IOSR Journal of Applied Chemistry (IOSR-JAC)
e-ISSN: 2278-5736.Volume 15, Issue 10 Ser. I (October 2022), PP 15-22
www.iosrjournals.org

Photo degradation of biphenyl in prior to the ecological elimination of polychlorinated biphenyls "PCBs"

Oumarou Tidjani Malam Mani[1]
Département de chimie, faculté des Sciences et Techniques, Université Dan Dicko Dan koulodo de Maradi/Niger

Rabani Adamou[2]
Département de chimie, faculté des sciences et Techniques, Université Abdou Moumouni de Niamey/Niger

Abstract: *Polychlorinated biphenyls (PCBs) are part of persistent organic pollutants which are very harmful for environment and human beings. The international community envisaged the complete elimination of PCBs for 2028. However, the techniques available of destruction are very expensive because of consuming energy, with environmental and health risks. To offset these difficulties, we investigate a simple and effective method for elimination of PCBs in liquid phase. This technique is based on catalyzed photodégradation. Because biphenyl is the major products of PCBs dechlorination , the photodegradation of biphenyl were studied in prior to that of PCBs. The ultraviolet radiations UVA, UVB and visible radiations were used to investigate the effect of type of radiation on the direct photolysis. The effect of oxidant and photocatalyst were determined respectively by UV/H_2O_2 andUV/Fe_2O_3 processes. The highest degradation in direct photolysis were obtained under UVA+ UVB + Visible (73.21%) follow-up by UVB (72%). On the other hand, UVB/H_2O_2 process was the greatest (75.24%), while the addition of Fe_2O_3 did not produce the expected effect of a photocatalytic. Finally, this performance of these processes, (UV, Vis/H_2O_2) allowed suggesting the use of solar radiation for an ecologically rational elimination of PCBs.*

Keywords: *photocdegradation, , PCBs , photonique effect , Biphenyl, H_2O_2.*

Date of Submission: 14-10-2022 Date of Acceptance: 30-10-2022

I. Introduction

Polychlorinated biphenyls are chlorinated organic compounds, which are among the most important and dangerous pollutants of the twentieth centuries [1]. Also called PCBs, they are still in the twenty-first century (decades after their commercial production), a major global concern because of their thermal stability. Despite the cessation of their production since the 1980s. PCBs are still used, mainly as dielectric fluids in transformers, capacitors and radiators or as lubricants in turbines and pumps [2] The word global PCB production is around 2 million tons, with 30% dispersed in the environment and 70% stored and/or in use [3,4]

Over the word, especially in Africa, it is mainly the electricity production and mining companies which are the biggest users and holders of PCB waste. This is the case in Niger where a large quantity of waste has been stored at Nigerien electricity company (NIGELEC) and mining companies (SOMAIR and old COMINAK) [5]

Furthermore, the worrying characteristics of PCBs (persistence, bioaccumulation, ecotoxic activity) alerted the international community to classify PCBs on the list of persistent organic pollutants "POPs" in 2001 during the Stockholm Convention [6] Therefore, it has been established their complete elimination by the United Nations Environment Program (UNEP), for 2028. However, the available destruction techniques are very expensive, energy consuming, often causing health and environmental risks. ([7,8] Also, their combustion around 1100°C releases carcinogenic substances (dioxins and furans); while their incineration is done at temperatures between 3000 and 15000°C, and the alkaline reduction is explosive [9]. To offset these reactional and mechanicaldifficulties, we are investigating a simple and effective method for elimination of liquid PCBs using the catalyzed photodegradation techniques. Thus, in prior to the photodegradation of PCBs, the assisted photodegradation of biphenyl was studied. Becausephotocatalysis is a complex process, involving the cumulative effects of photons, solvent, oxidizing agent and the photocatalyst. [10,11], the effect of different types of irradiation (UVA, UVB, and Visible) on the photodegradation of biphenyl was first investigated. Also, the direct biphenyl photolysis in different solvents allowed to appreciate the role of solvent on the analytical

quality of spectrum and the by percentage of photodegradation. The effect of oxidanton photolysis was studied by adding hydrogen peroxide (H_2O_2). The addition of ferric dioxide (Fe_2O_3) did not confirm the expected beneficial effect of a photocatalyst.

