Removal of amitraz from aqueous solutions on clay by adsorption technique at industrial scale

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Article Information

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Amitraz (AZ) that is used as acaricide was extracted by using clay adsorbent. The experimental data were modeled via Langmuir and Freundlich isotherms in which adsorption data fit well. The monolayer adsorption capacity was found as 28.53 mg × g^{-1} at a temperature of 30 °C. The effects of the phases contact time, the initial solution pH value and the initial pesticide concentration were investigated regarding the points of adsorption equilibrium and yield. The adsorption kinetics were investigated by applying pseudo-first-order, pseudo-second-order and intra-particle diffusion laws. Adsorption of AZ was found to be best fitted by the pseudo-second-order model. The intra-particle diffusion also plays an important role in adsorption phenomenon. This adsorption is a physical and spontaneous phenomenon. The pesticide removal by adsorption technique was successfully applied in industrial plants.

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A synthetic pesticide is a poisonous chemical or mixture of chemicals that is intended to prevent, repel or kill any pest. In agriculture, pesticides are used to kill insects, weeds or fungi. Although they have many advantages, they present hazardous impacts far beyond their intended targets because of undesired effects on the nervous system of human being [1].

The development of new acaricides is a long and very expensive process. Unfortunately, there is an increasing resistance to available acaricides worldwide leading to the real possibility that our dwindling supply of effective acaricides will be exhausted unless action is taken to increase the number of new acaricidal products and reduce the rate of resistance development [2].

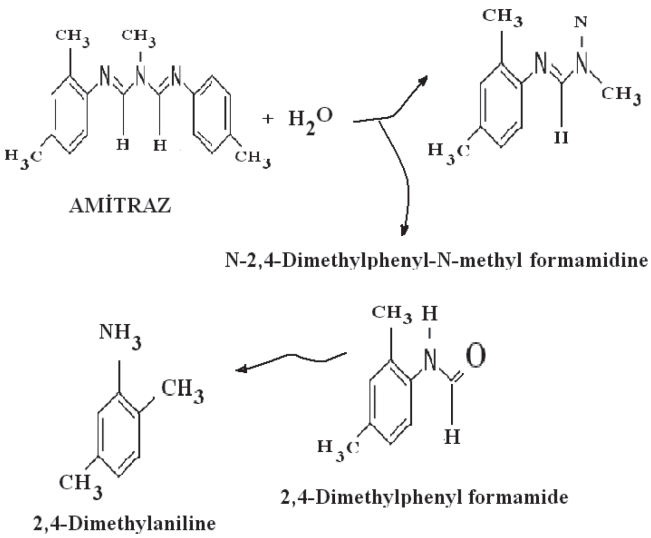


Figure 1: Structures of a) amitraz (N'-(2,4-dimethylphenyl)-N-[[(2,4-dimethylphenyl) imino]methyl}-N-methyl-methanimidamide), b) 2,4-dimethylaniline

Relatively cheap acarides (e. g., amitraz) is often used in combination with a relatively cheap insecticidal product. It has been estimated that annual spending on tick control by farmers can range from $ 2.5 to $ 25 per head of cattle, depending on the country and type of farming operation [2, 3].

Amitraz (N'-(2,4-dimethylphenyl)-N-{[(2,4-dimethylphenyl)imino]methyl}-N-methyl-methanimidamide) is a formamide acaricide. It is applied as a tropical spray or dip on cattle, pigs and sheep to control infections that is caused by ectoparasites [4, 5]. Amitraz (see Figure 1) is hydrolyzed under the exposure to sunlight (UV exposure) [6], low pH value [5] and bioaugmentation of bacteria such as escherichia coli and pseudomonas species present in cattle feecas [7]. Amitraz hydrolyzes to a series of intermediate compounds and finally forms the environmentally stable compound 2,4-dimethylaniline (2,4-DMA) (see Figure 1). The degradation of amitraz to stable aniline products may contribute to the environmental and health risks [8].

A common amitraz application technique is by plunge dipping or spraying of livestuck. Both of them have shortcomings

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parts in terms of dosing livestock at the correct concentrations.The plunge dipping method is rather problematic. Because dip water is frequently reused for further dosing of animals, adding additional pesticide to water. This reuse may contain some residual amounts of pesticide or harmful degradation products. Researchers have shown that unproper dosing of amitraz has led to treks and mites gaining resistance to the pesticides [9].

