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Low-cost sorbent for removing glyphosate from aqueous solutions for non-potable reuse

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ABSTRACT

This study aimed to determine the removal of glyphosate from aqueous solutions by adsorption with pulverized activated carbon, considering the possibility of including this method as an effluent treatment to be adopted for non-potable reuse. Pareto analysis techniques and response surface analysis were used to evaluate the efficiency and conditions of the process and its effects. The adsorbent used was Biocarbon PVU Tobasa, pulverized activated carbon, manufactured by Tobasa Bioindustrial de Babaçu S.A, from the endocarp of the babassu coconut (Attalea ssp) through a process of physical activation with water vapor. The adsorption tests were carried out keeping the initial concentration of the pesticide at 79.5 mg/L. The results show the effects of the correlated variables, obtaining the optimization of the experimental data, reaching the removal efficiency of approximately 60% of the glyphosate, for an adsorbent dosage of 3.2 g, pH 4.6 and speed of agitation 170 rpm. It is verified that activated carbon can be used as an adsorbent in the removal of glyphosate, even at high concentrations, proving to be an alternative treatment for wastewater, capable of obtaining water for non-potable reuse, regarding the presence of glyphosate.

Keywords: activated carbono, adsorption of glyphosate, wastewater reuse.

Sorvente de baixo custo para remoção de glifosato de soluções aquosas para reuso não potável

RESUMO

Este estudo objetivou determinar a remoção do glifosato de soluções aquosas por adsorção com carvão ativado pulverizado, considerando a possibilidade de inclusão desse método como tratamento de efluentes a ser adotado para o reúso não potável. A técnicas de análise de Pareto e a análise de superfície de resposta foram utilizadas para avaliar a eficiência e as condições do processo e seus efeitos. O adsorvente utilizado foi o Biocarbon PVU Tobasa, carvão ativado pulverizado, fabricado pela Tobasa Bioindustrial de Babaçu S.A, a partir do endocarpo do coco babaçu (*Attalea ssp)* através de um processo de ativação física com vapor de água. Os testes de adsorção foram realizados mantendo a concentração inicial do agrotóxico em 79,5 mg/L. Os resultados obtidos mostram os efeitos das variáveis correlacionadas, obtendo-se a otimização dos dados experimentais, atingindo a eficiência de remoção de aproximadamente 60% do glifosato, para uma dosagem de adsorvente de 3,2 g, pH 4,6 e velocidade de agitação. 170 rpm.

Verifica-se que o carvão ativado pode ser utilizado como adsorvente na remoção do glifosato, mesmo em altas concentrações, demonstrando ser uma alternativa de tratamento para águas residuárias, capaz de obter água para a prática do reúso não potável, quanto à presença do glifosato.

Palavras-chave: adsorção de glifosato, carvão ativado, reuso de efluentes.

1. INTRODUCTION

The tendency to reuse treated effluents as a form of management and sustainable use of the water resource entails the need to guarantee human and environmental safety, due to the presence of pollutants (WHO, 2017). There are different possible fields of reuse application; therefore, different categories of water quality are required with destinations and requirements for specific final dispositions, but eliminating or reducing the concentration of unwanted compounds, if necessary.

In general, technologies used for sewage treatment remove organic matter, nutrients and pathogenic organisms. However, for the removal of more complex compounds, especially those that are persistent, such as pesticides (Anumol *et al.*, 2016), it is necessary to introduce specific technologies.

Among pesticides, the presence of the herbicide glyphosate (N-phosphonomethyl-glycine) stands out as one of the main products of its degradation, aminomethylphosphonic acid (AMPA), due to its toxicity similar to the herbicide itself. Glyphosate is broad-spectrum and non-selective (Feng *et al.*, 2020), which allows it to be in different environmental compartments. Its presence has been reported in effluent samples (Poiger *et al.* 2017) as well as in surface, groundwater, rainwater, sediment, vegetation, and soil (Wijekoon and Yapa 2018; Silva *et al.* 2017; Ronco *et al.* 2016).

The removal of glyphosate, as well as other pollutants when using activated carbon treatment can be explained by the physicochemical properties. Positively charged compounds tend to be removed well, regardless of other properties (De Ridder *et al.*, 2011; Margot *et al.*, 2013). Thus, the sorption of negatively charged compounds present in wastewater across the activated carbon surface can change (if initially neutral or positive) or increase (if already negative) the charge, resulting globally in a negatively charged surface (Margot *et al.*, 2013; Yu *et al.*, 2012). In this case, the carbon surface has negative charges that induce strong electrostatic attraction of positive compounds.

