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Degradation Pathway Estimation of Pesticide Molecule by Molecular Modeling

Şimal KÜRÜMOĞLU[1], Selim ÖZGÜR[1], Yelda YALÇIN GÜRKAN[1]*

[1]*Tekirdağ Namık Kemal University, Faculty of Arts and Sciences, Department of Chemistry, 59030, Tekirdağ, Türkiye*

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ABSTRACT

Azinphos methyl (O,O-Dimethyl S-[(4-oxo-1,2,3-benzotriazin-3(4H)-yl)methyl] phosphorodithioate) is a broad spectrum organophosphate insecticide. Like other pesticides in its class, it owes its insecticidal properties to being an acetylcholinesterase inhibitor. Azinphos methyl is often used as organophosphorus pesticides such as active Guthion, Gusathion (GUS), Gusathion-M, Crysthyron, Cotnion, Cotnion-methyl, Methyltrizotion, Carfene, Bay9027, Bay17147 and R-1852. In the study, the possible reaction pathways between the Azinphos methyl molecule and the OH radical were examined theoretically. The optimized geometries of the molecule were drawn with the Gauss-View 5 program and the lowest energy states were determined using the Gaussian 09 program. By calculating the bond lengths and bond angles of the molecules, geometric structure analysis was performed. The main purpose here is to determine the most likely produced in the reaction between Azinphos methyl and OH radical in aqueous media and gaseous media. The products formed as a result of the reactions of the azinphos methyl molecule with the OH radical were determined and their geometric optimizations were carried out by semi-empirical AM1, Ab initio Hartree Fock HF/6-31G and Functional Density Theory (DFT) methods. COSMO was used as the solving model. Thanks to this method, the area where the reaction takes place between the polarizations on the surface of the molecule and the solvent is determined. Thanks to the dielectric property of water, the reaction medium is stabilized.

1. Introduction

Azinphos methyl (O,O-Dimethyl S-[(4-oxo-1,2,3-benzotriazin-3(4H)-yl)methyl] phosphorodithioate) is a broad spectrum acaric acid and mollusc acid organophosphate insecticide [1].

Azinphos suggested that methyl was directly related to the health problems of farmers. Azinfos methyl was phased out over 12 years in the USA, and its use was completely banned on September 30, 2013. Azinphos methyl has been banned in the European Union in 2006 and in Turkey since 2013 [2-4].

Azinphos methyl can enter the body through inhalation, ingestion and skin contact. Azinphos methyl is found in food residues and drinking water, albeit in small amounts. Once absorbed into the body, azinphos methyl may cause neurotoxic effects like other organophosphate insecticides. Azinphos methyl can act as an acetylcholinesterase inhibitor (AChE) in high concentrations, azinphos methyl can be toxic because it functions as an acetylcholinesterase inhibitor. But its toxicity is mostly due to cytochrome p450. In normal conditions, acetylcholine quickly and effectively lowers the neurotransmitter acetylcholine transmitting and limits its biological effect [2-4].

Azinphos methyl is very stable when dissolved in acidic, neutral or slightly alkaline water. However, in an environment above pH 11, it is rapidly hydrolyzed to anthranilic acid, benzamide and other chemicals. Microorganisms in the natural aquatic environment and sunlight can be used to show a faster degradation of azinphos-methyl. In this way, the half-life can be shortened from a few months to a few days. There are major routes of biodegradation and evaporation under normal conditions. Evaporated Azinphos methyl is exposed to excess UV light and undergoes photodecomposition. If not exposed to bioactivity and UV light, it reaches a half-life of 1 year [2-4].

Azinphos-methyl (AZM) and chlorpyrifos (CPF) are broad-spectrum organophosphate pesticides used for pest control in many parts of the world and have been shown to inhibit cholinesterase activity in the non-target freshwater gastropod Planorbarius corneus. This study was carried out to determine whether AZM and CPF cause oxidative stress in P. corneus and whether pesticides act together more than they do alone, causing increased oxidative stress. For this purpose, non-enzymatic and enzymatic parameters were measured in snail soft tissues acutely exposed to insecticides by single chemical and binary mixed studies. In conclusion, the data shown in this study prove that AZM, CPF and a mixture of both organophosphates cause oxidative stress and oxidative damage in P. corneus tissues [5-7].

