



Kinetic study of oxidation of schiff bases: Part-II. 5-Chloro-2-hydroxy-4-methylacetophenone-2'-chloroanil by Ce (IV) in acid medium

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ABSTRACT

Oxidation of schiff base and its kinetics has been studied by Ce^{+4}/Ce^{+3} redox system in aqueous sulphuric acid medium. The order of reaction with respect of Ce (IV) as well as schiff base was found to be one. A plot of k_1^{-1} Vs $[CHMA2CA]^{-1}$ was linear with an intercept on the rate axis which suggests the formation of an equilibrium complex between the reactants prior to the rate determining step. The effect of different salts viz. KCl, NaCl and NH_4Cl , the ionic strength, temperature and solvent on the rate of reaction have also been studied. The thermodynamic parameters viz. ΔE , ΔH , ΔG and ΔS and activation energy, "A" were also evaluated for the present oxidation process. On the basis of experimental data a possible mechanism is suggested for the oxidation of CHMA2CA.

Key words: 5-Chloro-2-hydroxy-4-methylacetophenone-2'-chloroanil (CHMA2CA), Ceric sulphate, oxidation, mechanism, kinetics and thermodynamics.

INTRODUCTION

The kinetic study of several organic substances has been well investigated by using Ce (IV) \rightarrow Ce (III) redox system[1-4]. Also the studies on oxidation of schiff base by ceric sulphate in sulphuric acid medium are reported[5-6]. Recently, we have reported[7] the kinetic study of the ketoanil viz. 5-Chloro-2-hydroxy-4-methylacetophenone-anil (CHMAA) by Ce(IV) \rightarrow Ce(III) redox couple. Our present communication deals with the kinetic study of schiff base, CHMA2CA, by ceric sulphate in aqueous sulphuric acid.

MATERIALS AND METHODS

All the chemicals and reagents used were of synthetic and AR grade respectively. The schiff base (CHMA2CA) was prepared by refluxing 5-chloro-2-hydroxy-4-methylacetophenone (CHMA) and 2-chloroaniline (2CA) in ethanol for 3-4 hours by adding sulphuric acid as dehydrating agent[7-9]. It was then purified by recrystallization and ascertained by TLC method. Stock solutions of ceric sulphate and ferrous ammonium sulphate were prepared in 2N sulphuric acid and standardised by known method[10].

Kinetic measurements: Oxidation of substrate i.e CHMA2CA, and its kinetics was carried out at constant desired temperature with the help of an electrically heated thermostat with an accuracy of ± 0.1 °C. The titrations were carried out by pipette out 5 ml aliquots from the reaction mixture at different intervals of time and the unreacted ceric sulphate was determined by titrating it against standard ferrous ammonium sulphate solution using ferroin as an indicator.

Method of calculations of the rate constant

For the unimolar quantities of reactants, value of first order rate constant were calculated using relation

$$k_1 = (2.303/t) \log \left[\frac{a}{a-x} \right]$$

For the equi-molar quantities of reactants, value of second order rate constant were calculated using relations

$$k_2 = (1/at) \left[\frac{x}{a-x} \right]$$

RESULTS AND DISCUSSION

Effect of substrate: To evaluate the order of reaction with respect to substrate, (CHMA2CA) the titrations were carried out at different concentrations of the substrate. The concentrations of oxidant and sulphuric acid were kept constant. The temperature was maintained at 298 K. The results are recorded in Table 1.

Table-1: Effect of concentration of Schiff base (CHMA2CA) on oxidation process by Ce(IV) in aq. H₂SO₄ at 298 K
 [Oxidant] = 2.40 x 10⁻² M Ionic strength = 0.288 (KCl)

[CHMA2CA] x 10 ⁻³ M	k ₁ x 10 ⁻⁴ sec ⁻¹ (Average)	k ₂ X 10 ⁻¹ mole ⁻¹ sec ⁻¹
0.9615	1.4262	1.4833
0.8650	1.2391	1.4325
0.7690	1.2050	1.5670
0.5770	1.0455	1.8120
0.3850	0.7985	2.0740

The k₁ values are found to be directly proportional to concentration of schiff base studied indicating that reaction follows first order kinetics with respect to Schiff base, CHMA2CA and are in the range of 0.7985 x 10⁻⁴ sec⁻¹ to 1.4262 x 10⁻⁴ sec⁻¹. The values of k₂ (Second order constant), calculated from k₁ / [CHMA2CA], are practically constant which also proves first order dependence of reaction on the Schiff base. Fig. 1 shows the plot of k₁⁻¹ Vs [CHMA2CA]⁻¹ which is linear making an intercept on rate axis indicating formation of equilibrium complex between Ce (IV) and CHMA2CA. Observed results and nature of curve is in concurrence with earlier[7] reports.

