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KINETICS AND MECHANISTIC STUDY OF ACID CATALYSED HYDROLYSIS OF N-BENZYL-2-FUROHYDROXAMIC ACIDS

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ABSTRACT

The kinetic rate of hydrolysis of some heterocyclic hydroxamic acids N-Benzyl-2-Furohydroxamic Acids BFHA have been investigated in mineral acids in 20 (v/v) dioxane-water medium. Activation parameters have been determined. On the basis of Bunnett, Bunnett-olsen and Cox-Yates excess acidity treatments the mechanism is seen as involving a pre-equilibrium protonation followed by rate determining A-2 type nucleophilic attack by water molecule on the protonated substrate.

INTRODUCTION

The chemistry of hydroxamic acids in the recent year have experienced enormous expansion boosted the new discoveries on the high applicability in diverse field [1-9]. Extensive works have been carried out on studying the synthesis, structure and nucleophilicities of hydroxamic acids [10, 11] metal complexation and hydrolysis of mono-, di- and trihydroxamic acids [12-14], kinetics [18-22], biological [15-17-], and medicinal applications [23-27]. Since very little work has been done on the kinetics and mechanistic studies of heterocyclic hydroxamic acids containing furon ring i.e. furohydroxamic acids. This paper reports a kinetic study of acid catalyzed hydrolysis of N-benzyl-2- furo hydroxamic acid in aqueous mineral acids (HCl, H₂SO₄ and HClO₄) using 20 % (v/v) dioxane-water at 55°C. The order of the reaction and the mechanistic information's obtained directly from the rate acidity profile has been described. A variety of rate acidity correlations have been applied in the deduction of mechanism of hydrolysis.

METHODS

All the furo hydroxamic acids used were prepared by standard method given by Priyadarshini and Tandon [1]. All the chemicals used were AR grade. The concentrations of mineral acids were determined by titration with standard alkali. The standard ferric chloride solution used for colorimetric method was prepared by dissolving 44.0 gm anhydrous ferric chloride in 1dm³ of distilled water containing 10 cm³ of concentrated hydrochloric acid during spectrophotometric determination 2 cm³ aliquot of reaction mixture containing 20 % dioxane was periodically removed and added to 2 cm³ of ferric chloride solution which was further diluted to 10 cm³ of distilled water and absorbance was measured with a UV-Vis. 118 spectrophotometer at 540 nm. The reaction rates were measured by using different ranges of acidities of hydrochloric, sulphuric and perchloric acids has been applied in the deduction of mechanism of hydrolysis

RESULTS AND DISCUSSION

A characteristic decrease in absorption of the iron (III) BFHA complex was observed while studying the kinetics of acid hydrolysis of N-benzyl-2- furo hydroxamic acid (BFHA) spectrophotometrically. As the hydrolysis was carried out in excess of hydronium ion hence it was concluded that the reaction followed pseudo first order kinetics.

$$-\frac{d[HA]}{dt} = K [HA] [H_3O^+]$$

$$= K [HA] \quad (\text{HA stands for hydroxamic acid})$$

The data in Table 1 represents the catalytic effect of different concentrations of hydrochloric, sulphuric and perchloric acid on the pseudo first order rate constant. It is clear from the data that the catalytic effect is in the order HClO₄ > H₂SO₄ > HCl in moderate concentrations for BFHA.



Table 1: Observed pseudo-first order rate constants for hydrolysis of BFHA at 55 °C.

Acid (mol dm ⁻¹)	k _p × 10 ⁴ min ⁻¹		
	HCl	H ₂ SO ₄	HClO ₄
0.75	3.70	2.78	17.3
1.45	5.34	5.69	18.9
2.20	8.54	9.94	20.8
2.90	11.9	12.6	34.8
3.50	14.6	14.2	38.8
4.50	16.3	19.8	35.2
5.00	21.4	25.7	20.6
5.80	23.7	28.4	24.8
6.50	29.9	31.3	25.9
7.50	38.6	36.9	-
8.50	43.5	54.1	-

The rates of acid catalyzed hydrolysis of hydroxamic acids were measured at 45°C, 55°C and 65°C using HCl, H₂SO₄ and HClO₄. Higher perchloric acid concentration brings about uncontrolled reaction; hence studies at higher molarities were not possible. The various activation parameters viz. energy of activation (E_a), free energy of activation (ΔG[‡]), enthalpy of activation (ΔH[‡]), and entropy of activation ΔS[‡]) were calculated. Table 2 shows the Arrhenius parameters at different molarities for BFHA represents the catalytic effect of different concentrations of hydrochloric, sulphuric and perchloric acid on the pseudo first order rate constant. It is clear from the data that the catalytic effect is in the order HClO₄ > H₂SO₄ > HCl in moderate concentrations for BFHA. Table 1: Observed pseudo-first order rate constants for hydrolysis of BFHA at 55 °C.