II. Materials And Methods

Chemical Reagents and Materials

Biphenyl (≥99%), was purchased from Merck Schuchardt OHG (Germany). Its solution was prepared in a mixture of distilled water and ethanol (99+% Wagtech International LTD). The hydrochloric acid HCl (37%) and the sodium hydroxide pellets which were used to adjust the pH of the solutions, were respectively from Prolabo (made in CE) and HANG Zhoo fine chemical industry, CO LTD (China). Hydrogen peroxide H_2O_2 (30%) was purchased from Han Zhoo (China) and ferric oxide Fe_2O_3 from Labosi (Paris, France). The pH of the solutions was measured using a multimeter, Multi 3430 SET (Germany) The photodegradation of biphenyl and its kinetic were measured using a UV-Vis spectrophotometer ((Thermo Fisher Scientific, Evolution 300 UV-Vis, Madison, USA)The UV radiation device is composed of **UVA** [320 – 400 nm] and **UVB** [290 - 320 nm]) provided respectively by five UVA lamps (Hitachi, FL 8BLB) and five UVB lamps (Luzchem Research INC). The visibleradiation, is obtained using five mercury lamps (Sylvania 5058, Hg F8T5/ C10, P= 8W, Mexico)

Figure 1. :photo irradiation Dispositive

Experimental procedures

Preparation of biphenyl solutions

Since biphenyl has very low solubility in water (6.17 $mg.L^{-1}$) [12], a stock solution ($1g.L^{-1}$) was prepared in a water-ethanol mixture (10:90, V/V). From this stock, other more diluted solutions (100 ppm) are prepared in different solvents in order to test the effect of the solvent. Then, the prepared solutions are enveloped with aluminum foil and put in the refrigerator to be protected from any radiation.

Photoirradiation procedure

The photo-irradiation consisted of preliminary tests. by direct photolysis of the biphenyl solution (100 mgL^{-1}), in different solvents, using UVA irradiation. So, samples of these different solutions, contained in a test tube (section 1 cm^2, volume 3 mL), were placed on an optical bench, 20 cm to the lamps and irradiated for 2 hours. The absorbance spectra of each solution before and after irradiation, allowed to deduce the quantity of biphenyl photodegraded according to the solvent used. Thus, the percentage of degradation can be calculated by:

$$d\% = \frac{A_0 - A_i}{A_0} \times 100\% \qquad (1)$$

The same procedure was followed to study different parameters (addition of H_2O_2 as oxidant, addition of Fe_2O_3 as photo catalyst, pH of irradiating solution, initial concentration, irradiation source) on the biphenyl photolysis.

Kinetic of biphenyl photodegradation

The kinetic of photodegradation of biphenyl was followed, using three different sources of irradiation, and adding some substances (H_2O_2, Fe_2O_3) at different pH in order to compare the intensity of radiation on the photolysis one hand, and the effects of pH, oxidant and photocalyst in the other hand. The solution (100 mL of concentration 100 mgL^{-1}) to be irradiated, contained in a 150 mL beaker, is placed on an optical bench at 10 cm from the lamps. At regular times (every 10 min during 1 hour, and every 20 min during 2 hours), some amount of sample is taken for uv-spectrophometric analysis. Then the reading absorbance (A) allowed to calculate the corresponding concentrations from the following formula (2): obtainedfrom Beer-Lambert low: $A = \mathbf{log}\left(\frac{I_0}{I_1}\right) = \varepsilon l C$using $\frac{A_i}{A_0} = \frac{\varepsilon l C_i}{\varepsilon l C_0} = \frac{C_i}{C_0}$

$$C_i = \frac{Ai \times Co}{A0} \qquad (2)$$

Where A_0 is the absorbance (t = 0 min),

Ai:absorbance at time t,

C_0:is the initial concentration.

