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RESEARCH ARTICLE

Kinetic and Mechanistic Study of the Oxidation of Some Para-substituted Benzhydrols by Cetyltrimethylammonium Bromochromate using Spectrophotometric Technique

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Abstract

Objectives: This study investigates the oxidation of para-substituted benzhydrols by cetyltrimethylammonium bromochromate (CTMABC) in dimethylsulfoxide (DMSO), aiming to elucidate the reaction kinetics and solvent effects. **Methods:** The oxidation was carried out under pseudo-first-order conditions, showing first-order kinetics for both CTMABC and benzhydrols. The role of hydrogen ions in catalysis was examined, and the reaction was analyzed in 19 different organic solvents. Solvent effects were quantified using Kamlet's and Swain's multi-parametric equations. **Findings:** The reaction produced the corresponding benzophenones and demonstrated a first-order dependence on both reactants. The presence of hydrogen ions accelerated the reaction. Solvent studies indicated that solute-solvent interactions significantly influenced reactivity. **Novelty:** This research provides a comprehensive kinetic and mechanistic understanding of benzhydrol oxidation, utilizing a novel multi-parametric approach to analyze solvent impacts, offering new insights into solute-solvent interactions in oxidation processes.

Keywords: Kinetics; Mechanism; Cetyltrimethylammonium bromochromate; Benzhydrol; Solvent effect

1 Introduction

Non-aqueous solvents in the oxidation of organic compounds have evolved as a tremendous image change-maker, it is a crucial but essential part of organic chemistry. A great diversification was reported in the field of hexavalent Chromium derivatives earlier[(1–10)]. Some new chromium(VI) based reagents developed in recent years are, Cetyltrimethylammonium dichromate (CTADC)[(11)], Tripropylammonium halochromate (TriPAFC and TriPACC)[(12)], N-methyl benzylammonium fluorochro-

mate (MBAFC) & N-ethylbenzylammonium fluorochromate (EBAFC)[13], tetraethylammonium bromochromate (TEABC)[14], Tetraethylammonium Chlorochromate (TEACC)[15], Tetramethylguanidium Halochromates (TMGFC and TMGCC)[16], Tripropylammonium fluorochromate (TPAFC)[17]. However, a few reports are available regarding the oxidation of organic substrates by Cetyltrimethylammonium bromochromate (CTMABC)[18,19] CTMABC is a more effective and valuable oxidizing agent for oxidation. Reports on the oxidation processes of substituted benzhydrols by a few reagents are also available[20–23]. The literature review revealed that no reports are available on the kinetics of oxidation of substituted benzhydrols by CTMABC. It is considered in a prime investigation of oxidation by CTMABC. In this current research, we present the outcomes of a kinetic analysis conducted on the oxidation of certain p-substituted benzhydrols in 19 distinct organic solvents using CTMABC. Studying the solvent effect and proposing an appropriate mechanism for the oxidation of the substrates are the main objectives of the investigation.

2 Experimental

2.1 Materials and Methods

Cetyltrimethylammonium bromide and chromium trioxide (CrO_3) were acquired from Fluka [Buchs, Switzerland]. The substituents of benzhydrols used were $[\mathrm{H}, \mathrm{p}-\mathrm{CH}_3, \mathrm{p}-\mathrm{OCH}_3, \mathrm{p}-\mathrm{NO}_2,$ and $\mathrm{p}-\mathrm{Cl}]$. The purity check of commercially supplied benzhydrols was done by their melting points. The solvents [acetone (Me_2CO), acetophenone (Ph_2CO), butanone (Bu), benzene (Bz), 1,2-dichloroethane (DCE), chloroform (CF), cyclohexane (CH), dichloromethane (DCM), CS_2, acetic acid (AA), dimethylsulfoxide (DMSO), nitrobenzene (NB), dimethylformamide (DMF), toluene (TE), tert-butanol (t-BuOH), tetrahydrofuran (THF), 1,2-dimethoxyethane (DME), 1,4-dioxane (DO), and ethyl acetate (EA)] were used and purified by conventional methods[24]. p-Toluene sulfonic acid (TsOH) is employed as the source of H^+ ions to catalyze the reaction.

The earlier reported method was used to prepare CTMABC[18]. The solid CTMABC obtained by filtration was washed with diethyl ether and isopropanol and dried out. The suitable crystals were obtained 1 week after the slow evaporation of the concentrated solution obtained in acetonitrile. The yield obtained was 4.68 g (85%) and M.P. 104°C.

