

The Photocatalytic Degradation of Aqueous Ammonia

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Abstract: Background: Agriculture is one of the most important sources of national income for Egypt. But it is one of the most important human activities contaminated watercourses. Egypt suffers from a severe shortage, that reflected on the water quality and the amount of pollution in the watercourses. Several studies have shown the contamination of many watercourses in Egypt with different nitrogen forms. The advanced oxidation processes (AOPs) one of the most competent methods in the disposal of pollutants. The effect of AOPs using UV, UV/H₂O₂, Fenton and photo-Fenton treatment on disposal NH₃ were investigated at laboratory scale. Experiments were conducted to optimize the operating variables like pH, H₂O₂ conc. and H₂O₂/Fe²⁺ molar ratio.

Results: The removal rate of NH₃ obeys the following sequence: photolysis < UV/H₂O₂ < Fenton < Photo-Fenton. The Photo-Fenton treatment had removed 92.11% of NH₃ content of the sample, at that conditions (900 mg L⁻¹ H₂O₂, H₂O₂/Fe²⁺ molecular ratio=20, and pH=3).

Conclusions: Most AOPs was capable of NH₃ disposal with varying degrees of success. The most effective processors were the photo-Fenton, but it needs to reduce the pH value. Which, requiring many additional and costly economic treatments. Therefore, it is necessary to conduct other experiments to increase the effectiveness of that process at pH 7.

Keywords: Fenton, NH₃, Photo-Fenton, photolysis, UV/H₂O₂.

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I. Introduction

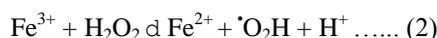
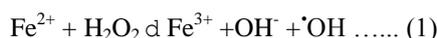
Agriculture has emerged as powerful platforms for supplying us with essential food, feed, fiber, and fuel. Agriculture also is a social and cultural phenomenon. It also is a common condition which has a considerable impact on the amount of pollution in surface watercourses through several human activities¹. Therefore, agriculture can play an important role in addressing the issue of water pollution through many influences². These impacts include (1) the water chemistry through nutrient leaches and the food network through eutrophication, (2) the changes in evaporation rates, thus runoff, (3) the modification of river flows and loss of irrigation water, (4) the impact of introduction of alien species into the environment and (5) modification physical properties of habitats through channels modification, dam, and drainage³. Agricultural activity leads to more urbanization and thus more wastes in watercourses⁴.

Egypt is a country heavily dependent on agriculture for its economic activity. So, the Nile is the main lifeline for the Egyptian people. The international agreements for the participation of the Nile water with Sudan allocated to Egypt 55.5 billion cubic meters annually^{5,6}. The problem has been increased after the construction of the Ethiopian Renaissance Dam. Therefore, the water amount per capita has been declined to put Egypt at a lower level than water poverty. So, the country suffers from water shortages. In terms of water scarcity, population growth and the tendency to more industrial and agricultural activity, pollution levels increased^{5,7}. Various agricultural activities cause nutrient leaching, especially nitrogen forms, and phosphorus, where 30 to 50% of the nitrogen used loses with irrigation water⁸. Several studies have shown that increasing the level of nitrates in water over 45 mg L⁻¹, leading to a severe health risk, including the so-called Blue baby syndrome (infant methemoglobinemia) in infants and pregnant women^{9,10}. It also increases the risk of stomach cancer¹¹. Nitrite is also toxic for many fish because it makes hemoglobin less oxygen-capable. The concentration of nitrite in fresh water should remain below 27 mg L⁻¹¹². It also leads to water eutrophication, which affects the aesthetic form of the water bodies, which turn into dark green and also affects their biological diversity¹³.

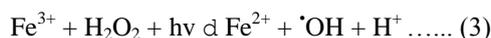
Several studies had shown that the concentration of different nitrogen forms exceeds the permissible limits in different watercourses in Egypt including the Nile River, Damietta and Rashid branches¹⁴⁻¹⁶. In our previous studies, We found a high concentration of ammonia and nitrite in the most studied areas, accompanied by an increase in COD and ultraviolet absorption values^{17,18}. These previous studies reported that the pollution in the studied regions (i.e., central and west Delta of Egypt) originated from the sewage and agricultural wastes.

