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Research Article

Oxidation of levofloxacin by acidic permanganate: a kinetic and mechanistic study

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ABSTRACT

The kinetic and mechanistic investigation of oxidation of levofloxacin (LF) has been studied by permanganate ion in aqueous sulphuric acid medium at 25°C. The reaction followed first-order kinetics with respect to [LF], and [H+] in their lower concentrations range, tending to zero-order at their higher concentrations. The effect of added products and dielectric constant of the medium was studied on the rate of reaction. Effect of varying salt electrolyte concentration was insignificant showing that the molecular species was involved in the rate determining step. The main products were identified by spot test, FT-IR, and LC-MS. A mechanism was proposed on the basis of experimental results. The activation parameters with respect to the slow step of the mechanism were evaluated, and the thermodynamic parameters were also determined and discussed.Potassium permanganate widely used as oxidizing agent in the kinetics of number of organic and biological active compounds. Permanganate is multi-electronoxidant, which can exist in various oxidation states, among which +7 is its highest oxidation state. In acidic medium it exists in different forms as HMnO4, HMnO4+, HMnO3, Mn2O7 and one depending on the nature of the reductant. Levofloxacin is a broad spectrum drug of activity against various bacteria, including gram-positive and gram-negative microorganisms. Kinetic measurements were performed on a Peltier accessory (temperature-Controlled) attached to a U.V.3000+ UV-Visible spectrophotometer (LABINDIA).The product analysis is characterized by LC-ESI-MS and FT-IR studies. The reaction stoichiometry indicates that 5 moles of levofloxacin require 2 moles of Mn(VII). The oxidation products were identified as 7-amino fluoroquinolone and Mn (II). The reaction shows first order kinetics with respect to MnO4- and fractional order with respect to levofloxacin and hydrogen ion concentration. The effect of added product, varying salt electrolyte were studied on the rate of reaction. The rate constant of the slowest step and other equilibrium constants involved in the mechanism are evaluated. Overall mechanistic sequence described here is consistent with product, mechanistic and kinetic studies.

Key words: *Kinetics, Oxidation, Mechanism, Levofloxacin, Permanganate ion, Sulphuric acid medium..*

INTRODUCTION

Levofloxacin (LF), (-)-(S)-9-fluoro-2,3-dihydro-3-methyl- 10-(4-methyl-1-piperazinyl)-7-oxo-7H pyrido [1,2,3-de]- 1,4-benzoxazine-6-carboxylic acid hemihydrates (Figure. 1), is one of the commonly used third-generation fluoroquinolone antimicrobials, being the active S-isomer isolated from racemic ofloxacin and is twice as active as the parent drug.

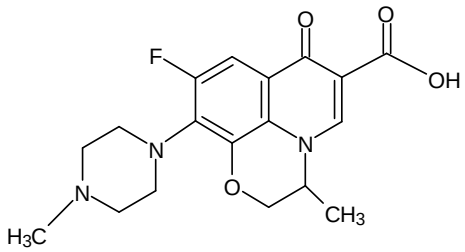


Figure 1 - Structure of levofloxacin (LF).

