Study of Some Parameters on the Rate of the Catalyzed Decomposition of Hydrogen Peroxide by [H$_5$LFe$_2$(II)(SO$_4$)$_2$•H$_2$O]Complex

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Abstract: Catalytic decomposition of H$_2$O$_2$ by [H$_5$LFe$_2$(II)(SO$_4$)$_2$•H$_2$O] complex was studying under different experimental conditions such as different concentration of H$_2$O$_2$ (10%, 15% and 20%), different temperature (25, 35 and 45°C) and different amounts of complex as a catalyst (0.1, 0.3, 0.5 and 0.7 gm). It was observed from the experimental results that the catalytic decomposition rate constant was found to increase by increasing the amount of [H$_5$LFe$_2$(II)(SO$_4$)$_2$•H$_2$O] complex as a catalyst. This can be explained by higher hydroxyl radicals are farmed in the reaction medium, and also increase in temperature accelerates the Kinetics of catalytic decomposition of H$_2$O$_2$. Also the thermodynamic parameters: (E_a), (ΔH), (ΔG) and (ΔS) were determined.

Keywords: Metal complexes, Decomposition, H$_2$O$_2$, Kinetics, Mechanism

1. Introduction

Hydrogen peroxide (H$_2$O$_2$) is involved in all life's vital processes as it is versatile in its uses and applications. Its varied utility ranges from fenton's reagent, bleaching, catalytic activity oxidant for industrial chemical effluents, biological and medical applications. [1]

The kinetics of H$_2$O$_2$ Catalytic decom-position over [Cu(II) fulvate] complex as a catalyst was investigated. The effect of different concentration of H$_2$O$_2$, different amount of catalyst and different temperature were studied Based on the rate constants obtained at different temperatures; the empirical Arrhenius expression of H$_2$O$_2$ decomposition was derived. The reaction was further studied and the values of (E), (ΔH), (ΔG) and (ΔS) were determined, its well described by an autocatalytic first order equation.[2]

The catalytic and photocatalytic activities of ramsdellite type manganese oxide, R-MnO$_2$ were studied from the initial rate of decomposition of H$_2$O$_2$ in aqueous solution. The kinetic study was followed by the production of O$_2$ via gas pressure monitoring (O$_2$ – monitored method) in the dark and under visible light irradiation (λ≥400 nm) at 20 °C. Experimental data showed that the rate of H$_2$O$_2$ decomposition, under visible light irradiation and in the dark, obeys the first order kinetic law. While in the dark the H$_2$O$_2$ decomposition rate by mass unit was around 6.88m mol g$^{-1}$ S$^{-1}$, under visible light in addition the H$_2$O$_2$ decomposition rate achieved a maximal value of 15.13m mol g$^{-1}$ S$^{-1}$. The increase in the H$_2$O$_2$ decomposition by expect of the visible light was observed in range of catalyst concentration from 16 to 374 mg L$^{-1}$. These results reflect the potential of R-MnO$_2$ as photoactive catalyst, being a consequence of pressured photo education of Mn$^{4+}$ centers. [6]

The decomposition rate of H$_2$O$_2$ by Fe(III)-nitrilotriacetate complex (Fe$^{Il}$NTA) has been investigated over a large range of experimental conditions: 3<P0<8H, [Fe(III)$_{T,0}$] : 0.05-1 m M ; [NTA]$_{T,0}$ / [Fe (III)$_{T,0}$] molaratios : 1-250 ; [H$_2$O$_2$]$_0$ : 1mM – 4 M) and concentration of OH radicals scavengers: 0-53 mM. Spectrophotometric analyses revealed that reactions of H$_2$O$_2$ with Fe$^{III}$NTA (1mM) at neutral pH immediately lead to the formation of intermediates (presumably peroxocomplexes of Fe$^{IIl}$NTA) which absorb light in the region 350-600 nm where Fe$^{III}$NTA and H$_2$O$_2$ were first order with respect to H$_2$O$_2$, and that the apparent first-order rate constants were found to be proportional to the total concentration of Fe$^{III}$NTA complexes.

