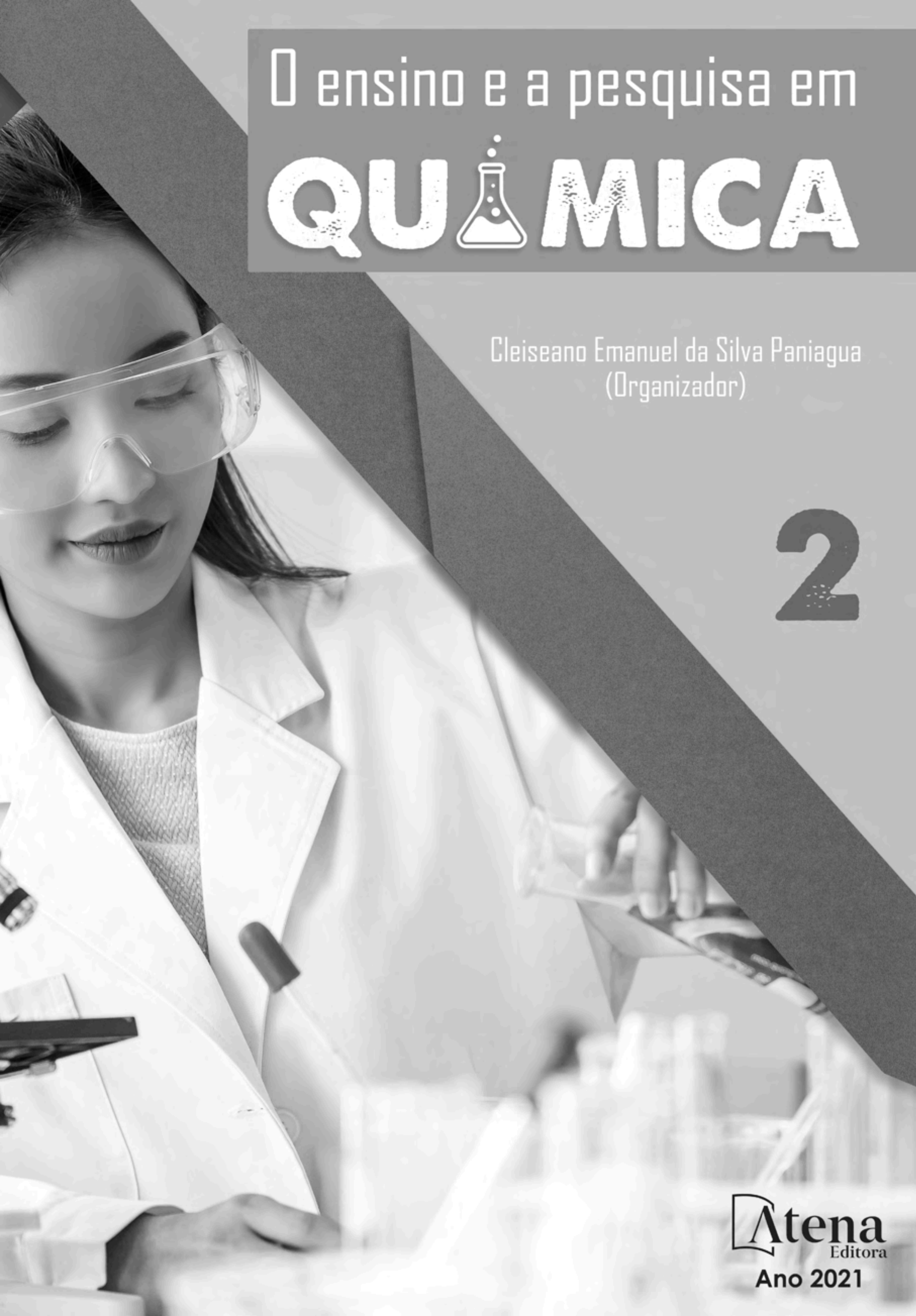
O ensino e a pesquisa em
QUÍMICA

Cleiseano Emanuel da Silva Paniagua
(Organizador)

2

Atena
Editora
Ano 2021



O ensino e a pesquisa em QUÍMICA

2

Cleiseano Emanuel da Silva Paniagua
(Organizador)

Atena
Editora
Ano 2021

Editora chefe
Profª Drª Antonella Carvalho de Oliveira
Assistentes editoriais
Natalia Oliveira
Flávia Roberta Barão
Bibliotecária
Janaina Ramos
Projeto gráfico
Natália Sandrini de Azevedo
Camila Alves de Cremo
Luiza Alves Batista
Maria Alice Pinheiro
Imagens da capa
iStock
Edição de arte
Luiza Alves Batista
Revisão
Os autores

2021 *by Atena Editora*
Copyright © Atena Editora
Copyright do Texto © 2021 Os autores
Copyright da Edição © 2021 Atena Editora
Direitos para esta edição cedidos à Atena Editora pelos autores.
Open access publication by Atena Editora

Todo o conteúdo deste livro está licenciado sob uma Licença de Atribuição *Creative Commons*. Atribuição-Não-Comercial-NãoDerivativos 4.0 Internacional (CC BY-NC-ND 4.0).

O conteúdo dos artigos e seus dados em sua forma, correção e confiabilidade são de responsabilidade exclusiva dos autores, inclusive não representam necessariamente a posição oficial da Atena Editora. Permitido o *download* da obra e o compartilhamento desde que sejam atribuídos créditos aos autores, mas sem a possibilidade de alterá-la de nenhuma forma ou utilizá-la para fins comerciais.

Todos os manuscritos foram previamente submetidos à avaliação cega pelos pares, membros do Conselho Editorial desta Editora, tendo sido aprovados para a publicação com base em critérios de neutralidade e imparcialidade acadêmica.

A Atena Editora é comprometida em garantir a integridade editorial em todas as etapas do processo de publicação, evitando plágio, dados ou resultados fraudulentos e impedindo que interesses financeiros comprometam os padrões éticos da publicação. Situações suspeitas de má conduta científica serão investigadas sob o mais alto padrão de rigor acadêmico e ético.

Conselho Editorial
Ciências Humanas e Sociais Aplicadas
Prof. Dr. Alexandre Jose Schumacher – Instituto Federal de Educação, Ciência e Tecnologia do Paraná
Prof. Dr. Américo Junior Nunes da Silva – Universidade do Estado da Bahia
Profª Drª Andréa Cristina Marques de Araújo – Universidade Fernando Pessoa
Prof. Dr. Antonio Carlos Frasson – Universidade Tecnológica Federal do Paraná
Prof. Dr. Antonio Gasparetto Júnior – Instituto Federal do Sudeste de Minas Gerais
Prof. Dr. Antonio Isidro-Filho – Universidade de Brasília

Atena
Editora
Ano 2021

Prof. Dr. Arnaldo Oliveira Souza Júnior – Universidade Federal do Piauí
Prof. Dr. Carlos Antonio de Souza Moraes – Universidade Federal Fluminense
Prof. Dr. Crisóstomo Lima do Nascimento – Universidade Federal Fluminense
Profª Drª Cristina Gaio – Universidade de Lisboa
Prof. Dr. Daniel Richard Sant'Ana – Universidade de Brasília
Prof. Dr. Deyvison de Lima Oliveira – Universidade Federal de Rondônia
Profª Drª Dilma Antunes Silva – Universidade Federal de São Paulo
Prof. Dr. Edvaldo Antunes de Farias – Universidade Estácio de Sá
Prof. Dr. Elson Ferreira Costa – Universidade do Estado do Pará
Prof. Dr. Eloi Martins Senhora – Universidade Federal de Roraima
Prof. Dr. Gustavo Henrique Cepolini Ferreira – Universidade Estadual de Montes Claros
Prof. Dr. Humberto Costa – Universidade Federal do Paraná
Profª Drª Ivone Goulart Lopes – Istituto Internazionele delle Figlie de Maria Ausiliatrice
Prof. Dr. Jadson Correia de Oliveira – Universidade Católica do Salvador
Prof. Dr. José Luis Montesillo-Cedillo – Universidad Autónoma del Estado de México
Prof. Dr. Julio Candido de Meirelles Junior – Universidade Federal Fluminense
Profª Drª Lina Maria Gonçalves – Universidade Federal do Tocantins
Prof. Dr. Luis Ricardo Fernandes da Costa – Universidade Estadual de Montes Claros
Profª Drª Natiéli Piovesan – Instituto Federal do Rio Grande do Norte
Prof. Dr. Marcelo Pereira da Silva – Pontifícia Universidade Católica de Campinas
Profª Drª Maria Luzia da Silva Santana – Universidade Federal de Mato Grosso do Sul
Prof. Dr. Miguel Rodrigues Netto – Universidade do Estado de Mato Grosso
Prof. Dr.Pablo Ricardo de Lima Falcão – Universidade de Pernambuco
Profª Drª Paola Andressa Scortegagna – Universidade Estadual de Ponta Grossa
Profª Drª Rita de Cássia da Silva Oliveira – Universidade Estadual de Ponta Grossa
Prof. Dr. Rui Maia Diamantino – Universidade Salvador
Prof. Dr. Saulo Cerqueira de Aguiar Soares – Universidade Federal do Piauí
Prof. Dr. Urandi João Rodrigues Junior – Universidade Federal do Oeste do Pará
Profª Drª Vanessa Bordin Viera – Universidade Federal de Campina Grande
Profª Drª Vanessa Ribeiro Simon Cavalcanti – Universidade Católica do Salvador
Prof. Dr. William Cleber Domingues Silva – Universidade Federal Rural do Rio de Janeiro
Prof. Dr. Willian Douglas Guilherme – Universidade Federal do Tocantins

