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Kinetic study by UV Spectrophotometry of Carzol degradation in aqueous medium

Hayet Bakhti * and Najib Ben Hamida

Laboratory of Analytical Chemistry and Electrochemistry,Department of Chemistry, University Al Manar,Faculty of Sciences of Tunis, 2092 El Manar, Tunis, Tunisia

Abstract: This paper deals with the kinetic hydrolysis in aqueous media of Carzol or (E) 3-dimethylamino-methylene aminophenyl-N-methylcarbamate hydrochloride. The Carzol is a bifunctional compound which belongs to the chemical families formamidine and carbamate. This work is carried out by UV Spectrophotometry. The successive determination of 3-aminophenyl-N-methylcarbamate and 3-aminophenol, as the main products of the formamidine and the carbamate groups of Carzol hydrolysis gives evidence for the significant reactivity of this insecticide-acaricide in aqueous media. The obtained negative activation entropy $\Delta S^{\neq}$ = - 32.39 J $mol^{-1}K^{-1}$ indicates a $B_{AC}2$ mechanism involving bimolecular collapse of the formamidine group of Carzol. While, the obtained positive activation entropy $\Delta S^{\neq}$ = +100.24J mol^{-1} $K^{-1}$and the absence of basic general catalysis indicate an E1cB mechanism involving unimolecular collapse of the carbamate group of Carzol via a methylisocyanate intermediate.

Keywords: Carzol; formamidine; carbamate; kinetic; mechanism; spectrophotometric UV.

Introduction

Carzol or (E) 3-dimethylaminomethyleneaminophenyl-N-methylcarbamate hydro-chloride is a bifunctional compound which belongs to the chemical families: formamidine and carbamate. Carzol is considered as an effective acaricide-insecticide, used for the treatment of citrus[1-3] (grapefruit, lemon, lime, orange), seeds, and some fruits (apples, pears, nectarines and peaches)[4-6]. Carzolacts by inhibition of the enzyme acetylcholinesterase[7-9], as all carbamate insecticidesdo, and inhibition of octopamine[10-13] as all formamidine acaricides. According to the literature, it appears that carbamates which do not have a mobile proton in α position relative to the carbonyl, hydrolyze in aqueous media following two reaction schemes $B_{AC}2$ or E1cB[14]. Christopher B. Divito and al., showed by ^{1}HNMR spectroscopy and ^{13}C NMR spectroscopy, that the carbamate function of Carzol is more stable in alkaline medium that the formamidine function[15]. The kinetic study of the hydrolysis reaction of Carzol in aqueous medium is carried out by UV absorption Spectrophotometry.

*Corresponding author: Hayet Bakhti
E-mail address: bakhti.hayet@yahoo.com
DOI: http://dx.doi.org/

Results and Discussion

Kinetics and mechanism of the alkaline hydrolysis of the formamidine group of Carzol

Determination of 3-aminophenyl-N-methylcarbamate obtained at the end of the hydrolysis reaction of the formamidine group of Carzol in aqueous medium

The determination of 3-aminophenyl-N-methylcarbamateformed during the hydrolysis of the formamidine function of Carzol at *pH* = 9.64, at *T* = 25°C, and at μ = 1M was confirmed by the good superposition of the UV absorption spectrum of the species produced (spectrum b) with that of a reference (spectrum c) obtained under the same experimental conditions (Figure1).

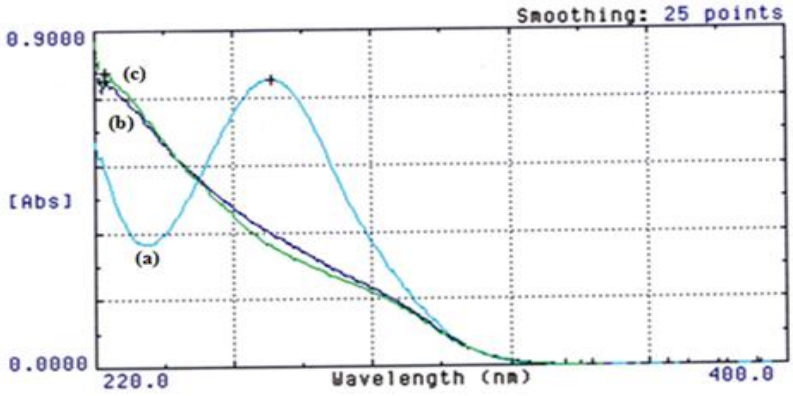


Figure 1. UV absorption spectra of 3-aminophenyl-N-methylcarbamate (c), of the hydrolysis product of Carzol (b) and of Carzol (a) (5×10^{-5} M). [Carzol] = [3-aminophenyl] = 5×10^{-5}M; at *pH* = 9.64, *T* = 25°C, and μ = 1M.

Determination of the rate constant k_{obs} of the hydrolysis reaction of the formamidine function of Carzol

The UV spectra show an isosbestic point at 251nm, indicating that there is no accumulation of intermediates and the constant rate of hydrolysis of the formamidine group of Carzol followed the pseudo-first order kinetics model (Figure2).

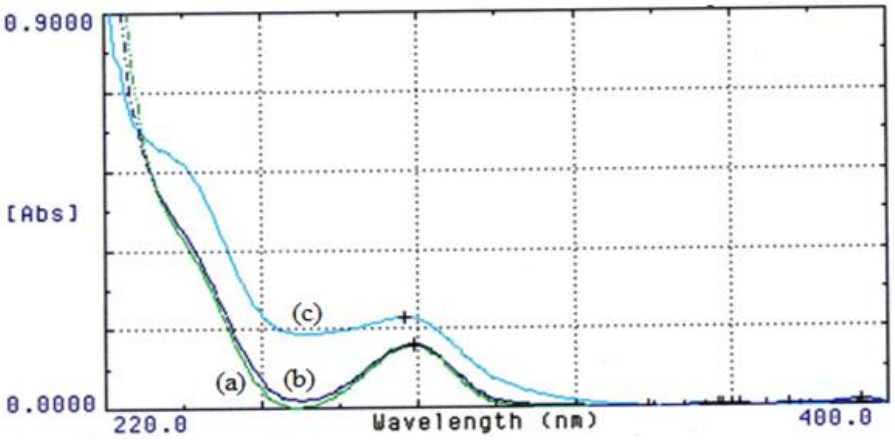


Figure 2. UV spectra of the hydrolysis reaction of the formamidine group of Carzol (5×10^{-5}M) in function of time; in alkaline solution at *pH* = 9.64, *T* = 25°Cand μ = 1M.