Levofloxacin is a broad spectrum drug of activity against various bacteria, including gram-positive and gram-negative microorganisms[1, 2]. Because of its effective antibacterial activity and low frequency of adverse effects on oral administration, levofloxacin has been widely used for the treatment of infectious diseases, such as community-acquired pneumonia and acute exacerbation of chronic bronchitis[3].The interaction of fluoroquinolone with metal ions is of interest not only for the development of analytical techniques but also to afford information about the mechanism of action of the pharmaceutical preparation[4]. Since the metal ions cause fluorescence quenching of the drug, the spectrofluorimetric method for quantitative determination of the quinolone type drugs has been developed[5] along with titrimetric[6], spectrophotometric[7,8], electrochemical[9],electrophoretic[10] and chromatographic[11]techniques. The increase of fluoroquinolone in aquatic environments, even in low concentration, may cause intimidation to the ecosystem and human health by including the multiplication of drug resistance bacteria owing to long term exposure[12]. Chemical oxidation of pollutant in drinking water and waste water by Chloramine-T[13] has been widely done. A number of kinetic study on oxidation of levofloxacin in alkaline, aqueous and acidic medium have been reported[7,13-16] . In view of potential pharmaceutical importance of levofloxacin and lack of literature on the oxidation of this drug and complexity of the reaction, a detail study of the reaction become important. Potassium permanganate widely used as oxidizing agent play key role in the kinetics of number of organic and biological active compounds[17-21]. Literature survey reveals that permanganate ions are widely used as oxidizing agent in synthetic, analytical chemistry[22,23]and also as a disinfectant[24,25]. It has been used in the determination of content of pharmaceutical formulation, [26-27] as oxidizing agent for removal of organic molecules and heavy metals from the nuclear waste[25]. Oxidation reactions by Potassium permanganate are of considerable academic and technological importance because of variable oxidation states. Permanganate is one such powerful multi-electronoxidant which can exist in various oxidation states, among which +7 is its highest oxidation state, which occurs in the Oxo compounds like MnO_4^-, Mn_2O_7, MnO_3F. Out of which MnO_4^- is the most commonly used well known oxidant species to carry out kinetic studies in acidic, neutral and alkaline media. In acidic medium it exists in different forms as $HMnO_4$, $HMnO_4^+$, $HMnO_3$, Mn_2O_7 and one depending on the nature of the reductant[29]. So this study is concerned with the identity of the redox reaction and to explore a suitable mechanism for oxidation oflevofloxacin by $KMnO_4$in acidic medium on the basis of kinetics parameters.

MATERIALS AND METHODS

Chemicals

All chemicals used were of analytical grade and doubly distilled water was used throughout this study. Standard solution of levofloxacinwas prepared by dissolving known amount of the drug in double distilled water.Permanganate solution was obtained by dissolving potassium permanganate (BDH Analar) in water and standardized by titrating against oxalic acid[30].Freshly prepared & standardized permanganate solutions were always used in kinetics experiments. The Mn (II) solution was made by dissolving manganese sulphate (BDH) in water. Na_2SO_4 (BDH) and H_2SO_4 (MERCK) were used to provide required ionic strength and acidity respectively.

Instrumentation

For kinetic measurements, a Peltier accessory (temperature-Controlled) attached to a U.V.3000$^+$ UV-Visible spectrophotometer (LABINDIA) was used.For product analysis, LC-ESI-MS, (Q-TOF Micromass, WATERS Company, UK), alpha-T FTIR spectrophotometer (BRUKER, Germany), and for pH measurementsMSW-552 pH meter were used.

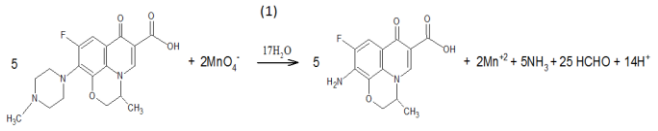
Kinetic Measurements

All kinetic measurements were conducted under pseudo-first-order conditions, where the concentration of levofloxacin was much greater than permanganate ion concentration at constant temperature 25± 0.1^{o}C unless otherwise stated. The reaction was initiated by mixing thermostated solution of permanganate and levofloxacin; in addition to that required quantities of H_2SO_4, Na_2SO_4 are added to provide required acidity and ionic strength of reaction. The progress of the reaction was followed spectrophotometrically at 525nm. The Beer's law verified in permanganate concentration range $(0.50 – 5.0) \times 10^{-4}$ $moldm^{-3}$ at 525nm. The molar absorptivity index of permanganate was found to be $\varepsilon = 2260 \pm 50$ $dm^3mol^{-1}cm^{-1}$ as a function of time (compared to the literature, $\varepsilon = 2200$ [31]). The kinetics reactions were followed more than 85 % completion of the reaction. The pseudo-first-order rate constants k_{obs}were calculated from the plots of the logarithm ofabsorbance versus time, which were linear. The values of k_{obs}were reproducible within ±5%.

