Furfural Removal from Simulated Wastewater Using Zno Nanoparticles / H2O2 in Solar Photocatalysis Reactor

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Abstract. Furfural is aromatic compounds that can cause a significant environmental problem particularly through discharged industrial water of oil processing. In this study, the using of the advanced oxidation methods (AOPs) were applied. The results of the experimental work indicated that the degradation of furfural in simulated wastewater and real wastewater from oil refinery was affected by using different concentrations of H₂O₂, the dosage of nanoparticles of ZnO with nanoscale (36 nm), pH and taking into consideration the effect of the solar radiation intensity with the exposure period. The optimal conditions (H₂O₂=600mg/l, ZnO NPs=80mg/l, pH=7, Temp=25±5°C and flow rate=50ml/min) at 100mg/l of furfural concentration. Furfural removal efficiency for the type of (AOPs) treatment (UVA Photolysis), (UVA/photocatalyst), (UVA/H₂O₂) and (UVA/H₂O₂/ photocatalyst) were recorded (38%, 55%, 68%, 96%) respectively after 240 minutes exposure time using simulated wastewater and the rate constant K of furfural degradation was increased at the same conditions (0.0023, 0.0041, 0.006, 0.022) min⁻¹ respectively while for real wastewater from petroleum refinery units, the removal efficiency has been reached to (97.5%) under the same conditions with applied (UVA/H₂O₂/ photocatalyst) option. HPLC was utilized to detect the degradation of the furfural.

Keywords: Furfural, ZnO Nanoparticle, UV sunlight Photo reactor.

1. Introduction

Oil refineries are considered one of the large industries and the most important part of the economy of some countries around the world. The impact of oil refineries on the environment is sometimes negative and has added to the health concerns of nearby communities because oil is essentially toxic to all forms of life, although extracting it may lead to climate change, and this has appeared in recent years. One of the generated pollutants by petroleum refineries
are the organic solvents that come with waste, which pose an environmental hazard because of their toxicity even at low concentrations, which are difficult to degrade naturally; therefore it remains a serious threat as it can accumulate in human and animal tissue while being excreted into the environment\cite{11}. Furfural is an organic chemical with the chemical formula C₄H₃OCHO that is used as a solvent in oil-solvent extraction processes as well as in extraction units in the petrochemical industry to separate hydrocarbons. It is considered a very resistant material and has a very slow degradation rate in the environment \cite{2}.

For furfural the allowable exposure level (PEL) was < 5 ppm, that is within the parameters of the global environment. Organic pollutants in industrial wastewater from refinery are considered non-biodegradability toxicity compounds; in many cases, using the tertiary biological treatment methods industrialized wastewater purification are more cost effective than chemical treatment method. But the biological method is subject to different operating conditions, it takes extended recovery time and results in ghastly odor and may lead to deadly volatile toxic products \cite{3}. Conventional physical methods (adsorption, filtration, reverse osmosis, coagulation) are very costly, and they do not eliminate organic molecules completely, but only convert them to another stage \cite{4}. Recently, researches have been done to Achieve new technology with low cost and lower energy inputs to remove these toxins from waste water. Then, by using solar photo catalysts, scientists worked to develop wastewater technology. A lot of studies have been conducted by several researchers who found that Photo catalysis chemical effluent degradation has been one of the strongest methodologies for the treatment of toxic effluents besides, they are clean and environmentally friendly technologies, maybe the biggest benefit of wastewater catalytic treatment is a low-cost one \cite{5, 6}.

The technique requires a source of light irradiation with oxidizing agents to generate hydroxyl radicals as the main process taking place is oxidation, as the generation of hydroxyl radicals is responsible for the degradation of the organic compounds, when irradiation of the photo catalyst, electron-hole pairs are created \cite{7, 8}. In order to investigate the ability for photo catalytic oxidation of toxins, several tests and experiments have been performed. Different contaminants, various photo reactors, and various catalysts support. Some Studies were using natural sunlight and others using artificial irradiation \cite{9}. In the current study, sunlight was used as a source of UVA; the fact that the geographical location of Iraq allows it to receive a large amount of solar energy makes the methods of solar treatment AOPs attractive to reduce many of the pollutants dissolved in wastewater in Iraq. There are maximal values for the normal variations in UVA in the spring and summer days, and low values in the fall and winter days \cite{10}, in addition to being a source of low-cost energy.