The absorption evolution of Carzol solution contained in a thermo regulated tank, corresponds to the disappearance of the substrate (λ = 267 nm) or the appearance of 3-aminophenyl-N-methylcarbamate (λ = 235 nm) in function of time (Figure3).

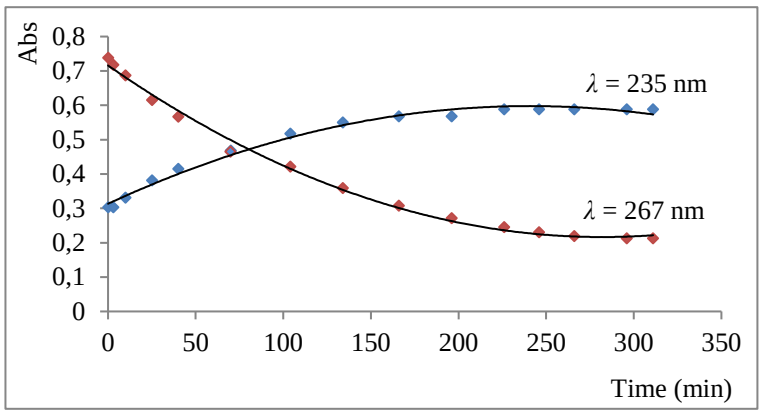
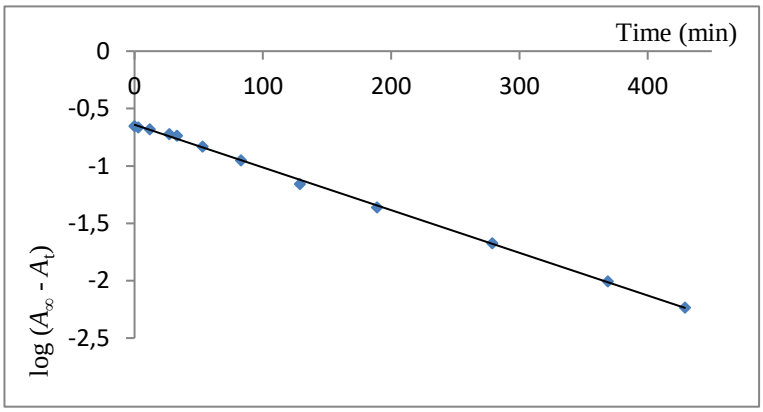


Figure 3. Absorption evolution in function of time at wavelengths 235 nm and 267 nm.

The rate constant k_{obs}= 0.73×10^{-2} min^{-1} was determined graphically from the slope of the following linear equation:

$$\log(A_\infty - A_t) = -\frac{k_{obs}}{2.303}t + \log(A_\infty - A_0) \qquad \text{Eq. (1)}$$

where A_0, A_∞ and A_t represent respectively the initial absorptions, final and at time *t*of the reaction mixture (Figure4).



Fifure4. Determination of the observed rate constant k_{obs} of the hydrolysis reaction of the formamidine group of Carzol at λ = 235 nm in a buffer solution of sodium bicarbonate at *pH* = 9.64, *T* = 25°C and μ = 1M.

Effect of pH on the rate constant of the hydrolysis reaction of the formamidine function of Carzol

The rate constants of pseudo first-order hydrolysis reaction of the formamidine function of Carzol in aqueous medium were determined at 235nm in buffered solutions at different *pH* values (from 8.16 to 11.75); by measuring the evolution of UV absorption of (E)-3-dimethylaminomethyleneaminophenyl-N-methylcarbamate versus time at 25°C and at a constant ionic strength μ = 1M (Figure5).

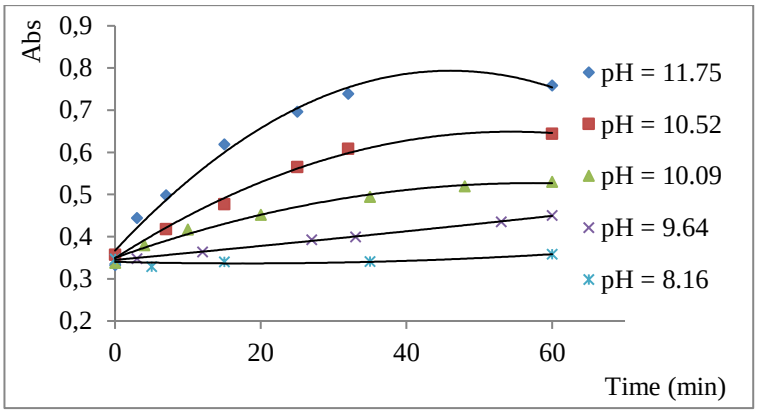


Figure 5. Effect of *pH* on the rate constant k_{obs} of the hydrolysis reaction of Carzol (5×10^{-5}M) at 25°C and μ = 1M.

The obtained results are shown in Table1:

Table 1: Rate constants k_{obs} of pseudo first-order hydrolysis reaction of the formamidine function of Carzol versus *pH* at 25°C and at ionic strength μ = 1M.

pH	8.16	9.64	10.09	0.52	11.75
$\boldsymbol{k_{obs}.10^2}$ **(min^{-1})**	0.02	0.73	2.07	5.79	55.46

The graphic representation of the logarithm of the observed rate constant k_{obs} of the hydrolysis reaction of the formamidine function of Carzol versus *pH* at 25°C, is a straight line which is represented by the following equation:

$$\text{Log } k_{obs} = 0.993\ pH - 11.78 \qquad \text{Eq. (2)}$$

with a regression coefficient R^2 = 0.992 (Figure6).