Ciências Agrárias e Multidisciplinar
Prof. Dr. Alexandre Igor Azevedo Pereira – Instituto Federal Goiano
Prof. Dr. Arinaldo Pereira da Silva – Universidade Federal do Sul e Sudeste do Pará
Prof. Dr. Antonio Pasqualetto – Pontifícia Universidade Católica de Goiás
Profª Drª Carla Cristina Bauermann Brasil – Universidade Federal de Santa Maria
Prof. Dr. Cleberton Correia Santos – Universidade Federal da Grande Dourados
Profª Drª Diocléa Almeida Seabra Silva – Universidade Federal Rural da Amazônia
Prof. Dr. Écio Souza Diniz – Universidade Federal de Viçosa
Prof. Dr. Fábio Steiner – Universidade Estadual de Mato Grosso do Sul
Prof. Dr. Fágner Cavalcante Patrocínio dos Santos – Universidade Federal do Ceará
Profª Drª Girlene Santos de Souza – Universidade Federal do Recôncavo da Bahia
Prof. Dr. Jael Soares Batista – Universidade Federal Rural do Semi-Árido
Prof. Dr. Jayme Augusto Peres – Universidade Estadual do Centro-Oeste
Prof. Dr. Júlio César Ribeiro – Universidade Federal Rural do Rio de Janeiro
Profª Drª Lina Raquel Santos Araújo – Universidade Estadual do Ceará
Prof. Dr. Pedro Manuel Villa – Universidade Federal de Viçosa
Profª Drª Raissa Rachel Salustriano da Silva Matos – Universidade Federal do Maranhão
Prof. Dr. Ronilson Freitas de Souza – Universidade do Estado do Pará
Profª Drª Talita de Santos Matos – Universidade Federal Rural do Rio de Janeiro

Atena
Editora
Ano 2021

Prof. Dr. Tiago da Silva Teófilo – Universidade Federal Rural do Semi-Árido
Prof. Dr. Valdemar Antonio Paffaro Junior – Universidade Federal de Alfenas

Ciências Biológicas e da Saúde
Prof. Dr. André Ribeiro da Silva – Universidade de Brasília
Profª Drª Anelise Levay Murari – Universidade Federal de Pelotas
Prof. Dr. Benedito Rodrigues da Silva Neto – Universidade Federal de Goiás
Profª Drª Daniela Reis Joaquim de Freitas – Universidade Federal do Piauí
Profª Drª Débora Luana Ribeiro Pessoa – Universidade Federal do Maranhão
Prof. Dr. Douglas Siqueira de Almeida Chaves – Universidade Federal Rural do Rio de Janeiro
Prof. Dr. Edson da Silva – Universidade Federal dos Vales do Jequitinhonha e Mucuri
Profª Drª Elizabeth Cordeiro Fernandes – Faculdade Integrada Medicina
Profª Drª Eleuza Rodrigues Machado – Faculdade Anhanguera de Brasília
Profª Drª Elane Schwinden Prudêncio – Universidade Federal de Santa Catarina
Profª Drª Eysler Gonçalves Maia Brasil – Universidade da Integração Internacional da Lusofonia Afro-Brasileira
Prof. Dr. Ferlando Lima Santos – Universidade Federal do Recôncavo da Bahia
Profª Drª Fernanda Miguel de Andrade – Universidade Federal de Pernambuco
Prof. Dr. Fernando Mendes – Instituto Politécnico de Coimbra – Escola Superior de Saúde de Coimbra
Profª Drª Gabriela Vieira do Amaral – Universidade de Vassouras
Prof. Dr. Gianfábio Pimentel Franco – Universidade Federal de Santa Maria
Prof. Dr. Helio Franklin Rodrigues de Almeida – Universidade Federal de Rondônia
Profª Drª Iara Lúcia Tescarollo – Universidade São Francisco
Prof. Dr. Igor Luiz Vieira de Lima Santos – Universidade Federal de Campina Grande
Prof. Dr. Jefferson Thiago Souza – Universidade Estadual do Ceará
Prof. Dr. Jesus Rodrigues Lemos – Universidade Federal do Piauí
Prof. Dr. Jônatas de França Barros – Universidade Federal do Rio Grande do Norte
Prof. Dr. José Max Barbosa de Oliveira Junior – Universidade Federal do Oeste do Pará
Prof. Dr. Luís Paulo Souza e Souza – Universidade Federal do Amazonas
Profª Drª Magnólia de Araújo Campos – Universidade Federal de Campina Grande
Prof. Dr. Marcus Fernando da Silva Praxedes – Universidade Federal do Recôncavo da Bahia
Profª Drª Maria Tatiane Gonçalves Sá – Universidade do Estado do Pará
Profª Drª Mylena Andréa Oliveira Torres – Universidade Ceuma
Profª Drª Natiéli Piovesan – Instituto Federacl do Rio Grande do Norte
Prof. Dr. Paulo Inada – Universidade Estadual de Maringá
Prof. Dr. Rafael Henrique Silva – Hospital Universitário da Universidade Federal da Grande Dourados
Profª Drª Regiane Luz Carvalho – Centro Universitário das Faculdades Associadas de Ensino
Profª Drª Renata Mendes de Freitas – Universidade Federal de Juiz de Fora
Profª Drª Vanessa da Fontoura Custódio Monteiro – Universidade do Vale do Sapucaí
Profª Drª Vanessa Lima Gonçalves – Universidade Estadual de Ponta Grossa
Profª Drª Vanessa Bordin Viera – Universidade Federal de Campina Grande
Profª Drª Welma Emidio da Silva – Universidade Federal Rural de Pernambuco

Ciências Exatas e da Terra e Engenharias
Prof. Dr. Adélio Alcino Sampaio Castro Machado – Universidade do Porto
ProFª Drª Ana Grasielle Dionísio Corrêa – Universidade Presbiteriana Mackenzie
Prof. Dr. Carlos Eduardo Sanches de Andrade – Universidade Federal de Goiás
Profª Drª Carmen Lúcia Voigt – Universidade Norte do Paraná
Prof. Dr. Cleiseano Emanuel da Silva Paniagua – Instituto Federal de Educação, Ciência e Tecnologia de Goiás
Prof. Dr. Douglas Gonçalves da Silva – Universidade Estadual do Sudoeste da Bahia
Prof. Dr. Eloi Rufato Junior – Universidade Tecnológica Federal do Paraná
Profª Drª Érica de Melo Azevedo – Instituto Federal do Rio de Janeiro

Prof. Dr. Fabrício Menezes Ramos – Instituto Federal do Pará
Profª Dra. Jéssica Verger Nardeli – Universidade Estadual Paulista Júlio de Mesquita Filho
Prof. Dr. Juliano Carlo Rufino de Freitas – Universidade Federal de Campina Grande
Profª Drª Luciana do Nascimento Mendes – Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte
Prof. Dr. Marcelo Marques – Universidade Estadual de Maringá
Prof. Dr. Marco Aurélio Kistemann Junior – Universidade Federal de Juiz de Fora
Profª Drª Neiva Maria de Almeida – Universidade Federal da Paraíba
Profª Drª Natiéli Piovesan – Instituto Federal do Rio Grande do Norte
Profª Drª Priscila Tessmer Scaglioni – Universidade Federal de Pelotas
Prof. Dr. Sidney Gonçalo de Lima – Universidade Federal do Piauí
Prof. Dr. Takeshy Tachizawa – Faculdade de Campo Limpo Paulista

Linguística, Letras e Artes
Profª Drª Adriana Demite Stephani – Universidade Federal do Tocantins
Profª Drª Angeli Rose do Nascimento – Universidade Federal do Estado do Rio de Janeiro
Profª Drª Carolina Fernandes da Silva Mandaji – Universidade Tecnológica Federal do Paraná
Profª Drª Denise Rocha – Universidade Federal do Ceará
Profª Drª Edna Alencar da Silva Rivera – Instituto Federal de São Paulo
Profª DrªFernanda Tonelli – Instituto Federal de São Paulo,
Prof. Dr. Fabiano Tadeu Grazioli – Universidade Regional Integrada do Alto Uruguai e das Missões
Prof. Dr. Gilmei Fleck – Universidade Estadual do Oeste do Paraná
Profª Drª Keyla Christina Almeida Portela – Instituto Federal de Educação, Ciência e Tecnologia do Paraná
Profª Drª Miranilde Oliveira Neves – Instituto de Educação, Ciência e Tecnologia do Pará
Profª Drª Sandra Regina Gardacho Pietrobon – Universidade Estadual do Centro-Oeste
Profª Drª Sheila Marta Carregosa Rocha – Universidade do Estado da Bahia

O ensino e a pesquisa em química 2

Diagramação: Camila Alves de Cremo
Correção: Giovanna Sandrini de Azevedo
Indexação: Gabriel Motomu Teshima
Revisão: Os autores
Organizador: Cleiseano Emanuel da Silva Paniagua

Dados Internacionais de Catalogação na Publicação (CIP)

E59 O ensino e a pesquisa em química 2 / Organizador Cleiseano Emanuel da Silva Paniagua. – Ponta Grossa - PR: Atena, 2021.

Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-65-5983-423-5
DOI: https://doi.org/10.22533/at.ed.235213108

1. Química - Estudo e ensino. I. Paniagua, Cleiseano Emanuel da Silva (Organizador). II. Título.
CDD 540.7

Elaborado por Bibliotecária Janaina Ramos – CRB-8/9166

Atena Editora
Ponta Grossa – Paraná – Brasil
Telefone: +55 (42) 3323-5493
www.atenaeditora.com.br
contato@atenaeditora.com.br

Atena
Editora
Ano 2021

DECLARAÇÃO DOS AUTORES

Os autores desta obra: 1. Atestam não possuir qualquer interesse comercial que constitua um conflito de interesses em relação ao artigo científico publicado; 2. Declaram que participaram ativamente da construção dos respectivos manuscritos, preferencialmente na: a) Concepção do estudo, e/ou aquisição de dados, e/ou análise e interpretação de dados; b) Elaboração do artigo ou revisão com vistas a tornar o material intelectualmente relevante; c) Aprovação final do manuscrito para submissão.; 3. Certificam que os artigos científicos publicados estão completamente isentos de dados e/ou resultados fraudulentos; 4. Confirmam a citação e a referência correta de todos os dados e de interpretações de dados de outras pesquisas; 5. Reconhecem terem informado todas as fontes de financiamento recebidas para a consecução da pesquisa; 6. Autorizam a edição da obra, que incluem os registros de ficha catalográfica, ISBN, DOI e demais indexadores, projeto visual e criação de capa, diagramação de miolo, assim como lançamento e divulgação da mesma conforme critérios da Atena Editora.

Atena
Editora
Ano 2021

DECLARAÇÃO DA EDITORA

A Atena Editora declara, para os devidos fins de direito, que: 1. A presente publicação constitui apenas transferência temporária dos direitos autorais, direito sobre a publicação, inclusive não constitui responsabilidade solidária na criação dos manuscritos publicados, nos termos previstos na Lei sobre direitos autorais (Lei 9610/98), no art. 184 do Código penal e no art. 927 do Código Civil; 2. Autoriza e incentiva os autores a assinarem contratos com repositórios institucionais, com fins exclusivos de divulgação da obra, desde que com o devido reconhecimento de autoria e edição e sem qualquer finalidade comercial; 3. Todos os e-book são *open access, desta forma* não os comercializa em seu site, sites parceiros, plataformas de *e-commerce,* ou qualquer outro meio virtual ou físico, portanto, está isenta de repasses de direitos autorais aos autores; 4. Todos os membros do conselho editorial são doutores e vinculados a instituições de ensino superior públicas, conforme recomendação da CAPES para obtenção do Qualis livro; 5. Não cede, comercializa ou autoriza a utilização dos nomes e e-mails dos autores, bem como nenhum outro dado dos mesmos, para qualquer finalidade que não o escopo da divulgação desta obra.

APRESENTAÇÃO

O e-book: “O ensino e a pesquisa em química” volume II é constituído por quinze capítulos de livro que foram reunidos em três grandes áreas temáticas, a saber: *i*) química analítica: determinação, otimização e validação; *ii*) desenvolvimento de adsorventes e catalisadores para remoção de diferentes classes de contaminantes e aplicação industrial e *iii*) temas diversos.

A primeira temática é constituída por seis capítulos e apresentam diversos estudos, entre os quais: *i*) determinação quantitativa de glicazida em comprimidos e os problemas provenientes do uso de comprimidos pelo sistema de partição não homogêneo; *ii*) a determinação de Hidrocarbonetos Policíclicos Aromáticos (HPAs) empregando-se a técnica de voltametria; *iii*) a validação de um sistema fotocolorímetro em análises para o ensino de química na Universidade Tecnológica de Gutiérrez Zamora na cidade de Vera Cruz no México;*iv*) a iportância da otimização para melhor entendimento dos estudos cinéticos em uma reação de hidroalogenação; *v*) a triagem fitoquímica e análise de propriedades antioxidantes e *vi*) avaliação de estruturas metálicas orgânicas como fase estacionaria em Cromatografia Liquida de Alta Eficiência (HPLC).

A segunda temática é composta por cinco capítulos e apresentam: estudo de revisão que demonstram: *i*) o potencial de extração de fósforo em efluentes líquidos; *ii*) estudo de Montmorilonita como potencial adsorvente e aplicação em sistemas de fluxo contínuo e *iii*) avaliação e estudo de diferentes catalisadores para remoção de inúmeras classes de poluentes em matrizes aquáticas e reforma do etanol com vapor d’água.

Por fim, a terceira temática que apresenta quatro diferentes estudos que contemplam a corrosão obtida por pulverização de gás frio, a importância e utilização de supressores de poeira na mineração, preparação de nanopartículas poliméricas enriquecidas com óleos essenciais poliméricas e estudo de revisão das propriedades químicas da série de lantanídeos.

Nesta perspectiva, a Atena Editora vem trabalhando por meio do incentivo de publicações de trabalhos de pesquisadores de todas as regiões do Brasil e de outros países com o intuito de colaborar com a publicação de e-books e, consequentemente, sua divulgação de forma gratuita em diferentes plataformas digitais de fácil acesso. Logo, a Atena Editora contribui para a divulgação e disseminação do conhecimento cientifico gerado dentro de instituições de ensino e pesquisa e que pode ser acessado de qualquer lugar e em tempo real por qualquer pessoa interessada na busca pelo conhecimento.

Cleiseano Emanuel da Silva Paniagua

SUMÁRIO

CAPÍTULO 6

MOFs (METAL ORGANIC FRAMEWORKS) AS A STATIONARY PHASE IN LIQUID CHROMATOGRAPHY (HPLC)

Data de aceite: 23/08/2021
Data de submissão: 15/06/2021

Tamires dos Reis Menezes
Instituto de Tecnologia e Pesquisa (ITP), Universidade Tiradentes (UNIT/PEP)
Aracaju-Sergipe
http://lattes.cnpq.br/1363799665554869

Kátilla Monique Costa Santos
Instituto de Tecnologia e Pesquisa (ITP), Universidade Tiradentes (UNIT/PEP)
Aracaju-Sergipe
http://lattes.cnpq.br/7513196907569585

Silvia Maria Egues Dariva
Instituto de Tecnologia e Pesquisa (ITP), Universidade Tiradentes (UNIT/PEP)
Aracaju-Sergipe
http://lattes.cnpq.br/8029656203911141

Juliana Faccin de Conto Borges
Instituto de Tecnologia e Pesquisa (ITP), Universidade Tiradentes (UNIT/PEP)
Aracaju-Sergipe
http://lattes.cnpq.br/6166704581313470

Cesar Costapinto Santana
Instituto de Tecnologia e Pesquisa (ITP), Universidade Tiradentes (UNIT/PEP)
Aracaju-Sergipe
http://lattes.cnpq.br/8458559657676452

ABSTRACT: The MOFs belong to a class of coordination polymers that can be used as micro and meso porous materials of high-capacity adsorption. These materials combine inorganic parts (metal ions) with organic parts (binders) creating three-dimensional crystalline structures with covalent bonds. The peculiar characteristics (high porosity, selectivity, multiple active sites) make the MOFs a promisor adsorbent as a new stationary phase of high performance for liquid chromatography. This work is an exploratory study of published articles in the literature in several scientific journals, between 2008 and 2018, in order to create summary and recommendations of experimental results regarding to MOF applications as a stationary phase in liquid chromatography (HPLC). In order to overcome the challenge of loss of column efficiency due to the irregular sizes and shapes of the particles, there is an absolute growth in pre-treatment and modifications area of the MOFs that aims to improve the efficiency and activity.

KEYWORDS: MOFs, ZIFs, liquid chromatography, HPLC.

1 I INTRODUCTION

The separation process for obtaining pure substances is of crucial importance for the chemical and allied industries. In this context, the chromatographic processes stand out. High-performance liquid chromatography (HPLC) is among the most widely used as a tool in both biochemistry and separation analyzes (HAYES et al., 2014).

Chromatography can be described as a physicochemical method of separating components from a mixture, accomplished by distributing these components into two phases, which are in contact. One phase remains stationary while the other moves through it. During the contact of the mobile phase on the stationary phase, the components of the mixture are distributed over the two phases so that each phase is selectively retained by the stationary phase, resulting in different retention times of these components (COLLINS et al., 2006).

