

Granular activated carbon optimization for enhanced environmental disaster resilience and malathion removal from agricultural effluent

Hajjar Hartini Wan Jusoh^{1,2*}, *Hafizan Juahir*^{1,2}, *Nurfarahana Mohd Nasir*^{3,5}, *Setyo Budi Kurniawan*⁴, *Ahmad Jusoh*⁵, *Nor Aida Mahiddin*^{1,6*}

¹East Coast Environmental Research Institute, Universiti Sultan Zainal Abidin, Kuala Terengganu 21300, Malaysia

²Faculty of Bioresource and Food Technology, Universiti Sultan Zainal Abidin, 22200 Besut, Terengganu, Malaysia

³Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

⁴Laboratory of Algal Biotechnology, Centre Algatech, Institute of Microbiology of the Czech Academy of Sciences, Opatovický mlýn, Novohradská 237, 379 81 Třeboň, Czech Republic

⁵Faculty of Ocean Engineering, Universiti Malaysia Terengganu, 21300 Kuala Terengganu, Terengganu

⁶Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin, 22200 Besut, Terengganu, Malaysia

Abstract. The study aimed to address the critical problem of malathion pesticide contamination in agricultural runoff and its adverse impact on the environment. It specifically focused on utilizing granular activated carbon (GAC), derived from both coal (CBAC) and peat (PBAC), as a promising solution for effective malathion removal. This study focused on the substantial influence of particle size and GAC dosage on the removal efficiency of malathion. It was determined that optimal conditions, resulting in an impressive 90% removal efficiency, were achieved when the initial malathion concentration of $7 \mu\text{g L}^{-1}$ was reduced to approximately $1.14 \mu\text{g L}^{-1}$ and $1.5 \mu\text{g L}^{-1}$ for CBAC with particle sizes of 0.063 mm and 1.0 mm, respectively. In contrast, PBAC exhibited a removal efficiency of $2.87 \mu\text{g L}^{-1}$ under similar conditions. The study further employed the Langmuir and Freundlich adsorption isotherms models to analyze the adsorption behavior of malathion on GAC. The equilibrium data closely aligned with both models, and the maximum adsorption capacity was determined to be an impressive 248.1 mg g^{-1} . These findings highlight the significant potential of GAC, whether coal or peat-based, as a highly effective absorbent material for mitigating malathion contamination in agricultural runoff. This research contributes to enhancing environmental disaster resilience by offering a viable method for optimizing GAC use, thereby reducing the detrimental effects of pesticide contamination on the environment.

* Corresponding author: hajjarjusoh@unisza.edu.my, aidamahiddin@unisza.edu.my

1 Introduction

Water consumption is increasing globally due to population growth and socioeconomic development, particularly in regions with dry climates. The increase in water use is putting pressure on already limited water resources and exacerbating the problem of water scarcity. Parameters such as temperature, dissolved oxygen (DO), pH, ammonium level, and total dissolved solids (TDS) are essential indicators of water quality. These properties can undergo changes due to natural occurrences and human interventions, thereby influencing the condition of water resources [1]. Thus, water resources management has become an important aspect that needs to be addressed. By implementing systematic and efficient water resources management practices, it becomes possible to ensure the production of high-quality wastewater without any pollution [2]. Wastewater can be categorized into a few which are domestic wastewater, industrial wastewater, and agriculture wastewater. Additionally, to domestic waste, agriculture waste is one of the major factors in contributing to water pollution [3]. To address this issue, there is a growing need for efficient and effective water management and treatment of agriculture wastewater to reduce the impact of pollutants, such as pesticides, on human health and the environment.

Effective disaster management involves comprehensive preparedness and planning to mitigate the impact of various emergencies, including those arising from pesticide contamination. Pesticides, commonly used in agriculture and pest control, can pose significant risks to ecosystems, water sources, and public health if not managed properly. This necessitates a strategic approach that integrates scientific research, such as the adsorption of pesticides using activated carbon, into disaster management protocols. This expert explanation explores how research in this area can enhance disaster preparedness and planning.

Enormous quantities of pesticides such as herbicides, insecticides, fungicides, rodenticides, and others enter the environment through agricultural, domestic, and industrial activities. Once pesticides are introduced into the environment, whether by application, disposal, or a spill, it can be influenced by many processes. Therefore, the long-term effects of low doses of pesticides on human health, non-target species, and the environment raise serious concerns [4]. Developing countries cannot stop the usage of certain pesticides due to the cost and efficiency. Thus, it is necessary to reduce and eliminate these life-threatening compounds from wastewater before it is discharged. Many researchers are interested in implementing advanced methods for removal of these insecticides from their major resources, primarily aquatic media [4-5].

The pesticides residues are often found in streams or rivers, groundwater and have even been found in rain. There are many factors that contribute to the risk of unwanted spread of pesticides to the environment, for example cropping, spraying techniques and natural conditions and processes (climate, soil, properties). Figure 1 shows the natural processes that occur to pesticides in the environment. The sprayed or used pesticides on fields can be transported to the surrounding land and water in many ways. Wind drift and evaporation are examples of the ways that pesticides can be transmitted away from the point of and then carried back to soil or water by rainfall. Surface run-off and percolation of water to the drainage system would contribute to the contamination of pesticide residues to the rivers and lake and pesticides residues seeping to the groundwater by the leaching of water through the soil. Besides, the other way that leads to pesticides going astray into the environment is the various spillages during handling pesticide compound.