Acaricides such as coumaphos 3-chloro-7-diethoxyphosphinothioyloxy-4-methyl-2-chromenone, amitraz N'-(2,4-dimethylphenyl)-N-{[(2,4-dimethylphenyl)imino]methyl}-N-methylmethanimidamide) and fluvalinate [cyano-(3-phenoxyphenyl)methyl] 2-[2-chloro-4-(trifluoromethyl)anilino]-3-methylbutanoate) [(RS)-α-cyano-3-phenoxybenzyl-N-(2-chloro-α, α, α-trifluoro-p-tolyl)-=D-valinate] are currently employed by beekeepers in different application forms in Europe and particularly in France [10]. Adsorption on solid adsorbents such as clay or activated carbon is a common method for removing organic contaminants from waters, therefore new materials termed as low cost and ecofriendly ones may be used [11].

De Villers et al. studied the adsorption of aqueous amitraz in anionic surfactant solutions. They found that the adsorbent yields are sequenced as coarse carbon > cation exchange resin ≥ anion exchange resin > fine carbon [12]. Pierpoint et al. studied the kinetics and mechanisms of amitraz hydrolysis [13]. Van Eeden et al. studied the degradation of amitraz under several conditions like pH, buffer composition, ionic strength, temperature and solubility in organic solvents [14]. Gülen et al. analyzed the adsorption process of amitraz from aqueous solution on clay samples at room temperature conditions [15]. The potential usage of these adsorbents can be increased by means of heat treatment [16]. In the present study, temperature parameter was especially investigated.

The clay mineral components have some negative and positive charges on their surface. Negative charges are compensated by inorganic cations situated on their surface such as Na^+, Ca^{2+}, etc. The water molecules present in the hydration sphere of solvated cations confer a hydrophilic nature upon such surfaces. This kind of mineral is no good adsorbent for hydrosoluble organic compounds, because they are unable to compete with the highly polar water molecules [17].

Clay plays an important role for sorption of polar herbicides [18, 19]. Besides clay, minerals have an important role in the adsorption of some nonionic and sparingly soluble pesticides. The clay mineral has also the ability to catalyze the hydrolysis of pesticides. To this end, this work is to leach amitraz from aqueous solution by using clay adsorbent.

Experimental details, materials and methods

Materials. Amitraz used is achieved by Hektaş AŞ in Turkey. Amitraz is a nonsystemic acaricide and insecticide. It has been synthesized by Boots Co. in UK in 1969 for the first time. Amitraz has been found to have an insect repellent effect, and it works as an insecticide and also as a pesticide synergist. Its effectiveness is traced back on alpha-adrenergic agonist activity, interaction with octopamine receptors of the central nervous system and inhibition of monoamine oxidases and prostaglandin synthesis. Therefore, it leads to overexcitation and consequently paralysis and death in insects. Because amitraz is less harmful to mammals, amitraz is among many other purposes best known as insecticide against mite or tick infestation of dogs. Its characteristics are listed in Table 1 [20]. The clay belongs to Bartın area of Black Sea region of Turkey. The chemical characteristics are given in Table 2.

Adsorption experiment. The adsorption experiments were carried out in a batch system and the adsorbent amount was kept constant as 0.1 g during the experiments. The molecular weight of amitraz is 293.4 g × mol^{-1}. Pesticide stock solution was prepared by dissolving 0.01 g amitraz in 100 ml distilled water. This stock solution was diluted to different concentrations. For calibration, 1, 2, 3, 4, 5, 6, .. ml pesticide solutions were diluted to 20 ml with distilled water in Erlenmeyer flasks. The absorbance-concentration relationship was found by UV readings as y = 0.5171x + 0.024 (R^2 = 0.9884).

For adsorption, a 5 ml stock solution was diluted to 40 ml with distilled water. Before UV analyzing, the 3 ml aqueous solution was diluted to 20 ml again for having better absorbance values. The concentration of the pesticide solution was 2 mg × l^1 (2 ppm). The adsorption experiment was conducted by adding 0.1 g clay to each of the flasks. The flasks were then inserted in a thermostath shaker (Nüve ST402) and set at 250 rpm at a temperature of 30 °C. At the end of the predetermined time intervals, the samples were centrifuged at 4000 rpm for 5 minutes. Changes in the concentration values of the mixture were analyzed every 30 minutes using ATI UNICAM UV/VIS spectrophotometer. The adsorption wavelength of the AZ was obtained at 245 nm from the first derivative absorption spectra. This system reached equilibrium after 3 hours. The experiments were accomplished at different temperatures (30, 40 and 50 °C) in order to see the temperature effects on the adsorption yield.

