

Oxidation of DL-methionine by Pyridinium Dichromate in Aqueous Acetic Acid Medium: A Kinetics mechanistic study

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ABSTRACT: The oxidation of methionine (Met) by pyridinium dichromate (PDC) in aqueous acetic acid solutions leads to the formation of corresponding sulphoxide. The reaction is of first order with respect to PDC and Met both. The reaction was studied in acid solutions of various compositions of acid and water. The solvent composition effect indicated that the rate of reaction increases with an increase in the polarity of the medium. The reaction failed to induce the polymerization of acrylonitrile. A mechanism involving formation of a halogenosulfonium cation in the slow step has been proposed.

Key Words: Dichromate, Kinetics, Mechanism, Methionine, Oxidation.

INTRODUCTION

Cr(VI) salts of have long been used as oxidizing reagents in synthetic organic chemistry. However these salts are rather drastic in nature and non-selective oxidants. Further, they are insoluble in most of the organic solvents. Thus miscibility is a problem. To overcome these limitations, a large number of organic derivatives of Cr(VI) have been prepared and used in organic synthesis as mild and selective oxidants [1-4]. One of such compounds is pyridinium dichromate [5]. We have been interested in the kinetic and mechanistic aspects of the oxidation by complex salts of Cr(VI) and several studies have already been reported on the oxidation by halochromates and dichromates[6-10]. It is, known however, that mode of oxidation depends upon the nature of counter-ion attached to the chromium anion. Methionine (Met), a sulphur-containing essential amino acid, is reported to behave differently from other amino acids, towards many oxidants [11,12], due to electron-rich sulphur center which is easily oxidisable. In continuation of our earlier work with chromium complexes, we report here the kinetics of oxidation of DL-methionine by PDC in aqueous acetic acid solution as solvent. A suitable mechanism has also been proposed.

2. EXPERIMENTAL:

2.1 Materials:

PDC was prepared by the reported method⁵ and its purity checked by an iodometric method. Methionime (Merck) was used as supplied. Due to non-aqueous nature of the solvent, toluene-*p*-sulphonic acid (TsOH) was used as a source of hydrogen ions. Acetic acid was refluxed with chromic oxide and acetic anhydride for 6 h and then fractionated [13].

2.2 Product Analysis:

Product analysis was carried out under kinetic conditions. The oxidation of Met by PDC resulted in the formation of corresponding sulphoxide, which was determined by the reported method[14]. The yield of sulphoxide was 94±3%. The oxidation state of chromium in completely reduced reaction mixtures, as determined iodometrically, was +4.

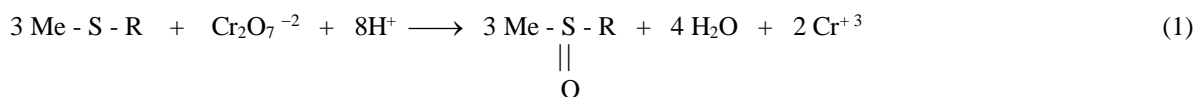
2.3 Kinetic measurements:

The pseudo-first order conditions were attained by maintaining a large excess ($\times 15$ or more) of the Met over PDC. The solvent was 1:1 (v/v) acetic acid-water mixtures, unless mentioned otherwise. The reactions were followed, at constant temperatures (± 0.1 K), by monitoring the decrease in [PDC] spectrophotometrically at 354 nm. No other reactant or product has any significant absorption at this wavelength. The pseudo-first order rate constant, k_{obs} , was evaluated from the linear ($r = 0.990 - 0.999$) plots of $\log [PDC]$ against time for up to 80% reaction. Duplicate kinetic runs showed that the rate constants were reproducible to within $\pm 3\%$. The second order rate constant, k_2 , was evaluated from the relation $k_2 = k_{obs}/[Met]$. Simple and multivariate linear regression analyses were carried out by the least-squares method on a personal computer.

3. RESULTS AND DISCUSSION:

3.1 Stoichiometry:

The oxidation of methionine by PDC resulted in the formation of the corresponding sulfoxides. The overall reaction may therefore, be represented as equation (1).



Where R is $\text{CH}_2\text{CH}_2\text{CH}(\text{NH}_2)\text{COOH}$

3.2 Rate Laws:

The reactions were found to be first order with respect to PDC. In individual kinetic runs, plots of $\log [\text{PDC}]$ versus time were linear ($r^2 > 0.995$). Further, it was found that the observed rate constant, k_{obs} , does not depend on the initial concentration of PDC. The reaction rate increases with an increase in the concentration of methionine, further, the order with respect to methionine was also found to be unity (Table 1). Figure 1 depicts a typical kinetic run.