The photoxidation of biphenyl followed the second order reaction [13,14]with this kinetic model:

$\frac{d[biph]}{dt} = -k_{biph,OH}[biph][OH^-]$. (3)

Because it is difficult to determine$[OH^-]$.concentration, the rate constant K is experimentally determinated from: $\frac{[biph]}{[biph]_0} = e^{\left(-(K_{biph})\right)'} \text{ x } t$

where $\left(K_{biph}\right)' = K_{biph,OH\bullet} \times [OH^-]$ and it is given in min^{-1}

III. Results And Discussion

Influence of the solvent on the photolysis of biphenyl

The analysis of UV-Vis spectrophotometry of biphenyl solutions (100 mgL^{-1}), prepared in different solvents, led to study the effect of the solvent on the absorption spectrum (figure 2), and on the photolysis rate of biphenyl (figure 3).Thus, the different spectra on Figure 2, show that the solvent, depending on its type (polar, apolar, protic, aprotic), can have a bathochromic or hypochromic effect on the spectrum of the dissolved substance [15] .Also, It is observed in figure 3that , for the same irradiation time, under the same conditions, the percentage of degradation depended on the type of solvent. This, show that the choice of solvent is strategic, not only for its influence on the photolysis, also for the quality of the analysis. The highest percentage of degradation is obtained with diethyl ether (81.5%). To improve an ecologically rational degradation, a water-ethanol mixture was preferred as the solvent for the rest of the work.

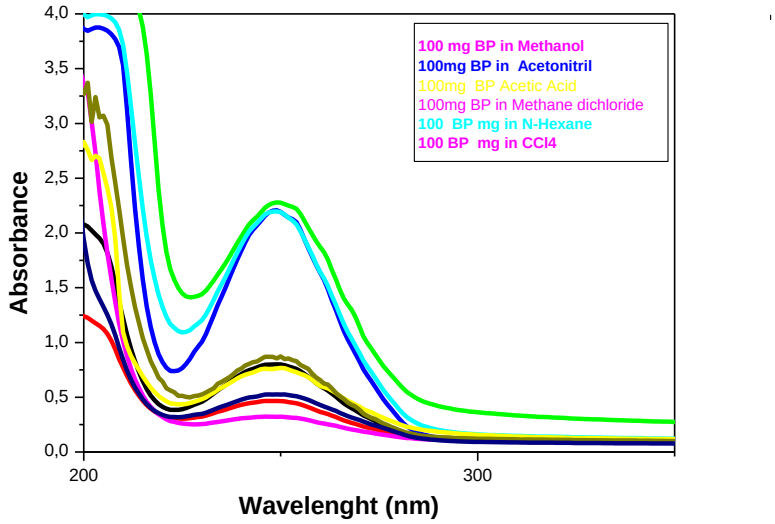

Figure 2: UV absorption spectrum of biphenyl in different solvents (pH = 6,8±0,1)

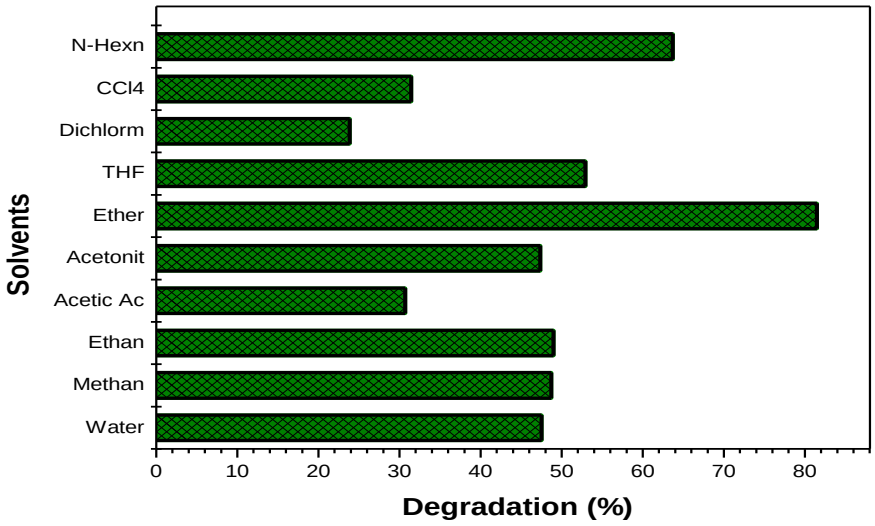

Figure 3 : Photolysis of biphenyl versus solvents after 2 hours, Under UVA irradiation
(Experimental conditions: pH=6.8±0.1; T= 30±0.5)