This pollution included various forms of nitrogen and the level of these pollutants exceeded the limits allowed either in Egyptian law¹⁹ or the World Health Organization²⁰ and the limits of wildlife according to Canadian Council of Ministers of the Environment²¹. Therefore, many water sources can become unsuitable for human or industrial use and must be purified. However, the purification of water contaminated with various nitrogen forms is difficult and expensive²².

There are several water purification techniques, including mechanical, biological, physical or chemical, and their various combinations²³. Advanced oxidation processes (AOPs) are a chemical process that relies on the addition of auxiliary oxidants, such as H₂O₂, O₃, or special catalysts such as TiO₂^{23,24}. These AOPs are an attractive alternative to physical water treatment processes such as filtration, sedimentation, and distillation, etc. Physical processes turn pollutants into another form, but advanced oxidation processes eliminate them by mineralization²⁵. AOPs also are characterized by highly reactive molecules (OH radicals) that can oxidize target organic or nonorganic pollutants. The Fenton's is one of the AOPs that require iron ions in the presence of hydrogen peroxide H₂O₂ to produce hydroxyl radicals. The Fenton reaction occurs in two steps²⁶:



The iron acts as a catalyst in its two synchronized forms (Fe²⁺/Fe³⁺) during the reaction, while H₂O₂ is continuously consumed, forming OH radicals²⁷. This process is simple however the main drawback of this process is that it leads to the production of iron sludge. To enhance the breakdown of pollutants, visible light and ultraviolet radiation are used (at wavelengths > 300 nm) in the interaction. The process differs from the previous Fenton process in that photolysis of Fe³⁺ allows Fe²⁺ to react with more H₂O₂²⁸. According to the following equation:



This process is more effective than the Fenton process as it reduces the formation of sludge waste. Several studies have dealt with the use of various advanced oxidation process in ammonia disposal^{29–31} but as one component of the landfill leachate matrix. There is a lack of research that deals with ammonia photocatalytic degradation. Therefore, the study aims to compare the various methods of photocatalytic oxidation (photolysis, UV/H₂O₂, Fenton and Photo-Fenton) in the disposal of ammonia in water samples.

II. Materials and Methods

The current agricultural practices may play a critical role in the maintenance or pollution of the agroecosystems including surface water. A study was carried out in order to compare the different methods of photocatalytic oxidation including photolysis, UV/H₂O₂, Fenton and Photo-Fenton in the disposal of ammonia in water samples. All chemicals used were an analytical grade (Table 1). Ammonium sulfate was used as a source of nitrogen content, while FeSO₄·7H₂O was used as a source of the Fe²⁺ catalyst substance. Concentrations of the stock solutions for ammonium sulfate, hydrogen peroxide, and ferrous sulfate were 0.009, 88.194 (30%) and 0.071 mol, respectively. The stock solution for the ferrous sulfate was prepared in 0.01 mmol sulfuric acid. All solutions were prepared in Pyrex, brown and light-resistant bottles. The pH was adjusted by adding the appropriate amount of H₂SO₄ or NaOH. A mercury lamp was used to produce ultraviolet (model Philips TUV 15W G15 T8, Holland) emit ultraviolet radiation in the UV C range (wavelength 254) with power 15.9 Watt.

Table 1: List of chemicals used

Compound	Formula	Vendor	Country	Purity
Ammonium sulfate	NH ₄ SO ₄	ADWIC	Egypt	99.9%
hydrogen peroxide	H ₂ O ₂	Aldrich	USA	30 wt.%
Ferrous sulfate	FeSO ₄ ·7H ₂ O	Chem-Lab	Belgium	99+%
Sulfuric acid	H ₂ SO ₄	ADWIC	Egypt	98%
Sodium hydroxide	NaOH	Panreac	Spain	99%
Sodium thiosulfate	Na ₂ S ₂ O ₃ ·5H ₂ O	Merck	Germany	99%
Sodium salicylate	C ₇ H ₅ NaO ₃	El Nasr Chemicals Co.	Egypt	99%
Trisodium citrate	Na ₃ C ₆ H ₅ O ₇ ·H ₂ O	SDFCL	India	99%
Sodium hypochlorite	NaClO	Merck	Germany	5%

2-1 Experimental Procedure

All experimental treatments were performed at room temperature (25±2°) and atmospheric pressure. Various experiments were carried out in a batch mode on a laboratory-scale using a 250 mL beaker (Fig. 1).