Ultraviolet radiation is usually classified into three bands UV-C (100–280 nm) which is completely absorbed by stratospheric ozone; UV-B (280–315 nm) which is only partially absorbed or scattered in atmosphere and UV-A (315–400 nm) which represents most of the UV radiation received at the earth. The researches which investigated solar radiation within ultraviolet radiation bands due to its biological, ecological effects created by short-wave radiation obtained from the earth's surface have gained considerable attention in the last few years \cite{10, 11}.

The purpose of this presented research was a development the design of photo catalytic reactor and studied the performance effectiveness of the photolysis reactor by the degradation of furfural in the presence of UVA from sunlight and catalyst ZnO NPs and investigation of the role of main factors that affecting the process.

1.1. Photo catalytic Reactor

1.1.1. Photo catalyst.
Several researchers have reported using semiconducting materials (TiO$_2$, SrTiO$_3$, ZnO, WO$_3$, Fe$_2$O$_3$, etc) as photo catalyst \[12,13\]. Photo catalyst for the degradation of organic compounds among the various semiconductor materials, this is in addition to the photovoltaic reactors that are powered by solar energy, the treatment of water is an environmentally sustainable solution, especially for areas that receive strong sunlight during the year. These solar photovoltaic reactors minimize the cost of operation, resources and repair associated with UV driven photo catalysis reaction systems \[14\].

In recent years, there have been a lot of researchers give great attention about oxidation of photo catalysis of semiconductor materials, especially non-material have received more attention due to their special physical and chemical properties, and they are applied in every field, because the reaction occurs on the surface of the catalyst, so the surface area of the catalyst is very important in heterogeneous photo catalysis \[15\].

Some researcher’s previous studies have been concerned with removing organic materials from the aqueous medium by using titanium dioxide as a photo catalyst \[16,17\]. But in this study ZnO NPs is a type of photo catalyst that is used in photo catalysis system absorbs more of the solar spectrum than other semiconductors. ZnO has a much greater quantum efficiency than TiO$_2$ in some cases, ZnO better activity detection than TiO$_2$ due to a faster electron transport rate in ZnO with a reduce recombination rate, its ease of crystallization and anisotropic growth, has a lower cost of production, easy availability, excellent chemical stability, non-toxicity in nature, eco-friendly properties and high efficiency \[18,19\]. ZnO has bang gap $\approx 3.37$ eV, which has become promising in the last few years due to its hygienic, catalytic and optoelectronics. The photo catalytic process includes excitation ZnO with a wavelength of $\lambda \leq 400$ nm from UV light, electron–hole pair ($e_{cb}^-, h_{vb}^+$) are generated. The energy of the absorbed photon should be equal to higher than the energy of the semiconductor "Bandgap" The hydroxyl radicals are created by the hole which can degrade the organic pollutants present in the wastewater. Oxygen is supplied from the air (when the system is stirred), dissolves in solution cleans the generated electron, and inhibits recombination of electrons and holes \[20\].

The process can be illustrated by the following set of equations:

\[
\begin{align*}
\text{ZnO} + h\nu &\rightarrow e^- + h^+ \quad (1) \\
e^- + \text{O}_2 &\rightarrow \text{O}_2^- \quad (2) \\
h^+ + \text{Organic} &\rightarrow \text{CO}_2 \quad (3) \\
h^+ + \text{H}_2\text{O} &\rightarrow \cdot\text{OH} + \text{H}^+ \quad (4) \\
\cdot\text{OH} + \text{Organic} &\rightarrow \text{CO}_2 + \text{H}_2\text{O} \quad (5)
\end{align*}
\]

1.1.2. Photo reactor.

Different types of reactors have been demonstrated in several studies by researchers \[21,22,23\]. The four shapes often utilized reactors are parabolic double-skin sheet reactor, DSSR; compound parabolic collector, CPC; thin-film fixed bed reactor, TFFBR; and parabolic trough reactor, PTR. Tube reactors are a variation of the other types of reactors such as (CPC) that have been used in the current research, something must be taken into consideration in choosing the design of the reactor to achieve the desired goal to provide better efficiency in the treatment of low pollutant concentration effluents, and high efficiency due to direct and diffuse radiation of which the materials used in the design of the photo catalytic reactor must be able to transmit UV light as well as resist the degradation of ultraviolet light. Many researchers have used material such as glass with low iron content, which is the preferred material to manufacture this tube \[24,25\]. In some other papers, usually fluoro polymers and acrylic
polymers are used to make the absorber tube but it is not very economically viable due to its high cost. In the current Work, the quartz was used to make the absorber tube has excellent UV transmission and temperature and chemical resistance, as well the reflective surfaces is play an important role to achieve high optical efficiency and solar concentration, therefore Aluminium is a better alternative for the reflector / concentrator than a conventional silver-coated mirror, owing to its high reflectivity and low cost [26].

