Kinetics and Mechanistic Approach of the Selective Oxidation of n-Butyric Acid Hydrazide to the Corresponding Acid by Thallium (III) in 1, 4-Dioxane Medium

Dr. Amit Shrikant Varale

*Department of Chemistry, A.S.P. College, Devrukh-415804 Dist-Ratnagiri Maharashtra State, India

Abstract: *The reaction between Thallium (III) and n-Butyric acid hydrazide is carried out in a mixture of perchloric and hydrochloric acid medium. The reaction proceeds through formation of complex with reactant, which decomposes in subsequent steps to give product. Effect of acrylonitrile shows, that there is no formation of free radicals. The increase in $[H^+]$ and $[Cl^-]$ decreases the rate of the reaction. The increase in ionic strength does not affect the rate of reaction. The effect of temperature was studied at four different temperatures ranging from 15^0C to 30^0C. The activation parameters were also determined and a mechanism is predicted.*

Keywords: kinetics, Thallium(III), Oxidation, n-BuAH

1. Aims and Background

Chemical kinetics, also known as reaction kinetics, is the study of rates of chemical processes. Chemical kinetics includes investigations of how different experimental conditions can influence the speed of a chemical reaction and yield information about the reaction's mechanism and transition states, as well as the construction of mathematical models that can describe the characteristics of a chemical reaction. In 1864, Peter Waage and Cato Goldberg pioneered the development of chemical kinetics by formulating the law of mass action, which states that the speed of a chemical reaction is proportional to the quantity of the reacting substances.

Generally, in most of the reactions, particularly organic ones, the products obtained are dependent on the course of the reaction which is governed by the reaction rates of several complicating reactions. Therefore, the investigation of reaction mechanism needs the study of reaction rates.

Thallium oxide is one of the versatile available oxidizing agents used for oxidation of hydrazide. The reaction of hydrazide with most oxidants give the corresponding acids[1] and in some cases[2] esters or amides. Thallium(III) salts are well known oxidants[3] in organic synthesis. The redox potential of Tl(III)/Tl(I) couple is sensitive to the anion present in the solution. In perchloric and sulphuric acid media[4] it has the highest value of 1.23V with eitherfreeTl[3+],TlOH[2+] or thallium(III) sulphate complexes as active species respectively. Therefore, thallium(III) can be utilized both as a strong (in perchloric acid and sulfuric acid media) and as a mild oxidant[5] (in hydrochloric acid medium) by changing the reactive species.

The hydrazides are pharmaceutically important compounds used as antitubercular[6]and antibacterial[10,11] agents, some of them have been reported to possess anti-inflammatory[12] and diuretic[13] activities. The reaction of hydrazides with most oxidants give the corresponding acids[14] and in some cases[15]

esters or amides. Thallium(III) salts are well known oxidants in organic synthesis. The redox potential of Tl(III)/Tl(I) couple is sensitive to the anion present in the solution. In perchloric and sulphuric acid media it has the highest value of 1.23V with either free Tl[3+],TlOH[2+] or thallium(III) sulphate complexes as active species respectively. Therefore, thallium(III) can be utilized both as a strong and mild oxidizing agent.Hence, the present work deals with the kinetics and mechanism of oxidation of n-Butyric acid hydrazide by thallium(III) in acidic medium.

2. Experimental

Thallium (III) solution was prepared by dissolving Tl_2O_3 (ACROS) in 1.0 moldm[-3] HCl and the concentration was ascertained by iodometric titration. The n-Butyric acid hydrazide was prepared from reported[16] procedure and characterized by determining their melting points. Stock solution of n-butyric acid hydrazide was prepared in 50 % v/v, 1,4-dioxan. Ionic strength was kept constant.

The reactions were carried out in 50 % v/v 1-4 dioxane (s.d.fine.chem) under pseudo first order conditions keeping concentration of hydrazide in large excess over that of the oxidant. The solutions containing the reactants and all other constituents were thermally equilibrated separately, mixed and the reaction mixture was analysed for unreacted thallium (III) iodometrically by titrating against standard thiosulphate. The pseudo-first order rate constants were determined from the slopes of linear log[Tl(III)] versus time plots. The results were reproducible up to ± 5 %. Kinetic runs were followed to about three half-lives of the reactions. Under the experimental condition oxidation of 1,4-dioxan did not occur.