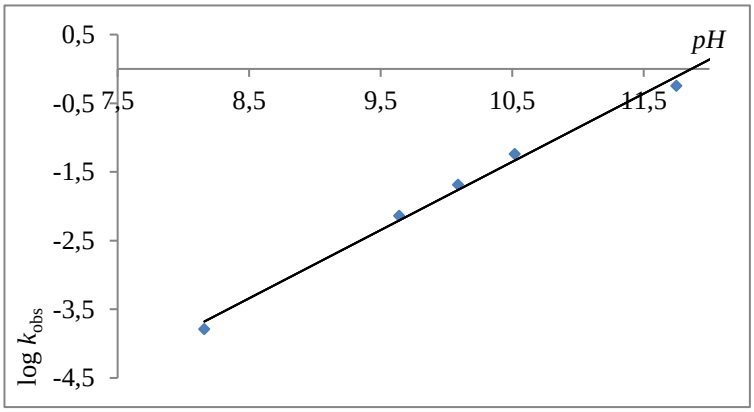


Figure 6. Logarithmic variation of the observed rate constant of the hydrolysis reaction of the formamidine function of Carzol versus *pH* at 25°C and at ionic strength μ = 1M.

The obtained slope of the line is close to the unity, so it is in perfect agreement with the limiting form of the rate law:

$$k_{obs} = k_2\ [OH^-] \qquad \text{Eq. (3) corresponding to the } B_{AC}2 \text{ mechanism.}$$

Determination of the activation entropy $\Delta S^{\neq}$ of the hydrolysis reaction of the formamidine function of Carzol

Generally, the thermodynamic parameters of activation may be an argument in favor of one or the other mechanism, $B_{AC}2$ or E1cB.

We therefore investigated the influence of temperature on the rate constants of the hydrolysis reaction of the formamidine function of Carzol in a phosphate buffer solution at *pH* = 10.9 and at ionic strength μ = 1M to determine its activation entropy $\Delta S^{\neq}$.

The experimental rate constants k_{obs} measured at different temperatures are reported in Table 2 and Figure7.

Table 2. The rate constants of the first hydrolysis reaction of Carzol versus the temperature at *pH* = 10.9 and at ionic strength μ = 1 M.

Température (°C)	20	25	35	40	45
$k_{obs}.10^2 min^{-1}$	6.08	11.05	29.24	40.27	63.24

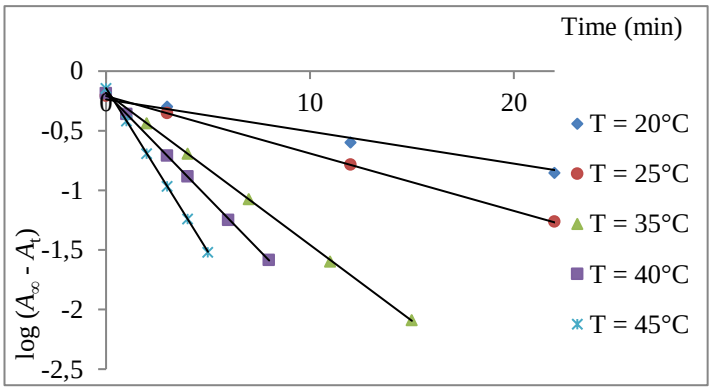


Figure 7. Effect of the temperature on the rate constants k_{obs} for the hydrolysis reaction of the formamidine function of Carzol.

The value of the activation entropy $\Delta S^{\neq}$ = - 32.39 J $mol^{-1}K^{-1}$ is derived from that of the activation energy E_a = 71.13 kJ mol^{-1}, calculated from the slope of the linear equation

$$\log k_{obs} = -3.720 \frac{10^3}{T} + 11.49, \qquad \text{Eq. (4)}$$

with a regression coefficient R^2 = 0.997(Figure8).

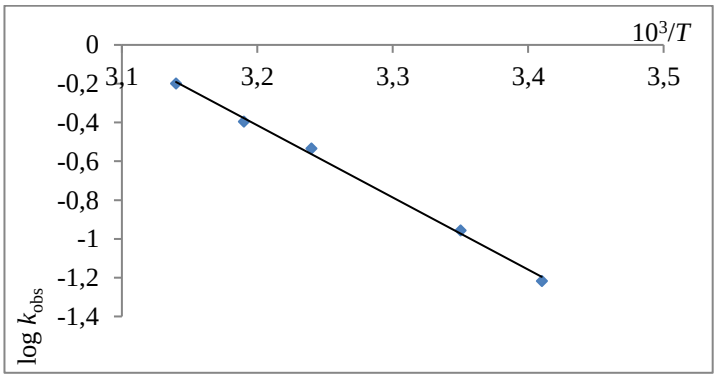
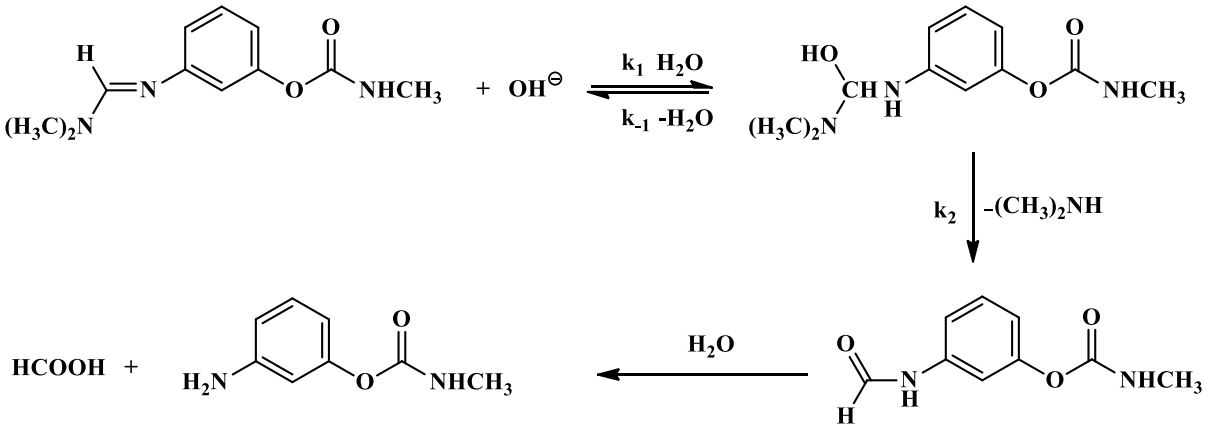


Figure 8. Logarithmic variation of the observed rate constant k_{obs} of the hydrolysis reaction of the formamidine function of Carzol versus the temperature at *pH* = 10.9 and at μ = 1M.