RESULTS AND DISCUSSION

Stoichiometry and Product Analysis

Different sets of concentration of reactants at constant concentration of sulphuric acid and ionic strength were kept over 24 hrsat25^{o}C in a closed container. When [permanganate] > [levofloxacin], the remaining permanganate concentration was assayed by measuring the absorbance at 525 nm. Estimation of unreacted[MnO_4^-] indicates that 5 moles of levofloxacin consumed 2 moles of Permanganate; the Stoichiometry ofthe reaction is given in equation (1).



[LF]

LC/MS analysis of levofloxacin oxidation reaction indicates the formation of product with molecular ions of m/z 279 (Figure. 2). The molecular ion of levofloxacin is m/z 361.4. The m/z 279corresponds to full dealkylation of the piperazine ring (i.e. the $–NH_2$ product). It is worth noting, that oxidation of piperazine moiety of levofloxacin between oxidized centres and nitrogen atoms lead to distinctive mass loss m/z = 69 and m/z = 83. This was attributed to ring opening, dealkylation and deamination process, which finally yielded 7-amino fluoroquinolone product.Theproduct was also short written as M-69, indicating the net mass loss of the product from the parent levofloxacin. Infrared Spectroscopy analysis confirmed the presence of $–NH_2$ group in the oxidation product (Figure. 3). The Infrared spectrum shows a peak at 3412.70 cm^{-1}which is due to -NH stretching of the $–NH_2$ group and the remaining peaks are of the parent compound (quinolone ring).Theby-product formaldehyde was identified by spot test[32]. The other product ammonia was detected by Nesseler's reagent test[33].

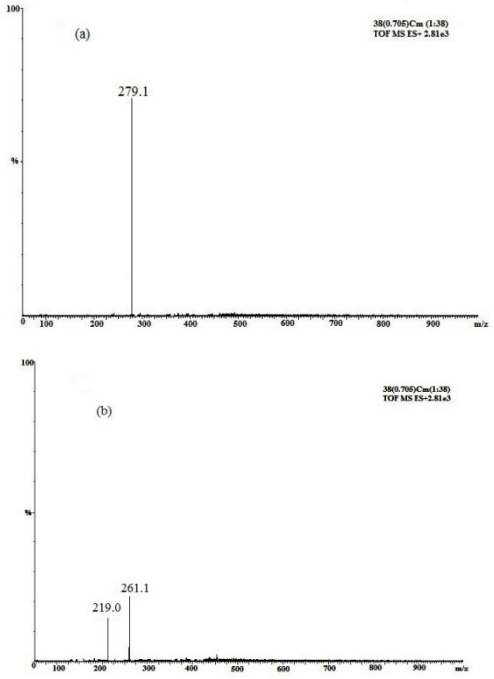


Figure 2 - LC-ESI-MS spectra of oxidation product of levofloxacin. (a) Molecular ion peak of m/z 279 (M-69). (b) Fragmentation of (M-69) product.

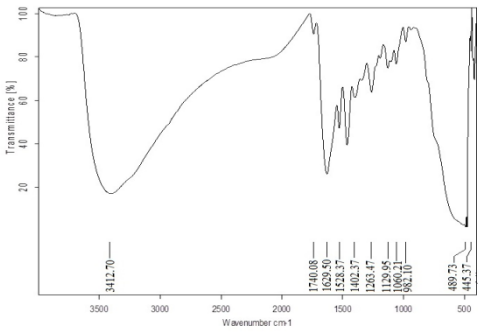


Figure3 - FT-IR spectra of the product of oxidation of levofloxacin by permanganate.

Reaction Orders

The reaction orders were determined from the slopes of log k_{obs} versus log [concentration] plots by different concentration of levofloxacin, permanganate and acid in turn, keeping all other concentration and conditions constant.

Dependence of Rate on the Concentration of Permanganate

The oxidant permanganate [MnO_4^-] concentration varied from7.5×10^{-5} to 6×10^{-4}moldm^{-3}, and all other concentrations and conditions were constant. The plot of log absorbance versus time was linear (Figure. 4) indicating that the reaction is first order with respect to [$KMnO_4$]. The observed pseudo first order rate constant (k_{obs}) were independent of the concentration of $KMnO_4$ (Table-1).