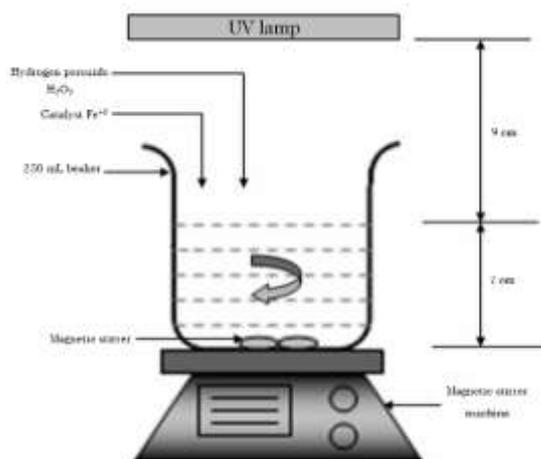


Fig. 1: Schematic diagram of the experimental setup

The results of the previous field experiment showed that the highest value of NH_3 concentration was $1.8 \text{ mg NH}_3\text{-N L}^{-1}$ ($2.18 \text{ mg L}^{-1} \text{ NH}_3$)¹⁷. In the current experiment, about 25 times this previous concentration was used. The concentration of the reaction substance NH_3 was 100 mg L^{-1} . These compounds were prepared in distilled water at a final volume of 200 ml. The desired pH value was adjusted by using 0.1 N sulfuric acid prior to starting. Then, the catalyst is added (a specific weight of the Ferrous salt Fe^{2+}), which is mixed well using the magnetic stirrer and then the addition of the appropriate volume of hydrogen peroxide. In the case of dark reactions (the Fenton reaction), time is calculated when H_2O_2 is added. In light-induced reactions (photo-Fenton), the time is calculated from the operation of the UV light. Then, the mixture was subjected to magnetic stirring and UV radiation (wavelength 254 nm), as shown in Fig. 1. A number of experiments have been conducted to measure the effectiveness of various AOPs. Experiments were performed using UV radiation alone and the Fenton catalyst; comparing it with the Fenton catalyst with UV radiation (photo-Fenton). In addition, it was studied the effect of pH and initial concentration of H_2O_2 and Fe^{+2} . The graded concentration of H_2O_2 (300, 600, 900 and 1200 mg L^{-1}) was prepared. The studied molecular ratios between hydrogen peroxide and catalyst Fe^{+2} were 5, 10, 15, 20, 40, 80 and 160.

1.2 Analytical methods

Three samples (1 ml) per treatment were taken at regular intervals from the reaction vessel and were analyzed immediately to avoid a further reaction. Fenton reactions are sensitive to pH and stop at $\text{pH} > 10$ ³². Therefore, the reaction was immediately stopped by adding 0.1ml NaOH 0.1N to the samples. One point of $\text{Na}_2\text{S}_2\text{O}_3$ was added to each sample to remove residual H_2O_2 and prevent it from interacting with the sample during analysis. The remaining NH_3 was estimated using the SM1200 UV-Vis Spectrophotometer (USA), by using the salicylate method³³. This method depends on the reaction of Berthelot where the phenols react (in this case the Sodium salicylate) produce the azo dyes in the presence of Sodium hypochlorite and in the alkali medium, the resulting indophenol produces a green color measured at a wavelength of 660 nm. The HI 2211 Hanna digital pH meter (Romania) was used to adjust the pH values.

1.3 Statistical analysis

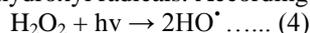
The mean and standard deviation of all test results was calculated using Microsoft Excel 2010. Statistical analysis was performed using a one-way ANOVA analysis (at a probability of < 0.05) using SASS program version 9.2 (2008). The averages were compared by the Duncan Multi-Range tests.