The variation of the activation entropy of the hydrolysis reaction of the formamidine function of Carzol has a negative sign, which is in perfect agreement with the bimolecular addition mechanism $B_{AC}2$.

Indeed, According to the data in the literature, it appears that $B_{AC}2$ mechanism occurs by the addition of OH^- ion on the carbon of the formamidine function, lead to a tetrahedral intermediate[16]. The proposed $B_{AC}2$ mechanism for the hydrolysis reaction of the formamidine function of Carzol is presented in the following scheme 1.



Scheme1. $B_{AC}2$ Hydrolysis mechanism of the formamidine function of Carzol.

The hydrolysis of the formamidine function of Carzol in basic medium leads to the formation of (E)-3-dimethylaminohydroxymethylaminophenyl-N-methylcarbamate. This adduct is converted to dimethylamine and m-formamidophenyl-N-methylcarbamatewhich decomposes to turn to give 3-aminophenyl-N-methylcarbamate and formic acid.

Kinetics and mechanism of the alkaline hydrolysis of the carbamate function of Carzol

Determination of 3-aminophenol obtained at the end of the hydrolysis reaction of the carbamate group of Carzol in aqueous medium

The determination of 3-aminophenolformed during the hydrolysis of the carbamate function of Carzol was confirmed by the good superposition of the UV absorption spectrum of the species produced (spectrum b) with that of a reference (spectrum c) (Figure 9).

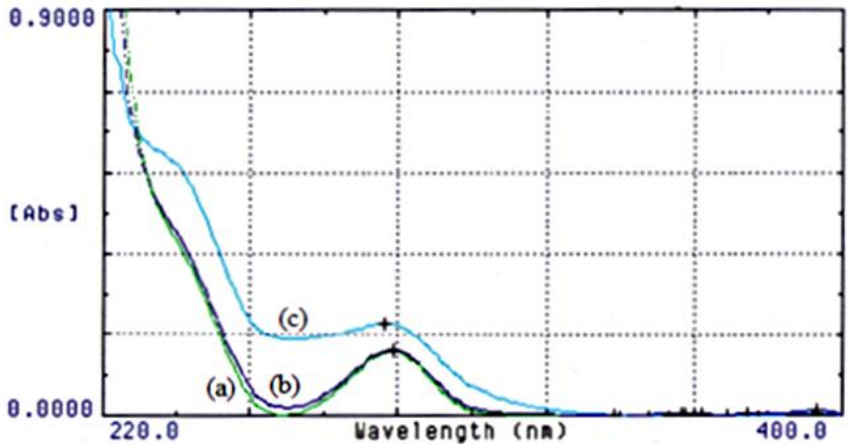


Figure 9. UV absorption spectra: of the product (c) (5×10^{-5}M), of 3-aminophenol (b) and of the hydrolysis products (a) in solution at *pH* = 12.4, *T*= 50°C and μ = 1 M.

UV spectra in Figure-10 have been stored in a phosphate buffer solution at *pH* = 12.4, at ionic strength μ = 1M and at temperature *T* = 50°C. They show that the Carzol (spectrum a) is hydrolyzed quantitatively in 3-aminophenol and methylamine.

Determination of the rate constant k_{obs} of the hydrolysis reaction of the carbamate function of Carzol

UV spectra recorded in function of time in phosphate buffer solution at *pH* = 12.4, at a temperature *T* = 50°C and at an ionic strength μ = 1M exhibit an isosbestic point at λ = 230 nm. This indicates that there is no intermediate accumulation and the rate constant for the alkaline hydrolysis of the carbamate function of Carzol is pseudo-first order (Figure10).

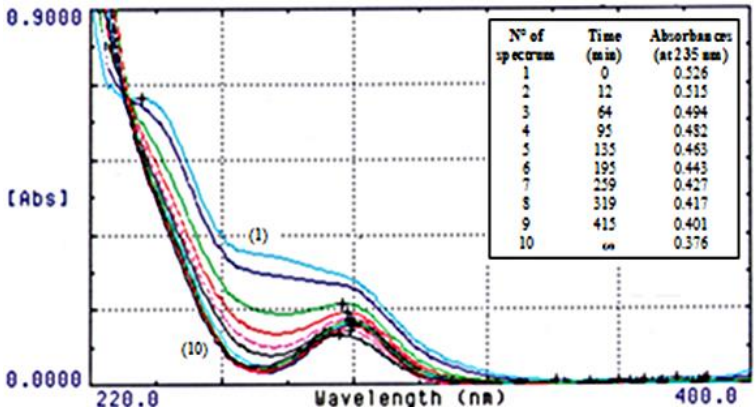


Figure 10. UV spectra in function of time of the hydrolysis reaction of the carbamate function of Carzol (5×10^{-5}M) in phosphate buffer at *pH* = 12.4, at *T*= 50°C, and at μ = 1M.

The absorption evolution of the Carzol solution contained in a thermostated tank corresponds to the appearance of 3-aminophenol in function of time (Figure11).

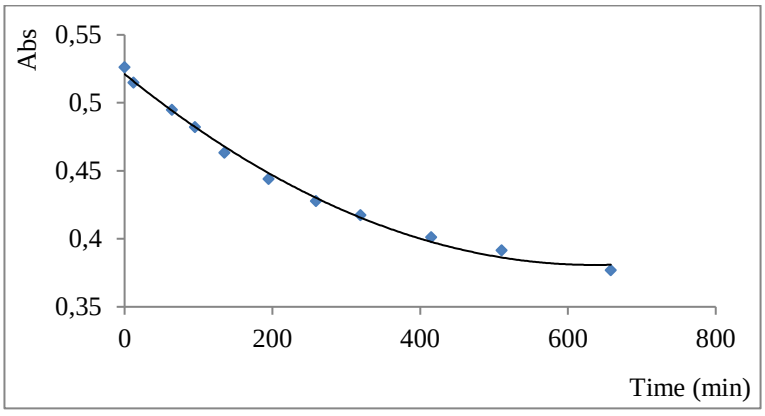


Figure 11. Absorption Variation of Carzol by UV spectrophotometry in function of time at λ = 235nm, *pH*= 12.4, μ = 1M and at 50°C.