Table 1:"Effect of variation of [MnO_4^-], [LF] and [H^+] on the oxidation of levofloxacin by acidic permanganate at 25°C and I = 0.02 mol dm^{-3}"

S. No.	10^4MnO_4(mol dm^{-3})	10^3 [LF] (mol dm$^-$)	10^2 [H^+] (mol dm^{-3})	10^3k_{obs} (s^{-1})
1	0.75	1.0	1.0	8.25
2	1.0	1.0	1.0	8.23
3	2.0	1.0	1.0	8.25
4	3.0	1.0	1.0	8.25
5	4.0	1.0	1.0	8.25
6	5.0	1.0	1.0	8.23
7	6.0	1.0	1.0	8.23
8	2.0	2.0	1.0	9.06
9	2.0	3.0	1.0	13.22
10	2.0	4.0	1.0	15.53
11	2.0	5.0	1.0	17.38
12	2.0	6.0	1.0	19.23
13	2.0	7.0	1.0	20.4
14	2.0	2.0	0.5	4.71
15	2.0	2.0	0.6	5.46
16	2.0	2.0	0.7	6.24
17	2.0	2.0	0.8	7.49
18	2.0	2.0	0.9	8.33
19	2.0	2.0	1.0	9.06
20	2.0	2.0	1.5	9.89
21	2.0	2.0	2.0	10.62

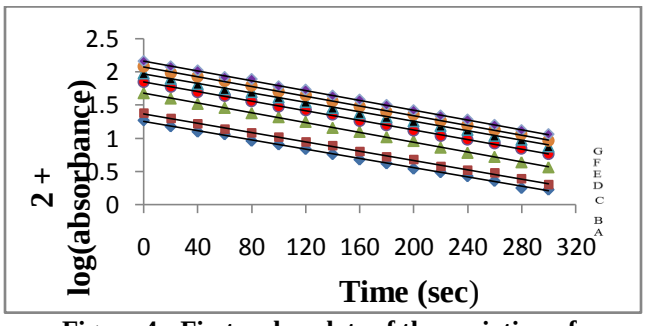


Figure 4 - First order plots of the variation of permanganate concentration at 25oC.

[LF]=1.0×10-3mol dm-3,[H+] = 1.0×10-2 mol dm-3and I = 0.02mol dm-3. [MnO4-]×10-4 mol dm-3 = (A) 0.75, (B) 1.0,(C) 2.0, (D) 3.0, (E) 4.0, (F)5.0, (G) 6.0

Dependence of Rate on the Concentration of Levofloxacin

The effect of concentration variation of levofloxacin on the rate of reaction was studied in the range 2×10^{-3} to 7×10^{-3}mol dm^{-3} at constant concentration of permanganate, acid and ionic strengthat three temperatures viz. 20°, 25°,30°Crespectively. The rate of reaction increases with increasing concentration of levofloxacin (Table 1). A plot of log k_{obs} versus log [LF] was linear with a slope of 0.64, thus indicating a fractional-order dependence on levofloxacin concentration. This was confirmed by the plot of $1/k_{obs}$ versus 1/ [LF] (Figure.5) which was also linear with a positive intercept.

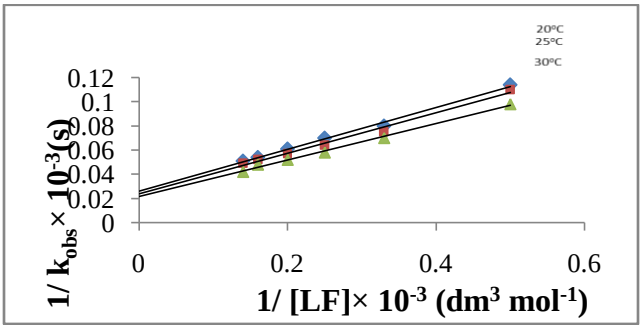


Figure 5 - Plots of 1/kobs versus 1/ [LF] at three different temperatures. [KMnO4] = 2.0 x 10-4 mol dm-3, [H+] = 1.0 x 10-2 mol dm-3 and I = 0.02 mol dm-3.