2.2 Product analysis

The oxidation process investigation was performed under kinetic conditions. Corresponding benzophenones are obtained as the products of the oxidation process. The distillation and re-crystallization processes are used for the purification of residual products. All boiling points and melting points of oxidized compounds are verified accordingly.

The free radical test [DNPH-test] was conducted as the reaction is not affected by radical scavengers like excess of the saturated solution of 2,4-dinitophenylhydrazine [DNPH] in HCl solution that was refrigerated overnight. The solvent was separated by filtration and the precipitated DNP was dried, weighed, re-crystallized by using ethanol, and weighed again. The yield of DNP before and after was identical. The experiment was also done with other derivatives of benzhyldols that induced the formation of DNP of the corresponding benzophenone compounds. The obtained result shows that this oxidation process does not involve any free radicals. The iodometric method used for determinations of the oxidation state of Cr in the product obtained observed was +3.

2.3 Kinetic measurements

The pseudo-first-order conditions accustomed to conduct the reaction attained by using significantly excess ($\times$15) of benzhydrols over CTMABC. The UV/vis spectrophotometry having temperature control ($\pm$00.1K) thermostatic bath was used to monitor the progress and completion of the reaction at 350nm wavelength. k_{obs}, were evaluated from Equation (1).

$$ln(A_t - A_\infty) = ln(A_0 - A_\infty) - K_{obs}.t \quad (1)$$

Here,

A_t- Represents the absorbance of the oxidant at time t,

A_∞ - Represents the absorbance of the oxidant at equilibrium state.

The plot of log[CTMABC] against the time obtained is linear (r =0.990–0.999). Clean kinetics was observed with the completion of the reaction with 80% extent in all cases.

3 Results and Discussion

Table 1 presents the observed kinetic data and results obtained for substitutedbenzhydrols [p-H, p-Cl, p-CH_3, p-OCH_3, and p-NO_2].

Table 1. At 298 K value of Rate constants for the oxidation of p-substituted benzhyrols by CTMABC

[BH] (mol/dm^3)	10^3 [CTMABC] (mol/dm^3)	[TsOH] (mol/dm^3)	$10^4 K_{obs}$ (1/s)				
			H	p-OCH_3	p-CH_3	p-Cl	p-NO_2
0.01	1.00	0.10	2.00	7.94	3.09	1.980	0.270
0.01	1.00	0.20	2.25	8.97	3.48	1.480	0.237
0.01	1.00	0.40	2.76	11.00	5.63	1.703	0.246
0.01	1.00	0.60	3.04	12.08	5.87	1.980	0.669
0.01	1.00	0.80	3.35	12.98	5.98	2.209	0.149
0.01	1.00	1.00	3.67	14.57	7.209	2.350	0.310
0.01	1.00	0.00	1.52	6.02	3.98	1.280	0.132
0.02	1.00	0.00	2.90	11.47	5.79	1.780	0.147
0.03	1.00	0.00	4.04	16.14	8.06	2.432	0.209
0.05	1.00	0.00	7.10	28.08	14.03	4.298	0.361
0.10	1.00	0.00	10.2	40.73	19.97	6.162	0.574
0.15	1.00	0.00	13.4	52.82	25.62	8.423	0.682
0.20	1.00	0.00	15.6	61.61	30.19	10.169	0.824
0.20	2.0	0.00	15.2	59.89	28.94	10.452	0.843
0.20	4.0	0.00	15.4	60.35	29.78	10.236	0.854
0.20	6.0	0.00	15.8	62.76	30.04	10.362	0.902
0.20	8.0	0.00	15.7	57.80	30.78	10.491	0.904
0.20	1.0	0.00	15.6*	61.98*	30.64*	10.760*	0.899*

* Contained 0.001 mol/dm^3 acrylonitrile

3.1 Stoichiometry

To investigate the oxidation reaction of substituted benzhydrols by CTMABC, several reaction sets were performed using varying concentrations of substrate and oxidant. The reaction yielded benzophenones as the product, and the overall reaction is represented by Equation (2).

$$(C_6H_5)_2CHOH + \underset{[CTMABC]}{CH_3(CH_2)_{15}N^+(CH_3)_3CrO_3Br^-} \rightarrow (C_6H_5)_2CO + H_2O + Cr(III) \quad (2)$$

3.2 Rate law

The observed reaction is characterized as first order with respect to both the substrate and the oxidant. Linear plots of 2+log(a-x) versus Time(s) (Figure 1) and $1/_{K_{obs}}$ versus 1/[BH] (Figure 2) indicate the first-order dependency on the oxidant. Similar results were observed with respect to the substituted benzhyrols also. The data given in Table 1 also supported the first-order dependency with respect to the oxidant.