The silica stands out as the most used material in the processes with HPLC, however, new porous materials emerge as a possibility to compose the stationary phase, as the coordination polymers.

A new class of microporous coordination polymers appears as an alternative to HPLC stationary phase are the so-called MOFs (Metal-Organic Frameworks). Metallurgical networks consist of clusters or metal ions coordinated to organic binders containing potential voids. The recent interest in these materials is a consequence of the combination of important characteristics such as crystallinity, porosity and the existence of strong metal-binder interaction. This unique combination of properties elevates MOFs to a special class of adsorbents as it conducts materials with greater thermal stability and greater mechanical stability. In this way, the MOFs are materials with great potential of adsorption and chromatography applications, besides others such as catalysis and controlled release of drugs (AHMAD et al., 2009; NORDIN et al., 2015).

The synthesis and development of MOFs are relatively recent, with the consolidation of the pioneering work of the so-called reticular chemistry in the late 1990s (YAGHI, 1999). Materials and methods for the preparation of materials with significant chemical, mechanical and nanoporosity robustness emerged exponentially in the later decades (LONG and YAGUI, 2009; LI et al., 2009). These adsorbents exhibit a great potential of application, especially in the manufacture of chemical products, separation processes, catalysts among others, in the area of fine chemistry. Due mainly to the possibility of modulation of the porous structure and the electronic properties of the active sites. The porosities of the MOFs are located between the mesoporous zeolites and the mesoporous silicates, being considered as nanostructured materials (KINIC et al., 2017).

Another class of MOFs that presents a high interest are the ZIFs (Zeolite Imidazole Frameworks), since these materials present high thermal and chemical stability of zeolites, with the specific advantages of MOFs as high surface area, Zeolite Imidazole Frameworks). ZIFs are porous and crystalline networks obtained from zeolites in which the metal ions are bound to the backbone by imidazole units (ZHU et al., 2017).

In particular, the possibility of post-synthesis modification of these MOFs, from the change of the organic part, promotes different chemical environments and can serve as a reaction medium with control of chemical properties. It thus becomes a promising class of adsorbent materials. The peculiar characteristics such as high porosity, shape selectivity, and multiple active sites make the MOFs a promising adsorbent as a new high-performance stationary phase for liquid chromatography (EHRLING et al., 2018).

The literature-based approaches based on MOFs are very important for knowledge of the ability of MOFs in the adsorption/separation process and for better knowledge of the material, obtaining good results due to high adsorption rates (ZHANG and CHEN, 2017).

Since the advent of this new material the investigations have focused mainly on the adsorption to a gas phase, however, some works dealing with MOFs for separations of liquid phases have been receiving a lot of attention. Three interesting reviews have been published (Vororde et al., 2014, ZHANG et al., 2017 and MUKHERJEE et al., 2018) containing the MOF studies for liquid phase separations. MUKHERJEE and collaborators also focus on their study on the pore flexibility of metal-organic structures in the face of the evolution of studies already published in the literature.

In this context, the objective of this review was to conduct an exploratory study of the evolution of the articles published in the literature, concerning the applications of MOFs as a stationary phase in high performance liquid chromatography (HPLC), with the aim of highlighting the evolution of these stationary phases, from the use of the pure, as well as, in the supports made to overcome the problem of efficiency loss in the column due to the non-uniformity of the particles. The abstract has articles published between the years 2008 and the present year, 2018. Initial surveys identified that in the period prior to 2008 there is a shortage of articles that describe in greater detail.

2 | EXPLORATORY STUDY

2.1 MOF in Liquid Chromatography

Cychosz et al. (2008), although they did not perform a work using the liquid chromatography technique, developed a study based on the liquid phase adsorption by microporous coordination polymers (MCPs), MOFs and subfamily of MOFs, to remove organosulfide compounds that later served as a basis for several other studies. MCPs exhibit superior adsorption capacity when compared to activated carbon and zeolite, but the quantitative determination on adsorption of large molecules by MCPs (Microporous coordination polymers) is still poorly exploited, although they exhibit adequate pore size.

In the work, 5 types of MCPs (UMCM-150, MOF-505, HKUST-1, MOF-5 and MOF-177) were studied for the adsorption of benzothiophene, dibenzothiophene, and 4,6-dimethyldibenzothiophene from isooctane solutions. The choice of the MCPs was an attempt to ascertain different structures with different pore sizes and different metal clusters. Saturation was not achieved for all the isotherms studied in the work, indicating that these materials have a potential for even greater amounts of adsorption, Figure 1. Another factor that attracted a lot of attention in the study was the comparison of the capacities of these materials in relation to reference zeolite, Na (Y). For comparison, the adsorption capacities were measured and MOF structures were adsorbed 5 to 6 times more than the reference zeolite.

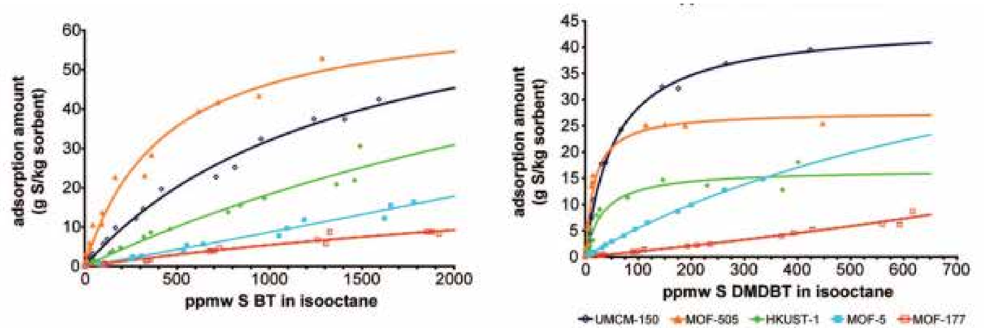


Figure 1. Adsorbent isotherms of benzothiophene and 4,6-dimethyldibenzothiophene in isooctane solutions with the MCPs: UMCM-150, MOF-505, HKUST-1, MOF-5 e MOF-177. Reprinted (adapted) with permission from (CYCHOSZ *et al., 2008).* Copyright American Chemical Society.

The work of ALAERTS et al. (2008) established how essential it is for the application of MOFs that they undergo an activation process being pretreated to obtain a larger volume of pores because during the process of synthesis or modification some organic binders or even non-volatile solvents can lodge in the pores.

Alaerts and colleagues proposed the total removal of the terephthalic acid housed in the pores of MOF MIL-47 during the calcination process that was performed at 573k, suggesting that there would be greater accessibility by increasing the pore volume and, consequently, maximizing the adsorption rate of xylenes, reporting that this step is essential to apply the MOFs to selective separations in the liquid phase. They also performed pulse and breakthrough chromatographic experiments using a stainless steel 5 cm long and 4 mm internal diameter filled with MIL-47 using hexane as the mobile phase. It was noted, then, that the temperature increases both completely removed the terephthalic acid from the pores, as it prevented the oxidation of the MIL-47 before pretreatment. However, under the activation conditions, it was not possible to avoid oxidation. The application of MIL-47 to the separation was impaired since the acid removed contributes in the selectivity between p-xylene and m-xylene. However, the activated MIL-47 is quite selective for separations of para-meta-mixtures of aromatics like ethyl toluene, xylenes, dichlorobenzenes, toluidines, and cresols.

The activation process of the MOFs, conditioned for a certain time and a high temperature, which varies with the type of MOF according to the temperature that the structure begins to degrade or collapse, has been carried out as a standard pretreatment of the material prior to characterizations and / or applications in both liquid adsorption and gas adsorption studies to obtain greater pore access and better adsorption rates.

Ahmad points out that analyzing previous work such as Cychosz's, MCPs, MOFs, offer an attractive alternative to other materials already used as a stationary phase because of their adjustable pore sizes, high surface area and commercial availability. It thus becomes an excellent material with high potential for adsorption and high selectivity for liquid chromatography. Then, a study was carried out with coordinated polymers of microporous polymers derived from carboxylates coordinated with copper (HKUST-1) and zinc (MOF-5), two of the materials studied by Cychosz. The two materials were packed on a HPLC column and hexane and dichloromethane were used as the mobile phase for the selective separation of organic compounds including; benzene, ethylbenzene, styrene, naphthalene, anthracene, phenanthrene, pyrene, 1,3,5-triphenylbenzene and 1,3,5-tris (4-bromophenyl) benzene and, in most cases, excellent separation with different retention and good adsorption rate, Figure 2 and 3. However, it was observed a high counter pressure and the existence of extended peaks.

