# REMOVAL OF DYES FROM COLORED TEXTILE WASTER BY Poly (methacrylicacid-cross-Nacrylate-N,N-dimethyl-N-dodecyl ammonium bromide) HYDROGELS: EQUILIBRIUM AND KINETIC STUDIES

Fasla Asmahane<sup>1,\*</sup>, Sebti Houari<sup>2</sup> and Iddou Abdelkader<sup>3</sup>

<sup>1</sup>Département de Chimie Physique, Faculté de Chimie, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf, BP1505, El Mnaouer, Oran, Algeria

<sup>3</sup> Laboratory of Materials Recovery and Nuisance Treatment, Mostaganem University, Mostaganem, Algeria

<sup>1</sup>asmahane.fasla@univ-usto.dz

<sup>3</sup>iddou@yahoo.fr

<sup>2</sup> Nationale Polytechnique Oran, Algeria <sup>2</sup>sebti.houari@yahoo.fr

Abstract- This paper reports synthesis of new hydrogel networks of poly (methacrylic acid-cross-dodecyle acrylate ammonium bromide) poly (MAA-cross-DAAB) were used as a novel sorbent to remove bemacid red  $(ET_2)$  dye from aqueous solution under various operating conditions. The kinetic sorption uptake for  $ET_2$  by Poly (MAA-cross-ADAB) at various initial dye concentrations was analyzed by pseudo-first, pseudo-second models and intra-particule diffusion. Three sorption isotherms, namely the Langmuir, Freundlich and Dubinin-Radushkevich isotherms, were applied to the sorption equilibrium data. The sorption kinetics of  $ET_2$  onto the hydrogels followed the pseudo-second-order kinetics model ( $R^2 = 0.999$ ) and the adsorption equilibrium data obeyed the Langmuir isotherm model ( $R^2 = 0.999$ ). It can be concluded that Poly (MAA-cross-DAAB) is an alternative economic sorbent to more costly adsorbents used for dye removal in wastewater treatment processes. *Keywords*- Methacrylic acid; N-acrylate-N,N-dimethyl-N-dodecyl ammonium bromide; Bemacid Red; Textil Waste

#### I. INTRODUCTION

The annual dye wastewater increases each year lead to severe hazard to the environmental pollution due to the rapid development of textile industries [1-3].

For the past few years, several method was used for wastewater treatment and remediation like conventional methods such as sedimentation, flocculation, coagulation and biological processes [3,4] or by ozonation, however it is not suitable to remove highly polar contaminant such as antibiotics [3,5]

Hydrogels are cross-linked polymers with three-dimensional network-structured construction and the capacity to absorb a large amount of water through hydroxyl, amide and carboxyl groups without compromising structural integrity [3,6]. Owing to its rapid swelling properties and porous structure of hydrogels, therefore dye molecules/antibiotics can be absorbed via chemical, electrostatic interaction and hydrogen bonding [3].

Among many pollutants, red dye of bemacide  $(ET_2)$  will do harm to skin and respiratory tract, which can cause carcinogenic, vomiting, non-biodegradable and affecting growth of marine organisms due to  $ET_2$  absorb light and oxygen [7,8].

In this study, we prepared Poly (MAA-cross- $M_1$ ) hydrogels as a novel sorbent to remove  $ET_2$  from aqueous solutions. Adsorption isotherm, the effect of initial dye and ADAB concentration were studied. The adsorption isotherms were fitted by the Langmuir, Freundlich and Dubinin-Radushkevich models. The adsorption was examined by using pseudo-first, pseudo-second models and intra-particule diffusion.

### **II. MATERIALS AND METHODS**

### II.1 Sorbent

The monomers methacrylic acid ( $C_4H_6O_2$ ) (MW = 86 g mol<sup>-1</sup>), dodecyle acrylate ammonium bromide ( $C_{19}H_{38}O_2NBr$ ) (MW = 392 g mol<sup>-1</sup>) were supplied by Merck-Schuchardt and the initiator, l'azobisisobutyronitrile (AIBN) was supplied by Merck, Darmstad, Germany. All chemicals were usedas received. The mole number of MMA is  $1.2 \times 10^{-1}$  mol, and the concentration of 1, 10, and 20 % of ADBA are  $1.2 \times 10^{-3}$ ,  $1.2 \times 10^{-2}$ , and  $2.4 \times 10^{-2}$  mol, respectively.