Equilibrium studies. The amount of adsorption at equilibrium, q_e(mg × g^{-1}) was calculated using the following equation

$$q_e = \frac{(C_0 - C_e)V}{W} \quad (1)$$

with C_o (mg × g^{-1}) and C_e (mg × g^{-1}): liquid phase pesticide concentrations at initial stage and at equilibrium, respectively, V: volume of the pesticide solution (l) and W: mass of adsorbent (g).

Kinetic studies. The amount of adsorption at time t, qt (mg × g^{-1}) was calculated by

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

with C_o (mg × l^{-1}) and C_t (mg × l^{-1}): pesticide concentrations (mg × l^{-1}) at the beginning and at time t, V: volume of the pesticide solution (l) and W: mass of adsorbent (g).

Effect of initial solution pH value. The pH value of the initial experimental solu-

Chemical name	N'-(2,4-Dimethylphenyl)-N-{[(2,4-dimethylphenyl) imino]methyl}-N-methylmethanimidamide
Molecular formula	$C_{19}H_{23}N_3$
Molecular weight	293.4 g × mol^{-1}
Melting point	86 to 87 °C

Table 1: Chemical #characteristics of amitraz [23]

	B_2O_3	SO_4^{-2}	CaO	Na_2O	SiO_2	MgO	SrO	Al_2O_3	Fe_2O_3	As_2O_3	Heat loss
wt.-%	14	2	13.53	6.87	13.8	11.8	1.15	0.94	0.35	0.0018	35.5582

Table 2: Chemical composition of clay

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tion was 5. Initial solution pH value was adjusted to the desired pH value by using 0.1 M HCl or 0.1 M NaOH. The effect of pH value on the removal of amitraz was studied by varying the medium pHs from 2.5 to 11 (studied pH values were 2.5, 3.5, 5, 7, 9 and 11). The measurements were performed using WTW series inoLab meter. After 3 hours, the absorbance equilibrium values were measured by UV spectrometer. The experiments were performed at 40 °C.

Effect of initial pesticide concentration. Initial pesticide concentration is one of the most important factors that affects adsorption kinetic. The effect of initial AZ concentration on the clay adsorbent was studied at different pesticide concentrations at 40 °C. To do this, 5, 10, 15, 20 ml pesticide solutions were diluted to 20 ml with distilled water. The experiments were performed at fixed adsorbent dose (0.1 g), initial solution pH value (pH = 4) (due to the maximum adsorption yield) and a phases contact time of 3 h.

Adsorption isotherms. Experimental data were modeled using some isotherms such as Langmuir and Freundlich.

The Langmuir equation [21, 22] is in the linearized form,

$$\frac{C_e}{x/m} = \frac{1}{K \cdot X_m} + \left(\frac{1}{X_m}\right) C_e \qquad (3)$$

with: $x \times m^{-1}$ represents the amount of pesticide ions adsorbed at equilibrium, Ce is the equilibrium concentration, X_m ($mg \times g^{-1}$) and K ($l \times mg^{-1}$) are Langmuir constants related to maximum adsorption capacity (monolayer capacity) and energy of adsorption, respectively [23].

The Freundlich equation [24, 25] is in the linearized form,

$$\log \frac{x}{m} = \log k + n \cdot \log C_e \qquad (4)$$

with: $x \times m^{-1}$ is the amount of pesticide ions adsorbed at equilibrium, Ce is the equilibrium concentration, k ($mg \times g^{-1}$) and n are Freundlich constants concerning the multilayer adsorption capacity and adsorption intensity, respectively [23, 26].

Adsorption dynamics. The study of adsorption dynamics describes the solute uptake rate, and evidently, this rate controls the residence time of adsorbate uptake at the solid-solution interface. The kinetics of amitraz adsorption on the clay were analyzed using pseudo-first-order [27], pseudo-second-order [28] and intra-particle diffusion [29] kinetic models. The conformity between experimental data and the model predicted values was expressed by the correlation coefficients (R^2 values close to or equal to 1). A relatively high R^2 value indicates that the model successfully describes the kinetics of amitraz adsorption.

The pseudo-first-order equation [27] is generally expressed by the following equation:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \qquad (5)$$

with: q_e and q_t: adsorption capacity at equilibrium and at time t ($mg \times g^{-1}$), k_1 is the rate constant of pseudo-first-order adsorption ($1 \times min^{-1}$).