 Were at a maximum at PH= 7.95 ± 0.10 and depend on the [NTA]$_{T,0}$/ [Fe(III)$_{T,0}$] molar atios. The addition of increasing concentration of tert-butanol or sodium bicarbonate significantly decreased the decomposition rate of H$_2$O$_2$, suggesting the involvement of HO radicals in the decomposition of H$_2$O$_2$. The decomposition of H$_2$O$_2$ by Fe$^{III}$NTA at neutral pH was accompanied by a production of...
dioxgen and by oxidation of NTA. The degradation of the organic ligand during the course of the reaction led to a progressive decomplexation of Fe(III)-NTA followed by a subsequent precip-itation of iron (III) oxyhydroxides and by a significant decrease in the catalytic activity of Fe(III) species for the decomposition of H$_2$O$_2$. [7]

2. Experimental

- **Materials and methods**
  All chemical were of analytical grade and were employed without further purification. The experimental apparatus as in Fig(1). It contains: (1) a reactor with a glass 500 ml volume. (2) A condenser to prevent evaporation of the reaction medium and maintaining constant the content of H$_2$O$_2$. (3) A heater thermally regulated flask to set the desired temperature (4) Thermometer. (5) A syringes to introduce the oxidant and take sample.

Working solutions of H$_2$O$_2$ were prepared weekly by volumetric dilution of 30% (v/v) H$_2$O$_2$ (AR, grade, Merck) and were standardized daily by titration with potassium permanganate KMnO$_4$. It was found that the natural decomposition rate of aqueous H$_2$O$_2$ Solution was less than 1% in 24 h.

The decomposition of H$_2$O$_2$ catalyzed by [H$_2$LFe$_2$(II)(SO$_4$)$_2$.H$_2$O] complex as in Fig(2) can be kinetically monitored by removing aliquots of the reaction mixture at predeterm99999ined intervals and titrating the unde decomposed H$_2$O$_2$ with standard KMnO$_4$ solutions (0.04-0.05N) standardized with (COONa)$_2$ (primary standard). The decomposition of H$_2$O$_2$ was carried out in a thermostat cell at different temperatures between 25 and 45 °C.

- **Preparation of catalyst [H$_2$LFe$_2$(II)(SO$_4$)$_2$.H$_2$O] complex**

  **A) Ligand preparation (H$_2$L):**
  Sodium salt added to hydrazine by different amount with stirring the suspension at 70 °C for one hour. The product is filtered and given a start, starting with glucose with stirring at 60 °C for an hour and filtered product the Ligand as Fig(3).

  **B) Preparation of metal complex (H$_2$L):**
  Iron(II) sulphate tetrahydrate dissolved in ethanol warmed at 60 °C was added to H$_2$L in the same solvent by different amount (1 mol). The mixture was warmed at 60 °C with stirring for 1 h, then the solution was filtered off and dark brown precipitate was obtained by evaporated the solution Fig(2).

3. Results and Discussion

- **(A) Kinetics of the catalytic decomposition of H$_2$O$_2$**:
  Many experiment were carried out to study the effect of H$_2$O$_2$ concentration, effect of the amount of catalyst [H$_2$LFe$_2$(II)(SO$_4$)$_2$.H$_2$O] complex and the effect of different temperature (25-45 °C) on the rate of catalytic decomposition of H$_2$O$_2$. Although the decomposition of H$_2$O$_2$ is very complex, it has been shown under certain operating conditions, the kinetics of decomposition of H$_2$O$_2$ can be described by a kinetic of pseudo-first order as described in the following the equation (1)

  \[
  \frac{d[H_2O_2]}{dt} = -k_{\text{app}ex} [H_2O_2] 
  \]

  Where \((k_{\text{app}ex})\): the apparent rate constant of the first order, \((t)\): reaction time and \([H_2O_2]\): the concentration of hydrogen.
peroxide at time (t). After integration we obtain the equation (2)

\[ \ln([H_2O_2]_0/[H_2O_2]) = k_{speff}t \]  

(2)

where \([H_2O_2]_0\): initial concentration of hydrogen peroxide.[8]