The basic cationic dye, bemacid red ( $C_{14}H_{17}NSO_3Cl$ ) [7], was obtained from the silk production (SOITEX) Tlemcen industry (Algeria). The structure of this dye is displayed in Fig. 1. A 500 mg L<sup>-1</sup> stock solution was prepared by dissolving the required amount of dye in distilled water. Working solutions of desired concentrations were obtained with successive dilutions.



Fig.1 Chemical structure of bemacid red

#### 2.3 Preparation of analytical method MAA-cross-DAAB

Poly (methacrylic acid-cross-dodecyle acrylate ammonium bromide) materials, henceforth designated as poly (MAA-cross-DAAB), were prepared by solution polymerization with a total concentration 10 wt.% (10 g of MAA). The concentration of 0.1 wt.% (0.1 g) was the initiator shown in Fig. 2. The free radical copolymerization was carried out under a nitrogen atmosphere in a three-necked flask equipped with a nitrogen inlet and a reflux condenser immersed in a constant temperature oil bath (yellow,  $\pm 1$  °C). The reaction mixture was stirred using a magnetic stirrer. A continuous supply of nitrogen was maintained throughout the reaction period. The solution polymerization proceeded for 24 h at 60 °C. Three various crosslinked poly (MAA-cross-DAAB) samples were prepared with nominal crosslinking ratios, X, of 1, 10 and 20 % mol DAAB/mol MAA. Then, the copolymers obtained were washed by CH<sub>2</sub>Cl<sub>2</sub> several times to extract unreacted monomers. The solid copolymer slab was cut into circular disks using punches.



Fig. 2 Chemical structure of poly (MAA-cross-DAAB)

#### 2.4 Characterization technique

The samples were analyzed using FTIR spectroscopy IFS66 in  $4000-400 \text{ cm}^{-1}$ . Before the measurement, the samples were dried under a vacuum until reaching a constant weight. The dried samples were pressed into the powder, mixed with 10 times as much KBr powder, and then compressed to make a pellet for FTIR characterization.

To study the morphology of poly (MAA-cross-DAAB) hydrogels, the HIROX SH400 M SEM-EDS BRUKER scanning electron microscope was used.

### 2.5 Kinetic and isotherm models

Equilibrium isotherms and adsorption properties describe the adsorbate–adsorbent interactions system, supply complete information about the type of the interaction [9], play an important role in providing practical information in the predictive modelling for the analysis and design of adsorption systems [10] and inferences on possible mechanisms of the adsorption processes [10].

For this work, linear forms of four different adsorption isotherms notably Langmuir (L), Freundlich (F) and Dubinin-Radushkevic (D-R) models were employed to obtain conclusive information on the adsorbent surface characters and its affinity to  $ET_2$  molecules (Table 1).

Modeling of adsorption isotherm data is important for predicting and comparing adsorption performance. Three parameter isotherm models are applied in this study available for modeling adsorption data of  $ET_2$  pollutants. Langmuir isotherm assumes that a single layer of adsorption takes place on the surface of adsorbent having certain number of vacant sites for adsorption of uniform strategies of adsorption [11]. The Freundlich adsorption isotherm is an empirical equation based, on the equilibrium distribution of a solute between the solid and aqueous phases. It assumes that multilayer occurs on the heterogeneous adsorbent surface [10]. The Dubinin-Radushkevic isotherm equation is more general than the Langmuir isotherm because it does not assume a homogeneous surface or constant adsorption potential. It was applied to distinguish between the physical and chemical adsorption of dye. Applicability of these equations was compared by judging the correlation coefficients [12].

To better understand the adsorption behavior, three linear kinetic models are used to test the experimental data. The pseudo-first-order (PFO), pseudo-second-order (PSO) and intra particule diffusion models were used to evaluate the adsorption of  $ET_2$  dye on hydrogels. Pseudo-first-order, pseudo-second-order Lagergren and intra particule diffusion models are given in Table 1.