Influence of H_2O_2 on biphenyl photolysis

In photocatalysis, the addition of hydrogen peroxide as an oxidant is an important parameter for efficient treatment [16]. To investigate the influence of H_2O_2 on direct photolysis, the solution of H_2O_2 (5.10^{-3}M) was added, at different volumetric proportions (H_2O_2 [1:9], [2:8], [3 :7] , [4:6] , [5:5]) in the way to obtain a total volume (10 mL) of biphenyl solution to be irradiated. It is observed in Figure 4 that the best photodegradation rate (69.72%) was reached with the addition of $H_2O_2$with the proportion [2:8]; after one hour of irradiation under UVA. So, this addition of H_2O_2 [2:8] means a concentration of 1 mM in the irradiated solution. In fact, the H_2O_2/UV process is one of the advanced oxidation processes, which is essentially based on the production of free radicals such as hydroxyls (OH•) having a great oxidizing powers. [17] The major mechanism for the production of hydroxyl radicals in the UV/H_2O_2 process is the photolysis of hydrogen peroxide [18]. This would suggest that increasing the concentration of H_2O_2 would increase the rate of degradation. But is not the case, since at high concentrations, hydrogen peroxide acts as a hydroxyl radical scavenger too; when it absorbs all the available light [19]. Therefore, $OH^{\bullet}$ radicals are generated by homolytic cleavage of the O-O bond of H_2O_2 , and would attack the benzene rings, thus reacting with the C-C double bonds [17,19]

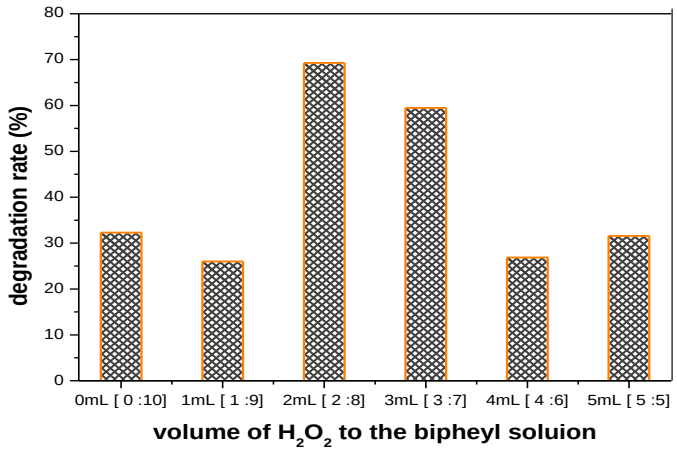

Figure 4: Effect of H_2O_2 on the biphenyl photodegradation
(experimental conditions : pH = 6,8 ±0.5.; T= 30°C , under UVA radiation, exposure time 60 minutes)

Effect of pH on the photodegradation of biphenyl

After 1 hour of irradiation under UVA, the best photodegradation performance (68.81%) was observed for a pH = 7 (figure 5). These results are better than those of the oxidation of biphenyl by the Fenton process observed by Li [14, 24], where after 2 hours of reaction 48% of the biphenyl remains. However, at pH=3 and at pH= 11 the degradation rates are respectively 51.16 and 46.7%.hese results suggest that the optimal pH of biphenyl photolysis is near to the neutral.

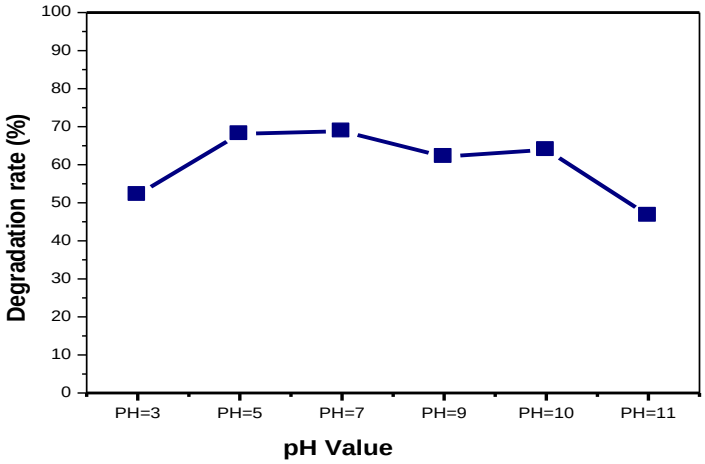

Figure 5 : pH effect on the biphenyl photolysis
(experimental conditions: Ci = 100 ppm, T= 30 ± 0.5°C; Exposure time: 1hour)