At acidic pHs (pH <5) the phosphate group of glyphosate tends to be easily protonated, being able to act as a strong electrophile, due to the high tendency to attack either the ortho or para positions of aromatic phenolic derivatives present on the surface of the activated carbon, driving the chemical adsorption mechanism through strong chemical bonding between the glyphosate molecule and the carbon surface (Herath *et al.*, 2016).

Different technologies have been tested and employed for the removal of glyphosate in water and wastewater, such as advanced oxidation, photoluminescence, electrocoagulation, membranes, and biological treatments (Hosseini and Toosi, 2019; Wijekoon and Yapa, 2018; Zhan *et al.* 2018; Sarkar *et al.* 2017).

However, the technological complexity and costs associated with these prevent their dissemination in remote or low-income locations. Considering that the development of technologies must meet local needs (Soares and Naval, 2021) regarding cost and ease of operation, adsorption using activated carbon as a technology has proved to be one of the most accessible and environmentally friendly, adequate removal methods, as it meets criteria related to separation efficiency, economy and absence of secondary pollution (Guo, 2020; Dissanayake *et al.*, 2019).

Activated carbon offers application advantages for large-scale treatments, as well as favorable results regarding the removal of pollutants in the aqueous phase. In addition to being easy to operate, low cost, activated carbon adsorption has shown good efficiency in removing contaminants emerging from water (Mayakaduwa *et al.*, 2016; Tran *et al.*, 2015), being able to remove soluble and insoluble organic pollutants without the generation of hazardous by-products, and has the possibility of recovering both adsorbent and adsorbate through desorption processes (Kołodyńska *et al.*, 2017; Abromaitis *et al.*, 2016).

Another advantage of this technique is the possibility of recirculating the powdered carbon, which involves a countercurrent principle that recycles partially charged carbon from the first adsorption stage and mixes it with the more concentrated influent water (Meinel *et al.*, 2016). Multi-stage reuse of powdered activated carbon is often applied to more efficiently exploit its ability to remove organic micro-pollutants (Zietzschmann *et al.*, 2015).

Glyphosate adsorption studies on activated carbon were also performed using different biomasses (Herath *et al.*, 2016; Mayakaduwa *et al.*, 2016). These studies adopted traditional analysis methods, which implies obtaining the influence of the parameters in isolation, that is, of the variables among themselves (Aleboyeh *et al.*, 2008). Using the analysis from the response surface methodology, it is possible to evaluate the effects of the correlated variables, obtaining the optimization of the experimental data (Ecer and Sahan, 2018).

In this study, the operational conditions are determined, considering: i) the adsorbent (pulverized activated carbon) for the removal of glyphosate in aqueous solution, under variation of experimental conditions for pH, temperature, agitation speed, contact time; ii) the initial concentration of the adsorbate and dosage of adsorbent, to obtain the best composition in relation to efficiency; iii) use of the three factorials to propose a simplified treatment configuration and Central Composite Rotational Design (DCCR); and, iv) data adjustment using a second-order polynomial model and analysis of the percentage contribution with the Pareto analysis and variance test techniques.

2. METHODOLOGY

In the study of the removal of the pesticide glyphosate (N-(phosphonomethyl)-glycine) adsorption tests were carried out according to ASTM 3860 - 98 (ASTM, 2003) to determine the adsorptive capacity of activated carbon by the isothermal technique in aqueous phase, which stipulates adsorbent dosage ranges according to the initial concentration of adsorbate to be removed. A concentration of 79.5 mg/L of glyphosate and dosages of activated carbon ranging from 0.1 to 4.0 g were adopted.

To prepare the stock solution of glyphosate (N-(phosphonomethyl)-glycine) at 79.5 mg/L, as recommended by the methodology of adsorption tests (ASTM, 2003), the herbicide trade named “Roundup Original DI”, manufactured by Monsanto do Brasil Ltda, glyphosate diammonium salt concentration 445 g/L (370 g/L acid equivalent).

For the adsorption tests, Biocarbon PVU Tobasa was used, pulverized activated carbon, manufactured by Tobasa Bioindustrial de Babaçu S.A, from the endocarp of babassu coconut (*Attalea ssp*), through the process of physical activation with water vapor and high temperature in continuous and controlled system. The physical-chemical analysis followed the recommendations (Table 1).

Table 1. Specifications of activated carbon in fine powder used in adsorption tests.