The rate constant k_{obs} = 0.23×10^{-2} min^{-1} was determined graphically from the slope of the linear equation:

$$\log (A_\infty - A_t) = -\frac{k_{obs}}{2.3} t + \log(A_\infty - A_0) \qquad \text{Eq. (5)}$$

where A_0, A_∞ and A_t are respectively the initial absorption, the final and absorption at time *t* of the reaction mixture (Figure12).

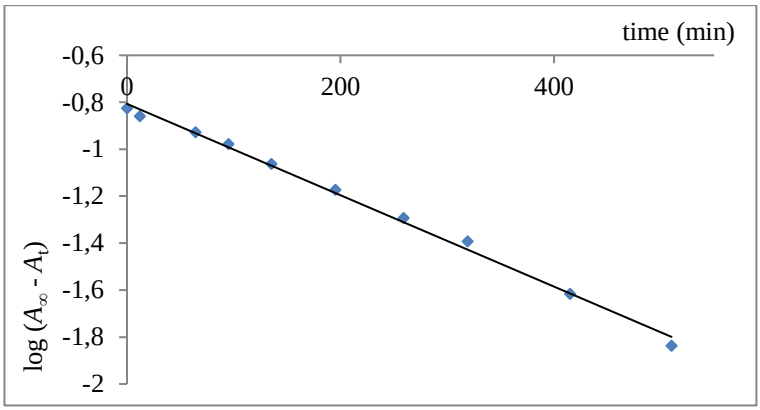


Figure 12. Determination of the observed rate constant k_{obs} of the hydrolysis reaction of the carbamate function of Carzol.

Effect of pH on the rate constant of the hydrolysis reaction of the carbamate function of Carzol

The rate constants for the pseudo-first order of the hydrolysis reaction of the carbamate function of Carzol in aqueous medium at 50°C and for an ionic strength μ = 1M were determined in buffered solutions at different *pH* (from 11.93 to 13.7) (Figure13).

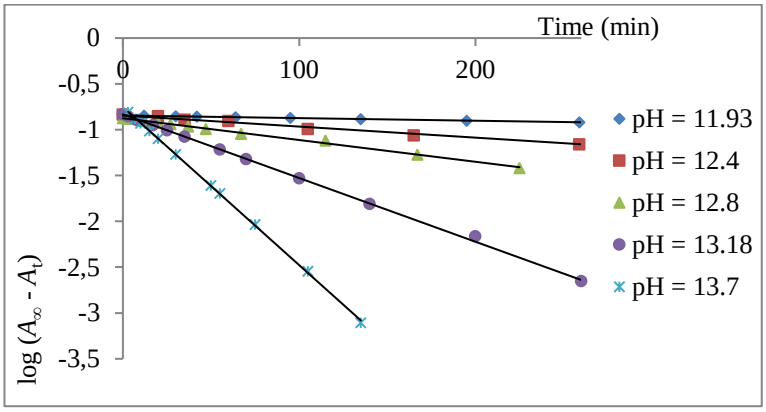


Figure 13. Effect of *pH* on the rate constants k_{obs} of the hydrolysis reaction of the carbamate function of Carzol (5×10^{-5}M) at 50°C and μ = 1M.

The experimental results are shown in Table3:

Table 3. The rate constants k_{obs} of pseudo-first order hydrolysis reaction of the carbamate function of Carzol versus *pH* at 50°C and at ionic strength μ = 1M.

pH	11.93	12.4	12.8	13.18	13.7
$\boldsymbol{k_{obs}.10^2 min^{-1}}$	0.073	0.230	0.461	1.610	4.018

The graph of the logarithmic variation of the observed rate constant k_{obs} of the hydrolysis reaction of the carbamate function of Carzol in function of *pH* at 50°C, is a straight line which represented by the following equation: log k_{obs} = 0.999 *pH* – 15.06 Eq. (6) with a regression coefficient R^2 = 0.992 (Figure14).

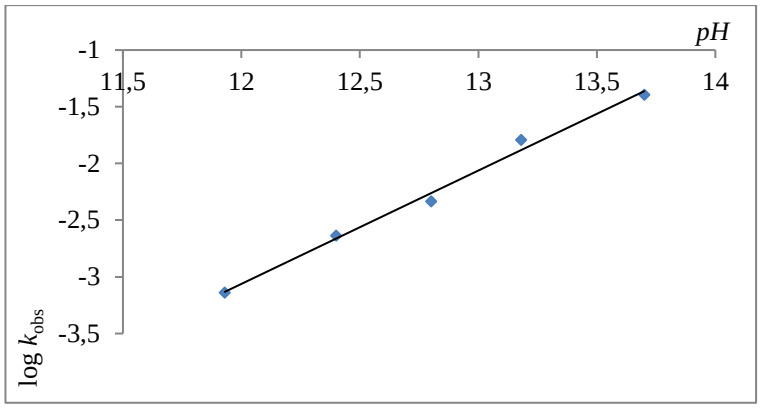


Figure 14. Logarithmic variation of the observed rate constant for the hydrolysis reaction of the carbamate function of Carzol versus *pH* at 50°C and at ionic strength μ = 1M.

