for the adsorption of acenaphthene onto **a** UiO-66 and **b** ZIF-8 MOFs under the condition: contact time of 35 min; dosage of 4 mg; concentrations of 2 mg/L, pH of 4 and temperature of 30 °C

$$\ln(q_e - q_t) = \ln q_e - k_1 t \tag{4}$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{5}$$

$$q_t = K_p t^{\frac{1}{2}} + C \tag{6}$$

$$q_t = \frac{1}{\beta} \ln() + \frac{1}{\beta} Int \tag{7}$$

where q_e (mg/g) and q_t (mg/g) represent the amount of the acenaphthene adsorbed by the MOFs at equilibrium and t (mins). k_1 (1/min) k_2 (q/mg/min) represented the

Table 2. ANOVA for the adsorption of acenaphthene onto UiO-66 and ZIF-8 MOFs

Source	UiO-66				ZIF-8					
	SS	df	MS	F-value	p-value	SS	df	MS	F-value	p-value
Model	0.0004	20	0.0000	33.44	< 0.0001	0.0014	20	0.0001	126.34	< 0.0001
A-Time	0.0004	1	0.0004	636.44	< 0.0001	0.0013	1	0.0013	2455.38	< 0.0001
B-Dosage	3.434E-06	1	3.434E-06	5.77	0.0238	0.0000	1	0.0000	22.62	< 0.0001
C-Concentration	3.811E-06	1	3.811E-06	6.40	0.0178	5.770E-06	1	5.770E-06	10.76	0.0029
D-pH	2.554E-06	1	2.554E-06	4.29	0.0484	3.105E-06	1	3.105E-06	5.79	0.0235
E-Temperature	1.980E-06	1	1.980E-06	3.33	0.0797	2.672E-07	1	2.672E-07	0.4985	0.4864
AB	8.016E-09	1	8.016E-09	0.0135	0.9085	3.309E-06	1	3.309E-06	6.17	0.0197
AC	8.144E-07	1	8.144E-07	1.37	0.2528	1.668E-07	1	1.668E-07	0.3112	0.5817
AD	4.568E-06	1	4.568E-06	7.67	0.0102	2.068E-06	1	2.068E-06	3.86	0.0603
AE	7.053E-07	1	7.053E-07	1.18	0.2865	4.333E-07	1	4.333E-07	0.8083	0.3769
BC	4.427E-08	1	4.427E-08	0.0743	0.7873	2.146E-08	1	2.146E-08	0.0400	0.8430
BD	2.858E-08	1	2.858E-08	0.0480	0.8283	3.603E-06	1	3.603E-06	6.72	0.0154
BE	5.467E-07	1	5.467E-07	0.9181	0.3468	2.582E-07	1	2.582E-07	0.4816	0.4938
CD	1.962E-06	1	1.962E-06	3.30	0.0810	9.847E-08	1	9.847E-08	0.1837	0.6718
CE	4.490E-07	1	4.490E-07	0.7540	0.3932	2.190E-07	1	2.190E-07	0.4085	0.5283
DE	7.972E-07	1	7.972E-07	1.34	0.2578	4.070E-07	1	4.070E-07	0.7592	0.3915
A ²	0.0000	1	0.0000	33.65	< 0.0001	0.0000	1	0.0000	86.03	< 0.0001
B ²	2.631E-08	1	2.631E-08	0.0442	0.8352	8.056E-08	1	8.056E-08	0.1503	0.7014
C ²	1.937E-07	1	1.937E-07	0.3253	0.5734	4.969E-07	1	4.969E-07	0.9270	0.3445
D ²	2.434E-07	1	2.434E-07	0.4088	0.5282	3.000E-07	1	3.000E-07	0.5595	0.4612
E ²	9.380E-09	1	9.380E-09	0.0158	0.9011	1.998E-08	1	1.998E-08	0.0373	0.8484

(continued)

Table 2 (continued)

Source	UiO-66				ZIF-8					
	SS	MS	df	F-value	p-value	SS	MS	df	F-value	p-value
Residual	0.0000	5.955E-07	26			0.0000	5.361E-07	26		
Lack of fit	0.0000	6.564E-07	22	2.52	0.1915	0.0000	6.146E-07	22	5.90	0.0484
Pure error	1.043E-06	2.607E-07	4			4.170E-07	1.043E-07	4		
Cor total	0.0004		46			0.0014		46		