Number of Iodine[1]	min. 800/g
Apparent Density[2]	0.3 to 0.45 g/cm
Hardness [3] (ASTM D 3802-79)	min. 90%
Abrasion Resistance	min. 85%
Moisture Conten[t4]	max. 12%
pH	8 to 10 (natural)
Through-mesh granulometry 325	mesh min. 80%
C% (wt./wt.)	89.70±0.90
H% (wt./wt.)	1.82±0.21
N% (wt./wt.)	0.30±0.10
S% (wt./wt.)	1.60±0.30
Ash Content % (wt./wt.)	1.52±0.31
Conductivity (mS/cm)	12.25±0.25

Source: Tobasa Bioindustrial de Babaçu S.A.

1- Iodine number: milligrams of iodine from an aqueous solution, adsorbed by one gram of activated carbon, under specific conditions determined by the method/porosity index relative to small pores (Standard MB-3410 (ABNT 1991a); 2 - Apparent Density: mass ratio per unit volume of activated carbon, including its volume of pores and interparticle spaces. 3 - Hardness: mechanical resistance to particle decomposition; 4 - Moisture content: result of weight reduction when the substance is heated, under specific conditions (ABNT, 1991b).

2.1. Adsorption: Using Factor Design

The adsorption process was subjected to the variation of experimental conditions (activated carbon dosage, agitation speed and pH) according to the Response Surface Methodology (MSR) and a Central Composite Rotational Design (CCRD), using the Protimiza software. Experimental Design.

For the CCRD, three independent variables and five levels were adopted, which included eight factor points (2n = 8), six axial points (2n = 6) and three central points (c = 3). The variables were activated carbon dosage (X1), agitation speed (X2) and pH (X3) (Table 2). The value of α (alpha) was set at 5. All variables at the zero level constitute the central points, while the combination of variables at a lower level (-1.68), or the highest level (+1. 68) are the axial points.

Table 2. Experimental factor and levels used in factorial design - range and levels of the three variables.

Independent Variables	**Factors**	**Coded Levels**				
		-1.68	-1	0	+1	+1.68
Activated Carbon (g)	X1	0.1	0.9	2.05	4	3.2
Agitation (rpm)	X2	150	4.6	200	250	6.4
pH	X3	4	170	5.5	7	230

2.2. Experimental Conditions

For the adsorption tests, a contact time of 2 hours and the temperature of 30ºC were adopted, as recommended by the ASTM 3860 – 98 (ASTM, 2003). The adsorbent dosages, pH and agitation values adopted were: dosages of activated carbon ranging from 0.1 to 4.0 g, pH between 4 and 7 and agitation speed between 150 and 250 rpm, according to the statistical optimization generated through the CCRD (Table 3).

The glyphosate stock solution was prepared by diluting Roundup Original DI in ultrapure water, obtaining a sample with neutral pH of 7. A total of seventeen trials were performed, as recommended by the statistical optimization through the central rotational composite design. Samples of 100 mL volumes were distributed in 250 mL Erlenmeyer flasks for pH adjustment, followed by addition of the correspondent adsorbent dosages, contact time and agitation, (Table 3). To adjust the pH, 1M HCl (1 Molar hydrochloric acid) and 1M NaOH (1 Molar sodium hydroxide) solutions were used.

A rotational incubator (Tecnal Model TE-4200) was used to stir the samples at the desired speeds and temperature. To filter the samples through the 0.47μm glass fiber membranes, a FANEM vacuum compressor was used. The USEPA Method 300 (USEPA, 1993) was used to determine the remaining glyphosate concentration, and the samples were tested using LC-MS/MS (Agilent 6460 LC/MS QQQ).

2.3. Determination of activated carbon adsorption capacity

The calculations of the amount of compound adsorbed by weight of carbon (adsorption capacity in mg/g) (ASTM, 2003) were performed from Equation 1.

$$X/M = \frac{(CoV - CV)}{M} \tag{1}$$

Where:

M = weight of carbon(g); X = amount of compound absorbed (mg); X/M = compound absorbed per unit weight of carbon (mg/g); Co = concentration of compound before carbon treatment (mg/L); C = concentration of compound after treatment with carbon (mg/L), and V = sample volume (L).

The analysis of the results of adsorptive capacity of activated carbon was performed from the amount of compound adsorbed by weight of carbon. For data processing, the Central Composite Rotational Design (CCRD) was used, adopting: k (factors/independent variables) ≥ 2. Cubic points coded for (± 1), axial points coded for (± α, where α= (2k)1/4).