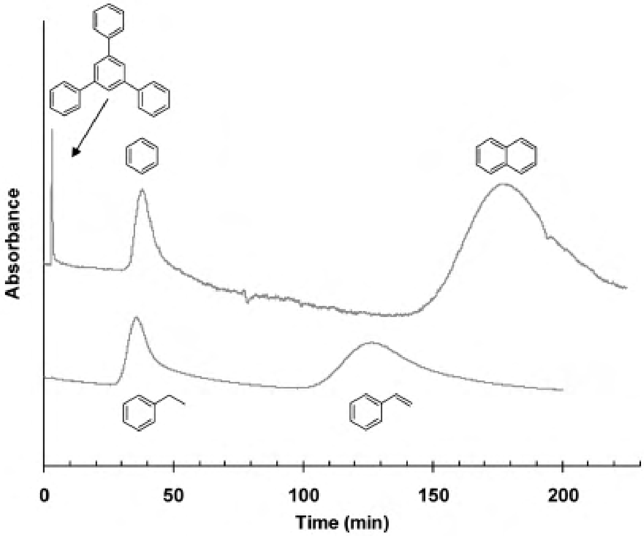


Figure 2. Chromatogram of a mixture of 1,3,5-triphenylbenzene, benzene and naphthalene. Chromatogram of styrene and ethylbenzene. Reprinted (adapted) with permission from (AHMAD *et al.2009).* Copyright American Chemical Society.

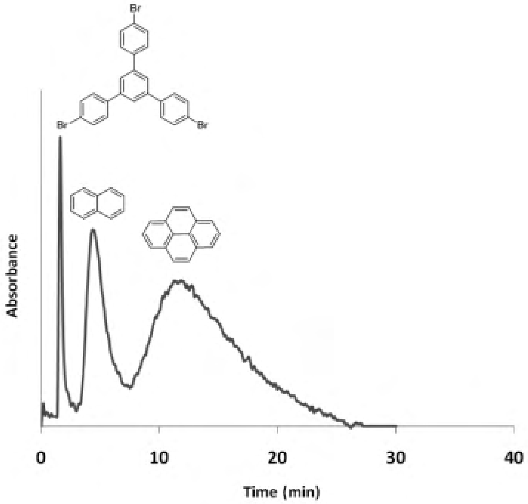


Figure 3. Chromatogram of 1,3,5-tris (4-bromophenyl) benzene, naphthalene and pyrene using MOF-5 as stationary phase. Reprinted (adapted) with permission from (AHMAD *et al.2009).* Copyright American Chemical Society).

Despite the several positive characteristics of MOFs, such as high adsorption rates and efficiency in the separation of several substances such as aromatic compounds studied by Ahmad, it is evident that the wide distribution of particle sizes and irregular shapes can generate against pressure and cause a decrease in efficiency of the HPLC columns filled with the MOF, as can be observed in Ahmad's work where peak amplification and low intensity occurred. Faced with this problem, after the year of 2009, some studies appeared seeking alternatives to minimize it and improve the efficiency of columns containing the stationary phase.

One of the alternatives to reduce separation time and improve column efficiency is to manufacture silica-MOF composites for fast and efficient HPLC separation, as can be seen in the work of Ameloot et al., By comparing the two columns , MOF and Silica-MOF. Although this manufacture of silica-MOF composites is highly relevant and promising, this activity requires great challenges.

AMELOOT et al. (2010) studied silica-MOF as a stationary phase in HPLC. The work consists in introducing a method based on a clear precursor solution that allows the formation of MOF within the pores of silica granules, often used in chromatography, leading to spheres with a uniform particle size of 3 µm. Silica was modified with MOF, [Cu 3 (BTC) 2]. In the study, we performed column tests containing MOF, [Cu3 (BTC) 2], unmodified silica and silica modified with MOF. They used heptane as the mobile phase and a column 15 cm long and 4.6 mm in diameter. As a result, the columns containing [Cu 3 (BTC) 2] showed high backpressure (around 200 bar) and fairly broad peaks. The column containing the unmodified silica despite having a lower counter-pressure (around 54 bar, could not separate the ethylbenzene-styrene mixture.) However, the column containing the silica-MOF compound was able to separate the mixture of ethylbenzene and styrene effectively with lower retention time, lower back pressure (around 47 bar) with intense and narrow peaks, Figure 4.

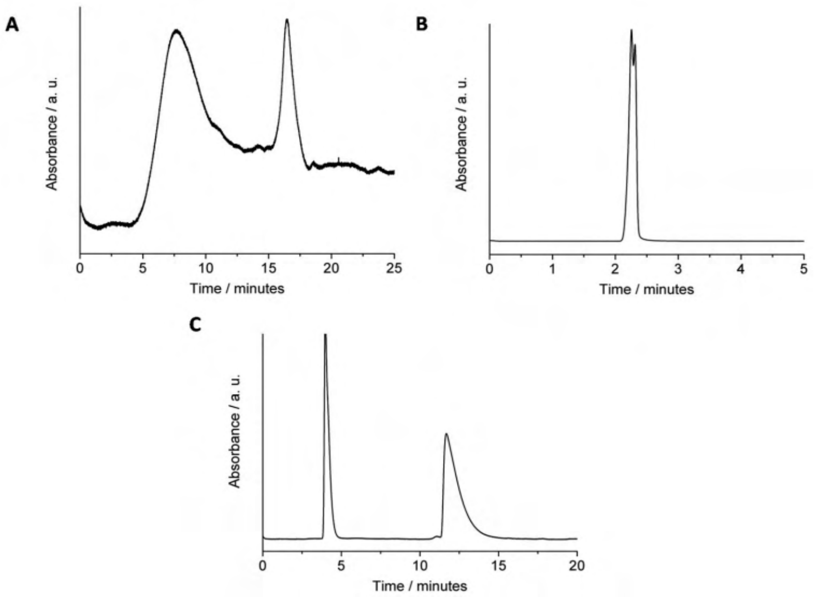


Figure 4. (A) Injection of a mixture of ethylbenzene styrene into a pure [Cu3 (BTC) 2] column. (B) Silica column without modification. (C) Silica column modified with [Cu3 (BTC) 2]. Reprinted (adapted) with permission from (AMELOOT *et al.,* 2010). Copyright American Chemical Society.

Aware of the positive characteristics of the MOFs and knowing the challenge that the irregular sizes and shapes of the particles can cause in an HPLC column, Fu et al. (2013) they studied a new possibility, using a subclass of MOFs called ZIFs. Among ZIFs, ZIF-8 was chosen for loading the structural advantages of MOFs and features present in the compounds as zeolites as high surface areas, high chemical and mechanical stability. They used ZIF-silica to separate EDCs (bisphenol A (BPA), b-estradiol (E2) and p- (tert-octyl) phenol) and pesticides (thiamethoxam, hexaflumuron, chlorantraniliprole and pymetrozine) and named the ZIF -8 @ SiO2 for this stationary phase. They obtained a rapid separation of EDCs and pesticides with low column backpressure. We have also demonstrated that ZIF-8 is effective for separating the large molecules tested because of the surface interactions between them and the analytes. This study offers the possibility of preparation of multifunctional composites based on large applications of MOFs in HPLC separation.

In addition, Fu et al. (2013) studied the effect of ZIF-8 density by testing the influence of different layers of the carrier, silica, on HPLC separation, which they called the number of growth cycles of ZIF-8. They found that the density was controlled by the number of growth cycles of ZIF-8. Resolutions of EDCs and pesticides were clearly improved and baseline separation was achieved in the column packed with ZIF-8â “¢ SiO2 prepared after three cycles of ZIF-8 bark growth, figure 5.

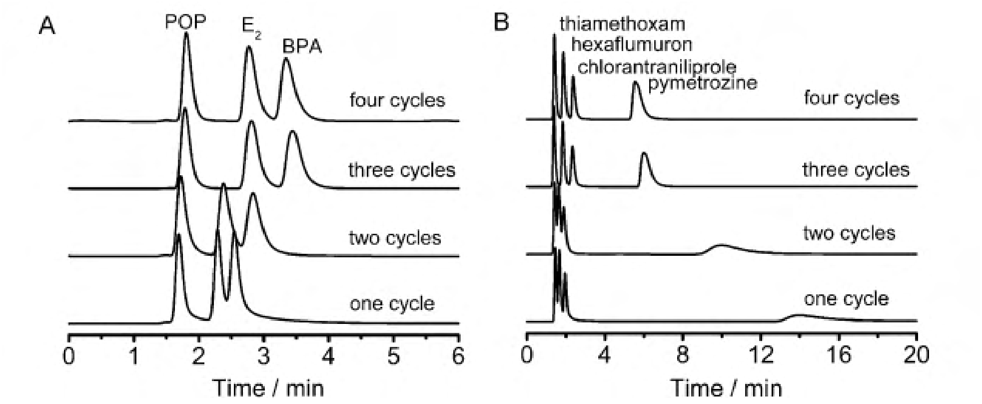


Figure 5. Chromatograms on ZIF-8 @ SiO2 columns with different numbers of growth cycles. (A) EDCs (B) pesticides. Reprinted (adapted) with permission from (FU *et al.,* 2013). Copyright American Chemical Society.