Table – 1. Rate constants for the oxidation of methionine by PDC at 298 K

$10^3 [\text{PDC}]$ ----- (mol dm ⁻³)	[Met] ----- (mol dm ⁻³)	$10^4 k_{\text{obs}}$ ----- (mol dm ⁻³)
1.0	0.10	1.86
1.0	0.20	3.84
1.0	0.40	7.65
1.0	0.60	11.7
1.0	0.80	15.3
1.0	1.00	18.9
1.0	1.50	28.8
1.0	3.00	58.5
2.0	0.40	7.74
4.0	0.40	7.56
6.0	0.40	7.83
8.0	0.40	7.70
1.0	0.20	3.96*

^a contained 0.001 M acrylonitrile

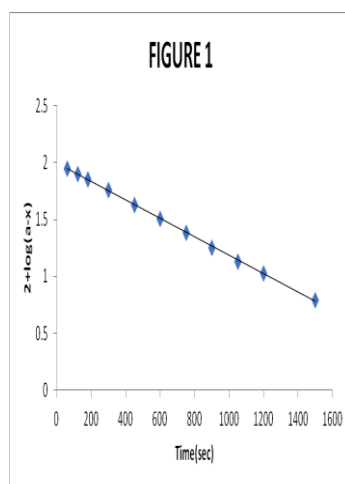


Figure 1. – Oxidation of Mrthionine by PDC: A typical Kinetic Run

3.3 Induced Polymerization of Acrylonitrile/ test for free radicals:

The oxidation of Met, in an atmosphere of nitrogen, failed to induce the polymerization of acrylonitrile. Further, the addition of acrylonitrile had no effect on the rate of oxidation (Table 1). Therefore, a one-electron oxidation, giving rise to free radicals, is unlikely. To further confirm the absence of free radicals in the reaction pathway, the reaction was carried out in the presence of

0.05 mol dm⁻³ of 2,6-di-*t*-butyl-4-methylphenol (butylated hydroxytoluene or BHT). It was observed that BHT was recovered unchanged, almost quantitatively.

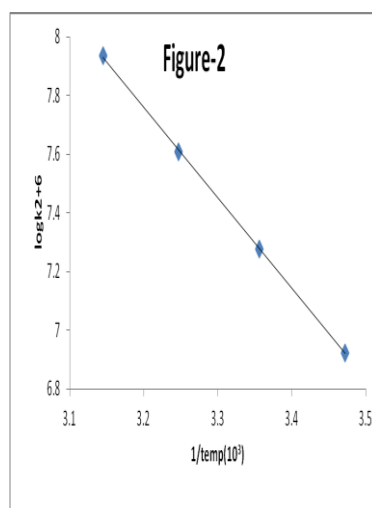
3.4 Effect of temperature:

The rates of oxidation of Met was determined at different temperatures and the activation parameters were calculated (Table 2). The log k_2 at different temperature is linearly related to the inverse of the absolute temperature in all cases (Figure 2). The Arrhenius equation is, therefore, valid for these oxidations.

Table – 2. Rate constants and activation parameters of the decomposition of PDC-met complexes

$10^4 k_2 / (\text{dm}^3 \text{mol}^{-1} \text{s}^{-1})$				ΔH^*	$-\Delta S^*$	ΔG^*
288 K	298 K	308 K	318 K	(kJ mol ⁻¹)	(J mol ¹ K ⁻¹)	(kJ mol ⁻¹)
8.37	18.9	40.5	86.4	56.6±0.4	108±1	88.5±0.3

Figure 2. – Oxidation of Methionine by PDC: Effect of temperature on rate



3.5 Effect of Solvent Composition :

The oxidation of Met was determined in solvents containing different proportions of acetic acid and water. The rate of reaction increases as the amount of water in the solvent is increased (Table 3).

Table – 3. Effect of Solvent composition on the oxidation of Methionine by PDC

[PDC] = 0.001 mol dm ⁻³ ;		[Met] = 1.0 mol dm ⁻³ ;			Temp. = 298 K
% AcOH	25	40	50	60	72
$10^4 k_2 (\text{s}^{-1})$	96.3	36.0	18.9	9.45	3.33

3.6 Solvent composition effect:

The increase in the rate constant with an increase in the polarity of the medium suggests that the transition state is more polar than the reactants. The plot of log k_2 against the inverse of the dielectric constant is nonlinear. The solvent effect was analysed using Grunwald- Winstein equation[15].