Influence of the type of radiation

To investigate the effect of the type of radiation, the photoirradiation was carried out with different UV lamps: (**UVA** [320 – 400 nm]; **UVB** [290 - 320 nm]) and visible lamps (8W power mercury lamps). The results in Figure 6 show that after five hours of radiation, the best photodegradation rate (73.82%) was obtained with the mix radiation (UVA + UVB + Visible) when the UVB radiation gave 72.02% of destruction .and the lowest one (65.03%) was attained under the UVA The performance of mixed radiation (UVA + UVB + Visible) on the degradation of biphenyl suggests a possible use of solar energy, then reinforcing the practice of ecologically photo-elimination of biphenyl; so of PCBs. [25]

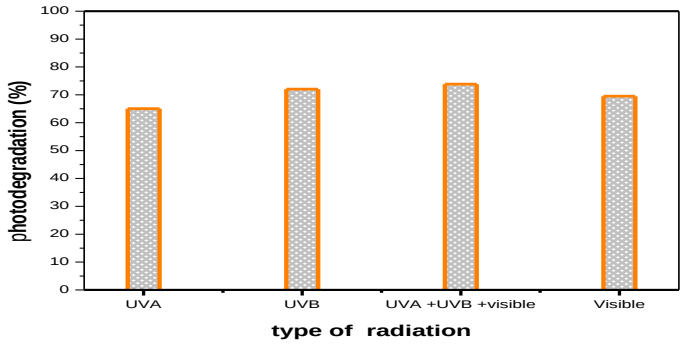

Figure 6: Influence of the radiation type on biphenyl photodegradation
(experimental conditions: pH= 7± 0.5 , T= 25±0.5°C, C_0 = 100 mgL^{-1} Exposure time: 5hour)

Biphenyl photodegradation kinetics

The major mechanism of biphenyl photodegradation proceeds by oxidation: It started by hydroxylationwith formation of hydroxybiphenyl, followed by the opening of benzene ring, giving carboxylic acids and Carbon dioxide CO_2. [14,26].

Kinetics according to the type of radiation

The different values of the rate constants (Table I) and the graph related to the type of irradiation(Figure 7: exposure time versus concentration), show the exclusive effectiveness of the photonic effect on the degradation of biphenyl. Thus, from UVA radiation (k = 0.0056 min^{-1}) to UVB radiation (k = 0.01436 min^{-1}) the rate constant was multiplied by 2.5, while with the mixture UVA+ UVB+ Visible (K=0.0146

min^{-1}), the rate constant is 2.6 times greater than the constant of UVA radiation use. Thus, these values of the different constants reflect the same photonic effects depending to the nature of radiation. [27]

Tableau I: Rate constant (K) and linear coefficient of regression(R^2) for Photodgradation kinetics of biphenyl proceeding under types of radiation

Type of radiation	Rate Constantes K(min^{-1})	linear coefficient of regression R^2
UVA	0.0046	0.9338
UVB	0.01436	0.9503
Visible	0.0104	0.973
UVA+UVB +Visible	0.0146	0.9243

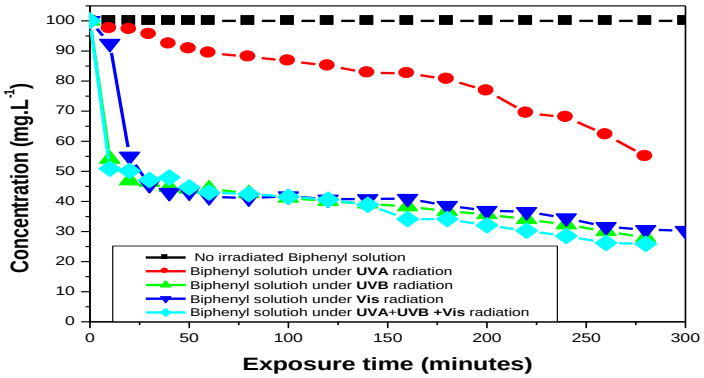

Figure 7 : Photodgradation kinetics of biphenyl proceeding under types of radiation (experimental conditions: pH= 7± 0.5 , T= 25±0.5°C, C_0 = 100 mgL^{-1} Exposure time: 5hour)