QIN et al. (2015), in his study, reported that there are few data on MOFs structures, one reason being the heterogeneity of the material with respect to particle size and morphology, making it difficult to accurately describe kinetic data. They demonstrate the manufacture of liquid phase epitaxy (LPE) MOFs with functional carboxylic groups on the nuclear surface and bind the first layer of MOF. The epitaxy process can produce, in support models, metallic-organic structures attached to the thinner surface, which is more ordered, oriented and homogeneous. Figure 6 (SURMOFs, surface attached metal-organic framework thin films).

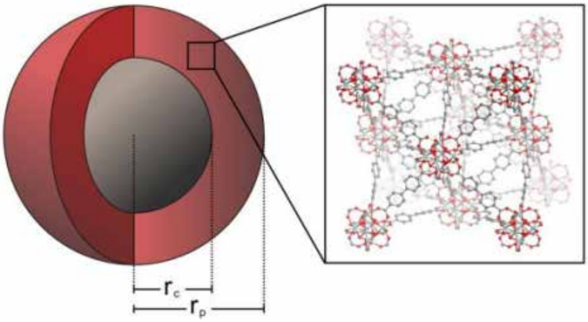


Figure 6. Schematic structure of the envelope of UiO-67 grown in carboxyl functionalized magnetic microparts: rc refers to the radius of the magnetic particle and rp defines the radius of the particle, including the shell. The structure of UiO-67 contains octahedral and tetrahedral pores of shared face. Reprinted (adapted) with permission from (QIN *et al.,* 2015). Copyright American Chemical Society.

Among the family of MOFs, the UiO series (University of Oslo) are of special interest because of their excellent thermal and chemical stability of the zirconium series UiO-67. The tests performed with the MOF in question were compared with simulations made from the ChromX software, developed for chromatographic modeling by the Institute of process Engineering in Life Sciences Section IV: Biomolecular Separation Engineering of the Karlsruhe Institute of Technology, in 2012. The experiments in HPLC were performed with ACN (acetonitrile) and water as the mobile phase on a 200 mm long and 1 mm internal diameter column.

Using phenolic derivatives (2,6-dimethyphenol, DMP, Benzene-1,3-diol, BZD and 2,6-dichlorophenol, DCP) to analyze kinetic properties in chromatographic experiments, it was noted that maximum loading capacity remained constant , however, the affinities of the studied molecules varied and showed a strong dependence of the applied solvent, ACN / H2O. The result was that the pore diffusivity was in the order of two or three times less than the diffusivity of the activated carbon. The results also indicate that, despite the simulations using a common diffusivity model, with the MOFs, the mass transfer is better elaborated, with surface diffusion effects and size effects exclusion.

In 2016, Lv et al. Used high performance liquid chromatography (HPLC) with fluorescence detector to determine thiols (organosulfur) compounds from waste water samples with MOF-5 prepared and used as a DSPE adsorbent for selective adsorption of wastewater sample. Chromatography experiments were performed using a 150 mm long and 4.6 mm diameter column and the mobile phase was composed of acetonitrile. In this work, a new carbazole-9-ethyl-2-maleimide (CAEM) reagent was also synthesized to improve the efficiency of MOF-5 and to increase its selectivity as the novel thioc fluorescent derivatization reagent was designed and synthesized based on a reaction between maleimide and thiol groups. However, (CAEM) had no fluorescence, obtaining a fast reactivity and high selectivity for thiol group under mild conditions. The application of (CAEM) and MOF-5 resulted in selectivity advantages for low-limit detection thiols compared to other methods exhibiting excellent separation efficiency, Figure 7.

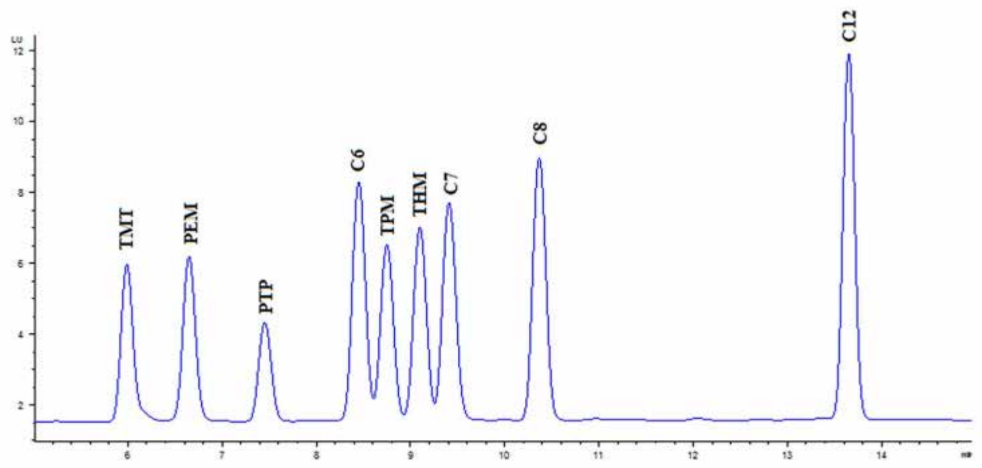


Figure 7. HPLC chromatogram of thiol derivatized: TPM: 4-(tert-butyl) phenyl methanethiol; PEM: 2-Phenylethylmercaptan; THM: Triphenylmethyl mercaptan; PTP: 2-Phenylthiophenol; TMT: 2-Thienylmethanethiol; C6: 1-Hexanethiol; C7: Heptyl mercaptan; C8: n-Octyl mercaptan; C12: Lauryl mercaptan. Reprinted (adapted) with permission from (LV *et al.,* 2016). Copyright American Chemical Society.

As already reported in the literature in previous years, despite the specific qualities of MOFs such as high surface area, crystallinity and large porosity, irregular shapes and wide particle size distribution hampered the separation efficiency and consequently increased backpressure in the HPLC column. In 2017 Qu and collaborators aiming to overcome this problem and obtain a larger pore volume and thus improve separation efficiency, have developed a new kinetic control method to deposit on the surface of the imidazolate structure (ZIF-8) shell-like silica beads as Figure 8, because small pores lead to slow mass transfer of analytes into the pores resulting in poor HPLC separation performance. Based on the above analysis, they proposed that if MOFs could be formed on the pore surface and not on the outer surface of the silica core, and with layers thin enough to make the original pore structure unaffected, the size of the pores of the obtained MOF beads would still be sufficiently large for HPLC separation and pore size deficiency could be overcome.

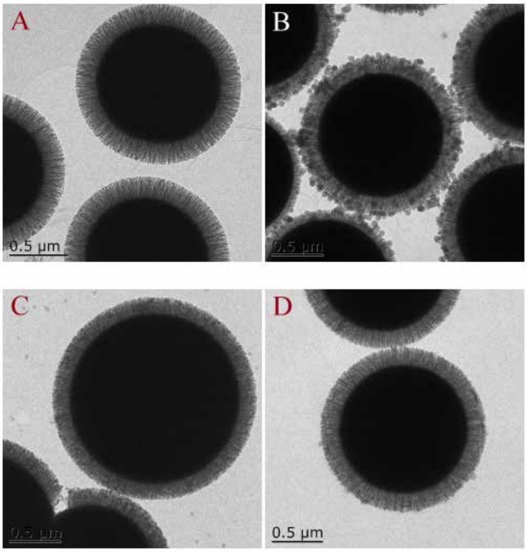


Figure 8. TEM images of SiO2 @ dSiO2 (A) SiO2 @ dSiO2-ZIF-8 using different mixtures of DMF-methanol as solvent. The volume ratios of DMF: methanol were: B 5.3: 14.7; C 5.6: 14.4; D 5.8: 14.2. Reprinted (adapted) with permission from (QU *et al.,* 2017). Copyright American Chemical Society.

In the HPLC experiments, a 50 mm long, 4.6 mm diameter column with a mobile phase composed of ACN was used for the separation of xylene isomers. Thus, this study resulted in the obtaining of composite particles maintaining the silica bead macrostructure with efficient separation performance, but also showed the microporosity, high surface area and adsorption properties of MOFs. Spheres with dendritic shells (SiO2 @ dSiO2) were used as a support, obtaining optimum yield and efficiency. It can be used to fill columns with the intention of maintaining the high level of separation.

In the same year, CHEN et al. (2017) have reported on the need to obtain pure m-p-DVB (divinylbenzene) as one of the essential constituents in the preparation of crosslinked styrene polymers used in the manufacture of ion exchange resins. In the knowledge of previous studies such as Yan et al. (1985) that showed the advantages of MOF MIL-53 (Fe) versus MIL-53 (Al, Cr) for the xylene, chlorotoluene and dichlorobenzene separations and FU et al. (2013) where aromatic compounds were separated using MIL -100 (Fe), CHEN et al. (DVB) and ethylvinylbenzene (EVB) isomers using MOFs, MIL-53 (Fe) and MIL-100 (Fe) as the stationary phase in HPLC with hexane as the mobile phase. In conclusion, they explained that separation was achieved in both columns, but the column with MIL-100 (Fe) provided a better separation of the DVB and EVB isomers than the MIL-53 (Fe) column. They also reported that the separation was not sufficient, showed short retention times and proposed that the particle uniformity should be increased to improve column efficiency.