$$(\mathrm{C_6H_5})_2\,\mathrm{CHOH} + \mathrm{CTMABC} \overset{k_1}{\rightleftharpoons} [\mathrm{Complex}] \quad (3)$$

$$[\mathrm{Complex}] \xrightarrow[\text{slow}]{K} \mathrm{Products} \quad (4)$$

$$\mathrm{Rate} = \mathrm{Kk_1[BH]\,[CTMABC]} \quad (5)$$

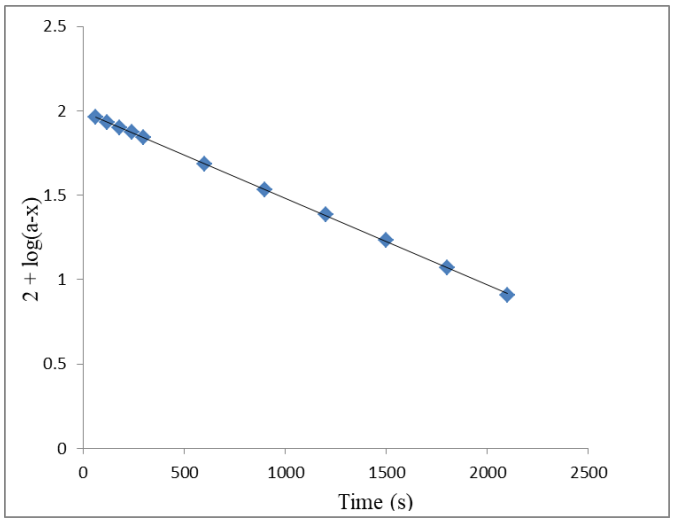


Fig 1. Plot of Oxidation [BH] by CTMABC in DMSO

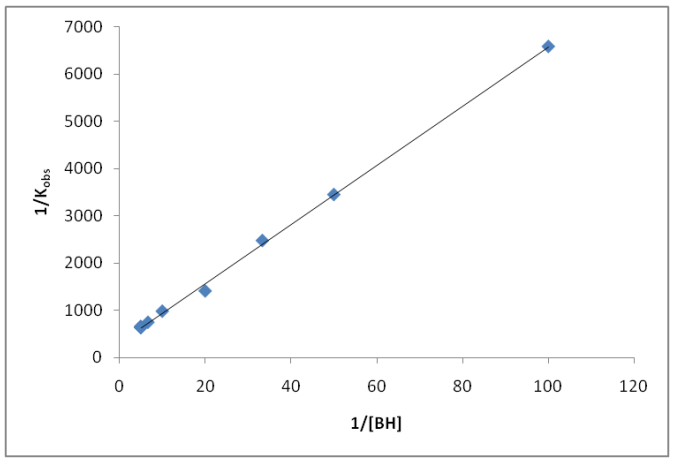


Fig 2. Plot between $1/K_{obs}$ and 1/[BH]

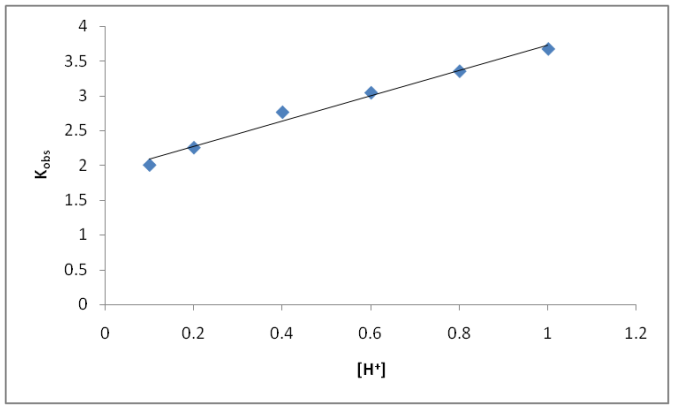


Fig 3. Effect of hydrogen ion concentration on the rate of reaction

3.3 Effect of acidity

Table 1 indicates the changes in reaction rate that correspond to varying H^+ ion concentrations, implying that the reaction is prompted by adding H^+ ions. The dependency on hydrogen ions can be expressed as $k_{obs} = a + b[H^+]$ and by the plot between K_{obs} and $[H^+]$ (Figure 3).

3.4 Free radical test

The oxidation reaction of substituted benzhydols observed the absence of free radicals and the polymerization of acrylonitrile failed to induce in the nitrogen atmosphere (Table 1). That is further confirmed by {2,6-di-tert-butyl-4-methyl phenol} or [BHT] that does not affect the reaction rate.