Kinetics of assisted photodegradation (UVA/H_2O_2; UVB/H_2O_2; UVA+UVB+Visible/H_2O_2)

The results registered in Table II and presented in figure 8 allowed to compare the rates of photo-degradation according to the rate constants K(min^{-1}) and the linear coefficient of regression R^2 related to the tree processes [28]. Thus it is noted that the rate constant of biphenyl degradation by direct photolysis (K= 0.0046 mi^1) in table I,under UVA has been multiplied by 2 when H_2O_2 is added (UVA/H_2O_2 process K = 0,089 min^{-1}) in table II. But for the other two processes (UVB/H_2O_2; UVA+UVB+Visible/H_2O_2)when H_2O_2 is added the constants have remained substantially the same. With the best degradation rate for the UVB/H_2O_2 process.

Tableau II : Rate constant (K) and linear coefficient of regression(R^2) for Photodgradation kinetics of biphenyl proceeding under UV, Vis /H_2O_2 processes

UV,Vis / H_2O_2 processes	Rate Constante K(min^{-1})	Linear Coefficient of regression R^2
UVA/H_2O_2	0.00897	0.9012
UVB/H_2O_2	0.01412	0.8953
Visible/H_2O_2	0.01316	0.8451
(UVA+UVB +ViS) /H_2O_2	0.009324	0.9773

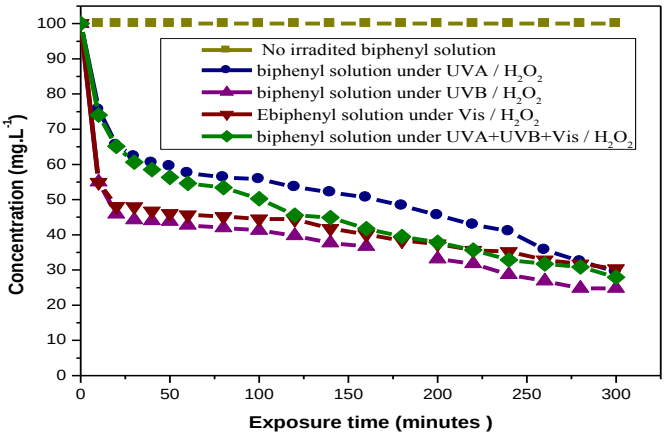

Figure 8 : : Photodgradation kinetics of biphenyl proceeding under UV, Vis / H_2O_2(experimental conditions: pH= 7± 0.5, T= 25±0.5°C, C_0 = 100 mgL^{-1} Exposure time: 5hour)

Influence of a photocatalyst (Fe_2O_3)

To investigate the effect of the photo catalyst, the preliminary tests were carried out with different initial concentrations of the photocatalyst Fe_2O_3 (50; 75; 100; 125; 150 and 200 mg L^{-1}). These outcomes allowed to retain 100 mgL^{-1} as the optimal concentration of the photocatalyst. Indeed, Fe_2O_3 is a semiconductor (gap = 2.91ev) of oxidant type ([21 ,29]The promising mechanism ofphotocatalysis follows the classical scheme[22].

After photon absorption, charge generation occurs (pairs (e-/h+)):

Fe_2O_3+ hv(UV) → Fe_2O_3 (e- BC + h+ BV) (4)

Nearby follows an ion sorption of oxygen:

Fe_2O_3 (e-BC) + O_2,ads → Fe_2O_3 + O_2• (5)

Because the main solvent is water the neutralization of the OH^- ions into the $OH^•$ radicals by h^+ BV tooke place:

Fe_2O_3 (h^+ BV) + (H_2O ↔ H+ OH^-)ads → Fe_2O_3 + H^+ + $OH^•$(6)

Finally; Biphenyl oxidation occurs through successive attacks by $OH^•$ radicals, or a direct reaction with the positive hole (h^+) [23]. Thus, from figure 9, itwas shown that the addition of the photocatalyst did not produce the expected effect since the three processes gave substantially the same result. This could be explained by the mismatch between the semiconductor (Fe_2O_3) and the type of irradiation received. [30]