An agricultural community of farm workers was investigated for changes induced by exposure to agricultural pesticides. A seasonally persistent correlation was found between the detected blood concentration of the insecticide azinphos-methyl and the taxonomic composition of the cheek oral microbiome. In this study, we show in human subjects that exposure to organic phosphate pesticides is associated

[1] *Tekirdağ Namik Kemal University, Faculty of Arts and Sciences, Department of Chemistry, 59030, Suleymanpasa-Tekirdağ, Türkiye*
E-mail address: yygurkan@nku.edu.tr

with large-scale significant changes in the intraoral buccal microbiota composition, with the extinction of all taxa in some individuals. The continuation of this association from spring/summer to winter also indicates that long-term effects on the common microbiota occur. The significant health implications of pesticide-associated microbiological disruptions to these agricultural community members are currently not understood. Future research should index medical and dental records for common and chronic diseases that may be affected by this association between pesticide exposure and microbial change [8-9].

Azinphos-methyl and chlorpyrifos are organophosphorus pesticides that pose a serious threat to the environment, including their harmful effects on humans, and therefore must be removed from the environment. Therefore, in this study, an ultrasound technique was applied for the removal of the above-mentioned hazardous compounds. For this, the effect of influential parameters such as pH, initial pesticide concentration, frequency, electric power and treatment time on the ultrasound degradation of azinphos-methyl and chlorpyrifos was well investigated and clarified. The obtained results showed that azinphos-methyl and chlorpyrifos were degraded effectively and rapidly by ultrasound technique. Two multiple regression-based equations were derived to describe the degradation process of pesticides by ultrasound. The result of this study showed that the polynomial equations satisfactorily describe the behaviour of the present process for various operating conditions [1-10].

The removal of the organophosphorus insecticide azinphos-methyl (AZM) from the water was investigated by the electro-Fenton method, which produces hydroxyl radicals electrocatalytically. The reaction between these radicals and AZM led to the oxidation of carbon dioxide and inorganic ions of AZM, demonstrating complete dissociation from water. It contains aromatic derivatives such as short-chain carboxylic acids and inorganic ions as end products. The identification and quantification of these intermediates have been thoroughly investigated by HPLC, GC-MS and ion chromatography analyses. Based on the identified intermediates, a general oxidation mechanism was proposed. The mineralization ability of the process was also tested using aqueous AZM solutions and its commercial formulation Gusathion M WP 25 (GMWP25) [11].

2. Materials and Methods

Gaussian 09W program was used in our studies. Gauss 09 program is the latest version of the Gauss series programs. The program we have used allows us to use state-of-the-art features in electronic structure modelling. The Gaussian 09W program is very comprehensive. We can use Ab initio, semi-experimental and molecular mechanics methods in the program. There are many basic sets and theoretical methods among the Ab initio, semi-experimental and molecular mechanics methods we have used.

Calculations can be made with the Gaussian 09W package program; Ideal geometric optimizations of atoms and molecules can be made. The vibrational frequencies that depend on the energies of the atoms can be calculated. The energies of atoms and molecules can be calculated. Force constants and dipole moments of atoms and molecules can be calculated. From the results obtained from the calculated IR and Raman spectra of atoms and molecules; Information about many specific properties of atoms and molecules such as electron affinities, ionization energies, NMR, magnetic susceptibility, vibrational intensities, atomic charges, molecular orbitals, reaction energies and thermochemical properties can be obtained. In addition, the stability of the molecular wave function can be examined with the help of the program. The Gaussian 09W program circulates through potential energy levels, showing the transition states and the pathways the reaction will take. These calculations can be done in crystal, solution and gaseous states of molecules [12-13].