3.5 Kinetic isotope effect

The involvement of α-C–H bond cleavage (primary kinetic isotope effect) in the rate-determining step was observed by the experiments conducted with α-C-D synthesized benzhydrol. Data observed (Table 2) suggested the presence of a cyclic transition state involving hydrogen transfer.

Table 2. Kinetic isotope effect on the oxidation of benzhydrols by CTMABC

Substrate	$10^5 k_1$, (s^{-1})			
	288 K	298 K	308 K	318 K
H	4.02	7.90	15.3	29.40
α-C-D	0.64	1.22	2.55	4.98
k_H/k_D	6.28	6.47	6.00	5.90

3.6 Structure – reactivity correction

The data observed express the influence of suitable para-substitutes of the benzhydrol molecule on the rate of oxidation. The reaction is prompted by electron-releasing substitutes while retard by the electron-withdrawing substitutes on the phenyl ring.

The structure-reactivity correction provides insight into the nature of the transition state. The reactivity order observed was as follows: ($p\text{-}OCH_3 > p\text{-}CH_3 > p\text{-}H > p\text{-}Cl > p\text{-}NO_2$).

3.7 Solvent effect

The investigation of the solvent effect on the oxidation of substituted benzhydrols was carried out in 19 distinct organic solvents, at a temperature of 308 K. The selection of 19 distinct organic solvents was based on their ability to dissolve both the substrates and oxidant, ensuring that the reactions occur efficiently in the solution phase. There was a limitation on the choice of solvents due to the solubility and reactivity of CTMABC and BH. All the solvent systems give similar or common reaction kinetics, k_2 observed for different solvents is represented in Table 3.

Table 3. Effect of solvents on oxidation of benzhydrols by CTMABC at 308K temperature

Solvents	K(dm^3 / mol)	$10^5 k_2$ (1/s)
Chloroform	5.9	6.2
1,2-Dichloroethane	5.78	8.15
Dichloromethane	4.8	6.23
DMSO	4.32	20.1
Acetone	4.54	5.9
DMF	4.62	10.8
Butanone	4.58	4.92
Nitrobenzene	5.01	8.04
Benzene	5.32	2.03
Cyclohexane	5.02	0.2
Toluene	4.98	1.75
Acetophenone	5.01	9.05

Continued on next page

Table 3 continued		
THF	4.2	3.01
t-Butanol	4.78	2.3
1,4-Dioxane	4.08	3.8
1,2-Dimethoxyethane	5.8	2.16
CS2	4.95	1.02
Acetic acid	5.1	1.3
Ethyl acetate	5.03	2.5

The impact of the solvents on the rate of reaction is expressed by solvation which is a stabilization process. The solvation phenomenon is based on the strength of the interactions between the solute molecules and the solvent. The solvation parameters are used to describe these interactions. Kamlet-Taft's solvation energy linear relationship (Equation (6))[25] correlated these solvent-solvent-solute interactions to get a better and deeper understanding of solvent interactions. This method helped to find that the rate constants were influenced by these interactions and showed a satisfactory correlation.

$$log\, k_2 \;=\; A_0 \;+ p\pi* + b\beta \;+\; a\alpha \tag{6}$$

Here,

π^*- The solvent polarity/polarizability (used for measurement of the ability of the solvent to stabilize charge by separating opposite charges in the transition state).

β - The hydrogen bond acceptor basicity [HBAB] of the solvent (solute to solvent hydrogen bond) (stabilize the anion of the transition state).

α- The H-Bond donor acidity (solvent donates electron pair to the substrate).

A_0- The intercept term.

The results from Kamlet's tri-parametric equation, involving α, β, and π^*, are given in equations Equations (7), (8), (9) and (10) to explain the major solvent effect.

$$\log\, k_2 \;=\; -4.01 + (1.65 \pm 0.25)\pi* + (0.15 \pm 0.08)\beta - (0.14 \pm 0.05)\alpha \tag{7}$$

R^2 = 0.8560; SD = 0.15; n = 18; ψ = 0.30

$$\log\, k_2 \;=\; -4.02 + (1.69 \pm 0.18)\pi* + (0.15 \pm 0.08)\beta \tag{8}$$

R^2 = 0.8524; SD = 0.13; n = 18; ψ = 0.23

$$\log\, k_2 \;=\; -4.03 + (1.71 \pm 0.17)\pi* \tag{9}$$

r^2 = 0.8464; SD = 0.15; n = 18; ψ = 0.29

$$\log\, k_2 \;=\; -3.10 + (0.40 \pm 0.35)\beta \tag{10}$$

r^2 = 0.0770; SD = 0.48; n = 18; ψ = 0.93

Here in correlation analysis,

n- The number of data points,

SD- The coefficient of standard deviation,

ψ- The Exner's statistical parameter[26] (used as the measure of the virtue of fitness),

R^2- The coefficient of determination.