In order to determine six pollutants of natural and residual waters (one polycyclic aromatic hydrocarbon (fluorene), two hormones (progesterone and estrone), two drugs (carbamazepine and triclosan) and one disinfectant (atrazine)). In addition, the MOF-1, MOF-5 (Zn), MIL53 (Al), UiO-64 and MOF-74 (Zn) monomers were synthesized, characterized and applied by ROCÍ-BAUTISTA et al. miniaturized solid-phase extraction method under dispersive mode (D-µSPE) optimized with high-performance liquid chromatography (HPLC). These pollutants have different natures and were selected because of the hydrophobicity, polarity, and aromaticity of each. The MOFs were chosen according to the versatility, extraction capacity, metallic nature, structure, and pore size. During the processes, it has been noted how difficult it is to predict how much each MOF will adsorb. The pore size and aperture, the presence of unsaturated metals and the nature of the metal have much influence on efficiency. However, MIL-53 (Al) proved to be the most suitable MOF in this case, obtaining the best selectivity, the methods were optimized and validated with this material.

In the same year, EHRLING et al. (2018) have challenged the relevant problems of industrial separation, such as the separation of aromatic isomers. With the knowledge that high performance liquid chromatography (HPLC) is the most used technique to combat these challenges, there is a need to find more efficient adsorbents. It also points out that the potential of the MOFs in HPLC had already been studied, however, they were used as a crystalline powder, resulting in high backpressure and low column efficiency. To do so, they proposed a study using silica and MOF in an attempt to combine the good silica packaging characteristics and the specific influence of the MOF material used.

In the study, they functionalized mesoporous silica beads with two chemically different structures with variable porosity, MIL-101 (polar) and UiO-67 (non-polar), to be used as a stationary phase in HPLC columns for the separation of C8 isomers, dichlorobenzene isomers, styrene and ethylbenzene. The method proposed in the work was layer-by-layer (lbl), thin films. They found from the SEM and the PXRD that the composites obtained after 20 cycles for MIL-101 @ SiO2 and 18 cycles for UiO-67 @ SiO2 obtained the best degree of functionalization of the surface being homogeneously coated and presented micro and mesoporosity, Figure 9.

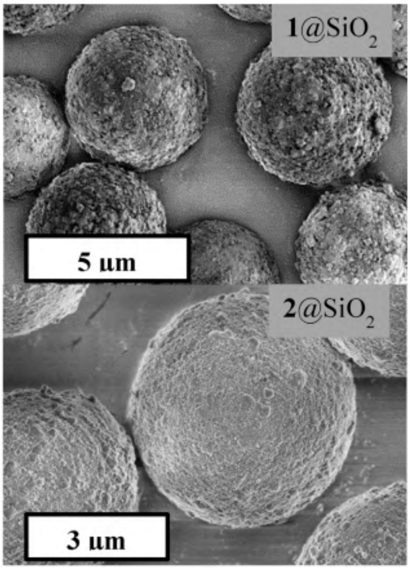


Figure 9. SEM images of MIL-101 @ SiO2 structures (20 layer-by-layer cycles) and UiO-67 @ SiO2 (18 layer-by-layer cycles). Reported as 1 SiO2 and 2 SiO2, respectively. Reprinted (adapted) with permission from (EHRLING *et al.,* 2018). Copyright American Chemical Society.

After application of the new stationary phase, it was observed that the silica / MOF composites showed higher affinity with the ortho-substituted analytes indicating that the polarity of the analytes directly influences the selectivity. Another important point is the influence of the solvent used to dilute the analytes, proving at work that small amounts of polar solvent can greatly reduce the separation efficiency.

Advances in the studies using liquid chromatography using MOFs as stationary phase are notorious and quite expressive. Within this context investigations for separations of chiral compounds appear. The chiral stationary phases behave analogously the stationary phases for non-chiral chromatographic separations, however, there is a need to use in these phases an optically active material or to produce a phase known as chiral MOF that is selective for the chiral compounds which are want to sort. Studies using MOFs for this purpose are quite recent and face major challenges as there is a clear need to find chiral stationary phases that are quite selective for a wide range of materials.

2.2 MOF em Cromatografia Líquida para separações quirais

Tanaka et al. (2012) drew attention to the homochiral separations, are the chromatographic separations of enantiomers. Only one article in 2007 would have addressed this issue. In the study, they reported a new homochiral compound synthesized from a mixture of (R) -H2BDA, Cu (NO3) 2 and monodisperse spherical silica gel, as a new stationary HPLC for the enantiomeric separation of various sulphoxides, also known as phase stationary. Two eluents were evaluated: hexane-EtOH (50/50) and one less polar, hexane-i-PrOH (90/10). Nine sulfoxides (2,3,4,5,7,9,10,11,12) were completely separated from their corresponding enantiomers using the first eluent as the mobile phase. Two (14 and 16) were separated using the less polar eluent. However, the sulfoxides (6,8,13,15 and 17) did not show good separation in both solvents. This work may serve as a relevant basis for others in the future in enantioselective separation.

In 2014 Zhang's research group reported that although there were some papers bringing MOF studies for chiral separation, they still had a low enantioselectivity range and the irregular particle size was high and thus difficult to collect. In the study, they presented a chiral helical MOF [(CH3) 2NH2] [Cd (bpdc) 1.5], tested to separate several racemates as observed in Figure 10. They also studied the effect of temperature on retention and selectivity, since it is known that influence directly on most analytes. They realized that with increasing temperature the retention time decreased showing that the process was exothermic. As a result, they reported that the phase was promising and presented lower pressure in the column with good selective capacity.

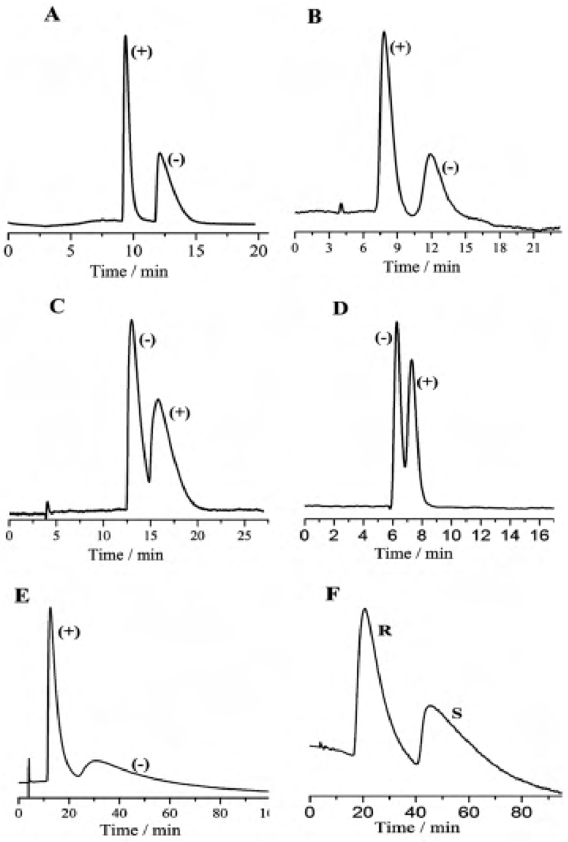


Figure 10. Chromatograms for the separation of racemates: (A) 1- (1-Naphthyl) ethanol, (B) metoprolol, (C) Troger base, (D) trans-tolylene oxide, (E) 1,1'- 2-naphthol and (F) Furion. Reprinted (adapted) with permission from (ZHANG et al., 2014). Copyright American Chemical Society.

Hailili et al. (2015) drew attention to a pharmaceutical problem, the chiral recognition to obtain optically pure enantiomers since each enantiomer has physicochemical properties different from its other pair, that is, they have different pharmacological effects and may present toxicity. Faced with this problem, they performed a study for the separation of racemates such as (±) -ibuprofen and (±) -1-phenyl-1,2-ethanediol. They developed a new homochiral structure based on cluster Mn4O with ptO and a D-camorphic enantiopure acid. As results, figure 11, it can be seen that the column has excellent chiral recognition ability, peak broadening and retention time can be justified because of the intense interactions of the analytes with the chiral MOF.

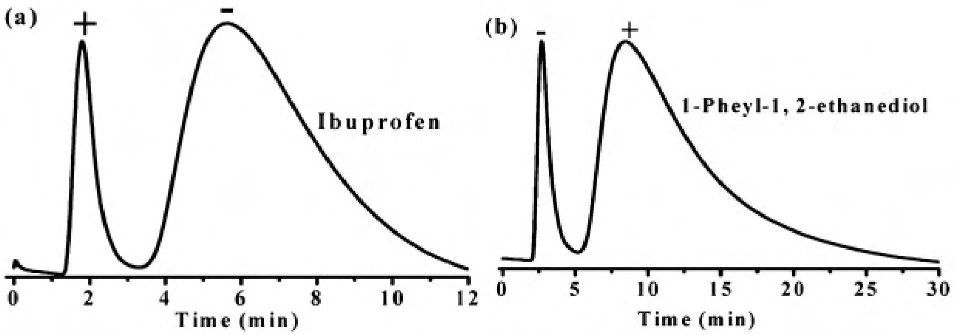


Figure 11. Chromatogram of enantioseparation (a) (±) -buprofen and (b) (±) -1-phenyl-1,2-ethanediol. Reprinted (adapted) with permission from (HAILILI *et al.2015).* Copyright American Chemical Society).