Kinetic studies in the conditions mentioned above showed that the initial rate of the decomposition of \(H_2O_2\) is proportional to the concentration of hydrogen peroxide and the amount of catalyst \([H_3LFe_2(II)(SO_4)_2]H_2O\) complex as a catalyst and the proposed mechanism of this reaction may be as the following:

\[ V_w = -d[H_2O_2]/dt = k_{dec}[[H_3LFe_2(II)(SO_4)_2]H_2O]Complex[H_2O_2] \]  

(3)

4. Studies the different factors effecting in the Catalytic Decomposition of \(H_2O_2\)

1- Study the effect of temperature

The experiments were performed with 10% \(H_2O_2\) and 0.3 g \([H_3LFe_2(II)(SO_4)_2]H_2O\) complex. Temperatures of our experimental are carried out between 25 to 45 °C. As can be seen, the increase in temperature accelerates the kinetics of decomposition of hydrogen peroxide. Indeed, at 45 °C the decomposition is slow. The rate constants of \(H_2O_2\) decomposition as a function of temperatures are given in (Table 1) and (Figure 4-11).

| Temp (°C) | Log k | 1/T |
|----------|-------|-----|
| 25       | -6.38 | 0.00315 |
| 35       | -6.20 | 0.00342 |
| 45       | -5.79 | 0.00397 |

When we draw \(\ln([H_2O_2]_{dec})\) versus time (t) at constant temperature 25,35 and 45 °C as shown in Figure (4, 5 and 6) its clear straight line:

Figure 4: The rate constants of \(H_2O_2\) decomposition temperature 25°C.

Figure 5: The rate constants of \(H_2O_2\) decomposition temperature 35°C.

Figure 6: The rate constants of \(H_2O_2\) decomposition temperature 45°C.

The activation energies of the catalytic decomposition of \(H_2O_2\) at temperature range 25-45°C are calculated from Arrhenius plots and the values obtained are given in Fig (7). It seems that the activation energy \((E_a)\) evaluated from \((k)\) values, \((E_a)\) indicating that the decomposition of \(H_2O_2\), we see that Arrhenius equations:

\[ \log k = -E_a/2.303RT + log A \]  

(10)

Given with slope equal to \((-E_a/2.303R)\) and intercept equal to \((log A)\). This result are illustrated in Fig (7).

2- Study the Thermodynamic Parameters for the Catalytic Decomposition of \(H_2O_2\)

The thermodynamic parameters \((E_a), (\Delta H), (\Delta G)\) and \((\Delta S)\) were also determined and illustrated in Table (2). The automatically first order plots derived from following equation:

\[ \log k/T = \log k_B + \Delta S /R - \Delta H/ RT \]  

(11)

Here, \((k)\) is the rate constant for the reaction, \((T)\) is absolute temperature, \((k_B)\) is Boltzmann’s constant, \((h)\) is Planck’s constant, \((\Delta S)\) and \((\Delta H)\) are activation entropy and enthalpy, respectively. The slope of the line obtained using this equations proportional to the activation enthalpy, while the activation entropy can be extracted from the intercept. By performing each reaction at a series off our temperatures and using the empirical rate law to determine the rate constant at each temperature, activation entropy and enthalpy can be calculated. Are illustrated in Fig. (8),and equation (12):

\[ \Delta G = \Delta H - T \Delta S \]  

(12)

Table 2: Thermodynamic parameter for decomposition of hydrogen peroxide by \([H_3LFe_2(II)(SO_4)_2]H_2O\) Complex as a catalyst
The heterogeneous as catalytic decom-position of H₂O₂ over Fe₂O₃-MoO₃(2:4) is characterized by the presence of an induction period during which the active centers (Mo⁶⁺) are formed at the start of reaction [9]. In all cases studied an induction period has been encountered before the reaction assumes a significant rate. These results showed also that the induction period (tₑ) is largely by the amount of catalyst and the temperature of the reaction.