### 3. Results and discussion

3.1 Characterizations of hydrogel

### 3.1.1 FTIR analysis

The characteristics functional groups of prepared (MAA-cross-DAAB) hydrogels sample were characterized by FT-IR spectrum (Fig. 3). The FTIR spectrum of hydrogels contains a broad band at 3340-3565 cm<sup>-1</sup> related to contains large amounts of hydroxyl groups. The adsorption bands located at 2932 and 2857 cm<sup>-1</sup> correspond to the C–H stretching vibration of –CH<sub>3</sub> and –CH<sub>2</sub> groups, the stretching vibration of the formation bonds of (-C-N–) and (C=O) groups, 1482 and 1725.

# 3.1.2 SEM analysis

Photos provided by scanning electron microscopy allowed us to observe the morphology of the hydrogels we have prepared. This microscopy analysis aims to highlight the link between the morphology of these hydrogels and their swelling properties. Photos provided by scanning electron microscopy are shown in Fig. 4. According to the analysis by the scanning electron microscopy (SEM) we can see that the surface becomes more porous and filamentous gradually as the rate of ADAB incorporated into the network increases. These results are in agreement with those achieved by the swelling properties study [7].

### 3.2 Adsorption study

# 3.2.1 Adsorption kinetics

The initial dye concentration and the contact time between the dye solution and the adsorbent surface have a profound effect on the dye adsorption rate. The observed adsorption rate of the  $ET_2$  as a function of contact time at six different initial dye concentrations (16, 26, 36, 40, 50 and 60 mg/L) is presented in Fig. 5-7.Calculated parameters of adsorption kinetics for the three kinetics model used are summerarized in Table 2. For pseudo first order il is observed that the experimental data does not fit a straight line and well with the experimental data over the whole range of initial concentrations studied. The R<sup>2</sup> values obtained for this model did not show a consistent trend. This shows that the adsorption of  $ET_2$  dye on the adsorbent does not follow a pseudo first order kinetic model.

Models	Linear equation	Plot	Parameters	References
Pseudo first	$Ln(q_e - q_t) = Lnq_e - \frac{k_{1,s}}{2.303}t$	qt Vs.t	$q_{e}$ is the adsorbed amount at equilibrium, (mg/g), $q_{t}$ is the adsorb	[12,13]
ordre	_,		amount per unit weight of adsorbent at time (mg/g), $k_1$ is the rate constant of PFO sorption (min <sup>-1</sup> )	
Pseudo second	$\frac{t}{q_t} = \frac{1}{K_2 g_0^2} + \frac{1}{q_0} t$	t/qt Vs.t	$q_t$ and $q_e$ have the same meaning as in the PFO model, $k_2  is$ the	[12,13]
ordre			rate constant of PSO model (g mg <sup>-1</sup> min <sup>-1</sup> )	
Intraparticule diffusion	$q_t = k_{int} t^{1/2} + C$	$q_t \; Vs.t^{1/2}$	qt (mg g <sup>-1</sup> ) is the adsorption capacity at time t, ki (mg g <sup>-1</sup> min <sup>-1/2</sup> ) is the intraparticle diffusion rate constant, and the constant Ci is proportional to the thickness of the boundary layer i.	[13,14]
Langmuir	$\frac{c_e}{q_e} = \frac{1}{b \times q_e} + \frac{1}{q_e} c_e$	$c_e/q_eVs.c_e$	$C_e$ is the equilibrium concentration of the $ET_2$ (mg $L^{\text{-}1}$ ), $q_e$ is the	[15-17]
	46 2040 40		amount of dye adsorbed at equilibrium (mg $g^{-1}$ ), $q_0$ is the maximum adsorption capacity of the adsorbent (mg $g^{-1}$ ), and b is the Langmuir constant (L m $g^{-1}$ ) related to the free energy and affinity of adsorption.	
Freundlich	$Lnq_e = \frac{1}{n} \times Lnc_e + Lnk_f$	Lnq <sub>e</sub> Vs.Lnc <sub>e</sub>	$q_e$ is the amount adsorbed (mg $g^{-1}$ ), and $c_e$ is the equilibrium concentration of the adsorbate (mg $L^{-1}$ ). $k_f$ (mg $g^{-1}$ )(L $g^{-1}$ ) $^{1/n}$ and n, the Freundlich constants, are related to adsorption capacity and adsorption intensity, respectively.	[15-18]
Dubinin- Radushkevich	$Ln q_e = Ln (Q_s) - k\epsilon^2$	$Lnq_eVs.\epsilon$	qs is parameter to express the isotherm theoretical saturation, $\beta$ denotes to the constants of D-R isotherm (in mol <sup>2</sup> .kJ <sup>-2</sup> ), and the Polanyi potentials ( $\varepsilon$ ) were computed.	[13,15-17]
	$\varepsilon = \operatorname{RT} \operatorname{Ln} \left( 1 + \frac{1}{C_{e}} \right)$		Ideal gas constant's value (R) is $8.314 \text{ J.mol}^{-1}\text{K}^{-1}$ , and T is the solution	l-
	τ α <u>ε</u> ,		tion temperature in Kelvin.	
	$E = \frac{1}{\sqrt{2k}}$		D-R model is applied to differentiate between physical and chemi-	
			cal adsorption by calculating the free energy, E (in kJ/mol), necessary to eject molecule of an adsorbate out of its position to infinity at the active site of adsorption. If E is less than 8.0 kJ mol <sup>-1</sup> , the proce occurs through physical adsorption, and if it is more than 16.0 kJ m chemisorption takes place.	a- ess nol <sup>-1</sup> ,