The Gauss view 5.0.8 program is a program that we can calculate and transfer the molecules and atoms to the computer environment and prepare the input files [14]. Thanks to the program, he can visualize the molecules that we will calculate. We can ensure that the molecules are ideally positioned [15-16]. It also allows us to make the necessary rotations and positionings to optimize molecules. It presents the results of the molecules to us with certain graphical methods [16-17].

The results we achieved thanks to the program; Normal mode animations based on vibration frequencies, VCD spectra, NMR spectra, Raman spectra, Atomic charges, Electrostatic potential surfaces, molecular orbitals, and optimized molecular structures [18].

3. Results and Discussion

In the calculations, the molecular calculations of Azinphos methyl and OH radical, which are in the reactant position, were made by Ab initio Hartree-Fock HF/6-31G(d) and DFT, semi-empirical AM1 methods and they were geometrically optimized. The electronic properties of the optimized molecules were determined.

The conformation states with the lowest energy, that is, the most stable, were determined for each reactant. The Gaussview5 program was used to draw the organic molecules, which are the most stable in conformation.

In the search for a plausible mechanism for the photocatalytic decolourization /degradation reaction of Azin1, DFT Reactivity indices were employed to have information about the most susceptible sites for hydroxyl radical attack. Then the highest values were used to calculate the local softnesses. The calculated local soft-ness s^0 and Fukui functions f^0 are presented in Table 1, Fig. 1 shows the optimized structure of the Azin1 molecule and the numbering system that was used throughout the calculations.

Two main competing reaction pathways shown in Fig. 2 were determined by selecting the specific sites of the Azin1 molecule, based on their softness values being close to that of the •OH radical. These two possible pathways are named the cleavage of the sulfur bond and the cleavage of the C-S bond.