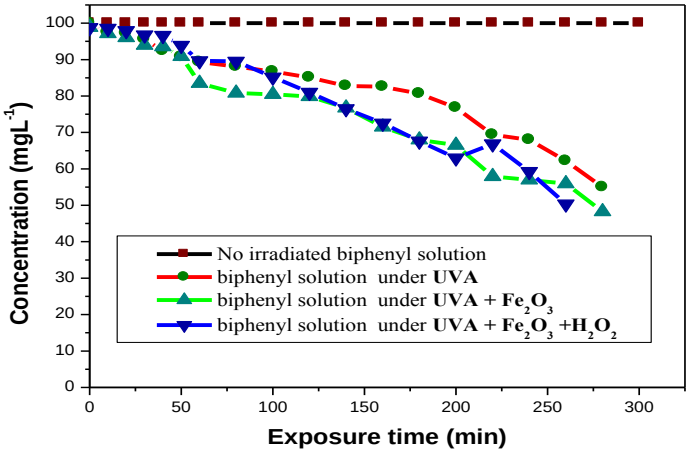

Figure 9: Photodgradation kinetics of biphenyl proceeding under UVA, Fe_2O_3 , H_2O_2 (experimental conditions: pH= 7± 0.5, T= 25±0.5°C, C_0 = 100 mgL^{-1},exposure time: 5 hour)

Conclusion :

The results of this study have established the evidence of photoreactivity of biphenyl through $OH^•$ radicals, under the performance of the (UV, Vis / H_2O_2) processes. Also it has been proven that the photonic effect, depending on the type of irradiation, remains the driving force of photocatalysis. However these results

showed a relatively slow degradation of biphenyl, the optimization of the operational conditions, can led to a degradation of PCBs until mineralization, after dechlorination or directly. Finally, the performance of direct photolysis under visible irradiation and UVA+UVB+Vsible, allowed suggesting the use of solar radiation, promising an ecologically rational elimination of PCBs.

References

[1] Bilal, M., Rasheed, T., Iqbal, H. M., et Yan, Y. (2018). Peroxidases assisted removal of environmentally-related hazardous pollutants with reference to the reaction mechanisms of industrial dyes. Science of The Total Environment, 644, 1-13.

[2] Malek, A. M., Barchowsky, A., Bowser, R., Heiman-Patterson, T., Lacomis, D., Rana, S., ... Talbott, E. O. (2015). Exposure to hazardous air pollutants and the risk of amyotrophic lateral sclerosis. Environmental pollution, 197, 181-186.

[3] Zhou. Z, Zhang. Y, Wang. H, Chen. T, Lu. W; The comparative photodegradation activities of pentachlorophenol (pcp) and polychlorinated biphenyls (pcbs) using UV alone and tio2-derived photocatalysts in methanol soil washing solution; PL$_O$S ONE; (2014); 9(9):

[4] Järv, L., Kiviranta, H., Koponen, J., Rantakokko, P., Ruokojärvi, P., Radin, M., ... & Simm, M. (2017). Persistent organic pollutants in selected fishes of the Gulf of Finland. Journal of Marine Systems, 171, 129-133.

[5] Tidjani, M. M. O., Issoufou, A., Rabani, A., & Zeinab, S. S. (2018). Contamination potentielle des aliments par des polychlorobiphényles (PCBs): Connaissance du polluant et évaluation de la perception du risque. International Journal of Biological and Chemical Sciences, 12(1), 168-179.

[6] Karkaba, A. (2017). Effets neurotoxiques et multigénérationnels d'une exposition périnatale aux faibles doses de polychlorobiphényles non-dioxin-like indicateurs (PCB-NDLi) dans un modèle murin (Doctoral dissertation, Université de Lorraine).

[7] Sangely M. 2010. Dégradation biologique des polychlorobiphényles.Génie des procédés et de l'environnement. Université de Toulouse, Toulouse (France), p. 246.

[8] Marek, R. F., Thorne, P. S., Herkert, N. J., Awad, A. M., et Hornbuckle, K. C. (2017). Airborne PCBs and OH-PCBs inside and outside urban and rural US schools. Environmental science & technology, 51(14), 7853-7860.