2. Materials and Method

2.1. Materials.
HPLC-grade methanol 99.8%, Hydrogen Peroxide (H₂O₂) 47%, Furfural 99.9%, Sodium Hydroxide NaOH (0.1 N) and Hydrochloric Acid HCl (0.1N) used to adjusted the pH all of these chemical reagents were purchased from commercial sources as certified grade and used as received without further treatment. De-ionized water was prepared in laboratory by using ultrapure water by generating device.

2.2. Methods

2.2.1. Method of design of solar photo catalytic reactor.
In the current study, the photo-reactor used was a tubular reactor consisting of five quartz tubes with dimensions of each tube were 62cm length and 1.2cm inside diameter connected by serial Pyrex connections placed on fixed supports from Aluminium reflective plate with a typical inclination angle (β=33.27°) inclined unit (Baghdad latitude) with for the horizontal plane and facing south, this provides performance improver; it was also agreed upon with some researchers [27]. The photo-reactor consists of various parts: glass container covered with a jacket capacity of (5 litters), in which it contains wastewater with various chemicals and resistant pipes to bring the reactive mixture to the actual reactor to provide steady mass flow. The plant was designed for operation in a continuous circulation. The reaction temperature is constant at 25±5 °C and is controlled by the cooling water flowing through the reactor jacket, where the reaction system is connected to a cooling system (Chiller) to ensure the solution remains at a constant temperature because the temperature increase caused by the thermal reaction can influence the reactor's efficiency.

Figure 1. Schematic diagram of solar photo catalytic reactor
Figure 2. Photograph of the experimental setup
A UVA ultraviolet radiometer model (UVA-365) was used to measure global ultraviolet radiation, which is the driving force for the experiments in this study wave, this device supplies the information in terms of the incident (UVA- W/m²), duration of exposure during experiments was 240min. ‘Figure1’. ‘Figure2’ shown the Schematic diagram of solar photocatalytic reactor & Photograph of the experimental setup.

2.2.2. Analysis method.
A standard solution of Furfural was prepared with purity (99%) by dissolving 1 g in 1000 ml of deionized water as stock solution and then 100 mg/l was prepared as furfural concentration used as a sample inside the photo reactor. Experiments were performed under various operating conditions, H₂O₂ dosage (200, 400, 600 and 800) mg/l, ZnO NPs dosage (40, 60, 80,100 and 200) mg/l , pH (3,7,10) and all degradation experiments were conducted at 25± 5 °C with circulation flow rate 50ml/min in the presence of UVA irradiation from sunlight as natural energy source with irradiation time (30,60,90,120,150,180 and 240) min. Before to analysis, a calibration curve was generated using a series of standard solutions with Known concentrations of furfural, (R² = 0.999) . Another sample was real wastewater from an oil refinery, with a concentration of furfural 50 mg/l had been treated at optimal conditions.

2.2.3. Method of furfural determination.
HPLC (High Performance Liquid Chromatography) was used in this study for the determination of furfural concentrations in the samples configured with UV detector, the type (CECIL, UK). The furfural analysis was isocratic and was conducted using Mobil phase consisting of 5% acetic acid w/v, water methanol (80:20), Column C 18 (5 µm), flow rate 1 ml/min, wavelength of UV absorption detector 285 nm [28].

Determination of removal percentage to determine the percentage of furfural removal efficiency using Eq. (6) [28]

\[
\%\text{Removal} = \frac{C_0 - C_t}{C_0} \times 100
\]

Where: \(C_0\) is furfural initial concentration and \(C_t\) furfural concentration at time \(t\) during the treatment process.

3. Results and Discussion

3.1. Experimental of degradation of Furfural

3.1.1. The effect of UV-photolysis.
Experiments were conducted to study the efficiency of furfural removal by using UVA flowing from solar radiation without adding any substances. Experiments at different concentrations of furfural (10, 20, 50,100,200 and 250 mg/l), the inherent pH was recorded to be 7, Temp=25±5 °C, flow rate = 50 mL / min. The results for the removal efficiency for each concentration versus irradiation time are plotted in the ‘figure 3’, ‘figure 4’ which Show the relation between the removal efficiency of furfural with the time of exposure to solar radiation energy for different initial concentration of furfural it can be noticed from this figures the removal present of furfural decreased with increasing the initial furfural concentration, from 85 % when the concentration is 10 mg/l to 20% when the concentration is 250 mg/l. That despite the increased duration of exposure to solar radiation. The result in the case of high concentrations of pollutants leads to depletion of the amount generated ’OH (Oxidizing agent) as a result of the absorption of the energy of solar radiation by the aqueous solution, so that single oxidation by UV-photolysis alone is not sufficient for high concentrations.
3.1.2. Effect of adding H$_2$O$_2$ (UV/H$_2$O$_2$) system.