Not significant

Not significant

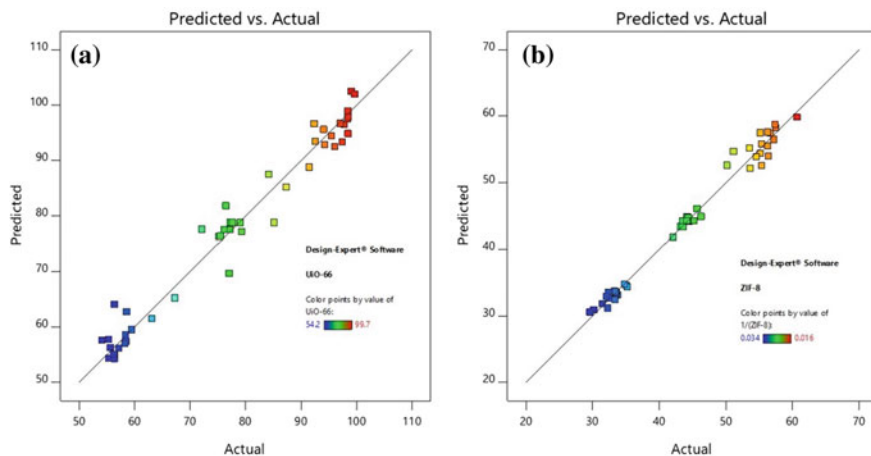
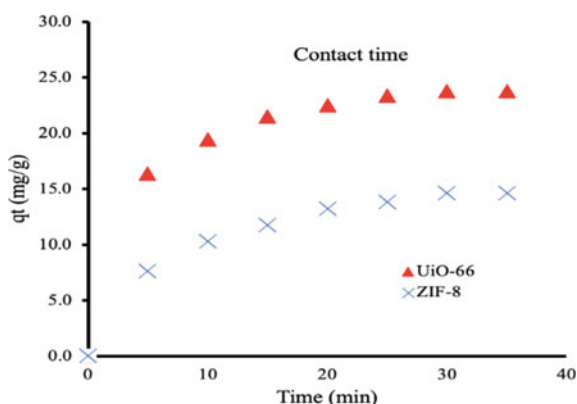


Fig. 3 Scatter plots for the RSM adsorption of acenaphthene onto UiO-66 and ZIF-8 MOFs

Fig. 4 Effect of contact time for the adsorption of acenaphthene onto UiO-66 and ZIF-8 MOFs



pseudo-first order and pseudo-second order rate constants, respectively. K_p represented the intraparticle rate constant and C is constant. The α (mg/gmin) and β (g/mg) were the initial desorption rate and desorption constant for the Elovich model, respectively.

Figure 5 depicted the plots of the kinetic models studied. The adsorption data was found to be precisely suited by the pseudo-second order model in comparison to other models evaluated. It is R^2 value was 0.9947 and 0.97780 for the UiO-66 and ZIF-8, respectively. Also, its calculated adsorption capacities were 24.80 and 15.87 mg/g for the UiO-66 and ZIF-8, respectively, very closer to the obtained experimental values of 23.814 and 14.627 mg/g for UiO-66 and ZIF-8, respectively, indicating the chemisorption is the rate limiting step of the process and the availability of the adsorption sites on the surface of the MOFs. Other reports have also described