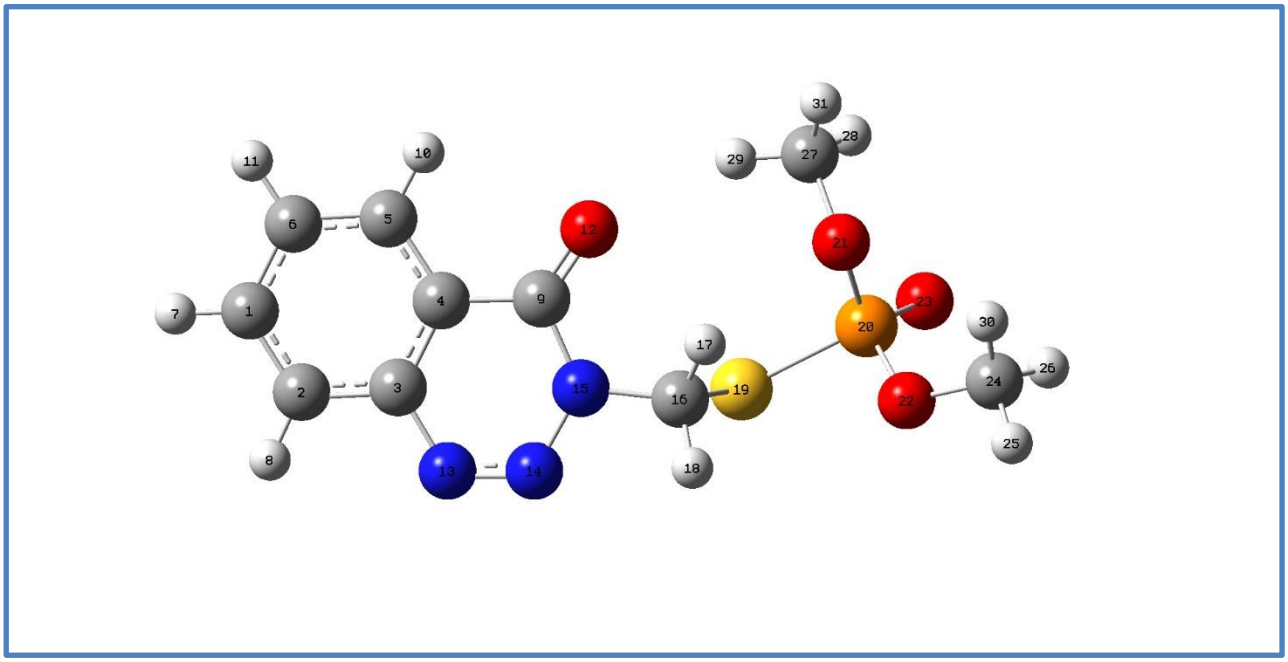


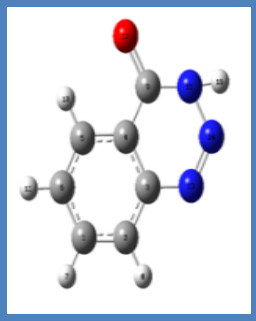
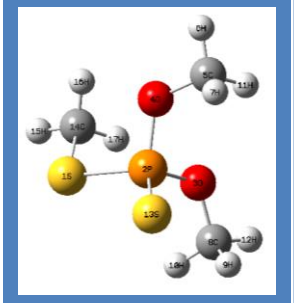
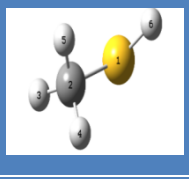
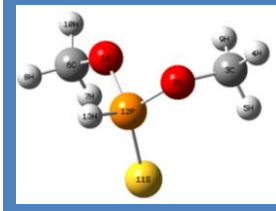
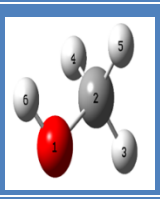
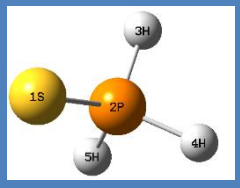
Fig. 1 Optimized structure of Azin1 and the numbering system (grey, carbon; red, oxygen; blue, nitrogen; white, hydrogen; yellow, sulfur; orange, phosphorus).

Table 1. Chemical Reactivity Descriptors for Azin1 and the •OH radical. Azin1 (S=6.30456).

Molecules	f^0	s^0	Δs^0
C 16	0.00725	0.05589	3.55623
N 13	0.00685	0.05245	4.36256
N 14	0.07196	0.58780	4.25348
N 15	0.06232	0.48124	4.12590
P 20	0.00645	0.05378	3.99210
S 19	0,00911	0.07055	3.34228
S 32	0.00802	0.06464	3.94908
•OH Radical (S=5.70523)			

The bond angles and bond lengths are given (Table 2). In energy, enthalpy and gibbs free energy values are given. Thefragment with the lowest energy is the most striking (Table 3).

Table 2. Components of Azinphos Methyl molecule.

		Bond Lengths (A°)	DFT	Bond Angles (°)	DFT
	**F1**	O12-C9	1.22	O12-C9-N15	121.37
		N14-N15	1.36	C9-N15-H16	117.49
		N13-N14	1.27	C9-N15-N14	129.01
		N15-H16	1.01	N15-N14-N13	118.94
		O12-C9	1.22		
		N14-N15	1.36		
		N13-N14	1.27		
		N15-H16	1.01		
	**F2**	S1-C14	1.84	C8-O3-P2	120.24
		S1-P2	2.09	O3-P2-O4	98.57
		P2-O3	1.93	O3-P2-S1	106.76
		P2-O4	1.62	O3-P2-13S	116.02
		P2-S13	1.94	13S-P2-O4	118.72
		O4-C5	1.44	S1-P2-13S	113.33
		O3-C8	1.44	P2-S1-C14	101.51
				P2-O4-C5	119.46
	**F3**	C2-S1	1.84	H6-S1-C2	96.92
		S1-H6	1.35		
	**F4**	H13-P12	1.40	H13-P12-O2	97.05
		O2-P12	1.61	O1-P12-O2	100.64
		O1-P12	1.63	11S-P12-O2	119.11
		11S-P12	1.94	H13-P12-11S	116.07
		O2-C3	1.44	C3-O2-P12	120.15
		O1-C6	1.44	C3-O2-P12	122.20
	**F5**	C2-O1	1.42	C2-O1-H6	107.67
		H6-O1	0.97		
	**F6**	H5-P2	1.42	S1-P2-H5	118.09
		H3-P2	1.42	S1-P2-H3	118.09
		H4-P2	1.42	S1-P2-H4	118.09
		S1-P2	1.96	H3-P2-H4	99.63
				H3-P2-H5	99.63