The analysis and optimization of response surfaces (3D surface and contours plots) was applied to obtain the relationships between one or more responses of interest, to verify, quantify and optimize the influence of the responses, as well as to calculate the main and interaction effects of the variables on the responses, specify the most significant effects and adjust a linear, first-order model, or a quadratic, second-order model, correlating the input variables and the responses. To assess the accuracy of the model, tests of Pareto analysis and variance (ANOVA) were performed.

3. RESULTS AND DISCUSSION

The removal efficiency of glyphosate, as well as other compounds, when using adsorption on activated carbon is highly dependent on the conditions established, in addition to the physical and chemical properties of the compound and the biomass used. Thus, pH, temperature, agitation speed, contact time, initial concentration of the adsorbate, and the dosage of adsorbent (Rojas *et al.*, 2015; Salman and Kadhim, 2017) define the removal efficiency.

As for the efficiency of glyphosate adsorption, the minimum percentage was 17.6, when using the dosage of 0.9 g of activated carbon, the agitation speed of 230 rpm and pH 4.6 (trial 5). The maximum adsorption was 59.7%, obtained when adopting the dosage of 3.2 g of activated carbon, agitation speed of 170 rpm and pH 4.6 (trial 2) (Table 3). As for the adsorption capacity, the lowest rate (0.9 mg/g) was obtained from the use of 2.05 g of activated carbon, speed of 200 rpm and pH 5.5, and the highest rate (18.5 mg/g) from the use of 0.1g of activated carbon, at a speed of 200 rpm and pH 5.5 (Trial 9) (Table 3).

Table 3. Experimental optimization (CCRD), glyphosate removal efficiency and adsorption capacity achieved.

Trials	X_1 (Activated carbon/g)	X (Agitation/rpm)	X_3(pH)	Y_1 (Efficiency Adsorption %)	Capacity Adsorption (mg/g)
1	0.9	170	4.6	23.9	2.1
2	3.2	170	4.6	59.7	1.5
3	0.9	170	6.4	39	3.4
4	3.2	170	6.4	57.2	1.4
5	0.9	230	4.6	17.6	1.6
6	3.2	230	4.6	50.9	1.3
7	0.9	230	6.4	21.4	1.9
8	3.2	230	6.4	58.5	1.5
9	0.1	200	5.5	23.3	18.5
10	4	200	5.5	54.7	1.1
11	2.05	200	4	48.4	1.9
12	2.05	200	7	44	1.7
13	2.05	150	5.5	39	1.5
14	2.05	250	5.5	45.3	1.8
15 C	2.05	200	5.5	27.7	1.1
16 C	2.05	200	5.5	23.3	0.9
17 C	2.05	200	5.5	23.9	0.9

C = central point

As for the Central Composite Rotational Design (CCRD) obtained for the glyphosate removal efficiency (Table 4), the resulting mathematical model suggests a second-order polynomial model based on the sum of the sequential model of squares according to Equation 2.

$$Y_1 = 25.13 + 12.98\, x_1 + 4.41\, {x_1}^2 + 6.96\, {x_2}^2 + 5.52\, {x_3}^2 \qquad (2)$$

Where: X1, X12 X22 and X32 are the values of the independent variables activated carbon (linear), activated carbon (quadratic), agitation speed (quadratic) and pH (quadratic), respectively. Both the linear variable for dosage of activated carbon and the individual quadratic operational variables of each of the factors studied had a significant influence on the efficiency of glyphosate removal, while the linear variables for agitation speed and for pH, as well as the interactions between the three variables studied, did not demonstrate a significant effect on the process.

Table 4. Central Composite Rotational (CCRD) design extract obtained for glyphosate removal efficiency.

	Coefficient	Standard Error	t calculated	p-value
Average	25.1	3.7	6.8	0.00002
Activated carbon	13.0	1.7	7.4	0.0000078
Activated carbon	4.4	1.9	2.3	0.0404
Agitation	7.0	1.9	3.6	0.0035
pH	5.5	1.9	2.9	0.0139

The results outlined in the Pareto analysis diagram (Figure 1) show that all the variables studied had a significant effect, at a 5% significance level, on the adsorption process, although the interaction between them did not have a significant effect on the results. This shows that the activated carbon dosage, agitation speed and pH influence the adsorption process.