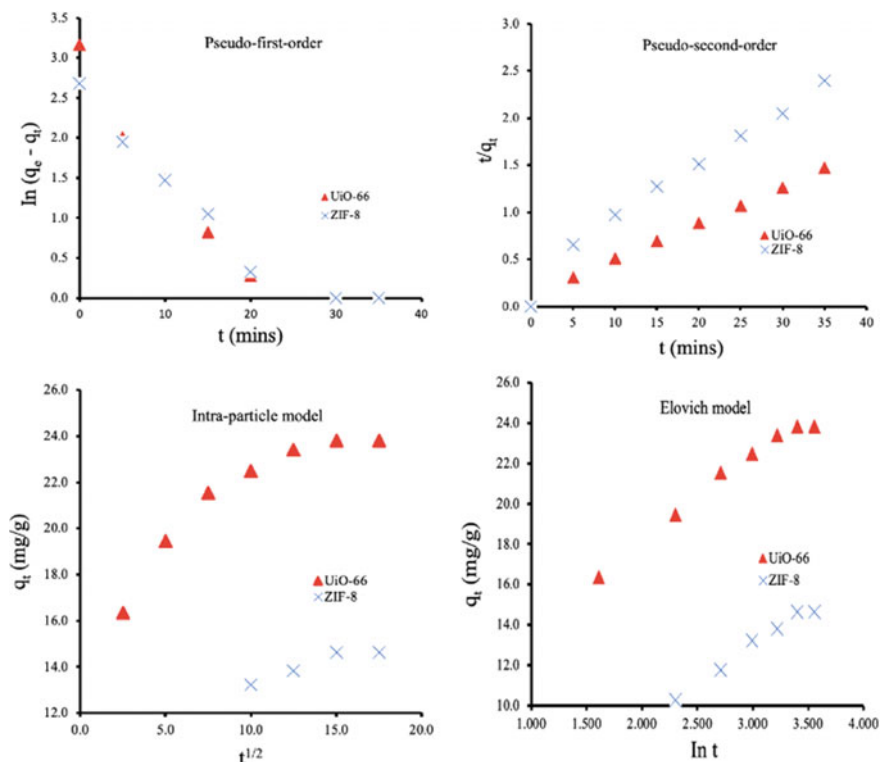


Fig. 5 Adsorption kinetics plots for acenaphthene adsorption onto UiO-66 and ZIF-8 MOFs

the adsorption of organic pollutants onto UiO-66 [38, 39] and ZIF-8 [40, 41] as pseudo-second order process.

4 Conclusion

RSM was used for the experimental design of acenaphthene adsorption onto UiO-66 and ZIF-8 MOFs. Five factor parameters were employed, and best performance of the MOFs was achieved for UiO-66 with adsorption efficiency of 99.7 due to its higher porosity in comparison to ZIF-8 which recorded adsorption efficiency of 60.7%, according to the experimental condition with contact time of contact time of 35 min, dosage of 4 mg, concentrations of 2 mg/L, pH of 4 and temperature of 30 °C. The overall model p-values were significant (< 0.0500) for both UiO-66 and ZIF-8 MOFs. The lack of fit test for the model was insignificant, which was desirable for both MOFs and the adequate precision was 17.3082 and 32.6708 for the UiO-66 and ZIF-8, respectively. Good agreement between the RSM and experimental findings.

Acknowledgements We would like to acknowledge UTP-UIR grant (015MEO-166) received from Universitas Islam Riau Indonesia and FRGS grant (FRGS/1/2020/STG04/UTP/02/3) received from Ministry of Higher Education Malaysia.