The solvent polarity has a major contribution of around 80% and both α and β have a minor contribution relatively. Swain's equation analyzed the solvent effect of the cation and anion[27]. The data observed putting in the solvating relation (Equation (11)).

$$\log\, k_2 = aA + bB + C \tag{11}$$

Here,

A- The anion-solvating power of solvents,

B- The cation-solvating power of solvents.

(A+B)- The solvent polarity in different solvents.

C- Intercept term.

The solvent effect on the reaction rate is analyzed by Equation (11) the results are shown as follows:

$$\log k_2 = (0.70 \pm 0.04)A + (1.79 \pm 0.04)B - 4.25 \quad (12)$$

R^2 = 0.9986; SD = 0.02; n = 18; ψ = 0.02

$$\log k_2 = (0.56 \pm 0.38)A - 3.01 \quad (13)$$

r^2 = 0.0295; SD = 0.05; n = 18; ψ = 0.98

$$\log k_2 = (1.78 \pm 0.08)B - 4.16 \quad (14)$$

r^2 = 0.9219; SD= 0.10; n = 18; ψ = 0.16

$$\log k_2 = (1.40 \pm 0.13)(A+B) - 4.16 \quad (15)$$

r^2 = 0.8564; SD = 0.16; n = 18; ψ = 0.26

An excellent correlation was observed in different organic solvents by Swain's equation [27]. Data observed from Equation (12) shows that the cation-solvating and anion-solvating powers played major and minor roles, respectively. (A+B) used here to represent the solvent-polarity that accounted for the relative permittivity of the solvents that stand for a major contribution.

The solvent effect data suggested that the polarity observed for the transition state is greater than the reactants that supported the formation of the SN^2-type transition state.

3.8 Thermodynamic parameters

The thermodynamic parameters were evaluated from observed values of k_2 at different temperatures. The Eyring relationships [28] and Eyring's plot help to evaluate the activation parameters. These parameters supported the formation of a cyclic intermediate as an activation complex of the reaction. The negative entropy suggested that the transition state is more organized as compared to the initial state.

The data observed from Eyring relationships and the negative entropy reveals that substituted benzhyrols oxidized via a common reaction mechanism (Scheme 1). The results obtained from the thermodynamic study on the formation and decomposition of the complexes are depicted in Tables 4, 5, 6 and 7.

Table 4. At different temperatures value of Formation constants of CTMABC-BH complexes

K (dm^3 /mol)			
288 K	**298 K**	**308 K**	**318 K**
7.16	5.64	4.33	3.24

Table 5. Thermodynamic parameters of CTMABC-BH complexes

$-\triangle$H (kJ /mol)	$-\triangle$S (J /mol K)	$-\triangle$G (kJ /mol)
21.9 ± 0.2	52 ± 2	6.7 ± 0.2

Table 6. For the decomposition of CTMABC-BH complexes the value of rate constants at different temperatures

10^4 k_2 (dm^3 /mol s) at			
288 K	**298 K**	**308 K**	**318 K**
7.20	14.5	28.6	56.0