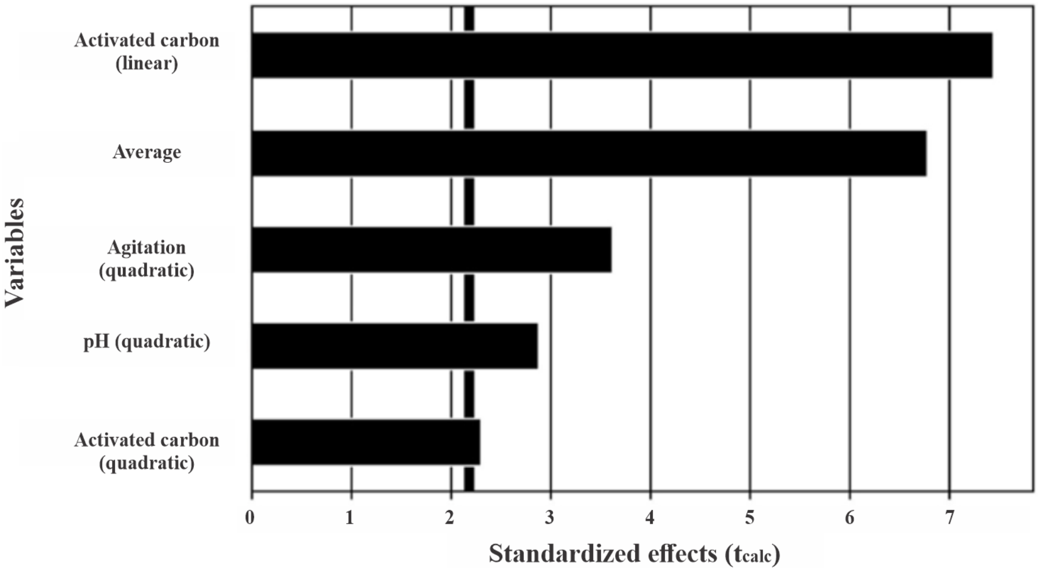

Figure 1. Pareto analysis diagram of the effects of each variable in the rotational core composite design for glyphosate adsorption efficiency.

From the relationship between the experimental and predicted values of glyphosate removal efficiency (Figure 2), it can be seen that both values are in agreement (R2 = 85.85%) with each other, which means that between the predicted and actual responses, of the total variation in the results, 85.85% was attributed to the independent variables investigated.

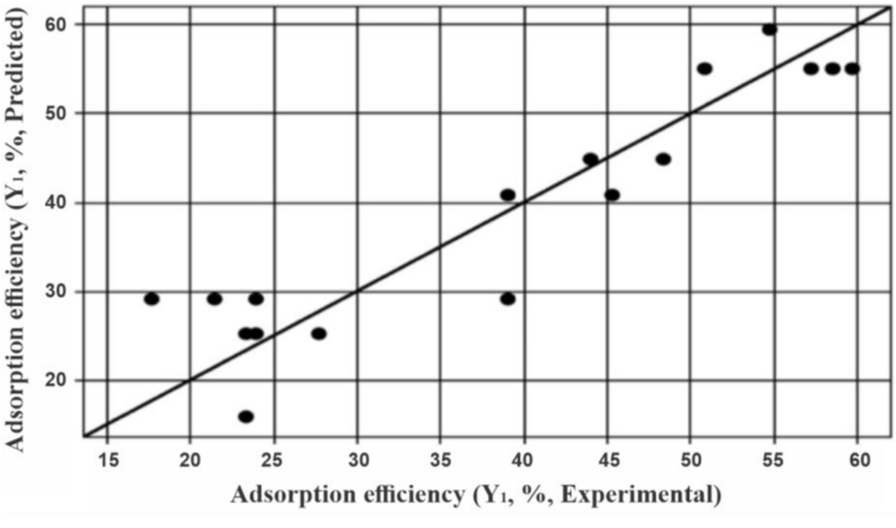

Figure 2. Relationship between predicted adsorption efficiency values and experimental adsorption efficiency values for glyphosate removal.

The adequacy of the models was justified by the analysis of variance (Table 5), in which the predicted F value of 18.2 implies that the model is significant at the 5% significance level ($p < 0.05$). All operational variables analyzed (activated carbon dosage, agitation speed and pH) played a relevant role in glyphosate adsorption.

Table 5. Analysis of variance (ANOVA) for quadratic response surface model for the operational variables analyzed (activated carbon dosage, agitation speed and pH) regarding the performance in glyphosate adsorption.