3- Study The effect of the amount of [H₃LFe₂(II)(SO₄)₂.H₂O] complex as a catalyst:
The level of concentrations of [H₃LFe₂(II)(SO₄)₂.H₂O] complex used in this study is (0.1, 0.3, 0.5 and 0.7 g). A significant increase in the rate of decomposition was observed by increasing the dose of [H₃LFe₂(II)(SO₄)₂.H₂O] complex. For high concentrations of [H₃LFe₂(II)(SO₄)₂.H₂O] complex, the kinetics of decomposition of H₂O₂ is fast. This can be explained by the fact that the higher the [H₃LFe₂(II)(SO₄)₂.H₂O] complex, the higher OH hydroxyl radicals are formed in the reaction medium. The relationship between the amount of catalyst and the catalytic decomposition of H₂O₂ at different temperature were illustrated in Fig (12-14).

Figure 8: Plot of log(k/T) vs (1/T) for the decomposition of H₂O₂ by [H₃LFe₂(II)(SO₄)₂.H₂O] Complex ; [H₂O₂]₀ = 10%.

Figure 9: Effect of temperature on the catalytic decomposition of H₂O₂ (at [H₂O₂]₀ = 10% , various amount of [H₃LFe₂(II)(SO₄)₂.H₂O] complex as a catalyst).

Figure 10: Effect of temperature on the catalytic decomposition of H₂O₂ (at [H₂O₂]₀ = 15% , various amount of [H₃LFe₂(II)(SO₄)₂.H₂O] complex as a catalyst).

Figure 11: Effect of temperature on the catalytic decomposition of H₂O₂ (at [H₂O₂]₀ = 20% , various amount of [H₃LFe₂(II)(SO₄)₂.H₂O] complex as a catalyst).

Figure 12: Effect of the amount of [H₃LFe₂(II)(SO₄)₂.H₂O] Complex on the catalytic decomposition of H₂O₂ (at various initial concentration of H₂O₂, at 25 °C).

Figure 13: Effect of the amount of [H₃LFe₂(II)(SO₄)₂.H₂O] Complex on the catalytic decomposition of H₂O₂ (at various initial concentration of H₂O₂, at 35 °C).

Figure 14: Effect of the amount of [H₃LFe₂(II)(SO₄)₂.H₂O] complex on the catalytic decomposition of H₂O₂ (at various initial concentration of H₂O₂, at 45 °C).

4- Study the Role of H₂O₂ Concentration
In this case, the concentration of [H₃LFe₂(II)(SO₄)₂.2H₂O] Complex is set equal to 0.1, 0.3, 0.5 and 0.7 g respectively. The temperature is varied between (25, 35, and 45°C) and the initial concentration of hydrogen peroxide is variable from (10, 15, and 20%). The evolution of the H₂O₂ concentration is reported in Figure (15-18).

As the figure shows the decomposition rate increased by increasing H₂O₂ conc-entration. This may be due to the competition between the (OH) radicals and other compounds. For high concentrations of H₂O₂ the kinetics of decomposition of hydrogen peroxide is fast. This is explained by the Fenton reaction to high concentrations of H₂O₂.
The catalytic decomposition of H$_2$O$_2$ in presence of [H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O]complex as a catalyst, depends upon the concentration of the catalyst, temperature and slowed with high concentrations of H$_2$O$_2$. The rate of the reaction is of pseudo first order with respect to the concentration of the catalyst and temperature.

(B) Mechanism of the Catalytic Decomposition of H$_2$O$_2$:

We suggested the reaction mechanism of decomposition of H$_2$O$_2$ by [H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O]Complex as the following:

$$2\text{H}_2\text{O}_2 = 2\text{HO}_2^- + 2\text{H}^+(4)$$

$$[(\text{H}_3\text{LFe(II)(SO}_4\text{)}_2\text{H}_2\text{O})\text{Complex}]^- + \text{HO}_2^- \rightarrow [(\text{H}_3\text{LFe(II)(SO}_4\text{)}_2\text{H}_2\text{O})\text{Complex}](\text{HOO})]_2^- (5)$$

$$[(\text{H}_3\text{LFe(II)(SO}_4\text{)}_2\text{H}_2\text{O})\text{Complex}](\text{HOO})]_2^- \rightarrow \text{H}_2\text{LFe(II)}(\text{SO}_4\text{)}_2\text{H}_2\text{O}(\text{Complex}) + (\text{HOO})]_2^- (6)$$