III. Results and Discussion

3.1 NH_3 degradation using UV radiation (photolysis) and UV/ H_2O_2

For photolysis, the ammonia solution NH_3 (100 mg L^{-1}) was exposed to UV light (at 254 nm) for two hours; at pH 7 and at room temperature (25 ± 2), with flipping the solution with a magnetic stirrer. There was a significant difference between the different measurements taken at intervals of time, with slight photolysis of the ammonia solution occurred during the 120 min treatment period (NH_3 degradation was 2.70%) (Table 2 and Fig. 2). Photolysis is a process sensitive to the wavelength of light used, where it occurs only in the wavelengths that the compound can absorb. It also carries enough energy to break the chemical bonds in the compound³⁴. It could be expected the negligible degradation attained by photolysis, because of NH_3 photolysis energetically possible for light with wavelength below 217.5 nm ³⁵. When NH_3 solution is treated with UV radiation and 300 mg L^{-1}

hydrogen peroxide, NH₃ degradation was mediocre after 120 min (49.68% removal). The decomposition rate is associated with time (correlation coefficient R²=0.9407). Here, the ammonia degradation depends on the photolysis of hydrogen peroxide to form hydroxyl radicals. According to the following equation:



There are several possible explanations for mediocre NH₃ degradation, this method needs a much longer UV exposure and/ or a fairly high dose of H₂O₂³⁴. The rate of photolysis of H₂O₂ is mainly pH dependent and increases with the increased pH no³⁶. The molar absorptivity of H₂O₂ is low at 253.7 nm. Also, the water has a higher absorbance at this wavelength and there is a penchant for it to compete with the H₂O₂ for radiation³⁷.

Table 2: Effect of UV or UV radiation and H₂O₂ on photolysis of NH₃ solution (100 mg L⁻¹) at pH =7

Time (min)	NH ₃ concentration (mg L ⁻¹) ± S. E	
	UV (photolysis)	UV+H ₂ O ₂
0	99.92 ± 0.03 a	99.75 ± 0.12 a
15	99.35 ± 0.18 b	90.02 ± 4.08 ab
30	98.68 ± 0.02 c	82.63 ± 1.59 bc
45	98.4 ± 0.08 cd	74.51 ± 2.73 cd
60	98.3 ± 0.03 de	69.88 ± 1.66 cde
75	98.04 ± 0.13 ef	68.45 ± 1.02 de
90	97.88 ± 0.09 fg	66.14 ± 0.95 de
105	97.58 ± 0.04 gh	60.99 ± 2.65 ef
120	97.3 ± 0.11 h	50.33 ± 0.76 f
F. test:	**	**
LSD 0.05=	0.3467	13.1491

* S.E: Standard error. Means followed by the same letter (s) are not significantly difference (P= 0.95 level).

3.2 Effect of Fenton and photo-Fenton on NH₃ degradation

At Fenton and photo-Fenton experiments, it had conducted several experiments to get the best tuning of the following process variables, H₂O₂ conc., and the H₂O₂/Fe²⁺ molecular ratio. To achieve this, it is prepared a gradual concentration of the studied variable with fixed the other variables. In each step, it was used the results of the previous step to adjust the variables affecting the process.