Source of Variation	Sum of Squares	Degrees of freedom	Mean Square	Fcalc	p-value
Regression	3025.3	4	756.3	18.2	0.000049
Residual	498.7	12	41.6	-	-
Lack of Adjustment	487.3	10	48.7	8.6	0.109071
Pure error	11.4	2	5.7	-	-
Total	**3523.9**	**16**	-	-	-

The results obtained for the effect of activated carbon dosages showed that the variable exerts both linear and quadratic influence on the adsorption process, with the optimal range between 2.5 and 4.0 g, with maximum glyphosate removal efficiency (59.7%) for the 3.2 g dosage.

Increasing the adsorbent dosage allows pollutants a greater opportunity to adhere to the surface of the activated carbon, increasing the surface area of the adsorbent (Bhaumik and Mondal 2015). However, it can promote the exhaustion of the surface available in the sorbent (Sen *et al*., 2017), with a concomitant decrease in the distribution coefficient, limiting sorption, as occurred when the dosage was increased to 4.0 g.

The maximum efficiency of glyphosate removal when the adsorbent dosage was increased up to 3.2 g, demonstrating that the surface area suitable for glyphosate removal is proportional to the amount of adsorbent; that is, increasing the adsorbent dosage, the area surface and active sites for adsorption of glyphosate increase (Meryemoglu *et al.*, 2016; Bhaumik and Mondal, 2015). However, when the dosage was increased, there was no increase in glyphosate adsorption, which may have been influenced by the non-optimization of the other parameters, or by the occurrence of aggregation of carbon particles, which reduced the available adsorption sites (Kumar *et al.,* 2014; Nam *et al*., 2014; Rahmanifar and Dehaghi, 2014).

In the adsorption tests, both agitation speed and pH exerted a polynomial (quadratic) influence on glyphosate removal (Figure 1). Although the adsorption efficiency was not directly proportional to the increase in agitation speed, it was possible to identify optimal speeds of 170 and 230 rpm for the process, which suffered a loss in efficiency at a speed of 250 rpm, showing that the operation is efficient even at lower agitation speeds, which allows energy savings (Zhou *et al.,* 2014). Even the increase in speed can cause the breakage of the particles of the compounds and the increase of desorption, which makes the process unfeasible (Omri *et al.*, 2016).

Regarding the influence of pH, it should be noted that glyphosate has at least four acid dissociation constants, pKa 2.0, 2.6, 5.6 and 10.6 and is negatively charged from pH 4.5 onwards. In this study, the maximum adsorption efficiency was obtained at pH 4.6 (Tomlin, 1994). For all pH values tested, high glyphosate removal efficiency was obtained, indicating that the pH range used had a positive effect on pesticide adsorption, so both acidic and neutral conditions are favorable for glyphosate adsorption in different media (Maqueda *et al.,* 2017; Mayakaduwa *et al.*, 2016).

For glyphosate remotion, using adsorption, studies report a good performance at lower pH levels. The zeta potential of charcoal decreased with increasing pH when increasing pH, which results in decreased adsorption at high pHs (Herath *et al*., 2016). This explains that the glyphosate adsorption process is governed by physicochemical mechanisms, providing efficiency in the treatment of different effluents, especially domestic effluents, which generally have a neutral pH (Posadas *et al.*, 2015).

The response surface for the results of the interactions between dosage of activated carbon and agitation speed (Figure 3a) and dosage of activated carbon and pH (Figure 3b), show that the relationship between the variables did not significantly influence the increase in removal of glyphosate. While there is an optimal range for dosage of activated carbon (2.5 - 4.0 g), the variation of agitation speed and pH had little influence on the efficiency of the process.

It is noteworthy that temperature has an important influence on the adsorption process. It has a greater influence on adsorption when higher (Ghosh *et al.*, 2016), with the balance between molecules that are adsorbed and those desorbed being governed by temperature, based on the analysis at a constant temperature (30ºC) and contact time of 2 hours. The adsorption equilibrium is also dependent on the biomass used in the removal of glyphosate (Mayakaduwa *et al.*, 2016; Herath *et al.*, 2016).

As for the adsorption capacity of activated carbon, the experimental condition that allowed the best adsorption performance by amount of adsorbent occurred at a dosage of 0.1 g of carbon, with an agitation speed of 200 rpm and pH 5.5 (Trial 9 - Table 3).

The adsorption capacity (mg/g) is different from the removal efficiency, the first being directly proportional to the initial concentration of the pesticide and the second inversely proportional. When the initial concentration of the pesticide increases, it provides the driving force needed to overcome the resistance to mass transfer between the aqueous and solid phases, resulting in high values adsorbed per gram of carbon, while the amount of glyphosate adsorbed relative to the initial concentration decreases (Sen *et al.*, 2017).