Table 2: Activation parameters for the hydrolysis of BFHA

Acid mol dm ⁻³	HCl				H ₂ SO ₄				HClO ₄			
	E _a	ΔH [‡]	ΔS [‡]	ΔG [‡]	E _a	ΔH [‡]	ΔS [‡]	ΔG [‡]	E _a	ΔH [‡]	ΔS [‡]	ΔG [‡]
1.45	64.7	61.9	-110.4	97.6	67.9	65.2	-100.5	98.2	66.8	64.0	-94.8	95.2
2.90	63.0	60.3	-109.8	96.0	63.9	61.3	-105.6	95.9	69.0	66.2	-83.1	93.5
5.80	69.3	66.6	-84.9	94.5	68.7	66.0	-85.3	94.0	60.4	57.6	-110.9	94.0

Acid catalyzed hydroxamic acid hydrolysis reaction can be discussed in terms of a two-step mechanism i.e. an equilibrium state in which the substrate is protonated and a rate limiting step. Acid catalyzed hydrolysis reactions in which the rate limiting step does not involve water are characterized A-1 while those which involve water in the rate limiting step have been designated as A-2. The value of ΔS[‡] is Positive or small negative for many A-1 reactions. Here the ΔS[‡] shows large negative values at lower concentration and at higher concentration it shows less negative values. The other activation parameters do not vary much at different concentrations of the mineral acids.



Rate correlation:

According to Bunnett correlation [18] following Equation-1, if $\log k_{\psi} + H_0$ are plotted against

$\log a_{H_2O}$ (log of activity of water) straight lines are obtained.

$$\log k_{\psi} + H_0 = \omega \log a_{H_2O} + \text{constant} \quad (1)$$

Figure 1 shows Bunnett ‘ ω ’ plots for BFHA. In the present investigation, linear free energy relationship developed by Bunnett-Olsen [19] ‘ ϕ ’ are obtained for acid catalyzed hydrolysis of BFHA following the Equation-2, if $\log k_{\psi} + H_0$ are plotted against $\log [H^+] + H_0$ (Figure 2).

$$\log k_{\psi} + HX = \phi [HX + \log [H^+]] \quad (2)$$

where $HX = H_0$ or HA

The correlation values of ‘ ω ’ and ‘ ϕ ’ are summarized in Table 3. The values of ‘ ω ’ are > 3.6 such values of ‘ ω ’ falls in the range where water is acting as a proton transfer agent in rate determining step and a bimolecular mechanism is favoured. The values of ‘ ϕ ’ obtained ranges from 0.26-1.5 indicative of water acting as nucleophile and proton transfer agent.

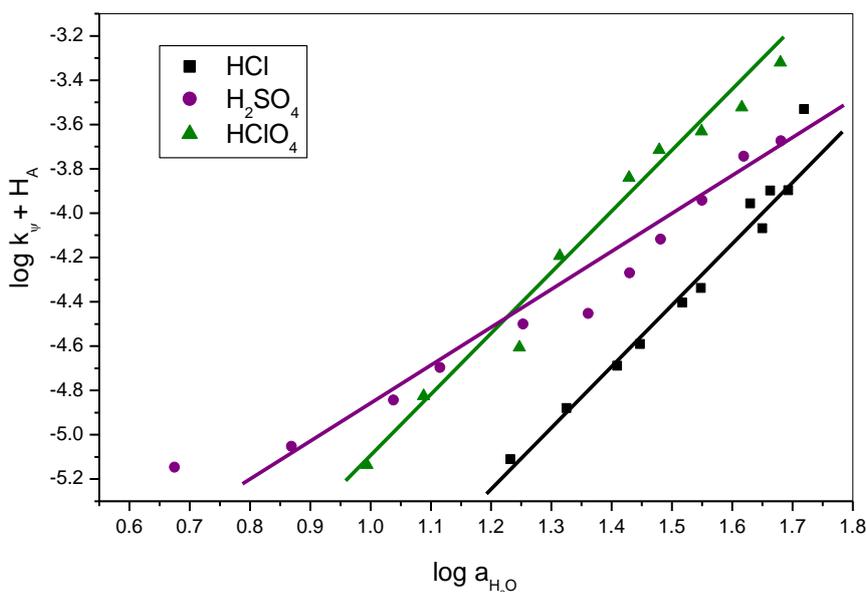


Figure 1: Bunnett ‘ ω ’ plots for the acidic hydrolysis of BFHA in 20 % (V/V) dioxane at 55 °C.

Recently, Cox-Yates excess acidity method [20, 21] was applied for investigation of reaction mechanism in strong mineral acids and Equation-3 has been derived for A-2 reaction.

$$\log k_{\psi} - \log [H^+] - 2 \log a_{H_2O} = (\log k_1 / K_{SH^+}) + m_2 \neq m^* X \quad (3)$$



Table 3: Rate correlation data for BFHA.

Hydroxamic acid	Mineral acid	Acid range [M]	Bunnett 'ω'	Bunnett Olsen 'φ'	Cox-Yates Excess Acidity $m_2 \neq m^*$
BFHA	HCl	0.75-8.50	2.9	0.9	0.45
	H ₂ SO ₄	0.75-8.50	1.5	0.8	0.77
	HClO ₄	0.75-8.50	2.6	1.4	0.21

The resulting plot is shown in Figure 3 for BFHA. The slope values giving $m_2 m^*$ for both furo and hydroxamic acid are shown in Table 3.

CONCLUSION

The acid catalyzed hydrolysis of p-CH₃BTHA takes place through A-2 mechanism. The carbonyl oxygen is rapidly protonated followed by slow reaction of water with the o-protonated form and after proton transfer the transition complex is obtained which on subsequent hydrolysis, due to N-aryl bond fission leads to formation of hydrolytic products. For these correlations, values of H_0 and $\log a_{H_2O}$ determined at 25°C in aqueous medium, were used while the reaction were carried out at 55°C and this might affect the magnitudes of the slopes.

Competing Interests

Authors do not have any competing interests with the publication of this work.

Authors' Contributions

Both authors contributed more or less equally to this work.

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Global Journal of Engineering Science and Research Management

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