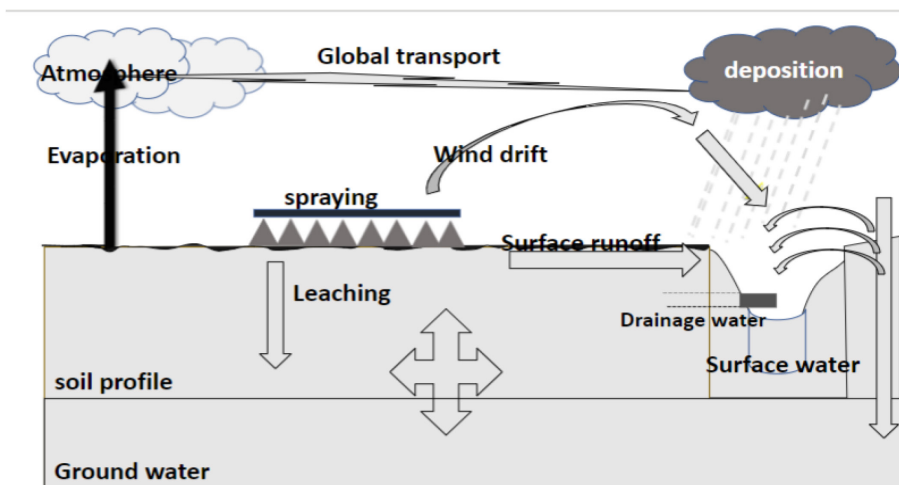


Fig. 1. Natural processes occur to pesticides in the environment adapted from [6].

Malathion S-1,2-bis (ethoxycarbonyl) ethyl O,O-dimethyl phosphorodithioate is a widely used organophosphorous pesticide that is effective in controlling various insects, including those on fruits, vegetables, and in the control of mosquitoes [7]. It is one of the most used active ingredients for pest control products globally, with massive quantities used in countries such as China and India for their agriculture production. The use of Malathion has been reported to result in residues of organophosphates, including malathion, which are toxic and carcinogenic in nature (Ch) toxicity is due to the ability of Malathion and other organophosphates to affect the nervous system by inhibiting cholinesterase activity [8]. The widespread use of Malathion highlights the need for careful monitoring and regulation of pesticides to ensure they do not pose a threat to human health and the environment.

Faced with an increasing contamination of natural waters by pesticides, many methods have been applied to overcome this contamination problem. This includes destroying ozonation, disinfection, photocatalysis or removal by adsorption. Many studies with various methods have been conducted for the removal of some pesticides such as [9] which remove some pesticide by electrocoagulation method (malathion, imidacloprid and chlorpyrifos), [10] using electrochemical methods, [11] using Nanofiltration treatment, [12] using mixed culture of bacteria and white-rot fungi and others. However, an increasing attention has been focused on adsorption techniques due to their efficiency in the removal of pollutant from aqueous solution [13]. The safe disposal of pesticides into the environment is a significant challenge, and a range of methods have been developed to address this issue. However, many of these methods are expensive and may not be feasible for widespread application. For example, chemical oxidation, photocatalysis, and biological degradation are effective methods for removing pesticides, but they are costly and may require specialized equipment and expertise.

In contrast, adsorption by activated carbon has emerged as a simple, cost-effective, and widely applicable method for removing organic pollutants, including pesticides, from water environments. Activated carbon can be derived from a range of natural materials, such as coconut shell, peat, wood coal, or palm shell, and can be produced at a low cost. Furthermore, adsorption by activated carbon is highly effective in improving taste, odour, and colour problems that are often associated with organic chemicals like pesticides.

Thus, the adsorption by activated carbon can be used to improve such impurities and it is important to monitor the concentration of the pollutant in water environment by carrying out a lab scale study such as batch experiment to understand the mechanism of the removal. From a batch experiment, the sorption capacity parameter obtained is useful in providing information about effectiveness of adsorbent system. The Freundlich and Langmuir adsorption isotherms were used to evaluate the adsorption capacity of GAC.

2 Methods

2.1 Adsorbate and adsorbent

Malathion with 95% of active ingredient was supplied by Sigma Aldrich. Malathion solutions were prepared with distilled water of a Mili-Q water purifier (Milipore Corporation). Two types of activated carbon used as sorbent (coal base and peat base) were purchased from an abroad manufacturer (Yujia Carbon). The raw material procured from the manufacturer was in the form of small, spherical, black brownish in colour with standard sizes of 0.8–1.5 mm. The activated carbon was crushed and sieves into two sizes (1.0 mm and 0.063 mm), washed with distilled water to remove fines and impurities, oven dried at 110 °C for 24 h and stored in plastic containers for further use. The adsorbent was characterized with the aim of assessing its various physical and chemical properties, so that a better interpretation of the mechanism involved during the adsorption process can be provided. The preliminary behaviour (solubility, absorbance characteristics, linearity and calibration) of the selected pesticide was determined spectrophotometrically on a Cary 50 UV Spectrophotometer at 230 nm k_{\max} . A morphology investigation was carried out by scanning electron microscope (SEM), model JOEL JSM 6360 LA, Japan. Surface area and pore size distributions for the samples were measured using a Micro-meritics ASAP 2010 surface area analyzer that uses a nitrogen adsorption–desorption method.