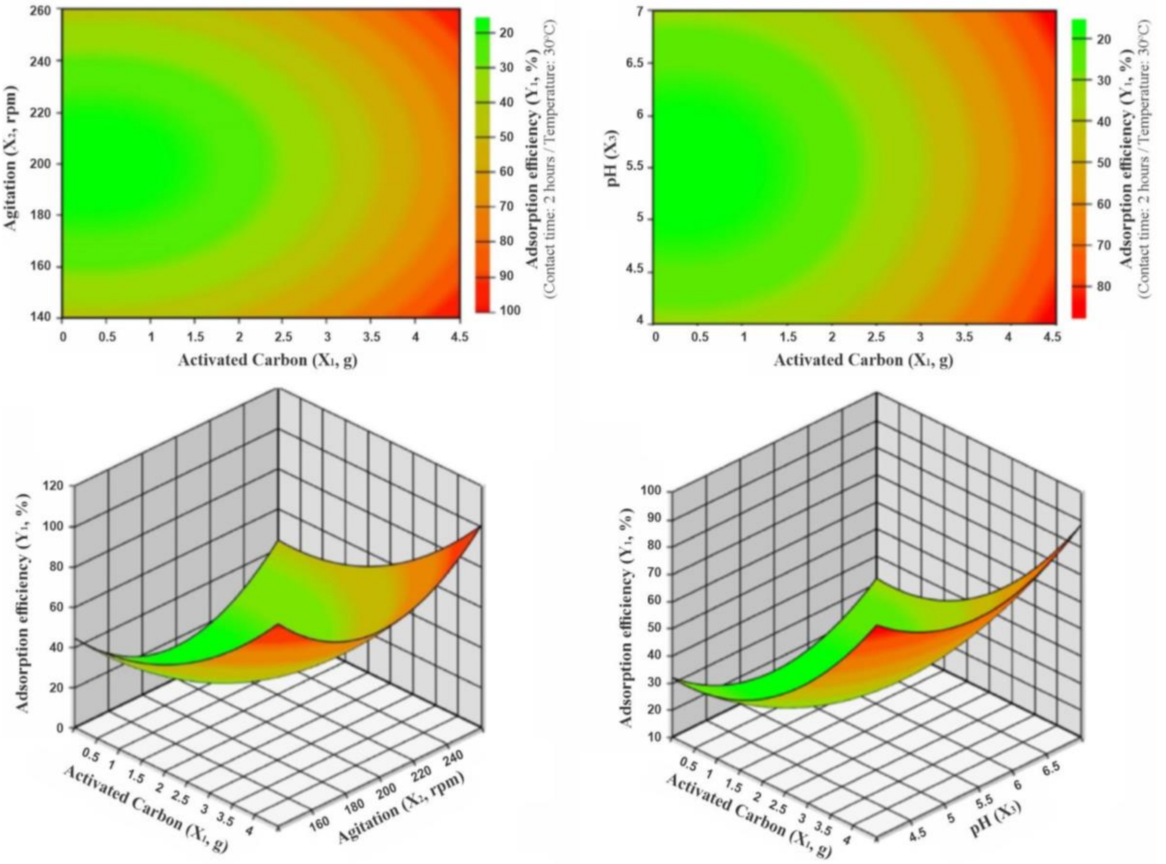

Figure 3. Estimated response surface, representing the relationship between adsorption efficiency (%), activated carbon (X1) and agitation (X2) in the contact time of 2 hours at 30ºC (a) and estimated response surface, representing the relationship between adsorption efficiency (%), activated carbon (X1) and pH (X3) in the contact time of 2 hours at 30ºC (b).

Although the response surface for the interaction between agitation and pH (Figure 4) shows a non-significant influence to increase the efficiency of glyphosate removal, it is observed that all values studied for the variables were favorable to the process, and it was not possible to identify optimal range for each one, evidencing a greater influence for the variation of the dosages of activated carbon studied on the efficiency of glyphosate adsorption. As agitation influences the speed at which the system reaches equilibrium, and not the stability itself, when the adsorption process reaches equilibrium (contact time between the adsorbent and the adsorbate), the adsorption values at different agitation speeds will be insignificant (Choong and Chuah, 2005).