References

1. Guieysse, B., Bernhoft, I., Andersson, B.E., Henrysson, T., Olsson, S., Mattiasson, B.: Degradation of acenaphthene, phenanthrene and pyrene in a packed-bed biofilm reactor. *Appl. Microbiol. Biotechnol.* **54**(6), 826–831 (2000). <https://doi.org/10.1007/s002530000442>
2. Zango, Z.U., Jumbri, K., Sambudi, N.S., Abu Bakar, N.H.H., Abdullah, N.A.F., Basheer, C., Saad, B.: Removal of anthracene in water by MIL-88(Fe), NH₂-MIL-88(Fe), and mixed-MIL-88(Fe) metal-organic frameworks. *RCS Adv.* **9**, 41490–41501, (2019). <https://doi.org/10.1039/c9ra08660arsc.li/rsc-advances>
3. Jiang, L., Zhang, B., Wang, Y., Sun, J., Ma, X., Wang, G., Fu, S., Lin, C., Li, Y.: Three new acenaphthene derivatives from rhizomes of *musa basjoo* and their cytotoxic activity. *Nat. Prod. Res.* pp. 1–6 (2019). <https://doi.org/10.1080/14786419.2019.1647422>
4. Hirano, Y., Iba, Y., Kuroda, N., Kubota, Y., Inagaki, S.: Catalytic carbonization of acenaphthene for the preparation of ordered mesoporous carbon CMK-1 toward application as electrochemical double-layer capacitor electrode with ionic liquid electrolyte. *Chem. Lett.* **48**(6), 521–524 (2019). <https://doi.org/10.1246/cl.190090>
5. Bukharkina, T.V., Grechishkina, O.S., Digurov, N.G., Kon'kov, I.I.: Catalytic oxidation of acenaphthene and its derivatives in acetic acid. *Org. Process Res. Dev.* **6**(4), 394–400 (2002). <https://doi.org/10.1021/op0100448>
6. Ye, Y.F., Ma, F.Y., Wu, M., Wei, X.Y., Liu, J.M.: Increase of acenaphthene content in creosote oil by hydrodynamic cavitation. *Chem. Eng. Process. Process Intensif.* **104**, 66–74 (2016). <https://doi.org/10.1016/j.cep.2016.03.001>
7. Radwan, A.M.Y., Magram, S.F., Ahmed, Z.: Adsorption of acenaphthene using date seed activated carbon. *J. Environ. Sci. Technol.* **11**(1), 10–15 (2018). <https://doi.org/10.3923/jest.2018.10.15>
8. Alade, A.O., Amuda, O.S., Ibrahim, A.O.: Isothermal studies of adsorption of acenaphthene from aqueous solution onto activated carbon produced from rice (*Oryza sativa*) husk. *Elixir Chem. Eng.* **46**, 87–95 (2012). <https://doi.org/10.1080/19443994.2012.677514>
9. Rani, C.N., Karthikeyan, S.: Feasibility study of acenaphthene degradation in a novel slurry UV photocatalytic membrane reactor: Effect of operating parameters and optimization using response surface modeling. *Chem. Eng. Process.-Process Intensif.* pp. 108051 (2020). <https://doi.org/10.1016/j.cep.2020.108051>
10. Safitri, R., Handayani, S., Surono, W., Astika, H., Damayanti, R., Kusmaya, F.D., Rukiah, Balia, R.L.: Biodegradation of phenol, anthracene and acenaphthene singly and consortium culture of indigenous microorganism isolates from underground coal gasification area. In: IOP Conference Series Earth Environment Science **306**(1) (2019). <https://doi.org/10.1088/1755-1315/306/1/012026>
11. Gracht Van Der, H.: Potential of lost fishing gears for adsorption of PAHs. *Centro Interdisciplinar de Investigacao Marinho e Ambiental* (2020)
12. Patrick, U.A., Chiwuike, A.-O.: A column experiment showing adsorption dynamics and kinetics of selected PAH using plantain and cassava peels. *Int. J. Adv. Sci. Technol.* **111**, 129–146 (2018). <https://doi.org/10.14257/ijast.2018.111.12>
13. Smol, M., Włodarczyk-Makuła, M., Włóka, D.: Adsorption of polycyclic aromatic hydrocarbons (PAHs) from aqueous solutions on different sorbents. *Civ. Environ. Eng. Reports.* **13**(2), 87–96 (2014). <https://doi.org/10.2478/ceer-2014-0017>