Effect of oxidant: In order to determine the order of a reaction with respect to oxidant, the reaction was studied at different concentration of the oxidant while keeping (Fig. 2) all other parameters constant. The reaction follows first order kinetics with respect to Ce (IV). The k₁ values are given in Table 2 and ranges from 1.8654 x 10⁻⁴ sec⁻¹ to 1.0325 x 10⁻⁴ sec⁻¹. The value of k₁ decreases with increase in concentration of oxidant which is contrary to our expectation. The results and nature of curve observed is in concurrence with earlier[7] reports. J Shorter[11] and other have also observed a similar effect in their studies. This fact shows the formation of an equilibrium complex between the reactants prior to the rate determining step. A plot of k₁ against [Ce(IV)]⁻¹ is linear with an intercept on the rate axis provides a positive evidence for the formation of complex (Fig. 2)

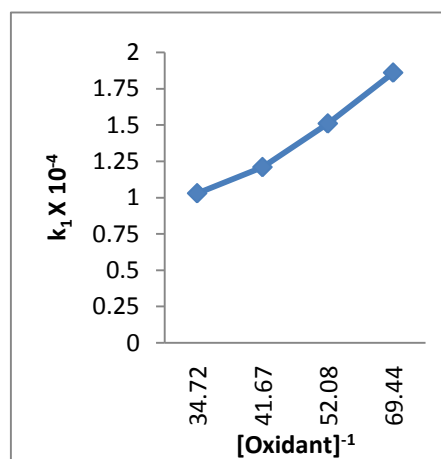
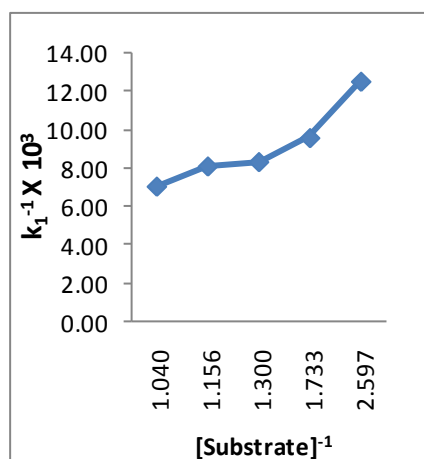


Fig.1: The plot of k₁⁻¹ Vs [CHMA2CA]⁻¹ i.e [substrate]⁻¹ **Fig.2:** A plot of k₁ against [Ce(IV)]⁻¹ i.e [oxidant]⁻¹

Table-2: Effect of concentration of oxidant on CHMA2CA oxidation process by Ce(IV) in aq. H₂SO₄ at 298 K
 $[CHMA2CA] = 0.9615 \times 10^{-3} M$ $Ionic\ strength = 0.288 (KCl)$

[Oxidant] x 10 ⁻² M	k ₁ x 10 ⁻⁴ sec ⁻¹ (Average)
1.440	1.8654
1.920	1.5167
2.403	1.2161
2.880	1.0325

Effect of ionic strength:

The reaction was carried out at five different values of ionic strength for each studied salt and at a constant temperature of 298 K. The concentrations of sulphuric acid, oxidant and substrate were kept constant. The ionic strength of the solution was varied separately with the addition of different salts viz. KCl, NaCl and NH₄Cl. The results are recorded in Table 3.

The k₁ value decrease with increase in ionic strength of the solution. Thus the retarding effect is observed on addition of potassium chloride salt and sodium chloride whereas this effect shows reversal in case of ammonium chloride. A plot of log k₁ against $\sqrt{\mu}$ is a straight line with negative slope (Fig. 3) indicating that the rate determining step of reaction probably involves the ions of opposite charges. Similar results were reported for the oxidation of Schiff bases from this laboratory[7].

Table-3: Effect of ionic strength on oxidation of CHMA2CA by Ce(IV) in aq. H₂SO₄ at 298 K
 $[H_2SO_4] = 2.0 N$ $[Oxidant] = 2.40 \times 10^{-2} M$ $[CHMA2CA] = 0.9615 \times 10^{-3} M$

Salt	Ionic strength →	0.288	0.303	0.318	0.333	0.348
KCl	k ₁ x 10 ⁻⁴ sec ⁻¹	1.4299	1.2943	1.1626	1.0154	0.8677
NaCl	k ₁ x 10 ⁻⁴ sec ⁻¹	1.4142	1.3226	1.2196	1.0929	1.0038
NH ₄ Cl	k ₁ x 10 ⁻⁴ sec ⁻¹	1.4148	1.5674	1.6528	1.7830	1.8269

Effect of cation size: Reaction was carried out using three different electrolytes having different cation in acidic medium. Rate increases with increase in the size of cation and decreases with decrease in the size of cation of the electrolyte.