2.2 Adsorption studies

Adsorption of malathion onto coal base and peat base activated carbon was monitored spectrophotometrically and the absorbance data of malathion obtained in thirty-minute intervals during adsorption were converted into concentration data using the corresponding calibration curves. Then the concentrations were plotted as a function of time. The adsorption performance of malathion onto both GAC were investigated under the range of temperature 30–80 °C using two different sizes of particle: 1.0 mm and 0.063 mm by employing the batch method. The measurement of adsorption kinetics of the adsorbents was carried out by shaking the amount of carbon dosage that used (1.0 g) samples of adsorbents with 20 mL of malathion solution of known concentration: 7 $\mu\text{g L}^{-1}$ in 250 mL conical flask. The samples were placed in the electrical shaker at room temperature of about 25 °C with fixed agitation speed of 150 rpm as suggested by Hamadi et al., (2004), using Bioscience Agitator 74574 model. The removal kinetics of the malathion was investigated by taking samples of the solution after the desired contact time (30 – 300 min) with 30 min time intervals and filtrate was analyzed for its malathion concentration by spectrophotometrically at λ_{\max} 230 nm of the adsorbate. Triplicate samples for each sorbent size were used in a duration time of 300 min.

The amount of malathion adsorbed (q_e in mg g^{-1}) was determined by the equation (1).

$$q_e = \left(\frac{C_o - C_e}{m} \right) V \quad (1)$$

where C_0 and C_e are the initial and final concentrations, respectively of the adsorbate in solution ($\mu\text{g L}^{-1}$), V the volume of solution (L) and m is the mass of adsorbent (g).

2.3 Statistical Analysis

All experiment data were analyzed in triplicate and graphical analyses were plotted using Origin 2022 software (Origin Lab Corp., USA) for the determination of interactions between factors. Statistical analyses were performed through IBM SPSS ver. 28.0. Normality and homogeneity of variances of the data were satisfied via Shapiro-Wilk test and Levene's test, respectively. The removal efficiency and sorption of activated carbon, Peat Base Activated Carbon (PBAC) and Coal Base Activated Carbon (CBAC) in different contact time was analyzed by One-Way Analysis of Variance (ANOVA), followed by Tukey HSD test. Results were considered as statistically significant at $p < 0.05$ in this experiment.

2.4 Preparedness and Planning for Disaster Management Services

Research on the adsorption of pesticides using activated carbon significantly contributes to the preparedness and planning of disaster management services. By comprehending the behaviour of pesticides in diverse environmental conditions, authorities can develop response plans and protocols tailored to potential pesticide-related emergencies. This research aids in optimizing mitigation strategies through the identification of optimal methods for employing activated carbon to counteract pesticide contamination. It also assists in pinpointing contamination sources and vulnerable areas, enabling disaster management agencies to allocate resources strategically and devise proactive measures. Ultimately, this knowledge fosters collaboration among stakeholders, enhances public awareness, and ensures effective responses that mitigate the impacts of pesticide-related disasters on both ecosystems and public health.

3 Results and Discussion

3.1 Physical and chemical characterization of GAC

This section is focused on the physical and chemical characteristics of activated used for this study. The physical characteristic consists of external pore size and shape of pores, surface area, pore volume and mean pore radius. Well-developed pores were clearly found on the surface of both GAC used for this study. The pores of different sizes and shapes could be observed. Figure 2 (a) and (b) show that the adsorbents have an irregular structure, asymmetrical pore distributions and porous surface with the external pore size varies from 2.80 to 4.49 μm for CBAC and 0.51 to 1.09 μm for PBAC. The pore sizes of all GAC used fall under a category of macropores that is larger than 50 nm. Therefore, it indicates that these GAC are highly appropriate for liquid phase adsorption. These macropores provide superb conditions for adsorption to occur since adsorbing material can interact with tremendous surfaces simultaneously as confirmed in the study that conducted by [14]. The size of pores that are formed would influence the porosity and the total surface. On top of that, the amount and distribution of pores play key roles in determining how well contaminants are adsorbed. The best performance of adsorption occurs when pores are barely large enough for the admission of contaminant pass through it.

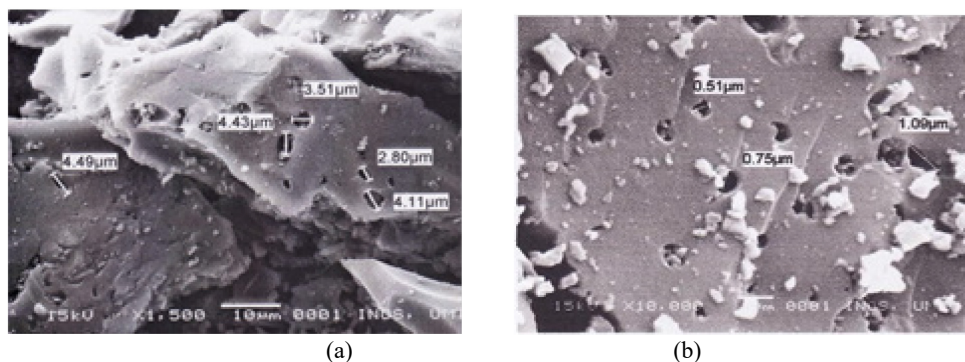


Fig. 2. The pore structure for (a) CBAC and (b) PBAC.

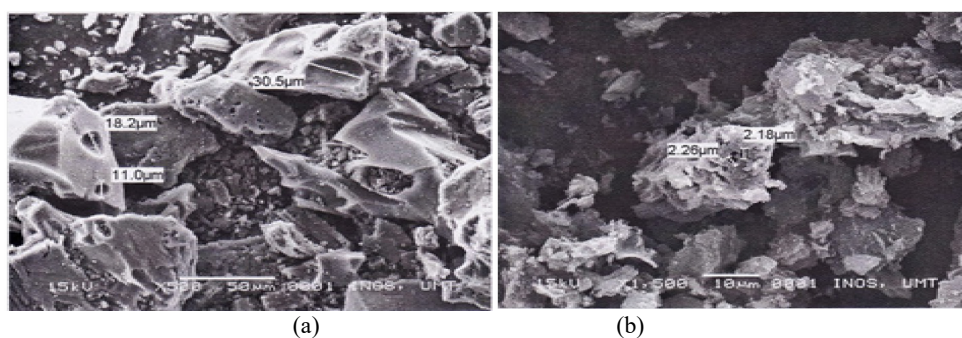


Fig. 3. The surface structure for (a) CBAC and (b) PBAC.