Dependence of Rate on the Concentration of Sulphuric Acid

The effect of concentration variation of sulphuric acid on the rate of reaction was studied in the concentration range 5×10^{-3} to 2×10^{-2}moldm^{-3} at fixed concentration of permanganate,levofloxacin and ionic strength at three temperaturesviz. 20°, 25°, 30°C respectively. Pseudo first-order rate constant(k_{obs})was found to be increased with increase in [H^+] (Table 1). A plot of log k_{obs} versus log [H^+] was linear with a fractional slope of 0.60. This was confirmed by the plot of $1/k_{obs}$ versus 1/ [H^+] (Figure.6) which was also linear with a positive intercept.

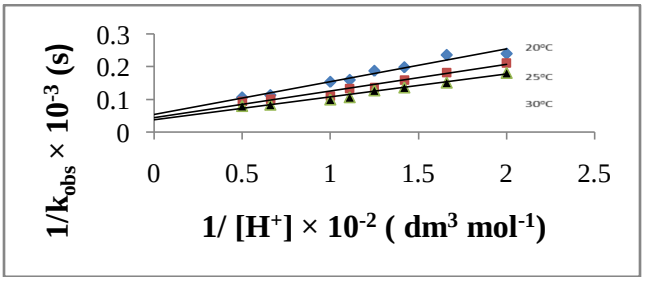


Figure 6 - Plots of 1/kobs versus 1/ [H+] at three different temperatures. [KMnO4] = 2.0 x 10-4 mol dm-3, [LF] = 2.0 x 10-3 mol dm-3 and I = 0.02 mol dm-3.

Dependence of Rate on Ionic Strength and Dielectric Constant

Effect of change in varying electrolyte concentration was monitored to establish the nature of intermediate species in the rate determining step by Na_2SO_4. It was observed that the change in an ionic strength of the medium does not alter the rate constant. The absence of salt effect indicates that the reaction does not take place between ionic species. The slope of plots between log k_{obs} against $\sqrt{\mu}$was zero, which confirms the presence of the molecular species in the rate determining step. At constant acidity and other constant conditions, as the t-butyl alcohol content increase from 0 to 50% (v/v) in the reaction, change in dielectric constant had negligible effect on the rate of reaction.

Neutral Salts Dependence

The effect of added neutral salt on the rate of reaction has been studied at varying concentration 1×10^{-2} - 4×10^{-2} mol $dm^{-3}$of $NaNO_3$, CH_3COONa and NaF at fixed concentration of other reactant and constant conditions. Addition of different sodium salts has no effect on the reaction rates.

Effect of Initially Added Products

The initial added products, Mn(II) was studied in the range of 5×10^{-5} to 5×10^{-4} mol dm^{-3} while other reactants concentration and conditions constant, does not change the rate of reaction.

Test for Free Radical

The reaction mixture (10ml) in which known quantity (2ml) of acrylonitrile has been added and kept in an inert atmosphere for 5 hours then diluted with methanol, white precipitate was formed, indicating the intervention of free radicals in the reaction. The blank experiment of reacting either $KMnO_4$ or levofloxacin alone with acrylonitrile did not induce polymerisation under the same conditions.

Permanganate ion, MnO_4^- ion is powerful oxidizing agentin acidic medium. The stable oxidation product of MnO_4^-in acid medium is Mn(II). Figure 7 illustrates the spectroscopic changes occurring in the oxidation of levofloxacin by acid permanganate at 25°C with scanning interval of 1minute. The literature survey reveals that[34]Mn(IV) ion absorbs in region 400-600 nm. Figure 7 shows no features in this wavelength area indicating that MnO_2 is not a reaction product.

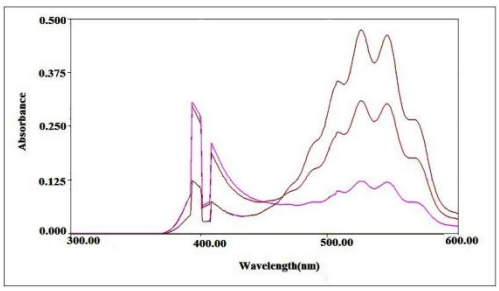


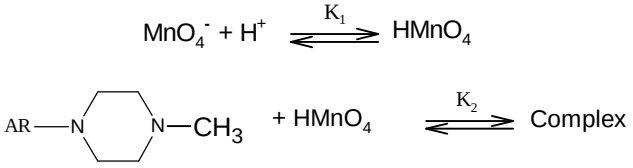
Figure 7 - Spectral changes during the oxidation of levofloxacin (LF) by permanganate in acidic medium at 25°C. [$KMnO_4$] = 2.0×10^{-4}mol dm^{-3}, [LF] = 2.0×10^{-3}mol dm^{-3}, [H^+] = 1.0×10^{-2}mol $dm^{-3}$and I = 0.02 mol dm^{-3}