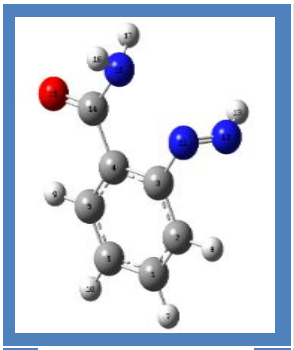
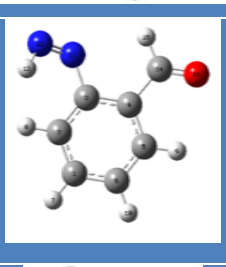
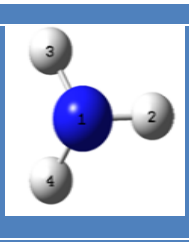
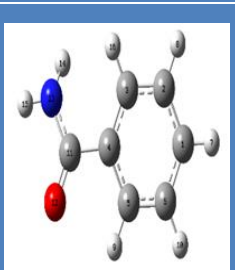
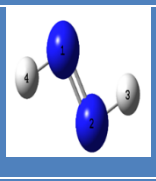
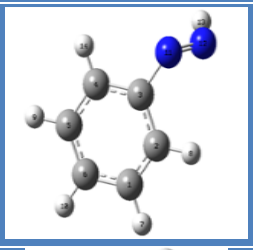
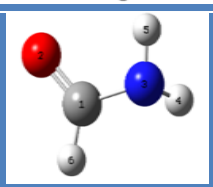
	**F7**	N12-H13	1.05	H13-N12-N11	111,14
		N12-N11	1.25	N12-N11-C3	120,88
		N11-C3	1.43	C4-C14-O15	119.75
		O15-C14	1.23	O15-C14-N16	122.53
		N16-C14	1.36	C14-N16-H17	117.13
		N16-H17	1.01	C14-N16-H18	121.58
		H16-H18	1.01	H17-N16-H18	121.28
	**F8**	O15-C14	1.22	C4-C14-O15	122.86
		C3-N11	1.43	H16-C14-O15	121.40
		N11-N12	1.25	C3-N11-N12	120.00
		N12-H13	1.05	N11-N12-H13	111.38
	**F9**	H3-N1	1.02	H3-N1-H2	105.76
		H4-N1	1.02	H3-N1-H4	105.71
		H2-N1	1.02	H4-N1-H2	105.76
	**F10**	N13-H14	1.00	H14-N13-C11	119.98
		N13-H15	1.01	H15-N13-C11	114.84
		N13-C11	1.38	H14-N13-H15	116.13
		C11-O38	1.22	N13-C11-O12	121.62
				O12-C11-C4	122.10
				N13-C11-C4	116.27
	**F11**	H4-N11	1.04	H4-N1-N2	106.1
		N1-N2	1.25	N1-N2-H3	106.1
		N2-H3	1.04		
	**F12**	H13-N12	1.05	H13-N12-N11	111.48
		N12-N11	1.25	N12-N11-C3	120.23
		N11-C3	1.43	C2-C3-N11	123.31
	**F13**	H4-N3	1.00	H4-N3-H5	119.00
		H5-N3	1.01	H5-N3-C1	119.18
		N3-C1	1.36	H4-N3-C1	121.81
				N3-C1-O2	125.00

Table 3. Energy-Enthalpy-Gibbs Free Energy Results of Compounds.