After integration and applying boundary conditions t = 0 to t = t and $q_1 = 0$ to $q_t = q_e$, the integrated form of Equation (5) becomes

$$\log(q_e - q_t) = \log(q_e) - \frac{k_1}{2.303} t \qquad (6)$$

The values of $\log(q_e\text{-}q_t)$ were linearly correlated with t. The plot of $\log(q_e\text{-}q_t)$ vs t should give a linear relationship from which k_1 and qe can be determined from the slope and intercept of the plot, respectively.

The pseudo-second-order adsorption kinetic rate equation is expressed as [28]

$$\frac{dq_t}{dt} = k_2(q_e - q_1)^2 \qquad (7)$$

with k_2: rate constant of pseudo-second-order adsorption ($g \times (mg \times min)^{-1}$).

For the boundary conditions t = 0 to t = t and $q_1 = 0$ to $q_t = q_t$, the integrated form of Equation (7) becomes

$$\frac{1}{(q_e - q_1)} = \frac{1}{q_e} + kt \qquad (8)$$

which is the integrated rate law for a pseudo-second-order reaction. Equation (8) can be rearranged to obtain Equation (9) which has a linear form:

$$\ln K_c = \frac{\Delta S°}{R} - \frac{\Delta H°}{R \cdot T} \qquad (9)$$

The intra-particle diffusion model is expressed as [29]

$$R = k_{id}(t)^{1/2} \qquad (10)$$

A linearized form of the equation is given by

$$\log R = \log k_{id} + a \log(t) \qquad (11)$$

with R: percent of pesticide adsorbed, t: contact time (h), a: gradient of linear plots and k_{id}: intra-particle diffusion rate constant (h^{-1}). The term "a" depicts the adsorption mechanism, k_{id} may be taken as a rate factor, i. e., percent pesticide adsorbed per unit time and k_{id} is also calculated by plotting R vs $t^{1/2}$. The value of k_{id} was calculated from the slope of such plot and the regression coefficient values led to the conclusion that the intra-particle diffusion is rather important in the rate limiting step. Higher values of kid illustrate an enhancement in the rate of adsorption, whereas larger kid values illustrate a better adsorption mechanism, which is related to an improved bonding between pesticide ions and the adsorbent particles.

Thermodynamic parameters. The variation in the extent of adsorption with respect to temperature has been explained on the basis of thermodynamic parameters, such as change in enthalpy (ΔH°), change in entropy (ΔS°) and change in Gibb's free energy (ΔG°), which were determined using the following equations [30, 31]:

The Gibb's free energy change of the process is revealed by the equilibrium constant K_c in the equation:

$$\Delta G° = -R \cdot T \cdot \ln K_c \qquad (12)$$

$$K_c = \frac{C_{Ae}}{C_e} \qquad (13)$$

$$\text{adsorption}\% = \frac{C_0 - C_e}{C_0} \cdot 100 \qquad (14)$$

with K_c: equilibrium constant, C_{Ae}: solid phase concentration at equilibrium ($mg \times l^{-1}$), T: temperature (K) and R: gas constant.

Results and discussion

Effect of phases contact time. Several surface phenomena take place during the phases contact time. Measured sorption capacity of some organic matrix or the soil for the pesticides like atrazine, alachlor, endosulfan sulfate and trifluralin were plotted as a function of the contact time. It was observed that the selected pesticide removal capacity increased with time up to adsorption equilibrium. However, the majority of adsorption was rapid in the first 20 minutes and then slowed down. In other words, it was also observed that pesticides were adsorbed on the adsorbents in a three stage process. In the first phase, 30 to 50 % of the pesticides were transported into the macropores after 20 minutes of contact with the adsorbent. The rapid initial adsorption of the studied pesticides is a surface phenomenon [32]. During the second phase, a slight de-

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crease in the adsorption kinetics was noted, most likely because of slow diffusion of the pesticide into the smaller pores and irregularities on the adsorbent surface [33], the final stage took place after 120 minutes of contact and remained even after 4 hours.

For AZ adsorption process, the experiments were carried out for different phases contact times with a fixed adsorbent dose of 0.1 g with 2 mg × l^{-1} initial AZ concentration at 30, 40 and 50 °C, respectively.

Figure 2 shows the relationships between equilibrium concentration and time at different temperatures and Figure 3 depicts the adsorption capacity as a function of time.