After carrying out the studies based on the variables considered (activated carbon dosage, pH and agitation speed) in the adsorption tests, using the Central Composite Rotational Design (CCRD), it was observed that all variables were significant to the process at the level of 95% confidence.

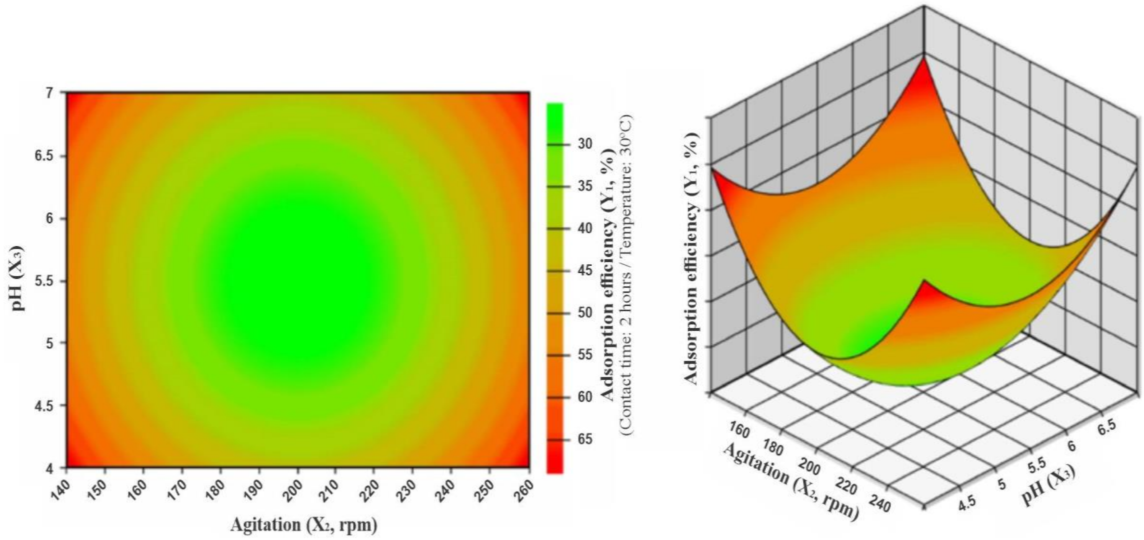

Figure 4. Estimated response surface, graphically representing the relationship between adsorption efficiency (%), Agitation (X2) and pH (X3) in the contact time of 2 hours at 30ºC.

From the best condition of the CCRD, with adsorbent dosage of 3.2 g, pH 4.6 and agitation speed of 170 rpm, it was verified that the adsorption process on activated carbon was efficient. The glyphosate removal rate from the initial concentration used was approximately 60%. As it is a low-cost and easy-to-operate treatment system, the removal obtained was considered relevant when compared to the glyphosate removal rate achieved by other technologies: activated sludge, with removal between 61.4 and 98.45%, under optimized conditions (Poiger *et al.*, 2017; Chen *et al.*, 2019, Jönsson *et al.*, 2013); removal of 80 to 94.8% using the nanofiltration process (Yuan *et al.*, 2018; Liu *et al.*, 2012); adsorption using nanoscale graphene oxide combined with Fe_3O_4, with removal of up to 86% (Li *et al.*, 2018).

Adopting the treatment from the adsorption process with activated carbon, with a removal rate of 60%, the permitted concentration of the active ingredient is reached, recommended by Brazilian regulations to meet the wastewater reuse.

4. CONCLUSION

The variables studied: activated carbon dosage, agitation speed and pH influence the adsorption process. It is noteworthy that when using the optimal dosage of activated carbon, the relationship between the variables does not significantly influence the removal of glyphosate, and the adsorption balance remains dependent on the biomass. The maximum adsorption of glyphosate was 59.7%, reached when the dosage of 3.2 g of activated carbon was adopted, agitation speed of 170 rpm and pH 4.6. As for the relative importance of the parameters that influence the removal of glyphosate, the concentration of the adsorbent had the greatest impact.

The results of glyphosate removal efficiency, using activated carbon adsorption, produced water with pesticide concentrations capable of meeting the requirements of Brazilian legislation for wastewater reuse.

The optimization results for the adsorptive process, under the conditions studied, show that it is possible to use an environmentally favorable removal method, from the use of an adsorbent to remove glyphosate in wastewater, with visits to non-potable reuse. It is also noteworthy that the raw material is abundant and comes from waste, which provides an environmentally correct solution for this biomass.

5. ACKNOWLEDGMENTS

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