End Product Analysis
For identification of products the reaction was carried out by using aqueous solution of hydrazide, Thallium(III), HCl and $HClO_4$. The flask containing reaction mixture was kept in thermostated water bath maintained at 50^0C for 24 hours

to complete the reaction, the residue obtained after filtration was analysed for acid as follows

1) The presence of n-Butyric acid group was detected by testing with bicarbonate.

2) The formation of acid was confirmed by IR and its melting point.

$$RCONHNH_2 + 2\,Tl\,(III) + H_2O \rightarrow R\text{-}COOH + N_2 + 4H^+ + 2\,Tl\,(I) \quad ...(1)$$

3. Results and Discussion

The reaction occurs rapidly in perchloric acid medium but in the presence of hydrochloric acid the rate is measurable. Therefore, the reaction was carried out in a mixture of both the acids. The effect of reactants on the reaction was studied at constant [HCl] and [HClO$_4$] of 0.1 mol dm^{-3} each and ionic strength of 0.6 mol dm^{-3}. Concentration of oxidant was varied from 6.4×10^{-4} to 6.4×10^{-3} mol dm^{-3} keeping the [hydrazide] constant at 1×10^{-1} mol dm^{-3}.Since,the pseudo first order rate constants were fairly constant($3.1 \pm 0.1 \times 10^{-4}$ s^{-1} for n-BuAH at, the order with respect to [oxidant] is unity. The effect of [hydrazide] was studied between the concentration range from 1×10^{-2} to 1×10^{-1} mol dm^{-3} keeping the [oxidant] constant at 3.0×10^{-3} mol dm^{-3}.The pseudo first order rate constants increases with increase in concentration and the order with respect to hydrazide is found to be fractional.
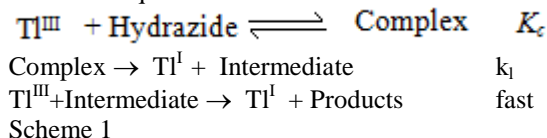
To study the effect of [H$^+$] and [Cl$^-$],[oxidant], [hydrazide] and ionic strength were kept as 3.0×10^{-3},1×10^{-1} and 0.6 mol dm^{-3} respectively. To vary [H$^+$] and [Cl$^-$], HClO$_4$ and NaCl were used. Increase in [H$^+$] from 0.13 to 0.60 mol dm^{-3} decreases 10^{-4} k(s^{-1}) from 28.71 to 0.21 for n-BuAH at 25^{0}C. Increase in [Cl$^-$] from 0.13 to 0.60 mol dm^{-3} decreases 10^{-4} k(S^{-1}) from 4.13 to 0.15 for n-BuAH at 25^{0}C. The relative permittivity was varied by changing the 1,4-dioxan content from 5 to 40 % v/v. The rate was found to decrease with decrease in relative permittivity.

Added acrylonitrile in the concentration range 0.5 to 2.5vol.% by keeping concentrations of oxidant,reductant,perchloric acid,hydrochloric acid and ionic strength fixed did not produce any precipitate due to polymerization of the added acrylonitrile on the pseudofirst order rate constants indicating absence of free radical

Effect of Temperature

Michalie's-Menten plot
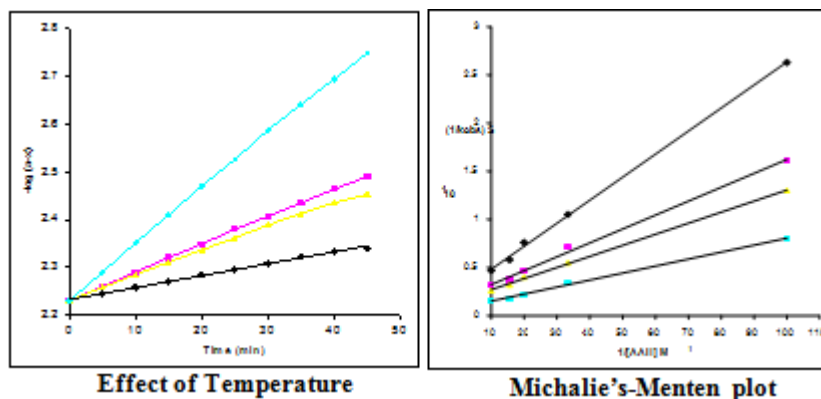
Since there is no formation of free radicals in the reaction, the reaction proceeds with two-electron transfer step. The order in thallium (III) was found to be unity and the order in hydrazide was found to be fractional. Such fractional order in substrate concentration is due to the prior complex formation equilibrium between the reactants.