Figure 3 (a) and (b) illustrate the surface structures of the adsorbents, CBAC and PBAC, respectively. CBAC exhibits a crystalline structure, whereas PBAC displays an irregular surface structure. The analysis indicates that CBAC possesses a more intact external surface structure compared to PBAC. Crystalline CBAC could exhibit a more uniform surface energy and hydrophobicity, which can influence the adsorption of hydrophobic compounds like malathion. Hydrophobic interactions between malathion molecules and the activated carbon surface are more favorable on a uniform and hydrophobic surface. The irregular surface of PBAC might have varying hydrophobic and hydrophilic regions, impacting the strength of hydrophobic interactions.

The surface areas of coal base activated carbon (CBAC) and peat base activated carbon (PBAC) were measured using Micromeritics ASAP 2010. The value of surface area, pore volume and pore radius of both activated carbon samples used were tabulated in Table 1. It was found that the specific surface area of CBAC is about 20 % higher than PBAC. As a result, it indicates that the extra 20% surface area of CBAC was attributed to the external surface area of the activated carbon itself. The values of surface area for both of GAC used in this study were in the range of typical values of BET (N₂, 77K) activated carbon, which is 500 – 1500 m² g⁻¹ [15]. The mean pore radius of both types of GACS used in this study is more than 17 Å, which requires the adsorption of malathion substances at the range of 17 to 21 Å [16].

If the molecular size of adsorbate is larger than the size of macropores, it cannot pass through the activated carbon structure where adsorption occurs in the internal surface area of activated carbon. Therefore, it requires the adsorption process to occur between the adsorbent and adsorbate, since malathion has a small molecular size with the chemical formula of C₁₀H₁₉O₆PS₂ and a molecular weight of 330.36 Da [17].

The results show that BET surface areas of the CBAC is higher than that of the PBAC with value of surface area 894 and 566 m² g⁻¹ respectively. This phenomenon is due to the characteristic of CBAC which has a predominance of pores in the macropores range. Macropores itself act as a transport path for adsorbate to be transported to the micropores where adsorption occurs [18]. Therefore, CBAC has the characteristics of more porous as compared to PBAC which may contribute to the higher adsorption capacity as well as higher percentage of Malathion removal.

Table 1. BET surface area of CBAC an PBAC.

GAC	Surface Area (m ² g ⁻¹)	Pore Volume (cm ³ g ⁻¹)	Mean pore radius (Å)
CBAC	894	295	18.9
PBAC	566	187	21.6

Three analyses of pH, moisture contents and ash contents were done to chemically characterize all adsorbents used in this study. The physico-chemical properties of the adsorbent are summarized in Table 2.

Adsorbent's pH may influence the removal efficiency and become an important factor for adsorption performance [19]. The adsorption is favored by more acidic condition because the pH values of both activated carbons used describe acidic condition. Distinctly, acidic adsorbent may react with the material to be removed and may hamper the surface properties of the adsorbents. This is consistent with the study conducted by [19], where it was found that the adsorbent is efficient enough to adsorb lanthanum (La) at pH 4 (slightly acidic) due to the presence of various functional groups, as well as in the acidic range (i.e., pH 3) due to electrostatic repulsion between surface functional groups and H⁺ ions. In fact, CBAC has lower pH compared to PBAC, this indicates better performance of adsorption. The pH of CBAC is more acidic because it is washed with acid in the activation process which affects the adsorption performance.

Based on moisture contents value, it shows that CBAC is a kind of impregnated carbon with the lower value of moisture contents compared to PBAC. For impregnated carbons, lower moisture results in an increase in efficiency, since the mechanisms of contaminant removal are chemical reactions that occur in the reagent solutions contained within the pores. One of the main ways that water can negatively impact the performance of activated carbon is by blocking the pores that are essential for adsorption. Activated carbon works by attracting and holding onto molecules of contaminants through physical or chemical forces, and the porous structure of activated carbon provides a large surface area for this adsorption to occur. When water enters the pores of activated carbon, it can displace or block the contaminant molecules, reducing the effectiveness of the adsorption process. Furthermore, water can impact activated carbon by causing it to degrade or break down over time.

Activated carbon is a stable material, but exposure to water and other environmental factors can cause it to deteriorate, losing its ability to absorb contaminants effectively. Hence, CBAC could give encouraging adsorption performance with low value of moisture contents that is in line with the study conducted by [20] have shown that lower moisture content (1 to 2.75 %) increases the rate of adsorption of contaminants.

The values of ash content for both adsorbents used were in the range of 3 to 9% and considered a low ash content. According to [21] the practical limit for the level of ash content allowed in the activated carbon varies between 2 to 5%. This statement is supported by [22] that stated the adsorbent with low ash contents is more active. So that, CBAC which has a lower value of ash content resembles as a good adsorbent due to the value of ash contents was 3.02 %. Different trends showed by PBAC with the value of ash contents

being 8.71 % respectively. Therefore, CBAC gives better characteristic compared to PBAC which affected the performance of adsorption in removing the malathion residues in agricultural wastewater. The same trend was also observed by [23] who clearly state that as the ash content is in the range of 3 to 4.45 % resembles good adsorbents.