**Table 1.** The Kinetics and isotherms models with their nonlinear forms



Fig.3 FTIR spectra of poly (MAA-cross-DAAB) : (b) 1%, (c) 10 % and (d) 20 % of DAAB



Fig. 4 Photos supplied by the scanning electronic microscopy of poly (MAA-cross-DAAB) : (a) 1%, (b) 10 % and (c) 20 % of DAAB



Fig.5 Pseudo first order kinetics plot for adsorption of  $ET_2$  onto poly (MAA-cross-DAAB) hydrogels : 1%, (b) 10 % and (c) 20 % of DAAB



Figure. 6 : Pseudo second order kinetics plot for adsorption of ET<sub>2</sub> onto poly (MAA-cross-DAAB) hydrogels : 1%, (b) 10 % and (c) 20 % of DAAB



Fig.7 Plot of intraparticule diffusion model for adsorption of ET2 onto poly (MAA-cross-DAAB) hydrogels : 1%, (b) 10 % and (c) 20 % of DAAB

Copyright © 2025 ISSN: 1737-9334 Fig. 6 shows the pseudo second order plots for adsorption of  $\text{ET}_2$  dye by poly (MAA-cross-DAAB) at various varoius initial dyes and DAAB concentration. The correlation coefficient values are higher than the values of pseudo first order model. It is also noticeable that with the increase of the initial concentration of the dye there was an increase in the adsorption capacity for the textile dye concentrations in the range 16–60 mg L<sup>-1</sup>. The intraparticle diffusion plot for the adsorption of  $\text{ET}_2$  onto the surface of poly (MAA-cross-DAAB) hydrogels exhibited two linear regions. The first linear region is due to the transfer of  $\text{ET}_2$  molecules from the liquid solution to the outer surface of the adsorbent. The second linear region is attributed to the intraparticle pore-diffusion process in which  $\text{ET}_2$  molecules diffuse throughout the porous surface of the hydrogel [13,19]. This also confirms that the adsorption of  $\text{ET}_2$  onto poly (MAA-cross-DAAB) hydrogels is a multistep process that involves adsorption on the external surface and diffusion into the interior [13,20] (Fig. 7).

### 3.2.2 Adsorption isotherm

Adsorption isotherm indicates the relationship between the adsorbate in the liquid phase and the adsorbate adsorbed on the surface of the adsorbent under equilibrium at constant temperature. Adsorption isotherms are important to describe the interaction of adsorbate molecules with adsorbent surface. In this study, Langmuir (Figure 8 (a-c)), Freundlich (Figure 8 (d-f)) and Dubinin–Raduskevich (Figure 8 (g-i)) isotherms have been employed for the treatment of the equilibrium adsorption data. The applicability of the isotherm equation is compared by judging the correlation coefficient  $R^2$ .