As it can be seen from Figure 2, the experiment became constant after 3 hours. q_t was determined from the formula given before. 65 % adsorption capacity was established in 1 hour of contact. This is the first phase of adsorption, in which the pesticide moves into the macropores of the clay adsorbent. This is a surface phenomenon. 80 % of pesticide removal was achieved at the end of adsorption in 3 hours that is the indicator of the smaller pores and irregularities of adsorbent (see Figure 3).

Kyriakpoulos et al. [34] reported that the adsorption became constant in a period of 4 hours or less for alochlor and trifluralin adsorption on porous polymeric adsorbents. Their results were in a good agreement for endosulfan adsorption on clay composted Indian soils reported by Kumar and Philip [32]. Jamil et al. [35] studied the adsorption of atrazine on two types of zeolite and found that atrazine adsorption increased gradually with contact time until 30 minutes in the case of Zeolit × and was completed in 4 hours and 6 hours in the case of Zeolite A, respectively.

Effect of pH value. The effect of pH value is shown in Figure 4 in terms of adsorption percentage versus pH value.

Adsorption percentage was determined from the formula given below:

$$\left(\frac{1}{q_t}\right) = \frac{1}{k_2 q_e^2} + \frac{q}{q_e}(t) \qquad (15)$$

with C_0: initial AZ concentration (mg × l^{-1}) and C_e: equilibrium AZ concentration (mg × l^{-1}).

The adsorption percentage was 23 % at pH = 2.5 and increased to 71 % at pH = 3.5. The acidic region (pH value between 2.5 and 5) leads to an increase of approximately 40 % in absorbance. These high values can be affected by the acidic character of pesticide and the anionic structure of clay. The adsorption% was found as 28 % at pH = 11 and at 40 °C.

A similar behavior was seen for the adsorption of amitrole by acid activated clay [33] and for the adsorption of 2,4,6-trichlorophenol by activated clay [37].

Effect of initial pesticide concentration. The results of initial pesticide concentration effect were shown in Figure 5. The experiments were carried out at the pH value with the highest pesticide removal (pH = 4). Maximum pesticide removal percentage is 85 % for 6 µg × ml^{-1}. Pesticide increases were performed every half an hour. Increasing the pesticide concentration led to an increase in the amitraz adsorption [38]. The increase of the pesticide concentration over 20 ppm did not affect the adsorption capacity significantly.

Adsorption isotherms. The Langmuir and Freundlich isotherms are given in the Figures 6 and 7, respectively. The constants of Langmuir and Freundlich isotherm models are given in Table 3. Langmuir constant (energy of adsorption) was given as negative values. The experimental values conform to the Freundlich isotherm at 40 °C with a high correlation value (R^2 = 0.99).

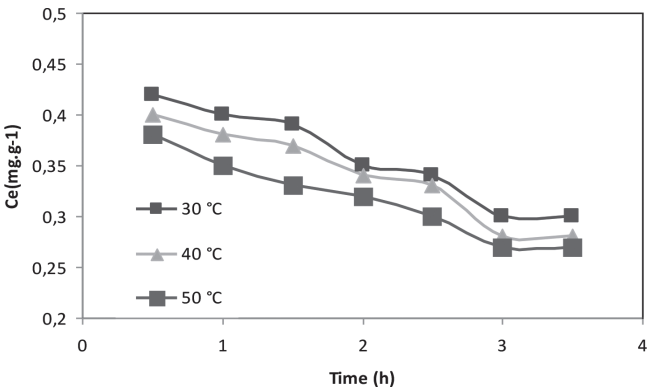


Figure 2: AZ concentration plotted versus time at different temperatures (30, 40 and 50 °C) at a clay dose of 0.1 g, C_{AZ}: 2 mg × l^{-1}, pH = 5

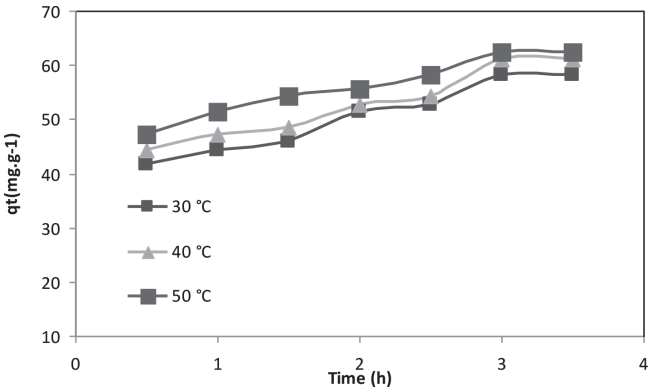


Figure 3: qt (mg × g^{-1}) plotted versus time at different temperatures (30, 40 and 50 °C) at a clay dose of 0.1 g, C_{AZ}: 2 mg × l^{-1}, pH = 5