Table 2. Main Characteristics of GAC.

Parameters	Value	
	CBAC	PBAC
Ash content (on dry basis) (%)	3.02 ± 0.01 ^a	8.71+ 0.02 ^a
Moisture content (%)	2.71 ± 0.00 ^a	4.71+ 0.08 ^a
pH	4.36 ± 0.03 ^a	5.17+ 0.01 ^a
Particle size	8–20 mesh	8–20 mesh

^aResults are expressed as means ± standard deviation; values are means of triplicates: n = 3.

3.2 Adsorption isotherms

Adsorption isotherms describe the interaction of adsorbate with adsorbent and so are important for optimizing the use of any adsorbent [24]. They play important roles in determining the optimum adsorption capacity of adsorbent and indicate how efficient an adsorbent can adsorb and allows an estimation of the validity of adsorbent’s application [25]. Therefore, several models, Freundlich and Langmuir models have been used to describe the experimental data of adsorption. The adsorption isotherm data for malathion adsorption were plotted and presented in Figure 4 (a) and (b).

The following expressions of a straight line for Langmuir stated as equation (2);

$$q_e = \frac{abC_e}{1+bC_e} \quad (2)$$

where C_e is the equilibrium malathion ion concentration (mg L^{-1}), the amount of malathion adsorbed at equilibrium (mg g^{-1}) and a (mg g^{-1}) and b (1 mg^{-1}) are Langmuir constants related to adsorption capacity and energy of adsorption, respectively.

The following expressions of a straight line for Freundlich stated as equation (3);

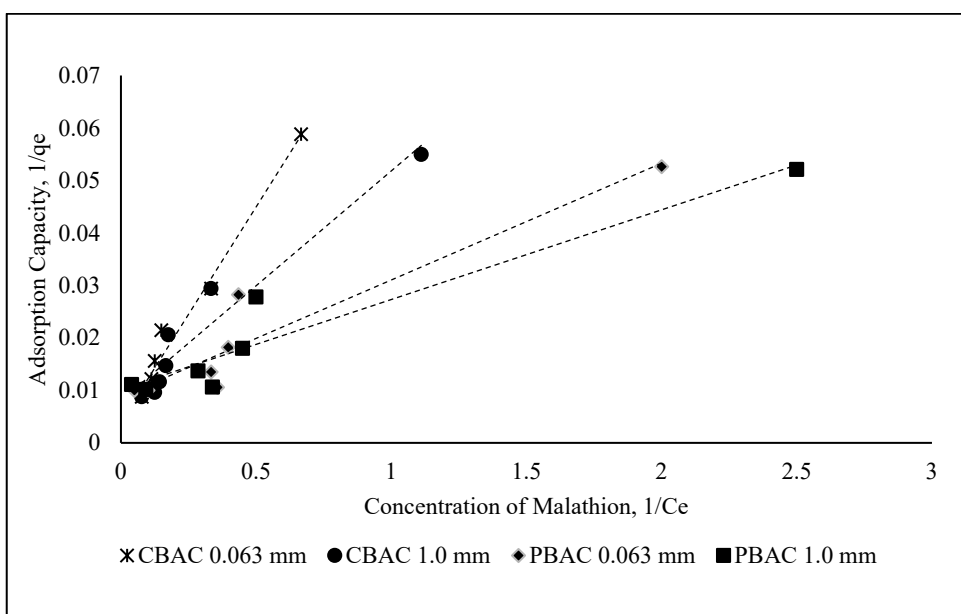
$$\text{Log } q_e = \text{Log } K_f + \frac{1}{n \text{Log } C_e} \quad (3)$$

where K_f and n are the Freundlich constants incorporating all factors affecting adsorption capacity, an indication of favorability of malathion adsorption onto both activated carbons.

The adsorption capacity is indicated as K_f and the value of the empirical constant $1/n$ is related to the energy of adsorption effectiveness of activated carbon. The comparison of Langmuir isotherm for CBAC and PBAC were summarized in Table 3. Based on this table, CBAC indicates the higher maximum adsorption capacity (q_{max}) as compared to PBAC. This is in accordance with the value of BET surface area and void volume of the CBAC that tabulated in Table 1, where it shows higher than PBAC. The data fitting of Langmuir and Freundlich isotherm were shown in Figure 4 (a) and (b). Langmuir adsorption isotherm fitted the experimental data better than that of the Freundlich adsorption isotherm since the value of correlation coefficient (R^2) of Langmuir isotherm near to one compared to Freundlich isotherm (Table 3). This implies that a monolayer sorption proceeds over a surface containing a finite number of the adsorption sites [26].

Normally, the higher the surface area and the larger the pore volume would contribute to the higher adsorption capacity. The adsorption capacity of CBAC for malathion with

sizes of 0.063 and 1.0 mm (248.1 and 123.5 mg g⁻¹) was higher than that of PBAC (113.9 and 100.6 mg/g) due to the difference of surface area value which is 894 m² g⁻¹ for CBAC and 849 m² g⁻¹ for CSAC. This could be due to the large surface area and pore volume of CBAC as compared to the PBAC with the value of 894 m² g⁻¹ and 295 cm³ g⁻¹ respectively. The result also shows that the particle size of activated carbon affects the performance of adsorption. Based on Table 3, the value of adsorption capacity, for particle size of 0.063 mm is higher compared to particle size of 1.0 mm. The smaller the particle size, the faster the malathion removal. The smaller particles size provides slightly higher external contact surface structure, more intact than PBAC, which enhances pesticide removal onto activated carbons. On top of that, CBAC has the widest distribution of pore sizes, and it indicates the presence of a wider spectrum of surface functional group as compared to PBAC. So that it tends to have the strong chemical bonding between the carboxylic group and adsorbate (malathion) which affected the performance of adsorption process.