DAAB Model Parameter		Parameter	$ET_2$ (mgL)					
(%)			16	26	36	40	50	60
	Pseudo first order	$k_1  10^{-3}  (min^{-1})$	1.1	2.3	2.5	2.5	2.9	2.9
		$q_{e,exp}$ (mg/g)	0.391	0.609	0.611	0.614	0.616	0.619
		$q_{e,cal}$ (mg/g)	0.287	0.552	0.529	0.529	0.505	0.588
		$\mathbf{R}^2$	0.981	0.974	0.969	0.967	0.957	0.967
1	Pseudo second order	k <sub>2</sub> 10 <sup>-3</sup> (min)	1.1	2.3	2.5	2.5	2.9	2.9
		$q_{e,exp}$ (mg/g)	0.391	0.609	0.611	0.614	0.616	0.619
		$q_{e,cal}$ (mg/g)	0.416	0.666	0.666	0.669	0.671	0.657
		$\mathbb{R}^2$	0.996	0.999	0.998	0.998	0.998	0.998
	Intraparticule k <sub>in</sub>	$_{\rm t}$ 10 <sup>-3</sup> (mg g <sup>-1</sup> min <sup>-0.5</sup> )	6.8	12.9	13.1	13.1	12.3	12.3
	diffusion	C 10 <sup>-3</sup>	6.5	47.0	49.4	59.7	87.7	58.0
		$\mathbf{R}^2$	0.956	0.953	0.943	0.629	0.928	0.933
	Pseudo first order	$k_1  10^{-3}  (min^{-1})$	2.5	2.3	2.7	2.6	3.2	2.1
		q <sub>e,exp</sub> (mg/g)	0.332	0.337	0.339	0.349	0.348	0.352
		$q_{e,cal}$ (mg/g)	0.303	0.317	0.335	0.353	0.393	0.318
		$\mathbb{R}^2$	0.828	0.883	0.984	0.946	0.967	0.823
10	10 Pseudo second order	$k_2 \ 10^{-3} \ (min)$	4.637	4.410	4.341	4.129	4.007	3.870
		q <sub>e,exp</sub> (mg/g)	0.332	0.337	0.339	0.349	0.348	0.352
		$q_{e,cal}$ (mg/g)	0.397	0.409	0.408	0.418	0.422	0.429
		$\mathbb{R}^2$	0.934	0.926	0.930	0.926	0.926	0.925
	Intraparticule k <sub>i</sub>	$_{\rm nt} 10^{-3} ({\rm mg}{\rm g}^{-1}{\rm min}^{-0.5})$	5.6	5.8	5.8	5.3	6.0	6.1
	diffusion	C 10 <sup>-3</sup>	51.6	49.9	49.9	75.0	47.5	46.4
		R <sup>2</sup>	0.826	0.826	0.826	0.814	0.837	0.849
	Pseudo first order	$k_1  10^{-3}  (min^{-1})$	1.5	2.0	1.7	2.1	2.2	2.1
		q <sub>e,exp</sub> (mg/g)	0.231	0.242	0.242	0.246	0.246	0.242
		$q_{e,cal}$ (mg/g)	0.221	0.242	0.230	0.250	0.246	0.232
		$\mathbb{R}^2$	0.919	0.945	0.707	0.954	0.940	0.951
20 Pseudo second order		$k_2 \ 10^{-3} \ (min)$	9.582	2.670	9.979	9.754	2.935	10.38
		$q_{e,exp} (mg/g)$	0.231	0.242	0.242	0.246	0.246	0.242
		$q_{e,cal}$ (mg/g)	0.397	0.409	0.408	0.418	0.422	0.429
		$\mathbb{R}^2$	0.993	0.996	0.996	0.996	0.995	0.996
	Intraparticule k	$m_{\rm int} 10^{-3} ({\rm mg}{\rm g}^{-1}{\rm min}^{-0.5})$	3.8	4.1	4.1	4.2	4.2	4.1
	diffusion	C 10 <sup>-3</sup>	24.4	27.3	27.6	27.7	30.6	29.1
		$\mathbb{R}^2$	0.967	0.937	0.932	0.933	0.926	0.921

Table 2. Kinetics parameters for the adsorption ET<sub>2</sub> onto poly (MAA-cross-DAAB)

Fig. 8 shows a linearized plot of  $C_e/q_e$  against  $C_e$ . Values of  $q_o$  and b are given in Table 2. Thus, it could be demonstrated that the adsorption of the three dyes using superadsorbent hydrogel is monolayer chemical adsorption process and confirms the presence of homogenous adsorption sites on it. Values of isotherm constants and parameters are presented in Table 2 [15]. In the case of the Freundlich model, the value of 1/n obtained for the dye is below 1 signifying the favorable adsorption condition. The comparison of maximum adsorption capacity of superadsorbent hydrogel towards three dyes shows that its efficiency was maximum in the case of  $ET_2$  and minimum for  $ET_2$  [15].