Effect of medium: The reaction was carried out at five different concentration of sulphuric acid keeping all other parameters constant. The values of k₁ are tabulated in Table 4. The graph of k₁ Vs $[H_2SO_4]^{-1}$ is depicted in Fig. 4 and the values ranges from 1.2817 x 10⁻³ sec⁻¹ to 1.7845 x 10⁻³ sec⁻¹.

Table-4: Effect of solvent, H₂SO₄ concentration on the oxidation reaction of CHMA2CA by Ce(IV) at 298 K
 $[Oxidant] = 2.40 \times 10^{-2} M$ $Ionic\ strength = 0.288 (KCl)$

[H ₂ SO ₄] N	2.0	3.0	4.0	5.0	6.0
k ₁ x 10 ⁻³ sec ⁻¹	1.2817	1.5527	1.6830	1.7541	1.7845

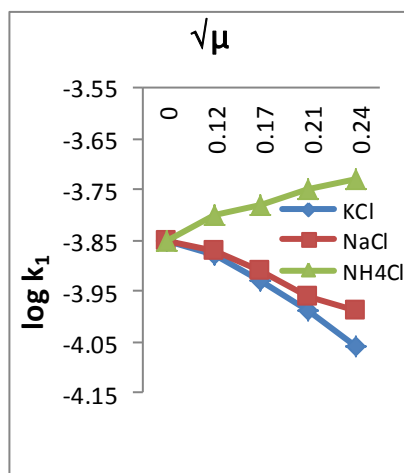


Fig. 3: The plot of log k₁ against $\sqrt{\mu}$.

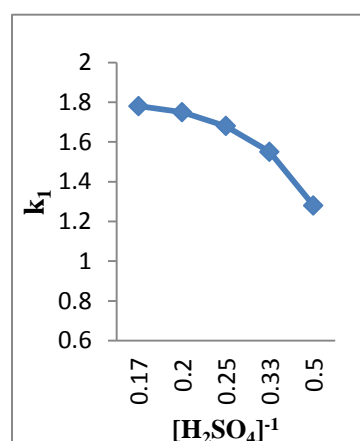


Fig. 4: The graph of k₁ Vs $[H_2SO_4]^{-1}$

The results of Table 3 indicate that k₁ increase with increase in concentration of sulphuric acid which is due to the unhydrolysed Ce (IV) species[7, 12] in this reaction.

Effect of temperature:

The kinetic parameters (rate constants) were determined at 298K, 303K, 308K, 313K, 318K and 323K, at constant $[\text{CHMA2CA}] = 0.9615 \times 10^{-3} \text{ M}$, in 2.0 N H_2SO_4 and the results obtained are tabulated in Table 5. The second order rate constant (Table 1) depends on the reaction temperature[13].

Table-5: Determination of kinetic and thermodynamic parameters for oxidation of CHMA2CA by Ce(IV) in aq. H_2SO_4
 $[\text{Oxidant}] = 2.40 \times 10^{-2} \text{ M}$ $[\text{CHMA2CA}] = 0.9615 \times 10^{-3} \text{ M}$
 $[\text{H}_2\text{SO}_4] = 2.0 \text{ N}$ $\text{Ionic strength} = 0.288 \text{ (KCl)}$

Temp.(K)	$k_1 \times 10^{-4} \text{ sec}^{-1}$	$^{\ddagger}\Delta E$ in KJ/mole	ΔH in KJ/mole	ΔG in KJ/deg/mole	ΔS KJ/mole	A, sec^{-1}
298	1.4262	17.7111	15.2320	95.1885	-268.2038	10.794
303	1.5645		15.1919	96.3364	-267.7553	
308	1.8901		15.1503	97.4866	-267.2668	
313	2.1649		15.1088	98.7531	-267.1925	
318	2.3402		15.0672	100.1664	-266.5668	
323	2.6998		15.0256	101.4058	-266.3703	

[†]Note: From Graph, $\Delta E = 17.1725 \text{ KJ/mol}$, which approximately matches to the experimental values.

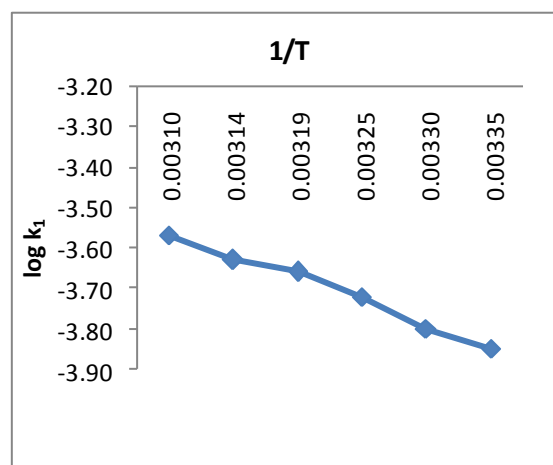


Fig.5: The graph of $\log k_1$ Vs $1/T$

The thermodynamic parameters viz. energy of activation (ΔE) is determined from the graph of $\log k_1$ Vs $1/T$ (Fig.5). Various thermodynamic parameters such as energy of activation (ΔE), enthalpy of activation (ΔH), free energy of activation (ΔG), entropy of activation (ΔS), and frequency factor (A) were calculated and are reported in Table 5.