3.2.1 The pH effects

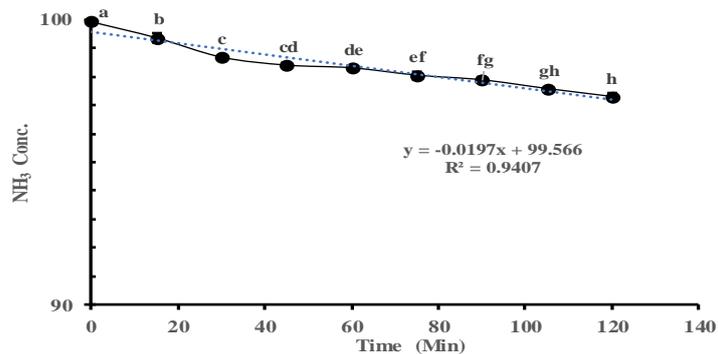
The pH value has a critical effect on the oxidation potential of OH[•] radicals, this is due to the mutual relationship between the oxidation potential and the pH value (E0=2.8V and E14=1.95V)³⁸. The rate of degradation of NH₃ at different pH was studied by carrying out the experiments at different pH (from 2 to 7). So, a solution of 100 mg NH₃ L⁻¹ and 300 mg L⁻¹ H₂O₂ were prepared while the H₂O₂/Fe²⁺ molecular ratio was =3 (800 mg L⁻¹ FeSO₄.7H₂O). The pH was adjusted by adding the appropriate amount of sulfuric acid 0.1 N without adding any buffer solutions. The results in Table 3 and Fig. 3 (A-B) show significant differences between all treatments, in both Fenton and photo-Fenton treatments. The maximum degradation of NH₃ was achieved at pH 3 and shows a decreasing trend of degradation at higher and lower pH. These results match those observed in earlier studies^{32,38}. The pH affects the activity of both iron speciation and H₂O₂ decomposition. Low removal efficiency can be explained at lower pH (< 2.5), the [Fe(H₂O)₆]²⁺ complex is formed instead of [Fe(OH)(H₂O)₅]⁺, that reacts more tardily with H₂O₂, producing a less quantity of hydroxyl radicals, reducing the degradation efficiency³⁹. Furthermore, at a low pH, the scavenging effect of hydroxyl radicals by hydrogen ions be important and it discouraged the reaction of Fe³⁺ with H₂O₂³². At higher pH (of > 4), iron reacts with the hydroxide ions (HO⁻), producing the Iron hydroxide precipitate (Fe(OH)₂ or Fe(OH)₃), which does not react with H₂O₂, preventing the Fenton reaction. Also, the increase of pH value decreases the oxidation potential of OH radical⁴⁰.

Table 3: Effect of pH on Catalytic (Fenton) or photocatalytic (photo-Fenton) removal of NH₃ (100 mg L⁻¹ NH₃, 300 mg L⁻¹ H₂O₂ and 800 mg L⁻¹ FeSO₄.7H₂O)

pH values	NH ₃ removal (%)	
	Fenton (H ₂ O ₂ / Fe ²⁺)	Photo-Fenton (UV/H ₂ O ₂ / Fe ²⁺)
2	38.63 ± 3.14 b	27.45 ± 6.09 b
3	53.98 ± 5.74 a	56.74 ± 0.86 a
4	27.99 ± 1.26 bc	15.48 ± 1.72 c
5	22.33 ± 1.85 cd	11.64 ± 0.31 c
7	9.53 ± 4.52 d	5.67 ± 2.36 c
F. test:	**	**
LSD 0.05=	14.2583	11.7624

* S.E: Standard error. Means followed by the same letter (s) are not significantly difference (P= 0.95 level).

A



B

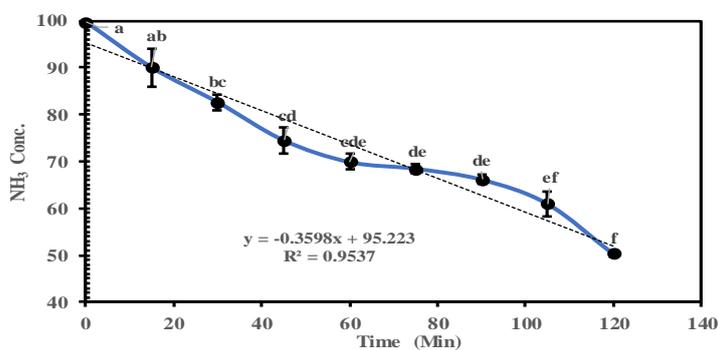
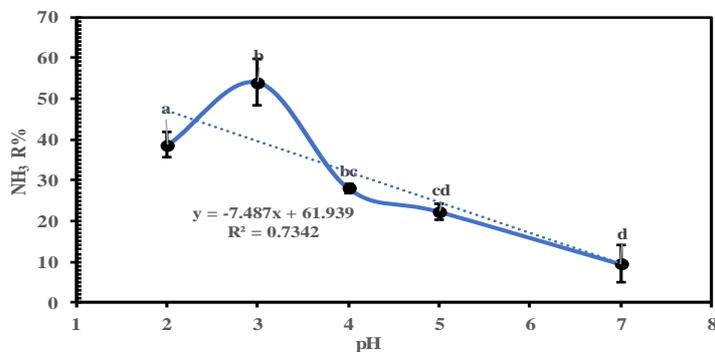


Fig. 2: Photolysis of ammonia solution NH₃ under the influence of UV (254 nm) A, UV/H₂O₂ (300 mg L⁻¹) B, at pH =7.