Table 7. Activation parameters for the decomposition of CTMABC-BH complexes

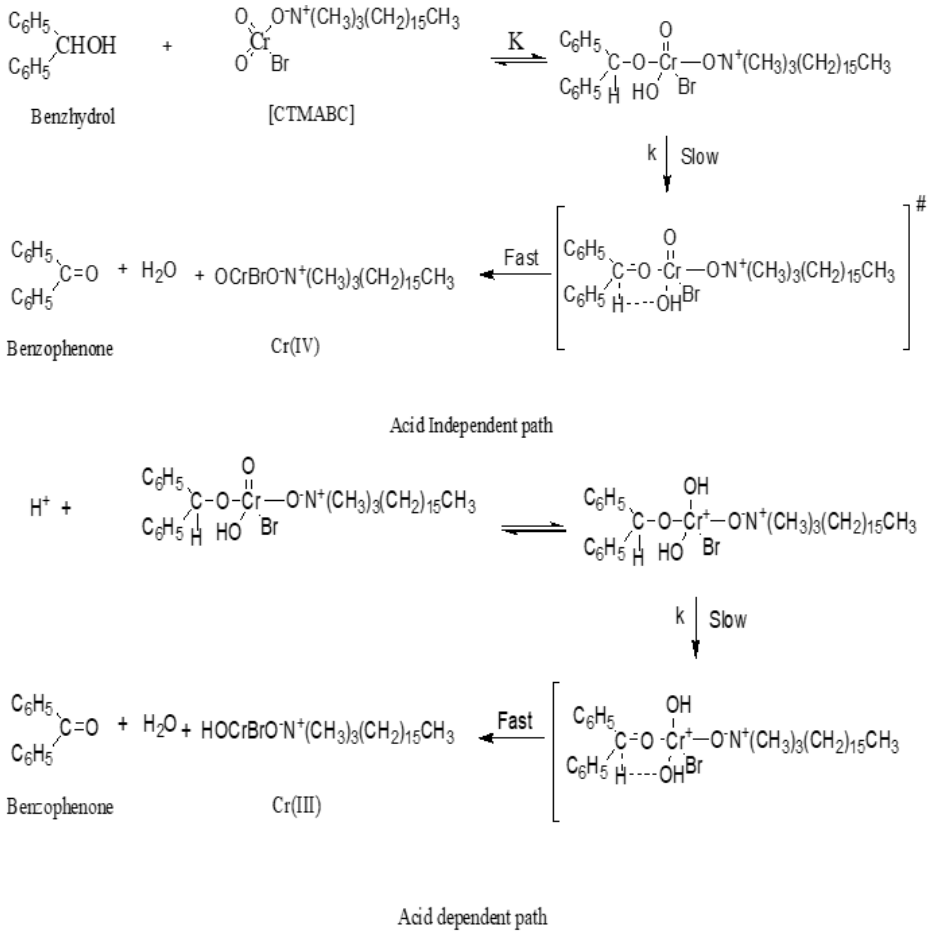
$\triangle$H* (kJ/mol)	$-\triangle$ S*	$\triangle$ G*
50 ± 0.5	129 ± 2	89 ± 0.5

4 Mechanism

The absence of any free radicals is found in the oxidation of benzhydrols by CTMABC. The added acrylonitrile and radical scavenger in the atmosphere of nitrogen do not affect the reaction rate. The oxidation process is compared with the oxidation approach of benzhydrols by tributylammonium chlorochromate (TriBACC)[22] and triethylammonium chlorochromate (TriEACC)[29]. The reaction order observed was first order concerning both the oxidant and the substrate. The hydrogen ion effect and the solvent effect are comparable to the discussed cases[22,29].

The transfer takes place via an ester intermediate during a cyclic process as given by Woodward and Hoffmann 1969[30] or via a one-step bimolecular process during an acyclic process. The transfer of hydride ion in the rate-determining step was suggested by the presence of negative reaction constants and the kinetic isotope effect (Scheme 1), The mechanism is supported by the kinetic isotope effect data and thermodynamic data. A cyclic, planar, and symmetrical transition state as ester intermediate decomposed to the product.

The following mechanism has been proposed:



Scheme 1: **Mechanism for the oxidation of Benzhydrols by CTMABC**

5 Conclusion

A mechanistic and kinetic aspect involved in the oxidation of various para-substituted benzhydrols by cetyltrimethylammonium bromochromate in dimethylsulfoxide is studied. The reaction produced corresponding benzophenones as the product of the reaction. The reaction was kinetically first-order dependent on both CTMABC and BH and was catalyzed by hydrogen ions. The solvent effect was analyzed and evaluated by using Kamlet's and Swain's multi-parametric equation, which showed that solute-solvent interactions played a significant role in the reaction's reactivity. The proposed mechanism for the oxidation reaction was

supported by several thermodynamic and kinetic parameters, and the validity of the isokinetic relationship was evaluated. This work provides valuable insights into the oxidation of benzhydrols, for further research in this field.