Fig. 8 Adsorption isotherm models of  $ET_2$  onto poly (MAA-cross-DAAB) hydrogels : (a, d and g) 1 %, (b, e and h) 10 % and (c, f and i) 20 % of DAAB

Table 2. Adsorption isotherm parameters							
Isotherm	Isotherm constants	DAAB					
		1 %	10 %	20 %			
Langmuir	$q_0 (mg/g)$	0.631	0.361	0.254			
	b (L/mg)	0.827	0.563	0.662			
	$\mathbf{R}^2$	0.999	0.999	0.999			
Freundlich	$k_{f}$ (mg/g)	0.518	0.290	0.202			
	1/n	0.0447	0.0469	0.0507			
	$\mathbb{R}^2$	0.848	0.880	0.891			
Dubinin	$Q_s(mg/g)$	0.635	1.266	1.120			
-Raduskevich	k 10 <sup>3</sup> (mol/kJ)	6	5	6			
	E (kJ/mol)	28,86	31,62	28.86			
	$\mathbb{R}^2$	0.944	0.948	0.950			

### 4. Conclusions

The (MAA-cross-DAAB) hydrogels with 1%, 10 % and 20 % DAAB were synthesized, characterized and used as an adsorbent for asdorption of dye  $ET_2$  from aqueous solutions. The adsorption capacity ( $k_f$ ) decreases with increase DAAB concentrations. It is observed that Langmuir isotherm is found to be more suitable and appropriate model to explain the adsorption isotherm of  $ET_2$  on poly (MAA-cross-DAAB) hydrogels.

Value of E and n (D–R and Freundlich constant) concluded that adsorption process is chemical in nature. However intraparticle model suggested that adsorption of  $ET_2$  on poly (MAA-cross-DAAB) hydrogels is diffusion controlled process. The results obtained from the kinetic study confirm the adsorption of  $ET_2$  on poly (MAA-cross-DAAB) hydrogels follows pseudo second order rate equation.