(a)

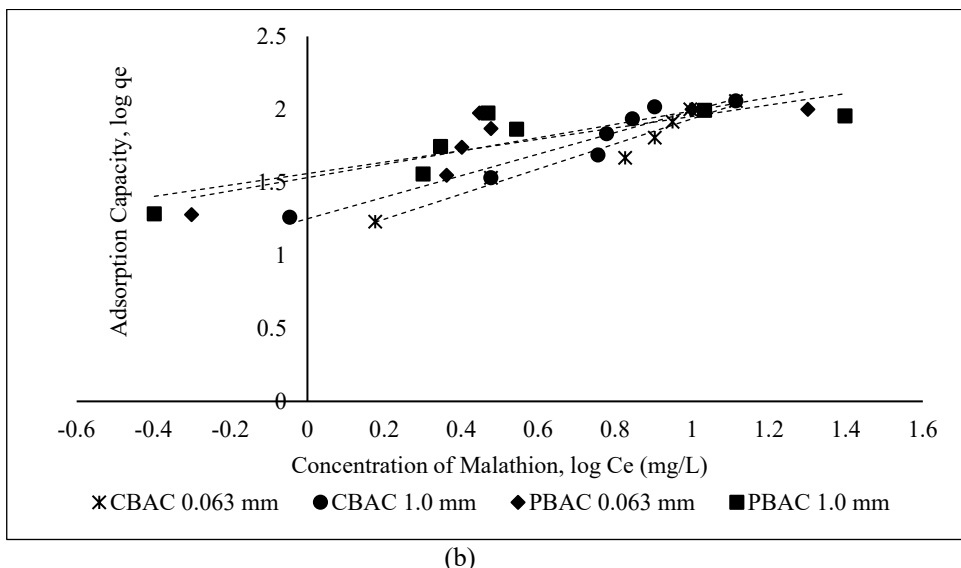


Fig. 4. Linearized form of a) Langmuir isotherm and b) Freundlich isotherm for adsorption of Malathion of different particles sizes for CBAC and PBAC.

Furthermore, the values of the dimensionless factor, R_L , were between 0 and 1. This also suggested a favorable adsorption between CBAC of 0.063mm particle size and Malathion. Therefore, this phenomenon will contribute to the higher value of adsorption capacity and will increase the amount of malathion removal.

Table 3. Isotherm Parameters.

Types of Isotherms	Parameters	CBAC		PBAC	
		0.063 mm	1.0 mm	0.063mm	1.0 mm
Langmuir	q_{max}	248.1	123.5	113.9	100.6
	K_L	0.05	0.18	0.39	0.58
	R_L	0.0001	8.4	16.7	24.0
	R_2	0.977	0.937	0.902	0.917
Freundlich	K_f	11.9	17.8	34.1	36.3
	$1/n$	0.86	0.74	0.46	0.39
	R^2	0.943	0.913	0.725	0.719

K_L is the Langmuir constant related to energy of the adsorption (L of adsorbate per mg of adsorbent). The value of adsorption energy, K_L obtained from the Langmuir isotherms with particle sizes of 0.063 and 1.0 mm for CBAC were 0.05 and 0.18 $L\ mg^{-1}$ and for PBAC, the K_L values were 0.39 and 0.58 $L\ mg^{-1}$. A different pattern was observed for the value of adsorption energy, K_L for all adsorbents. Based on the results, the value of K_L for PBAC were higher for both particle size of 1.0 mm and 0.063 mm. This is due to the different raw material of the adsorbent itself that will affect the energy of adsorption during the adsorption process [27]. Although the K_L value for CBAC is higher than those in PBAC, however it's not affected the adsorption performance of CBAC. The high adsorption energy did not guarantee to enhance the adsorption capacity.

The adsorption energy is an entirely different process, here, some molecules interact with the surface of another compound and there is no chemistry but mere physics (there is no formation or breaking of bonds) there are other interactions at play, van der Waals-type

interactions. So CBAC constantly gives a higher adsorption capacity compared to PBAC due to the higher value of surface area and pore volume. During the adsorption process the molecules of malathion will be attached on the surface of activated carbon used, although the adsorption energy high, the adsorption rate is still low for PBAC than CBAC due to the insufficient site or space for the adsorption process to be occurred. The high adsorption energy with less adsorptive site will lower the adsorption performance.

The difference pattern shown by the Freundlich isotherm where the adsorption capacity, for the CBAC (11.9 and 17.8 mg g⁻¹) which is much lower than that of PBAC (34.1 and 36.3 mg g⁻¹) for both particles' sizes of 0.063 and 1.0 mm. However, the value is higher than those show by CSAC and PSAC using the same method and adsorbate (Malathion) with the range of 0.9 to 1.5 mg g⁻¹ [28]. This circumstance is maybe since Freundlich isotherm obeyed by the adsorptions where the adsorbate forms a multimolecular layer on the surface of the adsorbent [29]. Thus, during the adsorption process the malathion (adsorbate) did not imply heterogeneity of adsorption sites layer on the surface of CBAC and CBAC itself did not give full up performance during the adsorption process resulted to the low adsorption capacity.