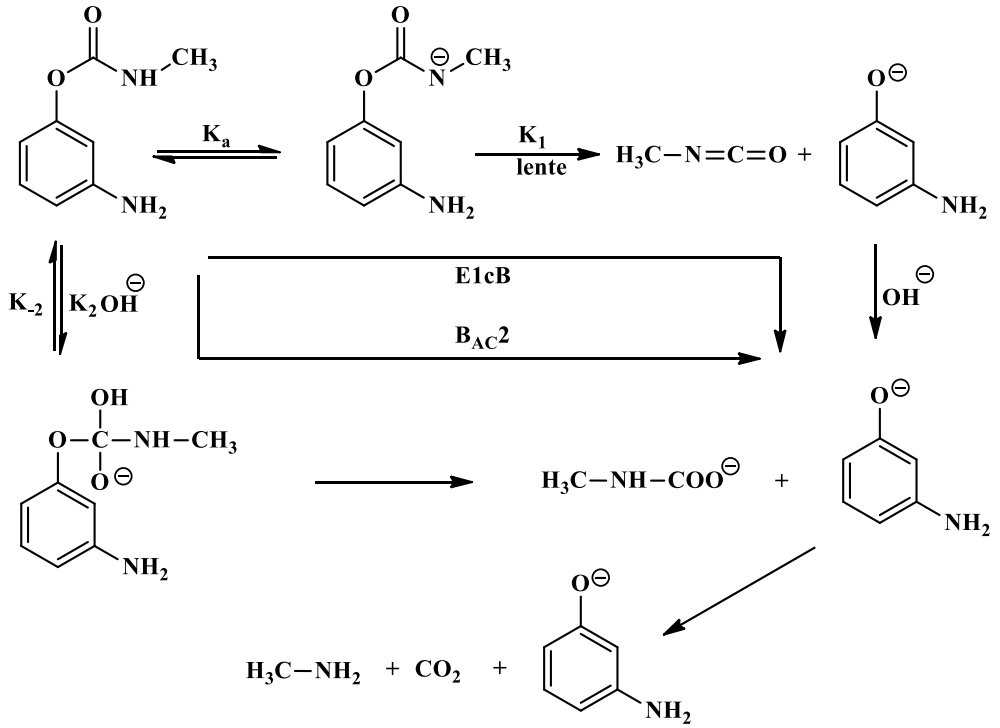
The value of the slope of this line is almost equal to unity. This is in perfect accordance with the limiting forms of the rate laws:

$$k_{\text{obs}} = \frac{k_1 K_{\text{a}}}{a_{\text{H}}} \qquad \text{Eq. (7)}$$

and

$$\text{k}_{\text{obs}} = \text{k}_2[\text{OH}^-] \qquad \text{Eq. (8)}$$

Corresponding respectively to E1cB and $B_{AC}2$ hydrolysis mechanisms for N-monosubstituted carbamates (Scheme 2).



Scheme2. Hydrolysis of the carbamate functions of Carzol according E1cB and $B_{AC}2$ mechanisms.

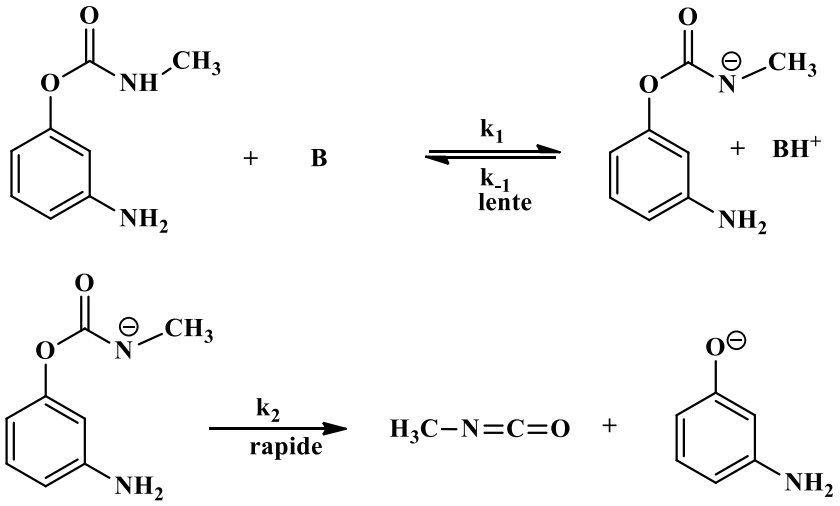
Both mechanisms E1cB and $B_{AC}2$ differ mainly by the formation of methylisocyanate, the only formal proof of E1cB process. The identification of this intermediate in the reaction

medium is very difficult because of its high chemical reactivity compared with the hydroxyl ion to form the N-methylcarbamic acid[17].

Possibility of a bimolecular elimination reaction E2– Search for general basic catalysis

For hydrolyzing the carbamate function of Carzol, a bimolecular elimination mechanism E2 in accordance with the formation of methylisocyanate, may be considered.

This mechanism was mentioned by Homer and Bender[18] for the hydrolysis of p-nitrophenyl-N-methylcarbamate. The formation of the p-nitrophenyl-N-methylcarbamate anion then, is the limiting step. In the case of Carzol, the elimination E2 leads to aminophenyl-N-methylcarbamate anion during the slow step of the mechanism (Scheme 3).



Scheme 3. E2 elimination mechanism for the hydrolysis reaction of the carbamate function of Carzol.

E2 mechanism was investigated from the study of the effect of the phosphate buffer concentration at *pH* = 12.4 on the rate of the hydrolysis reaction of the carbamate function of Carzol at temperature T = 50°C and at ionic strength μ = 1 M (Table4).

Table 4. Effect of the concentration of phosphate buffer solution at *pH*= 12.4 on the rate constant k_{obs} of the hydrolysis reaction of the carbamate function of Carzol at T = 50°C and μ = 1M.

$[HPO_4^{2-}].10^2$ mol L^{-1}	1	0.8	0.6	0.4	0.25
$k_{obs}.10^2$ min^{-1}	0.230	0.236	0.237	0.232	0.229

According to the found experimental results, we concluded that the observed rate constants of the hydrolysis of the carbamate group of Carzol in function of the phosphate buffer concentration remain unchanged. So there is no general base catalysis and it doesn't seem that the E2 mechanism can be retained. These results are consistent with those obtained for methiocarb, Bendiocarb, Zectran, Ethiofencarb and landrin[19-23].