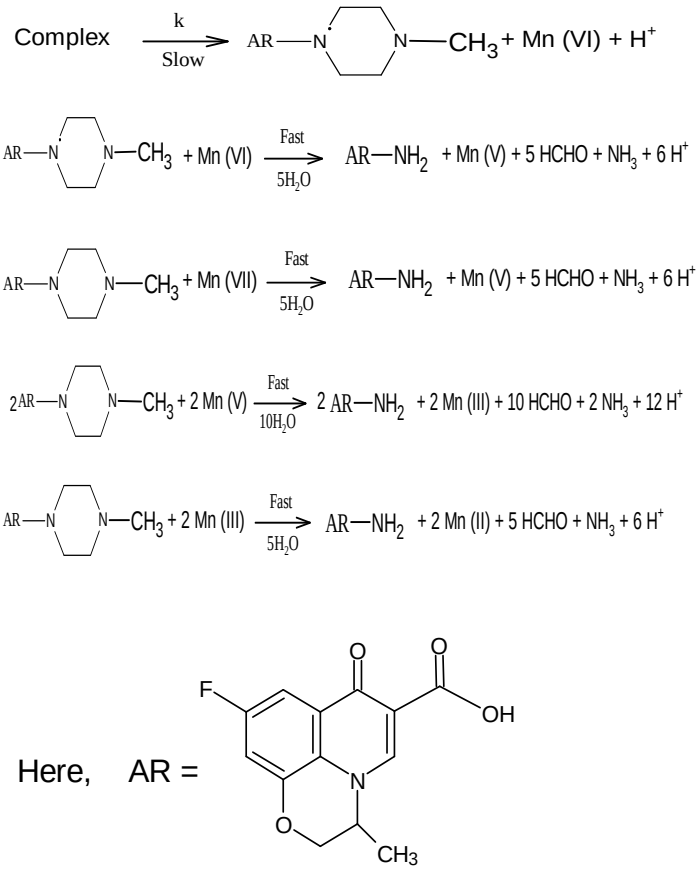
The reaction between levofloxacin and permanganate in sulphuric acid has Stoichiometry 5:2, with first order dependence with permanganate and less than unit order with H^+ concentration and levofloxacin concentration. The fact that Mn(II) is the reduced product of Mn(VII) in the reaction might indicate that levofloxacin shows a strong reducing character in H_2SO_4 medium. In view of the presence of sulphuric acid in thereactionmixture,theoxidationof LF by sulphuric acidwas checked, and it was found to be negligible compared to the oxidation of LF by permanganate. The active species of permanganate in aqueous acid solution may be deduced from the dependence of the rate on $[H^+]$, in the reaction medium. The order of $[H^+]$ is less than unity, which may be indicate the formation of permanganate acid from permanganate ion. Permanganate acid $HMnO_4$ is more efficient oxidant species of Manganese (VII) then permanganate ion[35]. It has been observed that the rate of reaction was tending to attain a limiting value at higher concentration of $[H^+]$ ion, which indicates that only the protonated form is active then acid permanganate[36].Thenegligibleeffectofionic strength ontherateofreactionalso confirmsthat$HMnO_4$istheactive species of MnO_4^-, can be represented by equation-(2)

$$MnO_4^- + H^+ \underset{}{\overset{K_1}{\rightleftharpoons}} HMnO_4 \qquad (2)$$

Where K_1 is the equilibriumconstant of $HMnO_4$.