The effect of adding different concentrations of H$_2$O$_2$ (200, 400, 600 and 800 mg/l) was examined in these experiments was tested for optimizing the amount of H$_2$O$_2$ required to degraded of furfural, was used with initial pH equal to 7 and the concentration of furfural =100 mg/l, the temperature was maintained at 25±5°C and flow rate =50ml/min through all the experiments. The results of removal efficiency for each concentration against irradiation time were plotted in ‘figure 5’ which shows the relationship between the removal efficiency and the irradiation time for different initial concentration of H$_2$O$_2$. From this figure, it can be observed that furfural degradation increased as H$_2$O$_2$ concentration increased from 200 to 800 mg/l reaching to the best removal efficiency was found to be 68% at 600 mg/L after 240 min of total irradiation time. But it was noticed in the concentration of H$_2$O$_2$ 800mg/l the removal value decreased to 60%, HO$_2^-$ is generated due to the interaction of hydrogen peroxide with these radicals, so these radicals (HO$^+$ and HO$_2^-$) can serve as inhibiting agents and thus low
degradation can be achieved. $\text{H}_2\text{O}_2$ is HO$^\cdot$ scavenger, so an excess of $\text{H}_2\text{O}_2$ can lead to a net reduction in the treatment efficiency.

All reactions are shown in the following equations:

\begin{align*}
\text{H}_2\text{O}_2 & + \text{ hr (UV energy)} \rightarrow 2\cdot\text{OH} \quad (7) \\
\text{H}_2\text{O}_2 & + \cdot\text{OH} \rightarrow \text{HO}_2^\cdot + \text{H}_2\text{O} \quad (8) \\
\text{H}_2\text{O}_2 + \text{HO}_2^\cdot & \rightarrow \cdot\text{OH} + \text{H}_2\text{O} + \text{O}_2 \quad (9) \\
2\cdot\text{OH} & \rightarrow \text{H}_2\text{O}_2 \quad (10) \\
2\text{HO}_2^\cdot & \rightarrow \text{H}_2\text{O}_2 + \text{O}_2 \quad (11) \\
\cdot\text{OH} + \text{HO}_2^\cdot & \rightarrow \text{H}_2\text{O}_2 + \text{O}_2 \quad (12)
\end{align*}

These explanations are identical to the different sources mentioned by many researchers $^{28, 29, 30}$.

3.1.3 Effect of UV/photo catalyst system.
Experiments were carried out using the combination of photo catalyst and UV without any amount of $\text{H}_2\text{O}_2$. The removal efficiency of furfural reached to 55% at optimal conditions (80 mg/l of ZnO NPs, Temp. = 25±5 °C, pH = 7 and flow rate =50 ml/min) with furfural concentration= 100mg/l. The results were plotted in ‘Figure 6’ shown that the removal efficiency was reached 55% only, When using the best dose of photo catalyst the best possible removal is obtained that may be due to the number of available 'OH radical generated on the surface of the catalyst is not sufficiently large to obtain the greatest removal.
3.1.4 Effect of ZnO nanoparticle loading at UV/H2O2/photo catalyst system.

Experiments were carried out using different concentration of ZnO nanoparticles (40, 60, 80, 100 and 200 mg/l) were used to show its effect UV/H2O2/photo catalyst system at optimal conditions (H2O2=600 mg/l, pH=7, Temp. =25±5°C, furfural conc. =100 mg/l and flow rate=50 ml/min.) with 100 mg/l of furfural concentration. From the ‘figure 7’, ‘figure 8’. It can be observed that the performance of removal improves to achieve a limit of 96% at 80mg/l of ZnO NPs, then it tends to decrease to reach 88% at 200 mg/L ZnO NPs. This is due to the increase in the amount of active sites on the surface of the catalyst, causing an increase in the number of photons absorbed, contributing to the formation of a significant number of OH radicals, and increasing the degradation of furfural molecules. When the dose of ZnO NPs was greater than 80mg/l, the amount of ZnO NPs was above a certain level (saturation stage) increase particles ≥100, The solution becomes turbid, the photon absorption efficiency decreases radially and the excess photo catalyst can prevent radiation penetration and thus create a screening of light, which decreases the radiation-exposed surface area by that reduces photo catalysis efficiency of the process, thereby reducing the effectiveness of catalyst activation during the UV irradiation. This is what many researchers observed [31, 32, 33].