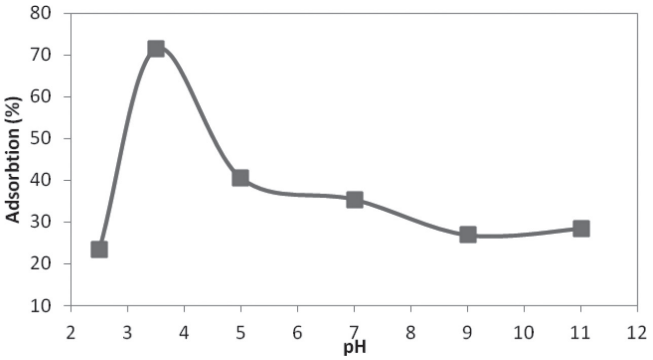


Figure 4: Effect of initial solution pH value on the adsorption of AZ on clay at clay dose of 0.1 g, C_{AZ}: 2 mg × l^{-1}, T = 40 °C

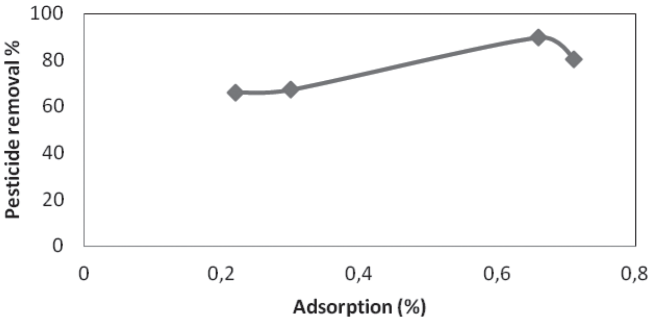


Figure 5: Effect of initial AZ concentration on the adsorption of AZ on clay at a phase contact time of 90 min

Similar negative values were found for the adsorption of endosulfan sulfate on sunflower seed shells and composted sewage sludge by de Wilde et al. [39]. This behavior may indicate that monolayer adsorption assumed in this model, which was not valid for these specific experiments. The same result was obtained by El Bakouri et al. [33] for the sorption of chlorinated pesticides onto natural organic substances, and by de Wilde et al. [39] for several of the studied pesticides on the tested organic residues.

Freundlich equation gives high correlation values for the adsorption of atrazine, alachlor, endosulfan sulfate and trifluralin by sunflower seed shells, rice husk, composted sewage sludge and soil adsorbents [40].

Adsorption dynamics. The pseudo-first-order, pseudo-second-order and intra-particle rate coefficients were calculated and given in the Figures 8 to 10 and Table 4. The values of kid were calculated from the slope of such plots and the R2 values led to the conclusion that the intra-particle diffusion is rather important in the rate limiting step. Higher values of kid illustrate an enhancement in the rate of adsorption, whereas larger kid values illustrate a better adsorption mechanism, which is related to an improved bonding between pesticide ions and the adsorbent particles (see Table 4). The process is governed by pseudo-second-order kinetic model that is supported by high correlation values.

Atrazine adsorption indicated that pseudo-first-order kinetic is important in the adsorption of sunflower seed shells, rice husk, composted sewage sludge and soil [43]. But alachlor is in good harmony for both pseudo-first-order model by the mentioned adsorbent and pseudo-second-order which also gave good values by the sunflower seed shells and rice husk. The sorption of endosulfan sulfate and trifluralin on the studied organic matrices and soil follows pseudo-second-order kinetic model [40].

Thermodynamic parameters. The plot of ln K versus 1/T was found to be linear and is shown in Figure 11. The ΔH° and ΔS° values were calculated from the slope and the intercept of the graph given in Table 5 by using the linear regression analysis. The negative value of ΔG° confirms the feasibility of the process and the spontaneous nature of adsorption with a high preference for amitraz onto clay. The value of ΔH° is positive, reflecting the endothermic adsorption reaction. The positive value of ΔS° indicates an increase in the randomness at the solid/solution interface during the adsorption process. The similar ΔH°, ΔS° and ΔG° values were found for the adsorption of oxamyl pesticide on the grapheme done by Agarval et al. [42].