A



B

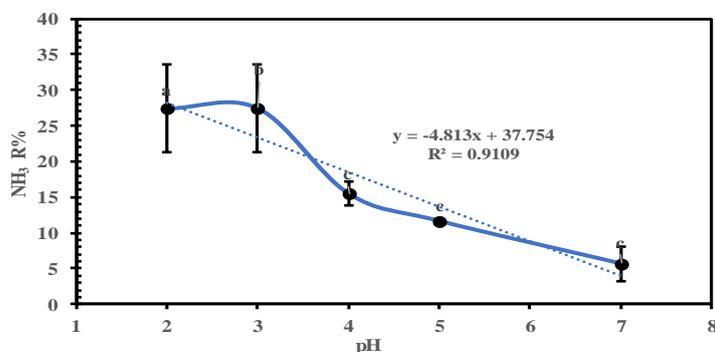


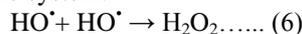
Fig. 3: Effect of pH on catalytic (Fenton) (A), or photocatalytic (photo-Fenton) (B) removal of NH₃ (at 100 mg L⁻¹ NH₃, 300 mg L⁻¹ H₂O₂, and 800 mg L⁻¹ FeSO₄·7H₂O)

3.2.2 H₂O₂ concentration effect

The effect of H₂O₂ concentration was studied on NH₃ removal in both Fenton and photo-Fenton interactions. The reaction conditions were as follows: 100 mg L⁻¹ NH₃, pH 3, 800 mg L⁻¹ FeSO₄.7H₂O, but with adding gradient concentration of H₂O₂ in each treatment. The removal percentage of NH₃ concentration after two hours of the reaction was measured (Table 4 and Fig. 4, A and B). The results showed that there were significant differences between all the means of the different treatments, in both Fenton and photo-Fenton experiments. We found that the highest NH₃ removal (R%) was recorded in case of adding 900 mg L⁻¹ H₂O₂ in both chemical reactions. The present findings seem to be consistent with other research who found that, the degradation efficiency increases with increasing H₂O₂ concentration, but further addition of H₂O₂, did not enhance the degradation efficacy⁴¹⁻⁴³. Where increasing H₂O₂ concentration results in the obstetrics of addition ('OH) hydroxyl radicals which boost the degradation process. On the other hand, at higher peroxide concentrations, H₂O₂ reducing the rate of the process due to the reaction of H₂O₂ itself with hydroxyl radicals (HO'), hence acts as an inhibiting agent or self-scavenging. Which, forming HO₂^{*}⁴⁴, which is also a free radical, but it is a less reactive oxidizing agent and therefore has a longer lifetime than the OH and the result is a decrease in the total reaction rate, (eq. 5)^{45,46}.



Hydroxyl radicals might recombine and take part in radical-radical reactions to form H₂O₂(Revers reaction) eq. (6). Also, H₂O₂ may absorb the lights in the system.



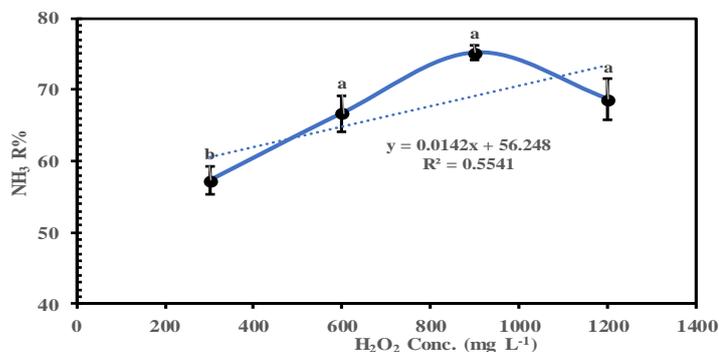
Form previous reasons, a balance must be maintained between excess and low levels of H₂O₂⁴³.