Furthermore, the CBAC was go through the high pressure during the activation process as compared to PBAC and Freundlich isotherm, though correctly establish the relation between adsorption and pressures at low values but does not predict the value of adsorption when pressure is high [30]. Therefore, CBAC did not match with the Freundlich isotherm theory and gives low adsorption capacity as compared to PBAC although CBAC have the higher value of the empirical constant 1/n, which is related to adsorption energy in CBAC (Table 3).

3.3 Adsorption Kinetics of Malathion

3.3.1 Effect of contact time

Figure 5 shows the amount of 7 µg L⁻¹ malathion solution removal in the meantime at 30, 60, 90, 120, 150, 180, 210, 240, 270 and 300 min for CBAC, PBAC for both size of particles used in this study which is 0.063 mm and 1.0 mm. The carbon dosage used was fixed at 1.5 g, due to the value of optimum dosage from the experiment determination the effect of carbon dosage. Results show the fast sorption occurred during the first 60 min and the equilibrium was achieved after about 150 min for both adsorbents and particle sizes. The rate of malathion adsorption is extremely high at the beginning and became more rapid after 60 min and achieved about 90% of adsorption for all sizes of particle of all adsorbents after 150 min. The same observation was also clarified by other researchers related to the adsorption performance. It was found that the initial malathion concentration of 7 µg L⁻¹ was reduced to the concentration of about 1.14 and 1.5 µg L⁻¹, for CBAC and 2.87 µg L⁻¹ for PBAC at respective sizes of 0.063 and 1.0 mm. All these final malathion concentrations are well below the safety limit concentration of malathion (Registration Eligibility Decision, RED) in water which is 3.0 µg L⁻¹ for malathion [31].

On the effect of particle size, smaller particle size with 0.063 mm recorded the higher adsorption capacity compared to the particle size of 1.0 mm. Besides, the smaller particle size which is 0.063 mm gives higher percentage removal compared to particle size of 1.0 mm for all types of GACS used for this study with the encouraging value of percentage removal. This is due to the smaller particles size providing slightly higher external contact surface of GAC itself. However, the effect of smaller particle size is just slightly better in terms of malathion removal for all adsorbents used in this study. This condition is due to the less contact time that conduct for this study, so the contact time needs to be prolonged for the detrimental effect of particle size for adsorption performance by the effect of contact

time. The removal efficiencies of CBAC and PBAC at different contact times were significantly different ($p > 0.05$). Similar removal efficiency was found between contact times 150 min and 180 min ($p > 0.05$), with percent distance greater than 90% via post hoc Tukey's HSD test and Bonferroni test. There was no significant change in equilibrium concentration after 90 min and 150 min for CBAC and PBAC respectively, the adsorption phase reached equilibrium. Therefore, the contact time is decided 180 min for all experiments.

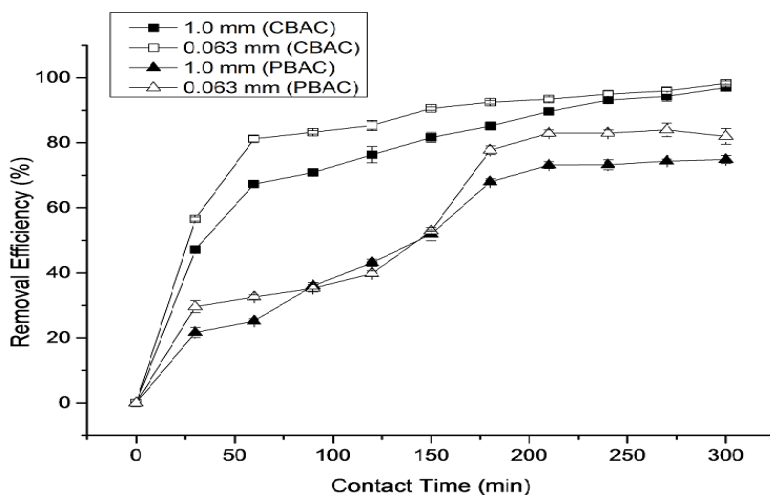


Fig. 5. Effect of contact time on the adsorption of malathion (a) CBAC and (b) PBAC.

The process of adsorption is influenced by the length of time that the activated carbon is in contact with the contaminant in the water [32-33]. Increasing contact time allows greater amounts of contaminant to be removed from the water. Effective time of adsorption is expressed in terms of equilibrium. At equilibrium, there will be no changes in the concentration of the solute or on the surface of adsorbent.

3.3.2 Effect of carbon dosage

The effect of the adsorbent dosage of CBAC and PBAC towards adsorption of malathion was studied between 0.5 to 3.0 g, and the results are illustrated in Figure 6. Initially, a small increase in dosage of activated carbon will result in a drastic uptake of the malathion and as a result any further increase of dosage will cause a gradual increase in the removal efficiency. These results are similar to the findings of [34] that found the removal efficiency of the activated carbons generally improves with increasing dose. Figure 6 presents the amount of malathion adsorbs as function of adsorbent dosage. It was found that increasing the dosage of activated carbons from 0.5, 1.0, 1.5, 2.0 and 3.0 g increases the quantity of malathion (contaminants) absorbed from the solution, due to the greater capacity of the adsorbent. These trends were observed with all the selected GAC used in this study. By increasing the adsorbent dosage from 0.5 to 1.5 g the removal efficiency of malathion was increased from 45 to 88 % for CBAC and 40 to 60 % for PBAC respectively and beyond this dosage it only caused a slight increase in the adsorption efficiency. The removal efficiency at various adsorbent dosage were significantly different for PBAC 0.063 mm and 1.0 mm with ($F = 359.852$, $p < 0.05$) and ($F = 183.655$, $p < 0.05$), while similar removal efficiency was discovered between the 1.5 g to 3.0 g via Post hoc Tukey's HSD test and Duncan test ($p > 0.05$). Therefore, the results are constant with the result reported in

literature [35]. Thus, the use of 1.5 g dosage of activated carbon is justified as optimum dosage for all the selected GAC used in this study.