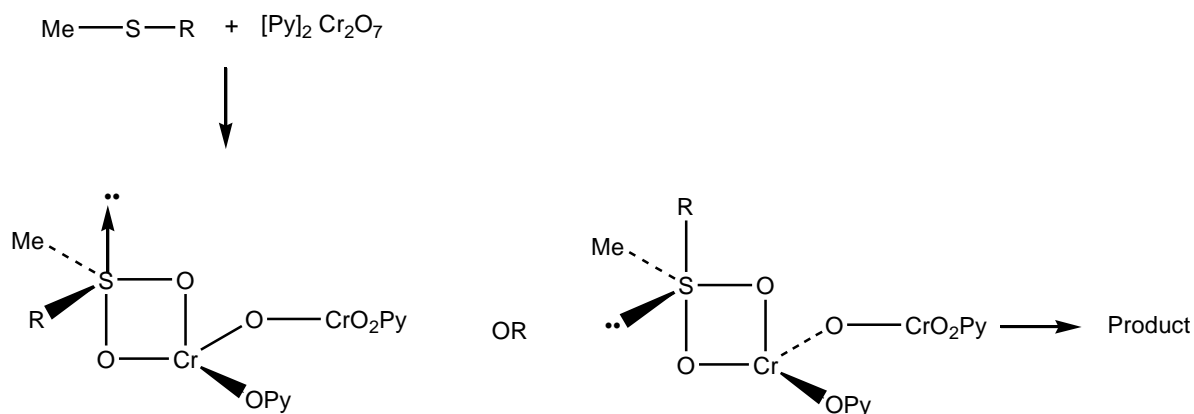
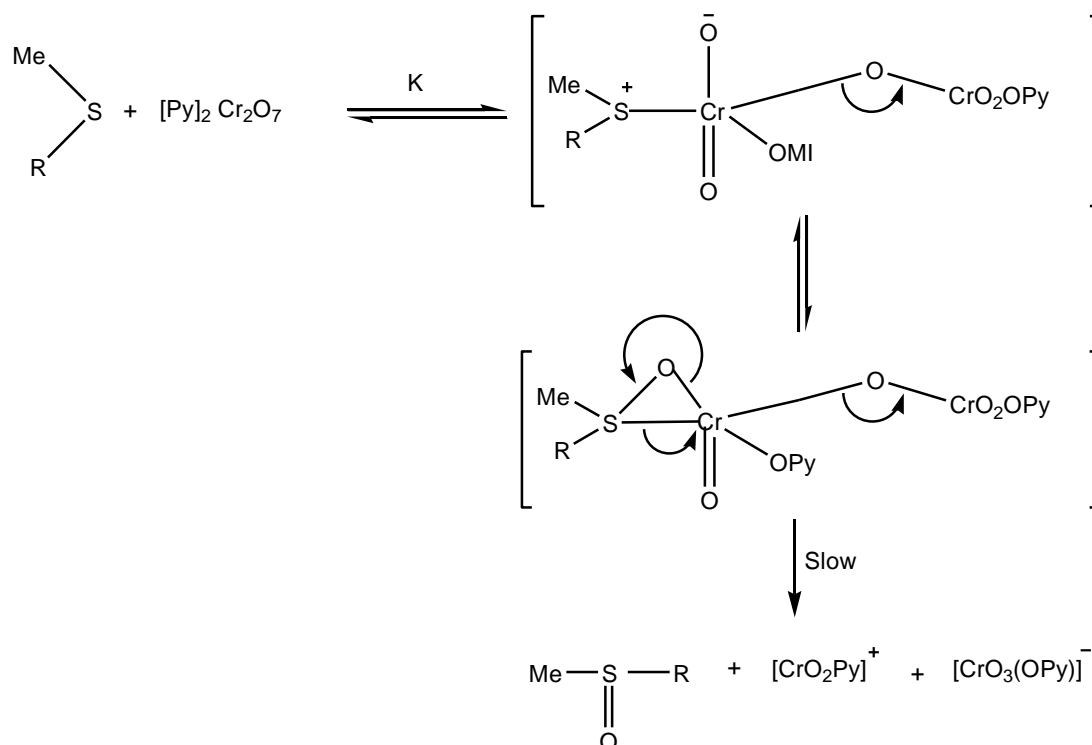
$$\log k_2 = \log k_0 + mY \quad (2)$$

The plot of log k_2 versus Y is linear ($r^2 = 0.9993$) with $m = 0.78 \pm 0.01$. The value of m suggests a transition state, which is more polar than the reactants. Thus considerable charge separation takes place in the transition state of the reaction.

4. MECHANISM

In view of the absence of any effect of radical scavenger, acrylonitrile, on the reaction rate and recovery of unchanged BHT, it is unlikely that a one-electron oxidation giving rise to free radicals is operative in this oxidation reaction. The experimental results can be accounted for in terms of electrophilic attack of methionine-sulphur at the metal *via* an intermediate complex. Similar mechanisms has been suggested for oxidation of sulfides and iodide ions by periodate ion[16] and for the oxidation of sulfides by hydrogen peroxide[17]. The electrophilic attack on the sulfide-sulphur can be viewed as an S_N2 reaction. An S_N2 like transition state is supported by observed solvent effect also.

The oxidation of methionine by PDC may involve a cyclic intermediate as has been suggested in many reactions of Cr(VI)[18] The cyclic transition state will be highly strained in view of the apical position of a lone pair of electrons or an alkyl group. The formation of a cyclic transition state entails a more exacting specificity of orientation and should result in much larger negative entropy of activation than that observed. (Scheme – 1)



5. ACKNOWLEDGEMENTS

Thanks are due to HODs of Department of Chemistry, J.N.V. University, Jodhpur and Department of Chemistry, Rajasthan University, Jaipur respectively for providing necessary facilities to work in a smooth manner.

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