Table 4: Effect of H₂O₂ conc. on catalytic (Fenton) or photocatalytic (photo-Fenton) removal of NH₃ (100 mg L⁻¹ NH₃, gradient concentration of H₂O₂ and 800 mg L⁻¹ FeSO₄.7H₂O, at pH=3)

H ₂ O ₂ concentration (mg L ⁻¹)	NH ₃ removal %	
	Fenton (H ₂ O ₂ / Fe ²⁺)	Photo-Fenton (UV/H ₂ O ₂ / Fe ²⁺)
300	57.23 ± 1.97 b	70.59 ± 0.98 b
600	66.68 ± 2.5 a	74.89 ± 0.92 a
900	75.15 ± 1.03 a	77.89 ± 0.8 a
1200	68.65 ± 2.91 a	76.65 ± 0.35 a
F. test:	*	**
LSD 0.05=	8.8469	3.2072

* S.E: Standard error. Means followed by the same letter (s) are not significantly difference (P= 0.95 level).

A



B

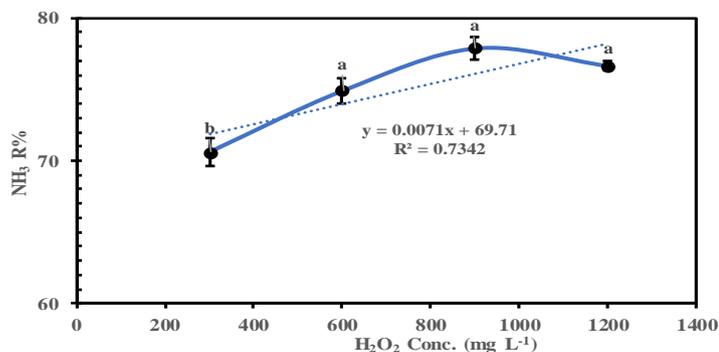


Fig. 4: Effect of H₂O₂ conc. on Catalytic (Fenton) (A), or photocatalytic (photo-Fenton) (B) removal of

NH₃ (at 100 mg L⁻¹ NH₃ gradient conc. of H₂O₂ and 800 mg L⁻¹ FeSO₄·7H₂O, at pH=3)

3.2.3 H₂O₂/Fe²⁺ molecular ratio effect

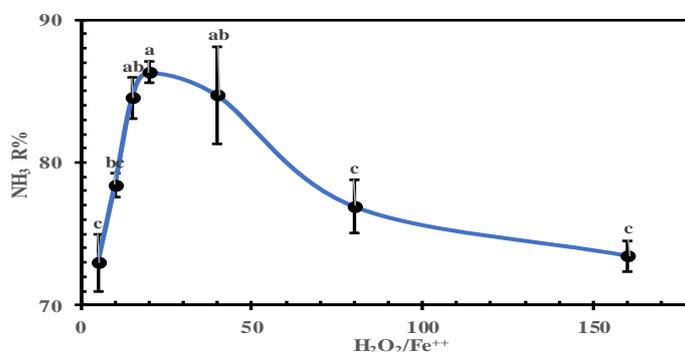
Finally, the effect of H₂O₂/Fe²⁺ molecular ratio was evaluated regarding the removal efficiency of NH₃. The reaction conditions were as follows: 100 mg L⁻¹ NH₃ and 900 mg L⁻¹ H₂O₂, at pH 3. A gradient conc. of Fe²⁺ catalytic was added so that the H₂O₂/Fe²⁺ molecular ratio ranged between 5 and 160. The appropriate weights of FeSO₄·7H₂O were added in order to give the following concentrations 1471.5, 735.75, 490.5, 367.5, 183.75, 92.25, 45.75 mg L⁻¹, which equivalent to 5, 10, 15, 20, 40, 80 and 160 as a H₂O₂/Fe²⁺ molecular ratio, respectively. The results may show that there are significant differences between all treatments, both in the Fenton and Photo-Fenton experiments (Table 5 and Figure 5, A and B). The NH₃ removal rate increased with the increase in H₂O₂/Fe²⁺ molecular ratio until the molar ratio reached to 20 in both reactions and then decreased again until the removal rate reached to its lowest value at the molar ratio of 160. Thus, the best molecular ratio to ammonia removal is 20 in both the Fenton and photo-Fenton interaction. The present findings seem to be consistent with other research which concluded that, there is an optimum value for H₂O₂/Fe²⁺ molecular ratio, above or below this value, it decreases the effectiveness of the process^{42,43,47}.