$$Tl^{III} + Hydrazide \rightleftharpoons Complex \qquad K_c$$

Complex $\rightarrow$ Tl^I + Intermediate $\qquad$ k$_1$

Tl^{III}+Intermediate $\rightarrow$ Tl^I + Products $\qquad$ fast

Scheme 1

The Micheatis - Menten plots of 1/k$_{obs}$ versus 1/[Hydrazide] were linear with an intercept in support of the complex formation. Therefore, in agreement with the results obtained the mechanism of the reaction can be represented as in Scheme 1. Equation 2 gives the rate according to Scheme1. Since, total [Tl^{III}] exists in the form of free [Tl^{III}] and the complex (Equation 3) therefore, the [Tl^{III}] free is given by Equation 6. The overall rate law is now expressed by Equation 7 and the Pseudo-first order rate constant k$_{obs}$, by Equation 8.

$$\text{Rate} = k_1[\text{Complex}] = k_1 K_c [\text{Hydrazide}]_{free} [Tl^{III}]_{free} \quad (1)$$
$$[Tl^{III}]_{total} = [Tl^{III}]_{free} + [\text{Complex}] \quad (2)$$

$$[Tl^{III}]\ total = [Tl^{III}]_{free} + K_c [\text{Hydrazide}] [Tl^{III}]_{free} \quad (3)$$
$$[Tl^{III}]_{free} = [Tl^{III}]_{total}/(1 + K_c [\text{Hydrazide}]) \quad (4)$$
$$\text{Rate} = k_1 K_c [\text{Hydrazide}] [Tl^{III}]_{free} \quad (5)$$
$$k_{obs} = k_1 K_c [\text{Hydrazide}]/(1 + K_c [\text{Hydrazide}]) \quad (6)$$

Rate law 8 is verified by plotting 1/kobs against 1/[Hydrazide] at four different temperatures and from the slopes and intercepts of these plots the values of k$_1$ and K$_c$ were calculated and are given in Table 1.

The effect of hydrogen and chloride ion concentrations on the reaction is due to the protonation of hydrazides[17] and different chloro – complexes[18] of thallium (III) present in the solution. in acid medium according to Equation 9. Hydrazides are known to be protonated, therefore, total [Hydrazide] can be expressed by Equation 10 and thereby the fact that there was no effect of free [Hydrazide] by Eq. 12. Since the rates of reaction decreases as the [H$^+$] increases, free hydrazide is the active species, this is in support of ionic strength on the reactions indicating one of the reactant is neutral.
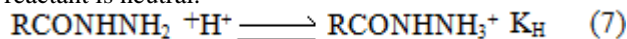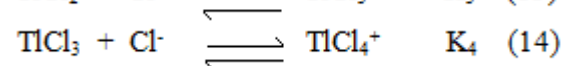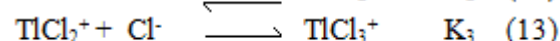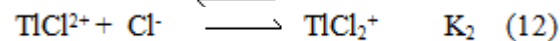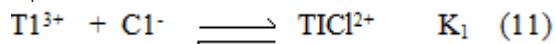
$$RCONHNH_2 + H^+ \rightleftharpoons RCONHNH_3^+ \quad K_H \quad (7)$$
$$[\text{Hydrazide}]_{total} = [\text{Hydrazide}]_{free} + [\text{Hydrazide}]_{protonated} \quad (08)$$

$$[Hydrazide]_{total} = [Hydrazide]_{free} + K_H [Hydrazide]_{free} \quad (09)$$

$$[Hydrazide]_{free} = [Hydrazide]_{total} /(I+ K_H [H^+]) \quad (10)$$

Thallium (III) forms strong complexes with chloride ions of the formula $TlCl_n^{3-n}$ where n is the number of chlorides complexes with thallium(III) as represented in equilibrium 13 to 16. The values of respective stability constants[19] are $K_1 = 1.38 \times 10^8$, $K_2 = 3.98 \times 10^{13}$, $K_3 = 6.02 \times 10^{15}$ and $K_4 = 1.0 \times 10^{18}$ $mol^{-1}dm^3$.