14. Huang, Y., Fulton, A.N., Keller, A.A.: Simultaneous removal of PAHs and metal contaminants from water using magnetic nanoparticle adsorbents. *Sci. Total Environ.* **571**, 1029–1036 (2016). <https://doi.org/10.1016/j.scitotenv.2016.07.093>
15. Lu, L., Lin, Y., Chai, Q., He, S., Yang, C.: Removal of acenaphthene by biochar and raw biomass with coexisting heavy metal and phenanthrene. *Colloids Surfaces A Physicochem. Eng. Asp.* **558**, 103–109 (2018). <https://doi.org/10.1016/j.colsurfa.2018.08.057>
16. Mortazavi, M., Baghdadi, M., Seyed Javadi, N.H., Torabian, A.: The black beads produced by simultaneous thermal reducing and chemical bonding of graphene oxide on the surface of amino-functionalized sand particles: application for PAHs removal from contaminated waters. *J. Water Process Eng.* **31** (2019). <https://doi.org/10.1016/j.jwpe.2019.100798>
17. Zango, Z.U., Sambudi, N.S., Jumbri, K., Ramli, A., Hana, N., Abu, H., Saad, B., Nur, M., Rozaini, H., Isiyaka, H.A., Osman, A.M., Sulieman, A.: An overview and evaluation of highly porous adsorbent materials for polycyclic aromatic hydrocarbons and phenols removal from wastewater, pp. 1–40 (2020)
18. Alade, A.O., Amuda, O.S., Afolabi, A.O., Adelowo, F.E.: Adsorption of acenaphthene onto activated carbon produced from agricultural wastes. *J. Environmental Sci. Technol.* **5**(4), 192–209 (2012)
19. Lu, L., Li, A., Ji, X., Yang, C., He, S.: Removal of acenaphthene from water by Triton X-100-facilitated biochar-immobilized *Pseudomonas aeruginosa*. *RSC Adv.* **8**, 23426–23432 (2018). <https://doi.org/10.1039/C8RA03529F>
20. Han, B., Li, Y., Qian, B., He, Y., Peng, L., Yu, H.: Adsorption and determination of polycyclic aromatic hydrocarbons in water through the aggregation of graphene oxide. *Open Chem.* **16**(1), 716–725 (2018). <https://doi.org/10.1515/chem-2018-0078>
21. Bueken, B., Vermoortele, F., Cliffe, M.J., Wharmby, M.T., Foucher, D., Wieme, J., Vanduyfhuys, L., Martineau, C., Stock, N., Taulelle, F., Van Speybroeck, V., Goodwin, A.L., De Vos, D.: A breathing zirconium metal-organic framework with reversible loss of crystallinity by correlated nanodomains formation. *Chem.-A Eur. J.* **22**(10), 3264–3267 (2016). <https://doi.org/10.1002/chem.201600330>
22. Connolly, B.M., Mehta, J.P., Moghadam, P.Z., Wheatley, A.E.H., Fairen-Jimenez, D.: From synthesis to applications: metal-organic frameworks for an environmentally sustainable future. *Curr. Opin. Green Sustain. Chem.* **12**, 47–56 (2018). <https://doi.org/10.1016/j.cogsc.2018.06.012>
23. Adesina Adegoke, K., Samuel Agboola, O., Ogunmodede, J., Oluyomi Araoye, A., Solomon Bello, O.: Metal-organic frameworks as adsorbents for sequestering organic pollutants from wastewater. *Mater. Chem. Phys.* **253**, p. 123246 (2020). <https://doi.org/10.1016/j.matchemphys.2020.123246>
24. Gomar, M., Yeganegi, S.: Adsorption of 5-fluorouracil, hydroxyurea and mercaptopurine drugs on zeolitic imidazolate frameworks (ZIF-7, ZIF-8 and ZIF-9). *Microporous Mesoporous Mater.* **252**, 167–172 (2017). <https://doi.org/10.1016/j.micromeso.2017.06.010>
25. Jin, Z., Yang, H.: Exploration of Zr-metal-organic framework as efficient photocatalyst for hydrogen production. *Nanoscale Res. Lett.* **12** (2017). <https://doi.org/10.1186/s11671-017-2311-6>
26. Zango, Z.U., Jumbri, K., Sambudi, N.S., Ramli, A., Bakar, N.H.H.A., Saad, B., Rozaini, M.N.H., Isiyaka, H.A., Jagaba, A.H., Aldaghri, O., Sulieman, A.: A critical review on metal-organic frameworks and their composites as advanced materials for adsorption and photocatalytic degradation of emerging organic pollutants from wastewater. *Polymers (Basel)*. **12**, 1–42 (2020). <https://doi.org/10.3390/polym12112648>
27. Zango, Z.U., Ramli, A., Jumbri, K., Sambudi, N.S., Isiyaka, H.A., Abu Bakar, N.H.H., Saad, B.: Response surface methodology optimization and kinetics study for anthracene adsorption onto MIL-88(Fe) and NH₂-MIL-88(Fe) metal-organic frameworks. In: *Series IOP Conference Science Materials* **88**, pp. 0–12 (2021). <https://doi.org/10.1088/1757-899X/1092/1/012035>
28. Petit, C.: Present and future of MOF research in the field of adsorption and molecular separation. *Curr. Opin. Chem. Eng.* **20**, 132–142 (2018). <https://doi.org/10.1016/j.coche.2018.04.004>