In view of increasing the rate with increase in $[H^+]$ ion, in the prior equilibrium step, H^+ reacts with MnO_4^- to form $HMnO_4$, which reacts with the one mole of levofloxacin to form a complex. Complex formed is dissociate in the rate determining step to give a free radical derived from levofloxacin and an intermediate Mn(VI). In further fast steps the intermediate Mn(VI) reacts with a free radical to produce the product 7-amino fluoroquinolone, NH_3, HCHO and intermediate Mn(V), subsequently reduced to the end product Mn(II). Although Mn(VI) and Mn(IV) are the final reduced species of MnO_4^- in alkaline and neutral media, it was observed that Mn(II) was the only reduced species of MnO_4^- in acid medium. Attempts were made to allow spectroscopic detection of intermediate Mn(V) and Mn(III) as the reaction proceeded in the oxidation of levofloxacin by permanganate. Unfortunately the low concentration of Mn(V) and Mn(III) intermediate obtained under our experimental conditions made the spectroscopic detection failure. However, the evidence for intermediate such as Mn(V) and Mn(III) are reported in the literature[37, 38].The results are accommodated in the following mechanism (Scheme 1).





Scheme-1Proposed mechanism for the oxidation of Levofloxacin by acidic permanganate.

Following rate law can be derived from scheme 1:

$$\text{Rate} = \frac{-d[MnO_4^-]}{dt} = k[\text{Complex}]$$

$$= kK_2[HMnO_4][LF]$$

$$= kK_1K_2[MnO_4^-]_f[H^+]_f[LF]_f \quad (3)$$

Total concentration of permanganate is given by

$$[MnO_4^-]_t = [MnO_4^-]_f + [HMnO_4] + [\text{Complex}]$$

$$= [MnO_4^-]_f + K_1[MnO_4^-]_f[H^+]_f + K_2[HMnO_4][LF]$$

$$= [MnO_4^-]_f + K_1[MnO_4^-]_f[H^+]_f + K_1K_2[MnO_4^-]_f[H^+]_f[LF]$$

$$= [MnO_4^-]_f \{1 + K_1[H^+]_f + K_1K_2[H^+]_f[LF]\}$$

$$[MnO_4^-]_f = \frac{[MnO_4^-]_t}{\{1 + K_1[H^+]_f + K_1K_2[H^+]_f[LF]} \quad (4)$$

$[MnO_4^-]_t$ and $[MnO_4^-]_f$are total and free concentration of Mn (VII) respectively.

Total concentration of levofloxacin is given by:

$$[LF]_t = [LF]_f + [\text{Complex}]$$

$$= [LF]_f + K_2[LF]_f[HMnO_4]$$

$$= [LF]_f \{1 + K_2[HMnO_4]\}$$

$$[LF]_f = \frac{[LF]_t}{1+K_2[HMnO_4]}$$

Very low concentration of $[MnO_4^-]$ were used in the experiment, so $K_2[HMnO_4] << 1$

$$[LF]_f = [LF]_t \quad (5)$$

Total concentration of $[H^+]$ is given by:

$$[H^+]_t = [H^+]_f + [HMnO_4]$$
$$= [H^+]_f + K_1[MnO_4^-]_f[H^+]_f$$
$$= [H^+]_f\{1+K_1[MnO_4^-]_f\}$$

$$\text{So, } [H^+]_t = [H^+]_f \quad (6)$$

Substituting equation (4), (5) and (6) in equation (3) and omitting "t" and "f" subscripts

$$\text{Rate} = \frac{-d[MnO_4^-]}{dt} = \frac{kK_1K_2[MnO_4^-][H^+][LF]}{1+K_1[H^+]+K_1K_2[H^+][LF]} \quad (7)$$

$$\frac{\text{Rate}}{[MnO_4^-]} = k_{obs} = \frac{kK_1K_2[H^+][LF]}{1+K_1[H^+]+K_1K_2[H^+][LF]} \quad (8)$$

Equation (8) can be rearranged as

$$\frac{1}{k_{obs}} = \frac{1}{kK_1K_2[H^+][LF]} + \frac{1}{kK_2[LF]} + \frac{1}{k} \quad (9)$$