2.3 Other Considerations

The composition of the mobile phase has a significant influence on retention time, peak shape, and resolution. In addition to the article by EHRLING et al., 2018, the reviews of VOORDE et al., 2014 and ZANG et al., 2017, conduct studies that discuss the influence of the mobile phase and report on the enantiomeric separations.

3 I CONCLUSION

The advances that the MOFs have undergone in the last 10 years are evident, important and essential in the area of adsorption. Because they present unique characteristics, such as: high porosity, selectivity and multiple active sites. MOFs emerged as promising stationary phases for separation on liquid chromatography.

There is an absolute growth in the area of pre-treatment and modification of MOFs that aims to improve their efficiency and activity. The influence on how it will be adsorbed and on what will be adsorbed, after all, the type of treatment and / or modification will define next to the type and composition of the MOF, the active surface area, the dimensions, pore diffusivity, affinity, high stability and high selectivity.

It is evident the importance and necessity of the advances in the stationary phases with wide selectivity to overcome the problem of non-uniformity of the particles that generate high pressure in the column and lose efficiency.

In summary, further studies are still needed on the subject, however, the observed results show the high potential of the MOFs for application in adsorption and chromatography.

REFERENCES

Ahmad, R., Wong-Foy, G. A., Matzger, A. J. (2009). Microporous Coordination **Polymers as Selective Sorbents for Liquid Chromatography**, *Langmuir Letter,* 25, 11977-11979.

Alaerts, L., Maes, M., Jacobs, P. A., Denayer, J. F. M., De Vos, D. E. (2008). **Activation of the metal–organic framework MIL-47 for selective adsorption of xylenes and other difunctionalized aromatics**, *Phys. Chem. Chem. Phys.,* 10, 2979-2985.

Ameloot, R., Liekens, A., Alaerts, L., Maes, M., Galarneau, A., Coq, B., Desmet, G., Sels, B. F., Denayer, J. F. M., De Vos, D. E. (2010). **Silica–MOF Composites as a Stationary Phase in Liquid Chromatography**, *Eur. J. Inorg. Chem.,* 2010, 3735–3738.

Chen, S., Li, X. X., Shu, L., Somsundaran, P., Li, J. R. (2017). **The high efficient separation of divinylbenzene and ethylvinylbenzene isomers using high performance liquid chromatography with Fe-based MILs packed columns**, *Chromatogr. A.*, 1510, 25–32.

Collins, C.H., Braga, G.L., Bonato, P.S. (2006). ***Fundamentos de Cromatografia***, Editora da UNICAMP, Campinas-SP.

Cychosz, K. A., Wong-Foy, A. G., Matzger, A. J. J. (2008). **Liquid Phase Adsorption by Microporous Coordination Polymers: Removal of Organosulfur Compounds**, *Am. Chem. Soc.,* 130, 6938–6939.

Ehrling, S., Kutzscher, C., Freund, P., Muller, P., Senkovska, I., Kaskel, S. (2018). **MOF@SiO2 core-shell composites as stationary phase in high performance liquid chromatography**, *Microporous and Mesoporous Materials,* 263, 268-274.

Fu, Y.Y., Yang, C.X., Yan, X.P. (2013). **Fabrication of ZIF-8@SiO2 Core–Shell Microspheres as the Stationary Phase for High-Performance Liquid Chromatography**, *Eur. J. Inorg. Chem.* 19, 3735-3738.

Hailili, R., Wang, L., Qv, J., Yao, R., Zhang, X.M., Liu, H. (2015). **Planar Mn4O cluster homochiral metal-organic framework for HPLC separation of pharmaceutically important (±)-ibuprofen racemate**, *Inorg. Chem. - ACS publication,* 54**,** 3713-3715.

Hayes, R., Ahmed, A., Edge, T., Zhang, H. (2014). **Core shell particles: Preparation, fundamentals and applications in high performance liquid chromatography**. *Journal of Chromatography A,* 1357, 3652.

Li, H., Eddaoudi, M., O'Keeffe, M., Yaghi, O. M. (1999). **Design and synthesis of an exceptionally stable and highly porous metal-organic framework**, *Nature,* 402, 276- 279.

Li, J. R., Kuppler, R. J., Zhou, H.C. (2009). **Selective gas adsorption and separation in metal-organic frameworks**, *Chem. Soc. Reviews*, 38, 1477–1504.

Lv, Z., Sun, Z., Song, C., Lu, S., Chen, G., You, J. (2016). **Sensitive and background-free determination of thiols from wastewater samples by MOF-5 extraction coupled with high performance liquid chromatography with fluorescence detection using a novel fluorescence probe of carbazole-9-ethyl-2-maleimide**, *Talanta,* 161, 228-237.

Long, J. and Yagui, O. M. (2009). **The pervasive chemistry of metal–organic frameworks**, *Chem. Soc. Reviews,* 38, 1213-1214.

Mukherjee, S., Desai, A. V., Ghosh, S. K. (2018). **Potential of metal–organic frameworks for adsorptive separation of industrially and environmentally relevant liquid mixtures**, *Coordination Chemistry,* 367, 82-126.

Nordin, A. N. H., Racha, S.M., Matsuura, T., Misdan, N., Aimie, N., Sani, A., Ismail, A.F., Mustafa, A. (2015). **Facile modification of ZIF-8 mixed matrix membrane for CO2/CH4 separation: synthesis and preparation**, *RSC Advances,* 5, 43110–43120.

Qin, W., Silvestre, M. E., Brenner-Weiss, G., Wang, Z., Schmitt, S., Hübner, J., Franzreb, M. (2015). **Insights into the Separation Performance of MOFs by High- Performance Liquid Chromatography and In-depth Modelling**, *Sep. and Puri. Technology*, 156, 249-258.

Qu, Q., Xuan, H., Zhang, K., Chen, X., Ding, Y., Feng, S., Xu, Q. J. (2017). **Core-shell silica particles with dendritic pore channels impregnated with zeolite imidazolate framework-8 for high performance liquid chromatography separation**, *Chromatography A.,* 1505, 63-68.

Rocío-Bautista, P., Pino, V., Pasán, J., López-Hernández, I., Ayala, J. H., Ruiz- Pérez, C., Afonso, A. M. (2018). **Insights in the analytical performance of neat metalorganic frameworks in the determination of pollutants of different nature from waters using dispersive miniaturized solid-phase extraction and liquid chromatography**, *Talanta*, 179, 775-783.

Tanaka, K., Muraoka, T., Hirayamaa, D., Ohnishb, A. (2012). **Highly efficient chromatographic resolution of sulfoxides using a new homochiral MOF–silica composite**, *Chem. Commun*., 48, 8577- 8579.

Voorde, B. V., Bueken, B., Denayer, J., Vos, D. (2014). **Adsorptive separation on metal–organic frameworks in the liquid phase**, *Chem. Soc. Rev*., 43, 5766–5788.

Yan, Z., Zhang, W., Gao, J., Lin, Y., Li, J., Lin, Z., Zhang, L. (2015). **Reverse-phase high performance liquid chromatography separation of positional isomers on a MIL-53(Fe) packed column***, RSC Adv*., 5**,** 40094– 40102.

Zhang, M., Xue, X.D., Zhang, J.H., Xie, S.M., Zhang, Y., Yuan, E L. M. (2014). **Nantioselective chromatographic resolution using a homochiral metal-organic framework in HPLC**, *Anal. Methods,* 6, 341–346.

Zhang, Q., Cui, Y., Qian, G., (2017). **Goal directed design of metal-organic frameworks for liquid phase adsorption and separation**, *Coordination Chemistry Reviews.*

Zhang, J., Chen, Z. (2017). **Metal-organic frameworks as stationary phase for application in chromatographic separation,** *Journal of Chromatography,* 1530, 1-18.

Zhu, Y., Ciston, J., Zheng, B., Miao, X., Czarnik, C., Pan, Y., Sougrat, R.(2017). **Unravelling surface and interfacial structures of a metal – organic framework by transmission electron microscopy**, *Nature Materials,* 5, 532-536.

ÍNDICE REMISSIVO

O ensino e a pesquisa em QUÍMICA

www.atenaeditora.com.br
contato@atenaeditora.com.br
@atenaeditora
www.facebook.com/atenaeditora.com.br

2

Atena Editora
Ano 2021

O ensino e a pesquisa em

QUÍMICA

www.atenaeditora.com.br
contato@atenaeditora.com.br
@atenaeditora
www.facebook.com/atenaeditora.com.br

2

Atena
Editora
Ano 2021