29. Shahmirzaee, M., Hemmati-Sarapardeh, A., Husein, M.M., Schaffie, M., Ranjbar, M.: A review on zeolitic imidazolate frameworks use for crude oil spills cleanup. *Adv. Geo-Energy Res.* **3**(3), 320–342 (2019). <https://doi.org/10.26804/ager.2019.03.10>
30. Zango, Z.U., Sambudi, N.S., Jumbri, K., Abu Bakar, N.H.H., Abdullah, N.A.F., Negim, E.S.M., Saad, B.: Experimental and molecular docking model studies for the adsorption of polycyclic aromatic hydrocarbons onto UiO-66(Zr) and NH₂-UiO-66(Zr) metal-organic frameworks. *Chem. Eng. Sci.* p. 115608 (2020). <https://doi.org/10.1016/j.ces.2020.115608>
31. Jamali, A., Shemirani, F., Morsali, A.: A comparative study of adsorption and removal of organophosphorus insecticides from aqueous solution by Zr-based MOFs. *J. Ind. Eng. Chem.* **80**, 83–92 (2019). <https://doi.org/10.1016/j.jiec.2019.07.034>
32. Yang, J.M., Ying, R.J., Han, C.X., Hu, Q.T., Xu, H.M., Li, J.H., Wang, Q., Zhang, W.: Adsorptive removal of organic dyes from aqueous solution by a Zr-based metal-organic framework: effects of Ce(III) doping. *Dalt. Trans.* **47**(11), 3913–3920 (2018). <https://doi.org/10.1039/c8dt00217g>
33. Bayazit, S.S., Şahin, S.: Acid-modulated zirconium based metal organic frameworks for removal of organic micropollutants. *J. Environ. Chem. Eng.* **8**(5) (2020). <https://doi.org/10.1016/j.jece.2020.103901>
34. Alamgir, Talha, K., Wang, B., Liu, J.H., Ullah, R., Feng, F., Yu, J., Chen, S., Li, J.R.: Effective adsorption of metronidazole antibiotic from water with a stable Zr(IV)-MOFs: Insights from DFT, kinetics and thermodynamics studies. *J. Environ. Chem. Eng.* **8**(1), p. 103642 (2020). <https://doi.org/10.1016/j.jece.2019.103642>
35. Shi, M., Huang, R., Qi, W., Su, R., He, Z.: Synthesis of superhydrophobic and high stable Zr-MOFs for oil-water separation. *Colloids Surfaces A Physicochem. Eng. Asp.* **602**, p. 125102 (2020). <https://doi.org/10.1016/j.colsurfa.2020.125102>
36. Yan, F., Liu, Z.Y., Chen, J.L., Sun, X.Y., Li, X.J., Su, M.X., Li, B., Di, B.: Nanoscale zeolitic imidazolate framework-8 as a selective adsorbent for theophylline over caffeine and diprophylline. *RSC Adv.* **4**, 33047–33054 (2014). <https://doi.org/10.1039/c4ra05293e>
37. Zango, Z.U., Ramli, A., Jumbri, K., Soraya, N., Ahmad, H.I., Hana, N., Abu, H., Saad, B.: Optimization studies and artificial neural network modeling for pyrene adsorption onto UiO-66(Zr) and NH₂-UiO-66(Zr) metal organic frameworks. *Polyhedron* **192**, p. 114857 (2020). <https://doi.org/10.1016/j.poly.2020.114857>
38. Zhang, W., Yang, J.M., Yang, R.N., Yang, B.C., Quan, S., Jiang, X.: Effect of free carboxylic acid groups in UiO-66 analogues on the adsorption of dyes from water: plausible mechanisms for adsorption and gate-opening behavior. *J. Mol. Liq.* **283**, 160–166 (2019). <https://doi.org/10.1016/j.molliq.2019.03.100>
39. Sun, W., Li, H., Li, H., Li, S., Cao, X.: Adsorption mechanisms of ibuprofen and naproxen to UiO-66 and UiO-66-NH₂: batch experiment and DFT calculation. *Chem. Eng. J.* **360**, 645–653 (2019). <https://doi.org/10.1016/j.cej.2018.12.021>
40. Noor, T., Raffi, U., Iqbal, N., Yaqoob, L., Zaman, N.: Kinetic evaluation and comparative study of cationic and anionic dyes adsorption on Zeolitic Imidazolate frameworks based metal organic frameworks. *Mater. Res. Express.* **6**(12) (2019)
41. Sun, S., Yang, Z., Cao, J., Wang, Y., Xiong, W.: Copper-doped ZIF-8 with high adsorption performance for removal of tetracycline from aqueous solution. *J. Solid State Chem.* **285**, p. 121219 (2020). <https://doi.org/10.1016/j.jssc.2020.121219>