Compounds	Energy (kcal/mol)	Enthalpy (kcal/mol)	Thermal Free Energy (kcal/mol)
Azin1 **gas phase** **(water phase)**	-1202132.925 *(-1202142.072)*	-1202176.523 *(-1202141.479)*	-1202132.333 *(-1202186.307)*
F1 **gas phase** **(water phase)**	-319450.270 *(-319456.640)*	-319449.670 *(-319456.050)*	-319475.390 *(-319481,760)*
F2 **gas phase** **(water phase)**	-883425.612 *(-883431.629)*	-883425.020 *(-883431.037)*	-883457.478 *(-883464.028)*
F3 **gas phase** **(water phase)**	-275255.780 *(-275258.270)*	-275255.190 *(-275257.680)*	-275273.230 *(-275275.750)*
F4 **gas phase** **(water phase)**	-608896.889 *(-608929.183)*	-608896.296 *(-608901.645)*	-608923.786 *(-608902.238)*
F5 **gas phase** **(water phase)**	-72577.470 *(-72580.670)*	-72576.870 *(-72580.080)*	-72593.790 *(-72597.010)*
F6 **gas phase** **(water phase)**	-465172.559 *(-465179.860)*	-465171.967 *(-465196.909)*	-465189.557 *(-465179.267)*
F7 **gas phase** **(water phase)**	-320185.650 *(-320192.990)*	-320185.060 *(-320192.390)*	-320213.350 *(-320220.790)*
F8 **gas phase** **(water phase)**	-285443.770 *(-285449.970)*	-285443.180 *(-285449.380)*	-285469.860 *(-285476.090)*
F9 **gas phase** **(water phase)**	-35460.880 *(-35464.740)*	-35460.290 *(-35464.150)*	-35473.990 *(-35477.850)*
F10 **gas phase** **(water phase)**	-251515.340 *(-251522.090)*	-251514.750 *(-251521.500)*	-251540.220 *(-251547.140)*
F11 **gas phase** **(water phase)**	-69406.400 *(-69409.100)*	-69405.810 *(-69408.510)*	-69421.350 *(-69424.050)*
F12 **gas phase** **(water phase)**	-214341.250 *(-214345.970)*	-214340.660 *(-214345.370)*	-214364.300 *(-214369.070)*
F13 **gas phase** **(water phase)**	-106575.870 *(-106582.370)*	-106575.270 *(-106581.780)*	-106594.240 *(-106600.220)*

4. Conclusion

As a result, the decomposition reaction requires energy. OH radicals are used to cleave the Azinphos Methyl molecule. As seen in our trailers, Azinfos Methyl, which is harmful, has been decomposed up to F13 and has become harmless to the environment. We aimed to break Azinfos Methyl into the smallest harmless substances. As can be seen from the results, this fragmentation occurred theoretically. In the computational part of the study, the most reactive sites of the Azin1 molecule for hydroxyl radical attack were determined by the application of the Conceptual Density Functional Theory. The predicted mechanism indicated that the N-N bond cleavage mechanism is a more preferable pathway over the C -S bond cleavage.

Declaration

Author Contribution: Conceive- S.Ö, Ş.K., Y.Y.G.; Design- S.Ö, Ş.K., Y.Y.G.; Supervision- S.Ö, Ş.K., Y.Y.G.; Experimental Performance, Data Collection and/or Processing S.Ö., Ş.K.; Analysis and/or Interpretation S.Ö.; Literature Review- Y.Y.G.; Writer- S.Ö, Ş.K., Y.Y.G.; Critical Reviews – Y.Y.G.

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Orcid ID

Şimal Kürümoğlu https://orcid.org/0000-0001-9456-5456
Yelda Yalçın Gürkan https://orcid.org/0000-0002-6316-5510

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