**Figure 6.** Effect of ZnO NPs (80 mg/l) on the degradation of furfural at(pH= 7, Temp. =25±5°C, furfural conc. =100 mg/l and flow rate=50 ml/min).

**Figure 7.** Effect of different concentrations of ZnO NPs on the degradation of furfural at 100 mg/l with (H2O2 = 600 mg/L, pH= 7, Temp. =25±5°C and flow rate =50).
Figure 8. Degradation of furfural as a function of ZnO NPs conc. at (pH=7, furfural concentration = 100mg/l, Temp=25±5 °C and flow rate =50ml/min).

‘Figure 9’ Shown that the removal efficiency was 38%, 68%, 55%, 96% from the all treatment type at optimal conditions.

Figure 9. Degradation of furfural as a function of treatment type.

3.1.5 Effect of pH.
A significant role is played by the impact of pH on furfural degradation. In this analysis, various pH values were investigated (3, 7, 10) while holding the other parameters and the dose unchanged. (H₂O₂ = 600mg/l, ZnO NPs conc. =80 mg/l temp=25±5°C, flow rate =50ml/min) with furfural conc. =100mg/L. From ‘figure 10’ can be observed that maximum removal efficiency of furfural was (98%) obtained at pH=10 and down to this value the removal efficiency was decreased gradually (96%) at pH=7, (89%) at pH=3. This is because catalytic water treatment is highly dependent on the pH after all it affects the charge of the catalyst molecules, as the point of zero charges (pHpzc) of ZnO NPS is about pH 8.60. furfural has an active site with a positive charge, therefore could be adsorbed on the surfaces of ZnO particles easily above its pH pzc. The positive charge for the active site of furfural ions and the positive charge for hydrogen ions compete for the negative charge site ZnO NPS at a low pH so that this leads to a lower furfural removal rate with lower pH. , these explanations have been studied by many researchers [34, 35, 36].
3.1.6 Effect of Intensity of solar radiation.

In general, the intensity of solar radiation depends on the season, location, times of day and weather. The accumulative UVA energy $Q(\text{kJ/l})$ has a positive effect on the degradation of furfural, because furfural oxidation is directly proportional to the photons absorbed through the solution as stated in some researches $^{35,37}$. The accumulated ultraviolet energy $Q(\text{kJ/l})$ can be calculated across the reactor surface is in the same position for the sun, per unit volume of water inside the reactor in the time period $\Delta t$, may be obtained via Eq. 13 $^{38}$

$$Q_{UV}(n) = Q_{UV}(n-1) + \frac{\Delta t_n \overline{U} \Gamma_{N A \text{collector}}}{V_{\text{total}}}; \Delta t_n = t_n - t_{n-1} \quad (13)$$

Where, $Q_{UVn}$ & $Q_{UVn-1}$: The (UV) energy gathered/litter (kJ/l) at the times $(n)$ and $(n-1)$ respectively. $\overline{U} \Gamma_{N}$: The average of mean incident radiation on the irradiated area, $\Delta t_n$: The testing time of each sample, and $A_{\text{collector}}$: The illuminated collector surface area (m$^2$).

The duration of exposure to ultraviolet radiation also played an important role in achieving photolysis of the organic compound, the creation of the electron-hole is optimal when the solar light intensity is high, and therefore it promotes the reshaping the electron-hole that plays an important role in achieving photolysis of the organic compound. These observations are following that obtained by researchers $^{35,38}$. The effect of accumulated UVA Q (kJ/l) was studied by exposing a real sample of oil refinery residues (furfural concentration 50 mg/l) to irradiation for 240 minutes during treatment by UV/H$_2$O$_2$/ photo catalyst in a photo catalytic reactor and under the same conditions used in previous experiments on the sample laboratory. After treatment, the furfural concentration reached (1.2mg/l). Figure 11’ Shown the change in furfural concentration against the accumulative UVA energy Q(kJ/l). This figure displays that the degradation of furfural is positively influenced by solar energy.