Determination of activation entropy $\Delta S^{\neq}$ of the hydrolysis reaction of the carbamate function of Carzol

According to the data in the literature, the activation entropy can be an argument in favor of one or the other E1cB and $B_{AC}2$ mechanisms[24-26].

We therefore proposed to study the influence of temperature on the rate constants k_{obs} of the hydrolysis reaction of the carbamate function of Carzol to determining the activation entropy $\Delta S^{\neq}$.

The observed rate constants were measured at different temperatures (from 35°C to 70°C) in a buffer solution at *pH* = 12.8 and at ionic strength μ = 1M (Table5) (Figure15).

Table 5. Rate constants of the hydrolysis reaction of the carbamate function of Carzol versus the temperature in a buffer solution at *pH* = 12.8 and at ionic strength μ = 1M.

Temperature (°C)	35	40	50	60	70
$k_{obs}.10^2$ **min^{-1}**	0.06	0.12	0.46	2.66	9.57

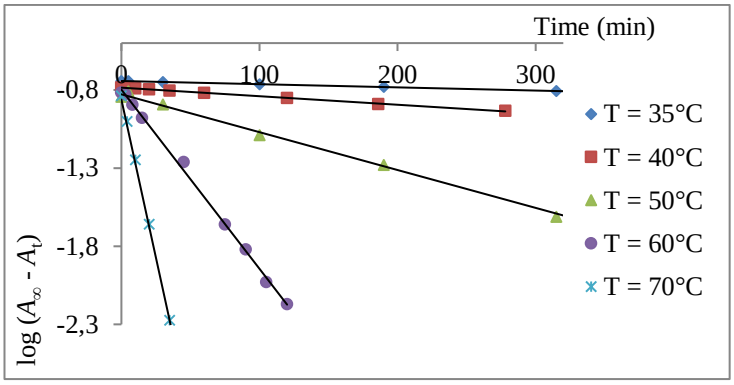


Figure 15. Influence of temperature on the rate constants k_{obs} of the hydrolysis reaction of the carbamate function of Carzol.

The value of the activation entropy $\Delta S^{\neq}$ = +100.24 J mol^{-1} K^{-1} is derived from that of the activation energy E_a = 128.65 kJ mol^{-1}, calculated from the slope of the linear equation

$$\log k_{obs} = -6.728 \frac{10^3}{T} + 18.57 \qquad \text{Eq. (9)}$$

with a regression coefficient R^2 = 0.994 (Figure16).

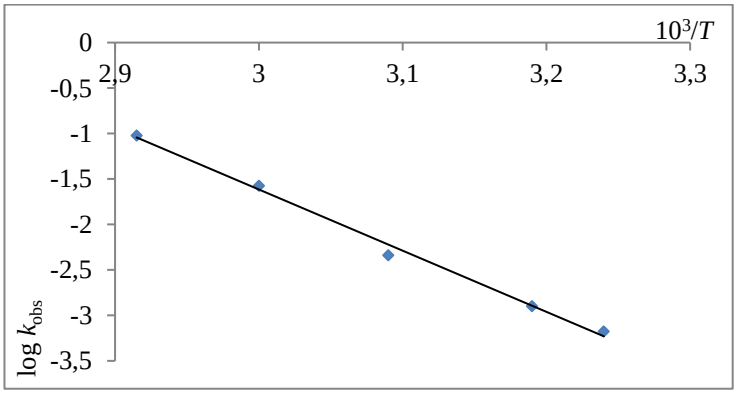


Figure 16. logarithmic variations of the observed rate constants k_{obs} of the hydrolysis reaction of the carbamate function of Carzol versus the temperature at *pH* = 12.8 and at μ = 1M.

The obtained positive activation entropy $\Delta S^{\neq}$ indicates an E1cB mechanism for the hydrolysis reaction of the carbamate function of Carzol. For a process in which

$$k_{OH} = \frac{k_1 K_a}{K_e / \gamma} \qquad \text{Eq. (10)}$$

The ionization entropies relative to K_a and K_e are negative while the value of $\Delta S^{\neq}$ is positive. Anyway, the positive entropy cannot be related to $B_{AC}2$ mechanism.

Indeed in this case, the bimolecular rate constant $k_{OH} = k_2$ is not composite and the slow addition of OH^- at the carboxyl group results in a negative activation entropy as that observed for thePirimicarb[27].

Conclusion

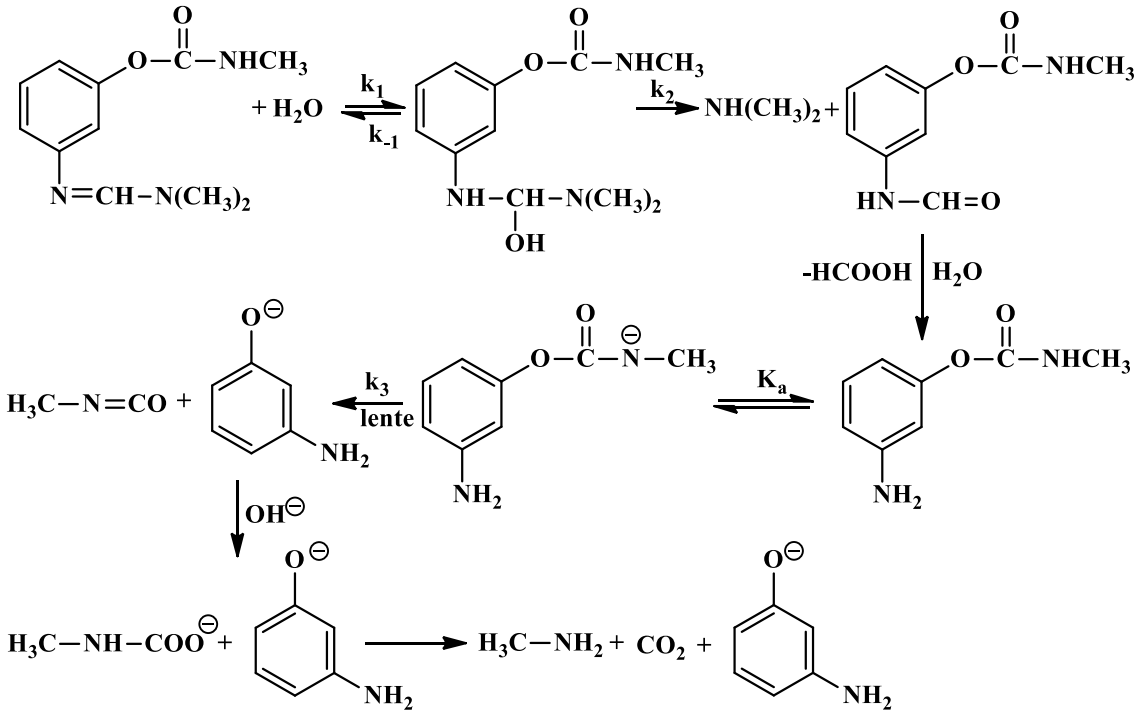
We discussed in this work the kinetic study and the degradation mechanism in aqueous medium of formamidine and carbamate functions of Carzol by UV spectrophotometry. The UV spectroscopic follow-up of Carzol degradation in aqueous medium reported that the formamidine function is more reactive than the carbamate function.