Based on the particle size of GAC used for this study, the smaller particle size, which is 0.063 mm gives higher percentage removal compared to particle size of 1.0 mm for all types of GACS used for this study with the value of percentage removal up to 88 %. The previous section shows a similar pattern with the value of adsorption capacity was increased with the decreased of particle size. Therefore, it can be concluded that the particle size affects the performance of adsorption process. This is due to the smaller particles size providing slightly higher external contact surface, which, contributes to the more binding site for the adsorption process to occur.

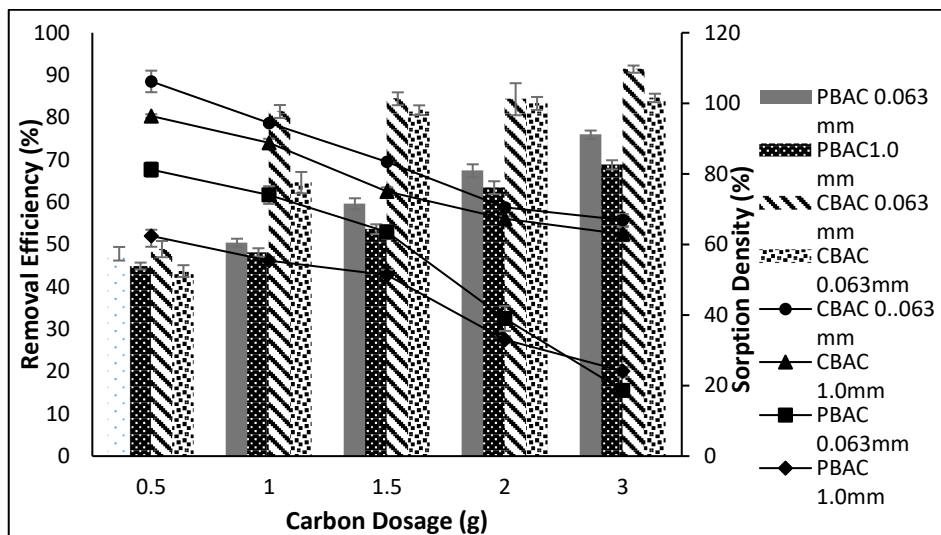


Fig. 6. Effect of adsorbent dosage and removal efficiency on the adsorption of malathion for CBAC and PBAC with particle sizes 0.063 mm and 1.0 mm.

The sorption density of all the GAC used was found to decrease as the dosage of the adsorbents was increased up to a point where further increases of the adsorbents did not increase the overall efficiency of adsorbate or decrease in the sorption density. The removal efficiency of malathion, CBAC was found to be most superior to PBAC for the same quantity of activated carbon. This is shown by the fact that CBAC can remove the adsorbate up to 90 % as compared to PBAC which can only remove approximately 80 % for the same dosage of activated carbon of about 3.0 g. These results agree with those obtained in previous section, which found that CBAC has the better characteristic compared to PBAC due to the higher value of pore size and BET surface area.

It was found that the specific surface area of CBAC is about 20 % higher than that of PBAC. Therefore, it indicates that the extra 20 % surface area of CBAC was attributed to the external surface area of the activated carbon itself. Besides, the characteristics of more porous of both CBAC as compared to the PBAC may contribute to the higher adsorption capacity as well as higher percentage of malathion removal. This corresponds to an increase in available sorption surface areas [36]. The increases in adsorption can be attributed to the increase in external surface areas, which in turn, means an increase in number of available sites for malathion uptake [37].

The increased external surface area provides more adsorptive sites for the removal to occur [33]. Thus, the order of sorption density is in accordance with the order of BET surface area and void volume of the respective GAC used, that is CBAC is ranked first

followed by PBAC as discussed on the section of physical characterization of GAC used in this study.

3.4 Environmental Disaster Management Service

Research has elucidated how different factors, such as temperature, pH, and the presence of other substances, influence the behaviour of pesticides in the environment. This knowledge is vital for disaster management agencies to predict the spread and persistence of pesticide contamination during emergencies. Researchers have identified the optimal conditions for using activated carbon to achieve maximum adsorption efficiency. Disaster management agencies can utilize these findings to design effective response strategies, such as deploying activated carbon filters in water treatment plants or directly applying activated carbon to contaminated sites.

4 Conclusion

To summarize, coal-based activated carbon outperforms peat-based activated carbon in industrial applications due to its higher BET surface area and pore volume. It is also a cost-effective option, readily available in large quantities. Coal-based activated carbon (CBAC) demonstrated the highest adsorption capacity for malathion, with a specific surface area of $894 \text{ m}^2 \text{ g}^{-1}$ and a greater size of macropores (from 2.80 to 4.49 μm). The adsorption process followed the Langmuir adsorption isotherm model and showed a strong correlation with the experimental data. Both GAC types showed promising results in removing malathion contaminants, with a maximum removal efficiency of up to 90% under the prevailing conditions. Therefore, the use of activated carbon as an adsorbent is an effective method for removing malathion from aqueous solutions. This research significantly enhances disaster preparedness and planning. This scientific knowledge forms a crucial foundation for effective disaster response and contributes to the overall resilience of communities and environments.

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