![Figure 10. Degradation of furfural at (100mg/l) as a function of pH at H$_2$O$_2$=600 mg/l, ZnO NPs concentration= 80mg/l, Temp =25±5°C.](image)

![Figure 11. The change in furfural concentration versus the accumulative UVA energy Q (kJ/l).](image)
3.2. Kinetic rate model
The known kinetic model of the pseudo-first-order was using in the degradation process, can be given in Eq (14) \[ \frac{dc}{dt} = KC \] (14)

The rate constant, \( K \) (min\(^{-1}\)), refers to as the degradation rate constant. The first-order kinetic expression shown in the equation (15) \((− \ln (C/C_0)) \) versus time (min) is plotted for the reaction type, UV/photoysis, UV/photo catalyst, UV/H\(_2\)O\(_2\), UV/photo catalyst/H\(_2\)O\(_2\)

\[ \ln \left( \frac{C_t}{C_0} \right) = -K t \] (15)

Where \( C_0 \) is the initial concentration of furfural and \( C_t \) is the concentration at irradiation time \( t \), \( K \) is the pseudo-first-order rate constants in min\(^{-1}\), \( t \) is the irradiation time (min).

Kinetic models were applied under optimal conditions for degradation furfural by the treatments system. For each experiment a plot of \( \ln \left( \frac{C_t}{C_0} \right) \) versus time lead to a straight line whose slope is \( K \) as shown in ‘Figure 12’. Evaluation was performed for model goodness via the estimation of the decision coefficient \( R^2 \). The values of rate constants and \( R^2 \) values for the treatments types are provided in table 1.

![Figure 12. Pseudo-first-order rate constant for furfural degradation by treatment types at furfural conc. = 100mg/l, H2O2 concentration=600mg/l, ZnO NPs=80 mg/l, Temp. = 25±5°C, pH=7 and flow rate = 50ml/min.](image)

| Treatment type                  | Removal % | K min\(^{-1}\) | \( R^2 \) |
|---------------------------------|-----------|----------------|-----------|
| UV/A/photolysis                 | 38        | 0.0023         | 0.967     |
| UV/A/photo catalyst             | 55        | 0.0041         | 0.983     |
| UV/A/H\(_2\)O\(_2\)            | 68        | 0.006          | 0.988     |
| UV/A/H\(_2\)O\(_2\)/photocatalyst | 96       | 0.022          | 0.991     |
4. Conclusions

There are several conclusions that summarize the study:

- The photo catalytic technology is environmentally friendly for the decomposition of recalcitrant organic compounds in water, and promising for the complete mineralization of aromatic organic pollutants as both contaminants and their direct mediators are completely removed.

- It was observed that the effect of UVA energy only it was slight, as the degradation of the low concentration was rapid but later slowed in the case of high concentration. The UV photolysis efficiency of furfural degradation was only 38%.

- The removal efficiencies of the system UVA/photo catalyst found to be 55% because the degradation of furfural. In the presence of ZnO NPs alone, solar irradiation was not successful since no oxidizing agent was present and the production of OH radicals was negligible.

- At the UV/H₂O₂ system increasing the hydrogen peroxide concentration from 200 to 800 mg / l increased removal of furfural from 40 to 68%. High concentrations of H₂O₂ (over 800 mg / l) may cause simultaneous reactions leading to H₂O₂ consumption.

- At alkaline pH=10 the removal efficiency of furfural was reached to 98%, while at an acidic pH =3 the efficiency of removal was reached to 89%. The improvement in reaction speed was observed at pH values close to neutral.

- The design of the reactor was chosen as a series of tubes of few diameters made of quartz to achieve uniform irradiation of the catalyst surface.

- The residual furfural concentration decreases during solution degradation with increasing accumulation UVA energy Q (kJ/l).

- It was noticed after a study and a comparison between the types of treatments used the removal efficiency of furfural were 38%, 55%, 68%, 96% respectively.

- The kinetic data were fitted to the pseudo-first-order model. The best degradation rate K was recorded 0.022 min⁻¹ at UVA radiation/H₂O₂/photo catalyst system.

- The use of solar energy as a source along with simple technology can provide, economical and practical solutions to treat polluted water, especially if solar energy is readily available.

- Studies at the level of laboratory models have shown that this photo catalytic process can be applied to remove phenol and furfural as toxic and dangerous substances from liquid wastes and industrial wastewater and convert it into a safe substance that can be dumped into the river.

- Concerning the degradation mechanism of furfural, there are three steps generally expected, including aldehyde group oxidation, photo-oxidation of aromatic ring, and cleavage of ring.

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