The formamidine function of Carzol hydrolyzes according to$B_{AC}2$ bimolecular process. Indeed, the negative activation entropy ($\Delta S^{\neq}$ = -32.39 J $mol^{-1}K^{-1}$) is in favor of this mechanism.

Based on literature data and obtained kinetic results on other N-methyl carbamates[28], E1cB hydrolytic degradation has been attributed to the carbamate function of Carzol.

Thus, the obtained positive activation entropy ($\Delta S^{\neq}$ = +100.24 J mol^{-1} K^{-1}) and the absence of basic general catalysis indicate an E1cB mechanism involving unimolecular collapse of the carbamate function of Carzol via a methylisocyanate intermediate which is converted to 3-aminophenol and methylamine.

In conclusion, the alkaline hydrolysis mechanism of the two functions formamidine and carbamate of Carzol is given by the following scheme 4:



Scheme 4. Hydrolysis of Carzol in alkaline medium.

Acknowledgement

The authors praise the Ministry of Higher Education, Scientific Research and Technology of Tunisia for financial and technical support.

Experimental Section

Reagents and Solvents

- Ultrapure water
- Carzol (Supelco) of 99.5% purity
- Buffer solutions prepared in the laboratory
- Carbonate $NaHCO_3$
- Phosphate Na_2HPO_4
- Borax $Na_2B_4O_7$, 10 H_2O Merck
- NaOH Across
-KCl Fluka
- HCl Merck
- HCl Merck
- Spectroscopic grade methanol (Lab-Scan, Ireland)

Instrumentation

- *pH*-meter: Digital *pH*meter Ph 744
- UV double beam spectrophotometer: Beckman DU 640B

Preparation of solutions

The stock standard solution of Carzol of 10^{-2} M was prepared by dissolving 0.0644 g in 25mL of spectroscopic grade methanol solution. The various aqueous solutions were prepared at different *pH*by the dilution of the stock standard solution at a concentration of 5×10^{-5}M in the appropriate buffer. The ionic strength μ of these solutions was kept constant by addition of KCl. The various buffers used were obtained from the following mixtures:

- Na_2HPO_4 (0.05 M) + NaOH (0.1 M) - $NaHCO_3$ (0.05 M) + NaOH (0.1M)
- Na2B4O7, 10 H_2O (0.025 M) + NaOH (0.1M)
- Na2B4O7, 10 H_2O (0.025 M) + HCl (0.1M)
- KCl (0.2 M) + NaOH (0.2M)

Calculation of activation entropy $\Delta S^{\neq}$

The activation free enthalpy is given by the following equation:

$$\Delta G^{\neq} = -\mathrm{R}\,T\log\frac{k_{\mathrm{obs}}\,\mathrm{h}}{\mathrm{K_B}\,T} \qquad \text{Eq. (11)}$$

Where hand K_B represent respectively the Planck and Boltzmann constants (h = 6.63×10^{-34}Js, $K_B = 1.38\times10^{-23}$ JK^{-1}).Using the reactions such as

$$\Delta G = \Delta H - T\Delta S \qquad \text{Eq.(12)}$$

and

$$\Delta H = E_a - \mathrm{R}T \qquad \text{Eq. (13)}$$

(for a reaction in homogeneous liquid medium), we can relate the rate constant k_{obs} to the activation entropy:

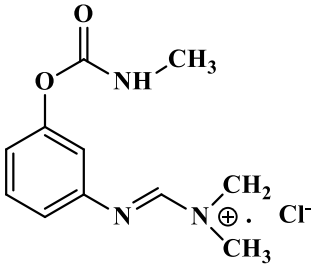
$$\Delta S^{\neq} = 2.3\ \mathrm{R}\left(\log k_{\mathrm{obs}} - \log\frac{\mathrm{e}\ \mathrm{K_B}}{\mathrm{h}} - \log T\right) + \frac{E_a}{T} \qquad \text{Eq. (14)}$$

with $\log\frac{\mathrm{e}\ \mathrm{K_B}}{\mathrm{h}} = 10.755$ and $\Delta S^{\neq}$ for each temperature. The activation energy E_a can be determined from the slope $\frac{E_a}{2.3\ \mathrm{R}}$ of the line $\log k_{\mathrm{obs}} = \mathrm{f}\left(\frac{1}{T}\right)$ where T and R represent respectively the absolute temperature and the gas constant.

Physico-chemical characteristics of Carzol

The physico-chemical characteristics corresponding to Carzol are shown in the following Table 6:

Table 6. Summary of physico-chemical properties of Carzol

Name	(E) 3-dimethylaminomethyleneaminophenyl-N-methylcarbamate hydrochloride
semi developped Formula	
Molecular formula	$C_{11}H_{16}ClN_3O_2$
Molar mass	257.8 g mol^{-1}
Melting point	202°C
Appearance	White crystalline solid
Toxicity	14.8 mg/kg
Solubility in water	Very slightly soluble
Purity	99.5 %
Biological property	Acaricide-insecticide

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