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References

1) Yajurvedi D, Kumbhani S, Shashtri I, Sharma PK. Kinetics and mechanism of the oxidation of DL-methionine by quinolinium bromochromate. *Journal of the Indian Chemical Society*. 2008;85(4):459–461. Available from: https://www.researchgate.net/publication/288752567_Kinetics_and_mechanism_of_the_oxidation_of_DL-methionine_by_quinolinium_bromochromate.
2) Soni N, Tiwari V, Kumbhani S, Shastri I, Sharma V. Kinetics and Mechanism of the Oxidation of Aliphatic Aldehydes by Morpholinium Chlorochromate. *Journal of the Indian Chemical Society*. 2008;85(8):857–861. Available from: https://www.researchgate.net/publication/287684888_Kinetics_and_mechanism_of_oxidation_of_aliphatic_aldehydes_by_morpholinium_chlorochromate.
3) Tiwari V, Kumbhani S, Shastri I, Sharma V. Kinetics and mechanism of oxidation of some thioacids by benzyl trimethylammonium chlorobromate. *Indian Journal of Chemistry*. 2008;47:1520–1523. Available from: https://nopr.niscpr.res.in/bitstream/123456789/2222/1/IJCA%2047A%2810%29%201520-1523.pdf.
4) Malani N, Baghmar M, Sharma PK. Kinetics and mechanism of the oxidation of some organic sulfides by morpholinium chlorochromate. *Int J Chem Kinet*. 2009;41(1):65–72. Available from: https://doi.org/10.1002/kin.20372.
5) Singh JV. Tetraethylammonium Chlorochromate: a novel oxidant, kinetic and mechanistic aspect. *Acta Ciencia Indica*. 2017;43(4):447–455. Available from: https://www.acta.co.in/acta-bo/files/published_general/5cd91add8cccc-164-C017.pdf.
6) Mohammadi MK. Dabco Ammonium Halochromates- Reagents for Efficient and Mild Oxidation of Organic Substrates. *Iran J Sci Technol Trans A Sci*. 2018;42(3):1185–1189. Available from: https://www.researchgate.net/publication/364054952_Dabco_Ammonium_Halochromates_C_6_H_14_N_2_comma_Cr_2_F_2_O_6_comma_--_DAXC_X_5_F_Cl_Reagents_for_Efficient_and_Mild_Oxidation_of_Organic_Substrates.
7) Venkatapathy M, Venkatesan M, Anbarasu K. Mechanistic aspect for the oxidation of Benzaldehyde by Piperidinium Chlorochromate. *J Adv Sci Res*. 2020;11(1):348–352. Available from: https://sciensage.info/index.php/JASR/article/view/453/356.
8) Arora B, Ojha J, Mishra P. Kinetics and mechanism of oxidation of aliphatic secondary alcohols by benzimidazolium fluorochromate in dimethyl sulphoxide solvent. *Orient J Chem*. 2021;37(3):626–633. Available from: http://dx.doi.org/10.13005/ojc/370315.
9) Rao A, Purohit T, Swami P, Purohit P, Sharma PK. kinetics and mechanism of oxidation of some thioacids by morpholinium fluorochromate. *Eur Chem Bull*. 2016;5(5):189–192. Available from: https://www.bibliomed.org/?mno=70092.
10) Rao A, Singh N, Mahawar DK, Mahawar P. Kinetics and mechanism of the oxidation of cysteine by imidazolium dichromate. *J Indian Chem Soc*. 2022;99(4). Available from: https://doi.org/10.1016/j.jics.2022.100386.
11) Patel S, Kuanar M, Nayak BB, Banichul H, Mishra BK. Cetyltrimethylammonium dichromate: a phase transferring oxidant. *Synth Commun*. 2005;35(8):1033–1037. Available from: https://www.researchgate.net/publication/250463524_Cetyltrimethylammonium_Dichromate_A_Phase-Transferring_Oxidant.
12) Hassanijoshaghani A, Ghammamy S, Bagi S, Moghimi A, Javanshir Z. Oxidative coupling of thiols to disulfides in solution with tripropylammonium halochromates, (c3h7)3nh[cro3x], (x=f,cl) adsorbed on alumina. *Phosphorus, Sulfur, and Silicon and the Related Elements*. 2008;184:164–170. Available from: https://doi.org/10.1080/10426500802081137.
13) Alangi SZS, Baei MT. N-Ethylbenzylammonium fluorochromate (VI) adsorbed on silica gel, a mild and selective heterogenous reagent. *Journal of the Mexican Chemical Society*. 2010;54(4):223–226. Available from: https://www.researchgate.net/publication/262614165_N-Ethylbenzylammonium_Fluorochromate_VI_Adsorbed_on_Silica_Gel_a_Mild_and_Selective_Heterogeneous_Reagent.
14) Mansoor SS, Shafi SS. Studies on the kinetics of tetraethylammonium bromochromate oxidation of some meta- and para-substituted benzyl alcohols in non-aqueous media. *Zeitschrift Für Physikalische Chemie*. 2011;225:249–263. Available from: https://doi.org/10.1524/zpch.2011.0044.
15) Mansoor SS, Shafi SS. Oxidation of methionine by Tetraethylammonium chlorochromate in non-aqueous media-a kinetic and mechanistic study. *Arab J chem*. 2015;8(4):480–486. Available from: https://doi.org/10.1016/j.arabjc.2011.01.031.
16) Şendıl K, Özgün HB, Üstün E. Two new 1,1,3,3-Tetramethylguanidinium halochromates (c5h14n3cro3x) (x: cl, f): efficient reagents for oxidation of organic substrates under solvent-free conditions and microwave irradiation. *Journal of Chemistry*;2016:1–7. Available from: https://onlinelibrary.wiley.com/doi/epdf/10.1155/2016/3518102.
17) Mansoor SS, Shafi SS. Correlation analysis of reactivity in the oxidation of some organic diols by tripropylammonium fluorochromate in non-aqueous media. *Arabian Journal of Chemistry*. 2016;9:S602–S609. Available from: https://www.sciencedirect.com/science/article/pii/S1878535211001870.
18) K MM, S G, H I. Microwave-assisted Oxidation of Alcohols and Polyarenes with Cetyltrimethylammonium Bromochromate. *Chinese Journal of Chemistry*. 2009;27(8):1501–1504. Available from: https://dx.doi.org/10.1002/cjoc.200990252.
19) Ghammamy S, Eimanieh H, Mohammady MK. Cetyltrimethylammonium bromochromate: a new and efficient oxidant for organic substrates. *Synthetic Communications*. 2007;37(4):599–605. Available from: https://doi.org/10.1080/00397910601055164.
20) Ramanujam VMS, Venkatasubramanian N, Sundaram S. Chromic acid oxidation of benzhydrols-kinetics and mechanism. *Australian Journal of Chemistry*. 1977;30(2):325–334. Available from: https://dx.doi.org/10.1071/ch9770325.
21) Basheer KM, Joseph J, Nair TD. Catalysis by onium salts on the monochromate oxidation of benzhydrols in non-polar media-A kinetic study. *Indian J Chem*. 2007;46:273–275. Available from: https://nopr.niscpr.res.in/bitstream/123456789/923/1/IJCA%2046A%282%29%20%282007%29%20273-275.pdf.
22) Mansoor SS, Shafi SS. Oxidation of benzhydrol by tributylammonium chlorochromate: a kinetic and mechanistic study. *Reaction Kinetics, Mechanisms and Catalysis*. 2010;100(1):21–31. Available from: https://dx.doi.org/10.1007/s11144-010-0148-4.