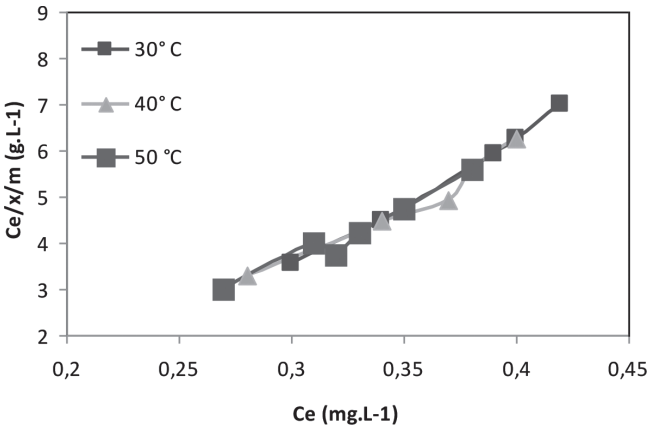


Figure 6: Linearized Langmuir isotherm for AZ adsorption on clay at different temperatures

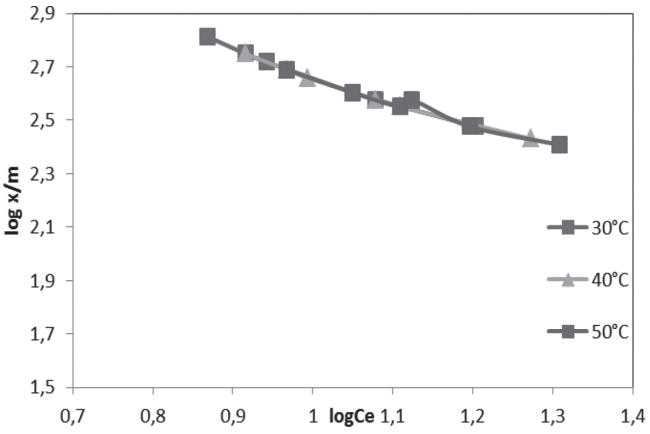


Figure 7: Linearized Freundlich isotherm at different temperatures

	Langmuir graphics			Freundlich graphics		
Temperature	XM	K	R^2	n	k	R^2
30 °CC	28.53	-5.14	0.99	1.00	3.66	0.99
40 °CC	23.47	-3.45	0.93	0.89	3.54	0.99
50 °CC	22.18	-2.99	0.93	0.72	3.38	0.87

Table 3: Langmuir and Freundlich isotherm parameters

Temperature	k_1 (min^{-1})	R^2	k_2 (g × (mg × min)$^{-1}$)	R^2	k_{id}	R^2
30 °CC	0.58	0.93	27.03	0.98	1.10	0.93
40 °CC	0.38	0.85	29.61	0.98	1.11	0.90
50 °CC	0.61	0.98	38.46	0.99	1.13	0.97

Table 4: The pseudo first order, pseudo second order and intra particle kinetic parameters