Table 5: Effect of H₂O₂/Fe²⁺ molecular ratio on catalytic (Fenton) or photocatalytic (photo-Fenton) degradation of NH₃ (100 mg L⁻¹ NH₃, 900 mg L⁻¹ H₂O₂ and gradient concentration of FeSO₄·7H₂O, at pH=3)

H ₂ O ₂ /Fe ²⁺ molecular ratio	NH ₃ removal (%)	
	Fenton (H ₂ O ₂ /Fe ²⁺)	Photo-Fenton (UV/H ₂ O ₂ /Fe ²⁺)
5	72.97 ± 1.98 c	84.58 ± 1.4 c
10	78.45 ± 0.85 bc	87.2 ± 1.23 bc
15	84.53 ± 1.44 ab	89.07 ± 0.49 ab
20	86.31 ± 0.76 a	92.11 ± 1.01 a
40	84.72 ± 3.4 ab	89.7 ± 0.58 ab
80	76.93 ± 1.83 c	87.41 ± 1.37 bc
160	73.46 ± 1.07 c	83.99 ± 0.74 c
F. test:	**	**
LSD 0.05=	6.7856	3.8380

* S.E: Standard error. Means followed by the same letter (s) are not significantly difference (P= 0.95 level).

A



B

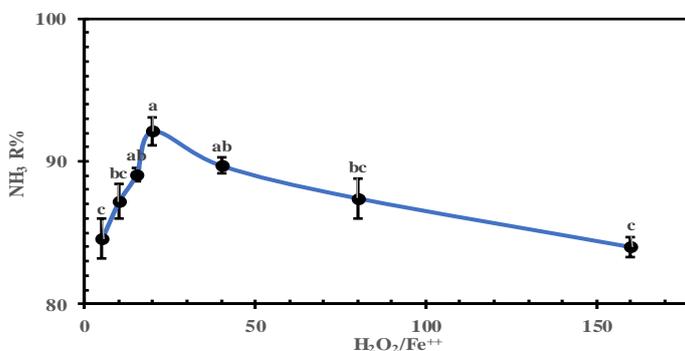
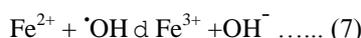


Fig. 5: Effect of H₂O₂/Fe²⁺ molecular ratio on catalytic (Fenton) or photocatalytic (photo-Fenton) removal of NH₃ (100 mg L⁻¹ NH₃, 900 mg L⁻¹ H₂O₂ and gradient concentration of FeSO₄·7H₂O, at pH=3)

The negative effect can be explained by that, adding of ferrous ions increases the optical density of the solution, which hinders the absorption of the UV light, required for the photo-Fenton process⁴⁸. Additional ferrous ions can react with hydroxyl radical decreasing the offensive of hydroxyl radical on NH₃ substrates (according to Eq. 7).



Also, excess Fe²⁺ can react with OH radical (HO[•]) output a compound which curbs reaction rate⁴⁹.

IV. Conclusion

Water is an important component in the agroecosystem and plays a key role in our life. The issue of pollution of water has received considerable critical attention in several regions of the world. It is expected that water deterioration will be increased the serious threat to the environment and human health. The recent assessments of the global water pollution suggest that the agriculture is one of the main causes of this exacerbated pollution including the discharge of huge amounts of nutrients, sediments, agrochemicals, organic matter, drug residues, and saline drainage. These water pollutants should be managed using different approaches. The ammonia is considered one of these water pollutants, which needs much more consideration in its disposal through advanced and conventional methods. Most AOPs was capable of ammonia disposal in water samples, with varying degrees of success. The most effective processors were the photo-Fenton (with that conditions, 100 mg L⁻¹ NH₃, 900 mg L⁻¹ H₂O₂ and 367.5 mg L⁻¹ of FeSO₄.7H₂O (H₂O₂/Fe²⁺ molecular ratio =20)). It had 92.11 NH₃ removal percentage. But it needs to reduce the pH. Which, requiring many additional and costly economic treatments. The experiment also assumed that ammonia presence individually in the samples. This is not true in water samples to be purified. It contains many organic and inorganic compounds that may interfere with that process. Therefore, it is necessary to conduct other experiments to increase the effectiveness of that process at pH 7. And also study the overlap of other compounds in the efficiency of that process.

Acknowledgments

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