23) Basheer KM, Joseph J, Nair TDR. Kinetics of the Oxidation of Benzhydrols with Permanganate under Phase Transfer Catalysis in Organic Solvents. *Modern Research in Catalysis*. 2013;02(02):35–38. Available from: https://dx.doi.org/10.4236/mrc.2013.22005.
24) Perrin DD, Armarego WL, Perrin DR. Purification of Laboratory Chemicals. In: Purification of Organic Compounds. Pergamon Oxford. 1966;p. 1–544. Available from: https://www.sciencemadness.org/scipics/refs/W.L.F.Armarego,%20D.D.Perrin%20-%20Purification%20of%20Laboratory%20Chemicals.%204th%20edition.pdf.
25) Kamlet MJ, Abboud JLM, Abraham MH, Taft RW. Linear solvation energy relationships. 23. A comprehensive collection of the solvatochromic parameters, .pi.*, .alpha., and .beta., and some methods for simplifying the generalized solvatochromic equation. *The Journal of Organic Chemistry*. 1983;48(17):2877–2887. Available from: https://dx.doi.org/10.1021/jo00165a018.
26) Exner O. Entropy–enthalpy compensation and anticompensation: solvation and ligand binding. *Chemical Communications*. 2000;17(17):1655–1656. Available from: https://dx.doi.org/10.1039/b002758h.
27) Swain CG, Swain MS, Powell AL, Alunni S. Solvent effects on chemical reactivity. Evaluation of anion- and cation-solvation components. *Journal of the American Chemical Society*. 1983;105(3):502–513. Available from: https://dx.doi.org/10.1021/ja00341a033.
28) Eyring H. The Activated Complex in Chemical Reactions. *The Journal of Chemical Physics*. 1935;3(2):107–115. Available from: https://dx.doi.org/10.1063/1.1749604.
29) Mansoor SS, Shafi SS, Ahmed SZ. Correlation analysis of reactivity in the oxidation of some para - substituted benzhydrols by triethylammonium chlorochromate in non-aqueous media. *Arabian Journal of Chemistry*. 2017;10:S1129–S1137. Available from: https://dx.doi.org/10.1016/j.arabjc.2013.02.005.
30) Woodward RB, Hoffmann R. The Conservation of Orbital Symmetry. *Angewandte Chemie International Edition in English*. 1969;8(11):781–853. Available from: https://dx.doi.org/10.1002/anie.196907811.