$$Tl^{3+} + Cl^- \rightleftharpoons TlCl^{2+} \quad K_1 \quad (11)$$

$$TlCl^{2+} + Cl^- \rightleftharpoons TlCl_2^+ \quad K_2 \quad (12)$$

$$TlCl_2^+ + Cl^- \rightleftharpoons TlCl_3^+ \quad K_3 \quad (13)$$
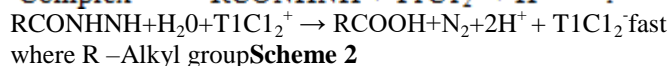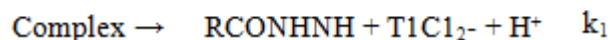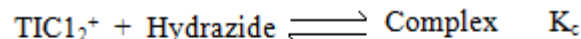
$$TlCl_3 + Cl^- \rightleftharpoons TlCl_4^+ \quad K_4 \quad (14)$$

All the thallium(III) will exists as $TlCl_2^+$ and its concentration can be expressed by Equation 17. The $[TlCl_2]^+_{free}$ can now be given by eq. 19 where, $\beta_1 = K_3/K_2 = 151$ and $\beta_2 = K_4/K_3 = 166$, further, using Equations 18 and 19 the concentrations of $[TlCl_2]^+_{free}$, $TlCl_3$ and $TlCl_4^-$ were calculated at different chloride ion concentrations and compared with the change in rate constant as the chloride ion concentration varied.

$$[Tl (III)]_{total} = [TlCl_2^+]_{total} = [TlCl_2^+]_{free} + [TlCl_3] + [TlCl_4] \quad (15)$$

$$[TlCl_2^+]_{total} = [TlCl_2^+]_{free} (1+\beta_1[Cl^-] + \beta_2[Cl^-]^2) \quad (16)$$

$$[TlCl_2^+]_{free} = [TlCl_2^+]_{total} / (1 + \beta_1[Cl^-] + \beta_2[Cl^-]^2) \quad (17)$$

The concentration of both of $[TlCl_2^+]_{free}$ and $TlCl_3$ parallel the values of rate constants as $[Cl^-]$ changes but the order $[Cl^-]$ is -1.5, which makes $[TlCl_2^+]_{free}$ as the only active species.

$$TlCl_2^+ + Hydrazide \rightleftharpoons Complex \quad K_c$$

$$Complex \rightarrow RCONHNH + TlCl_2- + H^+ \quad k_1$$

$$RCONHNH+H_2O+TlCl_2^+ \rightarrow RCOOH+N_2+2H^+ + TlCl_2^- fast$$

where R –Alkyl group**Scheme 2**

The mechanism considering $TlCl_2^+$ of oxidant and free hydrazide of the substrate as the active species can now be represented by scheme 2 with respective rate law and the expression for the pseudo-first order rate constants by Equations 20 and 21. The rate law 21 was verified by plotting $1/k_{obs}$ against $1/[Hydrazide]$ and $1/k_{obs}$ against $[H^+]$ which were found to be linear. From the slopes and intercepts of these plots the values of K_c and K_H were determined. The values of K_c are given in Table 1 and those of K_H were found to be 13 and 16 mol^{-1} dm^3 for heterocyclic acid hydrazides respectively.

$$Rate = \frac{k_1 K_c [Hydrazide]_{total} [TlCl_2^+]_{total}}{(1+K_c [Hydrazide]) (1+K_H[H^+]) (1+\beta_1[Cl^-]+\beta_2 [Cl^-]^2)} \quad (18)$$

$$k_{obs} = \frac{k_1 K_c [Hydrazide]_{total}}{(1+K_c [Hydrazide]) (1+K_H[H^+]) (1+\beta_1 [Cl^-]+\beta_2[Cl^-]^2)} \quad (19)$$

The electrophilic character of $TlCl_2^+$ among the thallium (III) chlorocomplexes is highest thus making it the reactive species. Table 1– values of Kc and k_1 [HCl] = 0.1 $moldm^{-3}$, $[HClO_4]$ = 0.1 $moldm^{-3}$ $[Tl^{III}]$ = 3.0 $\times 10^{-3}$ mol dm^{-3}, I = 0.6 mol dm^{-3}