The thermodynamic parameters such as (ΔH) and (ΔS) are important in controlling the rates of reaction. The low values of (A) and negative value of (ΔS) indicate the formation of a more rigid activated complex between Ce(IV) and CHMA2CA is less probable and rate is slower. The negative value of entropy indicates that there is formation of rigid transition state. Relatively small values of (ΔH) and negative value of (ΔS) are consistent with the reaction which generally proceeds through highly organized transition state[14].

If both the reactants are likely charged, the charge density on the surface in the transition state will be more and hence there can be increase in solvation leading to a negative (ΔS) value[15]. This observation is supported by our earlier report[7] by the oxidation of schiff bases by using the same reagent.

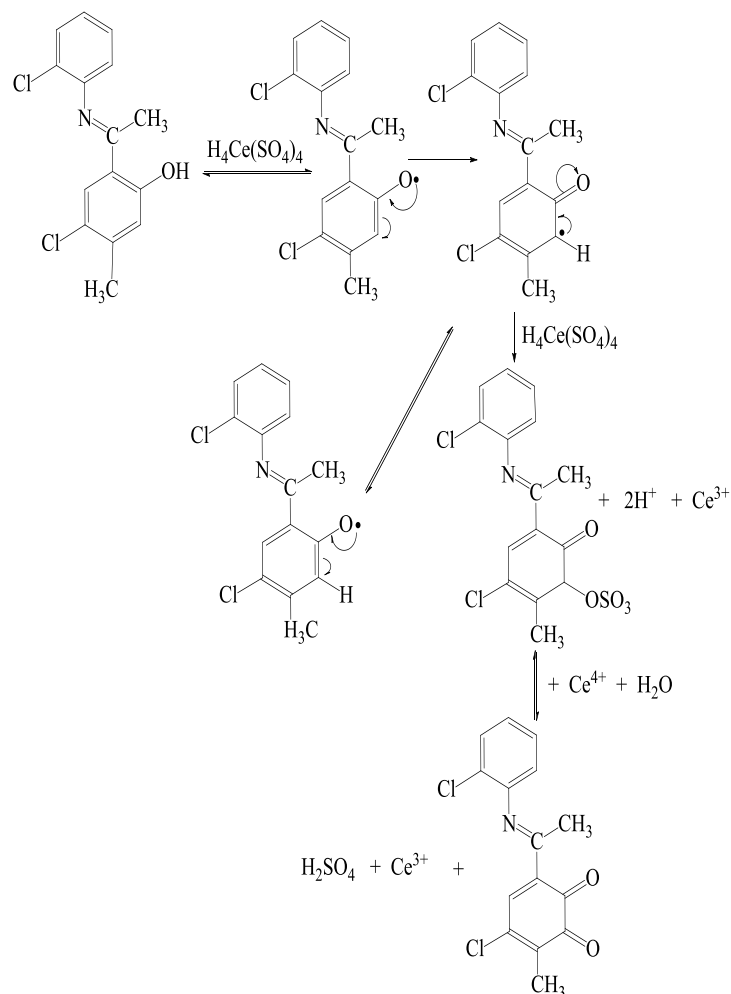
Mechanism of the Oxidation of the Schiff base under study:

On the basis of the data obtained, the mechanism of the oxidation of a schiff base by Ce(IV) may be given below:



which is similar to our earlier report[7] in case of the similar compounds by Ce(IV).

The species of cerium complexes in sulphuric acid has been widely investigate[4,6,16-19]. The isolation of number of cerium (IV) complexes from sulphuric acid has also shown by G. Hargraves L. H. Sutcliffe[3,7]. the existence of ceric sulphate coupled with the fact that cerium in solution is present only as complex anion, suggests that ceric sulphate exists as the complex sulphatoceric acid[17], $\text{H}_4\text{Ce}(\text{SO}_4)_4$ which must be reactive species in the reaction and the action of it, on the substrate may be a rate determining step[19,20]. Specifically the possible mechanism of oxidation of the CHMA2CA may be written as given in Scheme-1.



Scheme-1

The kinetics of oxidation of 2-Hydroxy-naphthalidene-anil and its substituted derivatives in the aniline part have been studied in aqueous sulphuric acid medium by Ce^{4+} to Ce^{3+} and reported the similar type of the reaction mechanism[21].

CONCLUSION

This study can be extended, to study the varied drug intermediates and pharmaceutical actives and important substances involving similar functional groups and based on the experimental data reaction mechanism can be ascertain.

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