$$[(\text{H}_3\text{LFe(II)(SO}_4\text{)}_2\text{H}_2\text{O})\text{Complex}](\text{HOO})]_2^- + \text{H}_2\text{O}_2^- \rightarrow [(\text{H}_3\text{LFe(II)(SO}_4\text{)}_2\text{H}_2\text{O})\text{Complex}]^- + \text{O}_2 + 2\text{HO}^- (7)$$

$$2\text{H}^+ + 2\text{HO}^- = 2\text{H}_2\text{O} (8)$$

It is assumed that step (3) is the rate determining step of the reaction, as the reduction of Fe(II) requires geometrical changes around the metal center. This mechanism is in agreement with the suggestion for other macromolecular systems and can explain the change in rate in going to more alkaline conditions, as the dependence of the redox potential of the couple HO$_2^-$/H$_2$O$_2$ (HO$_2^-$) on pH is very well known. It is obvious that the oxidation of H$_2$O$_2$ to HO$_2^-$ or O$_2$ by Fe(II) is more favorable in more alkaline conditions. This kind of mechanism does not involve any diffusible radical species in accordance to previous proposed mechanism, but several very rapid intermediate step between (3) and (4) may exist which include the participation of radicals.

Complexes of Fe(II) especially with various ligands acting as catalysts have been investigated in depth and disagreements over mechanistic details, involving intermediate radicals or complexes, have lasted for decades. The formation of iron peroxide complexes both in acidic and alkaline solutions has been confirmed and a mechanism not involving any radicals has been suggested. The difference in reactivity of Fe(II) complexes towards H$_2$O$_2$ is due to the change in the redox potential of Fe(II) ions as a result of ligation with different ligands. It was supposed that a superoxide iron (I) complex [HO$_2$-Fe(I)(Ligand)] is formed from the complex [HO$_2$-Fe(II)(Ligand)] in which an instantaneous electron transfer occurs.

The plot of $\log(dx/dt)/(a-x)^2$ against $t$, must be a straight line with slope equal to k/2.303 and intercept equal to $-\log a/k_w$. The autocatalytic first order plots derived from the following equation (16) are illustrated in Fig.(4,5 and 6) and evaluated.

$$\log(dx/dt)/(a-x)^2 = k/t/2.303 - \log a/k_w (9)$$

The specific reaction rate ($k$) were evaluated from the plot of (Ln[H$_2$O$_2$]$_{dec}$) against time ($t$) as shown in , Table (1), where:

$$[\text{H}_2\text{O}_2]_{\text{dec}} = [\text{H}_2\text{O}_2]_0 - [\text{H}_2\text{O}_2]_{\text{react}}$$

[\text{H}_2\text{O}_2]_{\text{dec}}$: concentration of H$_2$O$_2$ decom-position at time $t$

[\text{H}_2\text{O}_2]_0$: initial concentration of H$_2$O$_2$

[\text{H}_2\text{O}_2]_{\text{react}}$: Concentration of remaining H$_2$O$_2$

5. Conclusion

The catalytic decomposition of H$_2$O$_2$,[H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O] complex depends upon the concentration of the catalyst temperature and slowed with high concentration of H$_2$O$_2$. 

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**Figure 15:** Effect of initial concentration of H$_2$O$_2$ on the catalytic decomposition of hydrogen peroxide by 0.1g [H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O] Complex as a catalyst.

**Figure 16:** Effect of initial concentration of H$_2$O$_2$ on the catalytic decomposition of hydrogen peroxide by 0.3g [H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O] Complex as a catalyst.

**Figure 17:** Effect of initial concentration of H$_2$O$_2$ on the catalytic decomposition of hydrogen peroxide by 0.5g [H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O] Complex as a catalyst.

**Figure 18:** Effect of initial concentration of H$_2$O$_2$ on the catalytic decomposition of hydrogen peroxide by 0.7g [H$_3$LFe(II)(SO$_4$)$_2$.H$_2$O] Complex as a catalyst.
The rate of the reaction is of pseudo first order with respect to the Fe(II) to Fe(I), during the slow rate determining step.

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