Equation 9, indicates that the linear plots of $1/k_{obs}$ versus $1/[LF]$ and $1/k_{obs}$ versus $1/[H^+]$ were obtained with a straight line and positive intercept on the y-axis (Figure. 5, 6) at three different temperatures.This proves the validity of rate law, and the proposed reaction scheme has been derived. The rate constant k, of the slow step, scheme 1 was obtained from the intercept of the plots $1/k_{obs}$ versus $1/[LF]$ (Table 2). The energy of activation was determined by the plot of log kversus 1/T from which activation parameters were calculated (Table 2). The equilibrium constant of $HMnO_4$ (K_1) and the equilibrium constant of complex (K_2) in scheme-1 were calculated from the intercept and slope of the plot $1/k_{obs}$versus $1/[H^+]$ respectively (Figure.6) (Table 2). The value of K_1 is in good agreement with earlier work[37] at 25°C. Thermodynamic quantities were calculated from the Van't Hoff plot (Table 2). According to the rate determining step in Scheme 1, thechange in the ionic strength and dielectric constant of the medium does not alter thereaction rate, which suggests the involvement of non-ionic species at the rate-determining step[39]. The values of$\Delta H^{\neq}$and$\Delta S^{\neq}$arebothfavourable for electron transferprocess[40].The value of $\Delta S^{\neq}$ within the range of radical reaction has been ascribed[41] to the nature of electron pairing and unpairing process. The negative value of $\Delta S^{\neq}$ indicates that complex is more ordered than the reactants[42]. The observed modest enthalpy of activation and a relatively low value of the entropy of activation as well as a higher rate constant of the slow step indicate that the oxidation presumably occurs via inner-sphere mechanism[43].

According to the rate determining step in Scheme 1, the change in the ionic strength and dielectric constant of the medium does not alter the reaction rate, which suggests the involvement of non-ionic species at the rate-determining step[39].The values of $\Delta H^{\neq}$ and $\Delta S^{\neq}$ are both favourable for electron transfer process[40].The value of $\Delta S^{\neq}$ within the range of radical reaction has been ascribed[41] to the nature of electron pairing and unpairing process. The negative value of $\Delta S^{\neq}$ indicates that complex is more ordered than the reactants[42]. The observed modest enthalpy of activation and a relatively low value of the entropy of activation as well as a higher rate constant of the slow step indicate that the oxidation presumably occurs via inner-sphere mechanism[43].

Table 2: "Activation and thermodynamic quantities for the oxidation of levofloxacin by acidic permanganate from scheme 1"

Temperature (Kelvin)	**10^2 k (s^{-1})**	
293	3.84	
298	4.34	
303	4.76	
Activation parameters	**Value**	
E_a(kJ mol^{-1})	16.19	
$\Delta H^{\neq}$ (kJ mol^{-1})	13.72	
$\Delta S^{\neq}$ ± (J K^{-1} mol^{-1})	45.05	
$\Delta G^{\neq}$ ± (kJ mol^{-1})	80.77	
Equilibrium constants at different temperatures		
Temperature (Kelvin)	**$10^{-1}K_1$ (dm^3 mol^{-1})**	**$10^{-2}K_2$ (dm^3 mol^{-1})**
293	4.22	4.82
298	4.07	5.77
303	3.81	6.56
Thermodynamic quantities	**Using K_1 values**	**Using K_2values**
ΔH (kJ mol^{-1})	-19.14	23.16
ΔS ± (J K^{-1} mol^{-1})	-63.53	80.55
ΔG ± (kJ mol^{-1})	-1.14	-1.0

CONCLUSION

The oxidant MnO_4^- exists in acid medium as $HMnO_4$, which takes part in the chemical reaction. The oxidation of levofloxacin by permanganate in acidic medium has a Stoichiometry of 5:2.The oxidation products were identified as Mn(II), 7-amino fluoroquinolone, NH_3 and HCHO. Dealkylated products of levofloxacin have antimicrobial activity. Since dealkylated products are obtained in the present study, it is evident that the products of the title reaction haveantimicrobial activity after oxidation. So this study will be effectively used in waste water treatment at the sites contaminated by fluoroquinolone antibiotics.The rate constant of the slowest step and other equilibrium constants involved in the

mechanism are evaluated, and activation parameters with respect to slowest step were computed.

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