Hydrazide	Kc. (mol dm^{-3})			
	15°C	20°C	25°C	30°C
n-BuAH	9.20	9.22	9.23	9.25

Mechanism
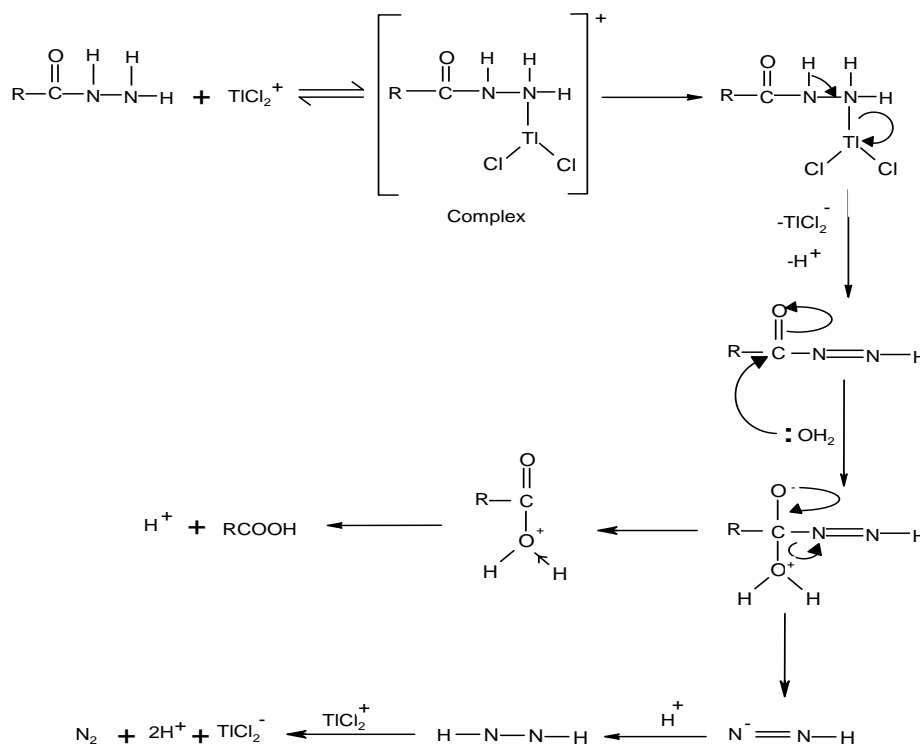
R=Alkyl group for acid hydrazides

Scheme 3

The detailed mechanism involves electrophilic substitution on the nitrogen of the hydrazide with the formation of N-Tl bond, which decomposes in the subsequent step with, direct two-electron transfer from hydrazide to thallium to give an intermediate followed by fast steps. (Scheme 3). Such N-T1 bond formation has been postulated during thallium (III) oxidation of nitrogen[20] containing compounds.

The activation parameters, with respect to slow step, k_1, $\Delta H^{\#}$(KJ mol^{-1}), $\Delta G^{\#}$ (KJ mol^{-1}) and $\Delta S^{\#}$ (JK^{-1}mol^{-1}) were found to be 38.54,118.16and -107.50respectively for n-BuAH. Considerable decrease in the entropy of activation is due to formation of more ordered transition state as shown in scheme 3. The mechanism involves neutral hydrazide as the active substrate thus the reaction is unaffected by the change in the ionic strength. The increase in 1,4-dioxan content in the reaction medium decreases; the rate such an effect of the solvent is due to the stabilization of the complex formed between reactants[13] in a medium of low relative permittivity[21-25].

4. Conclusion

The order of reactivity of n-Butyric acid hydrazide under investigation is -

n-BuAH <BAH.

In case of n-butyric acid hydrazide, the electron donating inductive effect of alkyl group is weaker and has negligible effect on reactivity.

5. Acknowledgement

References

[1] a) Ho T.L., Ho H. C. and Wong C. M., Synthesis., 1972,562.
b) SchnyderJ. and RttenbergM., Helv. Chim. Acta.,1975,521,58.
c) TsujiJ., TakayanagiH. and ToshidaY., Chem. Lett., 1976, 147.

[2] a) AylwardJ. B., NormanR. O. C., J. Chem. Soc.(C).,1968,2399.
b) Tsuji J and HayakawaH., Chem. Lett., 1975, 437.
c) TsujiJ, NagashimaT., QuiN. T, and TakayanagiH., Tetrahedron., 1980,1311,36.
d) HoffmanR. V. and.KumarA. J, J. Org. Chem., 1984,4014,49.

[3] Mckillop and TaylorE. C., Organic synthesis by oxidation with metal compounds., W. J. Mijs, C. R. H. J. de Jonge, Plenum: Newyork, ,5th edn., 1989,695.

[4] SouthJr. and OuelletteR. J, J. Am. Chem. Soc.,1980,7064, 90.