#### References

- [1] J. Meng, J. Cui, S. Yu, H. Jiang, C. Zhong, "Hongshun Preparation of aminated chitosan microspheres by one-pot method and their adsorption properties for dye wastewater,". *R. Soc. Open Sci.*, vol.6, pp.182226. 2019
- [2] P. Zhang, I. Lo, D. O'Connor, S. Pehkonen, H. Cheng, D. Hou, "High efficiency removal of methylene blue using SDS surface-modified ZnFe<sub>2</sub>O<sub>4</sub> nanoparticles," *J. Colloid Interface Sci.*, vol.508, pp 39–48. 2017
- [3] D. A. Barus, S. Humaidi, R.T. Ginting, J. Sitepu, "Enhanced adsorption performance of chitosan/cellulose nanofiber isolated from durian peel waste/graphene oxide nanocomposite hydrogels," *Environ. Nano. Monitor. Manag.*, vol. 17, pp.100650. 2022
- [4] G. Sharma, A. Kumar, M. Naushad, A. García-Penas, H. Ala'a, A. A. Ghfar, V. Sharma, T. Ahamad, F. J. Stadler, "Fabrication and characterization of Gum arabic-cl-poly (acrylamide) nanohydrogel for effective adsorption of crystal violet dye," *Carbohydr. Polym.*, vol. 202, pp 444–453. 2018.
- [5] N. M. Vieno, H. Harkki, T.Tuhkanen, L. Kronberg, "Occurrence of pharmaceuticals in river water and their elimination in a pilot-scale drinking water treatment plant," *Environ. Sci. Technol.*, vol.41, pp.5077–5084, 2007.
- [6] P. M. Pakdel, S. J. Peighambardoust, "Review on recent progress in chitosan-based hydrogels for wastewater treatment application," *Carbohydr. Polym.*, vol. 201, pp. 264–279. 2018.
- [7] H. Sebti, A. Fasla, S. Ould Kada, "Swelling properties of hydrogel networks of poly (methacrylic acid-cross-Nacrylate-N,N-dimethyl-N-dodecyl ammonium bromide. Application in the sorption of an industrial dye,". *Der. Pharma. Chemica.*, vol. 7 (11), pp. 17-25. 2015
- [8] A. Fasla, Z. Seghier, A. Iddou, L. Caserta, "Adsorption of Bemacid Red by Poly Tetra (Ethylene Glycol) Dimethacrylate Crosslinked with 2-Hydroxypropyl Methacrylate Hydrogels: Equilibrium and Kinetic Studies," *Indones. J. Chem.*, Vol.22(3), pp. 641-652. 2022
- [9] A. Mokhtar, S. Abdelkrim, A. Sardi, A. Benyoub A, H. Besnaci, R. Cherrak, M. Hadjel, B. Boukoussa, "Preparation and Characterization of Anionic Composite Hydrogel for Dyes Adsorption and Filtration: Non-linear Isotherm and Kinetics Modeling," J. Polym and Environ., vol.28, pp. 1710–1723. 2020
- [10] R. El Haouti, H. Ouachtak, A. El Guerdaoui, A. Amedlous, E. Amaterz, R. Haounati, A. Ait Addi, F. Akbal, N. El Alem, M. L. Taha, "Cationic dyes adsorption by Na-Montmorillonite Nano Clay: Experimental study combined with a theoretical investigation using DFTbased descriptors and molecular dynamics simulations". J. Molec. Liq., Vol.290, pp. 111139. 2019
- [11] (2018) The MATEC Web Conf. [Online]. Avaible: https://doi.org/10.1051/matecconf/201814402022
- [12] S. Kaur, S. Rani, R. K. Mahajan, M. Asif, V. K. Gupta, "Synthesis and adsorption properties of mesoporous material for the removal of dye safranin: Kinetics, equilibrium, and thermodynamics", J. o Ind. Eng. Chem., Vol. 22, pp. 19–27. 2015
- [13] H. Mittal, A. Maity, S. S. Ray, "Synthesis of co-polymer-grafted gum karaya and silica hybrid, organic-inorganic hydrogel nanocomposite for the highly effective, removal of methylene blue", *Chem. Eng. J.*, vol.279, pp. 166–179. 2015
- [14] H. Hosseini, A. Zirakjou, D. J. McClements, V. Goodarzi, H. Chen, "Removal of methylene blue from wastewater using ternary nanocomposite aerogel systems: Carboxymethyl cellulose grafted by polyacrylic acid and decorated with graphene oxide". J.Haz. Mat., vol.421, pp 126752. 2022
- [15] S. Sharma, G. Sharma, A. Kumar, T. S. AlGarni, M. Naushad, Z. A. ALOthman, F. J. Stadler, "Adsorption of cationic dyes onto carrageenan and itaconic acid-based superabsorbent hydrogel: Synthesis, characterization and isotherm analysis", *J.Haz.Mat.*, vol.421, pp. 126729. 2022
- [16] M. Luo, H. Lin, B. Li, Y. Dong, Y. He, L. Wang, "A novel modification of lignin on corncob-based biochar to enhance removal of cadmium from water", *Bioresource Technol.*, vol.259, pp312–318. 2018
- [17] A. Singh, D. B. Pal, K. Kumar, N. Srivastva, A. Syed, A. M. Elgorban, R. Singh, V. K. Gupta, "Studies on Zerocost algae based phytoremediation of dye and heavy metal from simulated wastewater", *Bioresource Technol.*, vol.342, pp. 125971. 2021

- [18] R. Katiyar, A. K. Patel, T. B. Nguyen, R. R. Singhania, C –W. Chen, C –D. Dong, "Adsorption of copper (II) in aqueous solution using biochars derived from Ascophyllum nodosum seaweed", *Bioresource Technol.*, Vol.328, pp. 124829. 2021
- [19] M. Bhaumik, H. J. Choi, M. P. Seopela, R. I. McCrindle, A. Maity, "Highly effective removal of toxic Cr(VI) from wastewater using sulfuric acid-modified avocado seed", *Ind. Eng. Chem. Res.*, vol.53, pp. 1214–1224. 2014
- [20] K. G. Bhattacharyya, A. Sharma, "Kinetics and thermodynamics of methylene blue adsorption on Neem (Azadirachta indica) leaf powder", *Dyes Pigments.*, vol.65, pp. 51–59. 2005