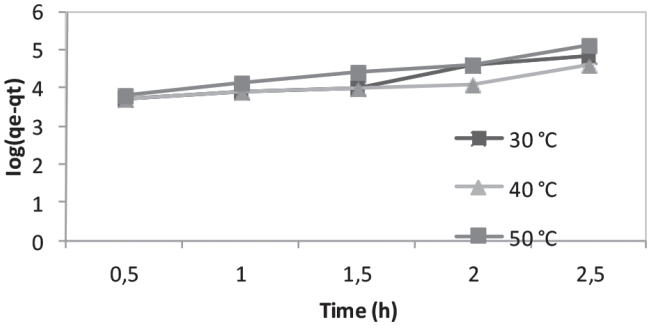


Figure 8: Pseudo-first-order kinetics for adsorption of AZ on clay

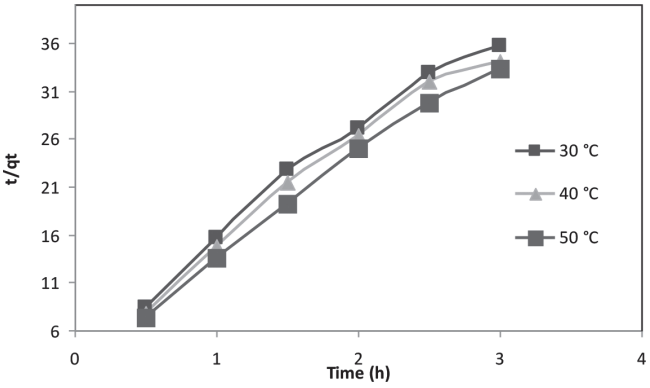


Figure 9: Pseudo-second-order kinetics for adsorption of AZ on clay

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Conclusions

Amitraz is a kind of acaricide which was extracted by a clay adsorbent. Adsorption tests were carried out as a function of phases contact time, initial solution pH value and initial pesticide concentration at fixed adsorbent dose. The adsorption process was completed in 3 hours. Removal of pesticide was almost 60 % in the first hour and at the end of the process, the yield increased to 80 %. The effect of pH value is dominant for amitraz removal. The fitness of the adsorption data to Freundlich isotherms worked well. The results show that pseudo-second-order kinetics governed the process. Intra-particle diffusion played an important role in the whole process. The Gibb's free energy value shows that this is a spontaneous type adsorption. It can be summarized by the facts that clay is ecofriendly and a low cost adsorbent which has a satisfying adsorption ability.

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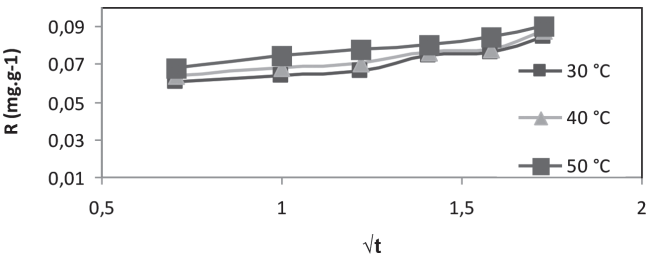


Figure 10: Intra-particle diffusion kinetics for different temperatures

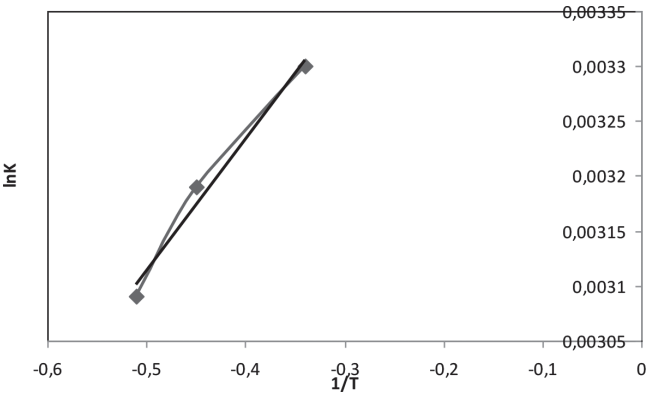


Figure 11: Plot of ln K versus 1/T for estimation of the thermodynamic parameters

Temperature	$-\Delta G°$ (J × mol^{-1})	$\Delta H°$ (J × mol^{-1})	$\Delta S°$ (J × (mol × K)$^{-1}$)
30 °C	3537.2	12.498	11.704
40 °C	3654.35		
50 °C	3771.5		

Table 5: Thermodynamic parameters

Abstract

Die Entfernung von Amitraz aus wässrigen Lösungen auf Ton mittels Absorptionstechnik im industriellen Massstab. Amitraz (AZ), das als Akarizid verwendet wird, wurde unter Verwendung eines Ton-Adsorptionsmittel extrahiert. Die experimentellen Daten wurden mittels Langmuir- und Freundlich-Isothermen modelliert. Die Adsorptionsdaten stimmen gut mit den Langmuir- und Freundlich-Isothermen überein. Die Adsorptionskapazität der Monoschicht wurde mit 28,53 mg × g^{-1} bei einer Temperatur von 30 °C ermittelt. Die Wirkung der Phasenkontaktzeit, der pH-Wert der Ausgangslösung und die Anfangspestizidkonzentration wurden anhand der Punkte des Adsorptionsgleichgewichtes und anhand der Ausbeute untersucht. Die Adsorptionskinetik wurde durch die Anwendung von pseudo-erster Ordnung, pseudo-zweiter Ordnung und zwischenmolekularer Teilchen Diffusionsgesetzen untersucht. Es stellte sich heraus, dass die Adsorption von Amitraz am besten durch das Modell der pseudo-zweiten Ordnung dargestellt werden kann. Die zwischenmolekulare Partikel-Diffusion ist ebenfalls für die Adsorptionsphänomene von Bedeutung. Es handelt sich um eine physikalische Art der Adsorption, die spontan ist. Die Pestizidentfernung durch Adsorption wurde in Industrieanlagen erfolgreich angewendet.

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