[5] a) MckillopA, HuntJ. D and J.TaylorE. C., Am. Chem. Soc.,1971,4918, 93.

b) Butler R.N., Morris G. J. and O'Donohue, J. Chem. Res.(S)., 1981, 61.
c).TaylorE.C, RobeyR. L, MckillopA. A., Angew.Chem. Int. Ed.,Engl.,1972),148,11.
d) TaylorE. C.,.RobeyR. L, MckillopA. A., J. Org. Chem., 1972,2797,37..
e). Silveria Jr. A, Angelastro M., Israel R., Totino F. and Williamsen P. J., J. Org. Chem., 1980,3522,45.

[6] WernerW. : J org chem,1953,133,18.

[7] MadzhoyanA.L. : Arm Khim Zh,1966,793, 19.

[8] Winterstein,A., HegedusH. Helv.Chem.Acta.,1956,229, 39.

[9] PfisterR, Soilman A.Chem Abstract,,1968,492,68.

[10] Jucker F. and Linde A., Nomann Helv chim Acta.,1962,2316,45.

[11] Vogel A. I., Textbook of practical organic chemistry., (ELBS &Longman Group) 4th Edn.,1975, 1125.

[12] WeastR .C., Handbook of chemistry and physics, 50th edn.,(CRC) 1970.

[13] a) Kazo K, Hirakazo T., Hisashi K and Zenzo T, Chem. Pharm. Bull., 1963,797,11..
b) Krishnarao P. V., Frank M. S. and Ramaih A. K, React. Kinet. Cata.Lett., 1978,59, 9..
c) Krishnarao P.V., Frank M. S. and. Ramaih A.K, Indian J. Chem., 1978,418,16A..
d) RamaihA.K., Frank M. S., Baburao G and Krishnarao P.V, Indian J. Chem.,1979,416,**18A.**

[14] WeastR. C. Handbook of chemistry and physics.edited by,50th edn.(CRC) 1970.

[15] a) KazoK,, HirakazoT., HisashiK. and ZenzoT.,Chem. Pharm. Bull,1963,797, 11.
b). KrishnaraoP. V., FrankM. S and Ramaih A. K, React. Kinet. Cata. Lett,1978,59, 9.
c) KrishnaraoP.V., FrankM. S.and RamaihA.K.Indian J. Chem,1978,418,16A..
d) RamaihA.K,Frank,M. S.Baburao,G. and Krishnarao, P.V. Indian J Chem, 1979,416,18A.

[16] LeeA. G.The Chemistry of Thallium, (Elsevier, London) 1971,48.

[17] a) Mckillop, A. HuntJ.D. , NaylorR. D. and TaylorE. C.,J. Am. Chem, 1971 4918,93.
b) Buttler R.N, MorrisG. J. and A. M O' Donohue :J. Chem. Res. (s) Soc,1981,61.

[18] Amis,E. S. Solvent effects on reaction rates and mechanisms,(Academic Press New York) 1966.

[19] Varale, A.S., .Hilage, N.P., Oxidation of nicotinic acid hydrazide by Thallium (III) in acidic medium: a kinetic and Mechanistic study, Int. J. Chem. Sci., 2009, 2173-22782,7(3).

[20] Varale, A.S., .Hilage, N.P.,Comparative Kinetic Study of Oxidation of Toluic Acid Hydrazides by Thallium(III) in Acidic Medium, Oxidation Communications., 2009,867–873 32(4).

[21] Varale, A.S., .Hilage, N.P.,Kinetic and Mechanistic study of oxidation of isonicotinic acid hydrazide by Thallium (III) in acidic medium, International Journal of ChemTech Research, 2009,) 270-274,1(2).

[22] Varale, A.S., .Hilage, N.P.,Kinetic and Mechanistic Study of Oxidation of Salicylic acid Hydrazide by Thallium (III) in Acidic Medium, International Journal of ChemTech Research., 2011,357-363,3(1).

[23] Varale, A.S., .Hilage, N.P., Comparative Kinetic and Mechanistic Study of Oxidation of Benzoic, o-Toluic,

p- Toluic Benzoic acid Hydrazides with Thallium (III) in Acidic Medium, Oriental Journal of Chemistry,2011,113-118, 27(1).

[24] Varale, A.S., .Hilage, N.P., Comparative Kinetic and Mechanistic Study of Oxidation of Heterocyclic Acid Hydrazides by Thallium(III) in Acidic Medium, Oxidation Communications., 2012, 371-377, 35(2)..

[25] Varale, A.S., .Hilage, N.P., Oxidation of o-Toluic Acid Hydrazide by Thallium (III) inAcidic Medium (A Kinetic and Mechanistic, Oriental Journal of Chemistry, 2013,667-672, 29(2)..