[9] Mebirouk, H., Hamma, W. et Boubendir-Mebirouk, F. (2018). Main sources of pollution and its effects on health and the environment in Annaba. Urbanism. Architecture. Constructions/Urbanism. Arhitectura. Constructii, 9(2).

[10] Achouri,F. (2016). Détoxification des eaux usées urbaines par photocatalyse solaire (Doctoral dissertation, Université de Lorraine).

[11] Skocic, M. (2016). Etude (photo)-électrochimique en réacteur simulé du phénomène de shadow corrosion des alliages de zirconium (Doctoral dissertation, Université Grenoble Alpes).

[12] Wu, J. R., Wang, C. Y., Tao, Y. C., Wang, Y., Li, C., et Yang, Y.W. (2018). A Water- Soluble [2] Biphenyl- Extended Pillar [6] arene. European Journal of Organic Chemistry, 2018(11), 1321-1325

[13] Shaban, Y. A., El Sayed, M. A., El Maradny, A. A., Al Farawati, R. K., Al Zobidi, M. I., et Khan, S. U. (2016). Photocatalytic removal of polychlorinated biphenyls (PCBs) using carbon-modified titanium oxide nanoparticles. Applied Surface Science, 365, 108-113.

[14] .Li, Y. (2007). Detoxification of selected chloro-organics by oxidation technique using chelate modified Fenton reaction. study Guide for Standards Synthesis.

[15] Anitha, P., & Sakthivel, P. (2016). Synthesis and Characterization of Silver Nanoparticles using Allium cepa and its Anti-Inflammatory activity against human blood cells. Indo American Journal of Pharmaceutical Research, 6(01), 4203-4210.

[16] Asilian, H., Gholamnia, R., Rezaee, A., Jafari, A. J., Khavanin, A., & Darabi, E. (2010). Photochemical of Polychlorinated biphenyl by the photolysis and solvent. Journal of Applied Sciences and Environmental Management, 14(4).

[17] Huang, W., Bianco, A., Brigante, M., & Mailhot, G. (2018). UVA-UVB activation of hydrogen peroxide and persulfate for advanced oxidation processes: Efficiency, mechanism and effect of various water constituents. Journal of hazardous materials, 347, 279-287

[18] Lee, M., Merle, T., Rentsch, D., Canonica, S., & Von Gunten, U. (2016). Abatement of polychoro-1, 3-butadienes in aqueous solution by ozone, UV photolysis, and advanced oxidation processes (O_3/H_2O_2 and UV/H_2O_2). Environmental science et technology, 51(1), 497-505

[19] Hashmi, M. Z., Kalim, M., Farooq, U., Su, X., Chakraborty, P., & Rehman, S. U. (2022). Chemical remediation and advanced oxidation process of polychlorinated biphenyls in contaminated soils: a review. Environmental Science and Pollution Research, 1-16.

[20] Viswanathan.B,Sivasanker.S,Ramaswamy.A.V2017 Catalysis, Principles and Applications;

[21] .Albini, A. (2016). Some remarks on the first law of photochemistry. Photochemical et Photobiological Sciences, 15(3), 319-324.

[22] Guitoum, D. E. (2008). élaboration et étude des couches minces photo-catalytiques à base de Tio2-Fe2O3

[23] Hamandi, M. (2017). Élaboration et caractérisation d'oxydes de Titane de Morphologie Contrôlée: application à la Photodégradation de Polluants Organiques (Doctoral dissertation, Université de Lyon).

[24] ElMetwally, A. E., Zeynaloo, E., Shukla, D., Surnar, B., Dhar, S., Cohn, J. L., ... & Bachas, L. G. (2021). Cu2O Cubes Decorated with Azine-Based Covalent Organic Framework Spheres and Pd Nanoparticles as Tandem Photocatalyst for Light-Driven Degradation of Chlorinated Biphenyls. ACS applied nano materials, 4(3), 2795-2805.

[25] Sánchez-Prado, L., Lores, M., Llompart, M., García-Jares, C., Bayona, J. M., & Cela, R. (2006). Natural sunlight and sun simulator photolysis studies of tetra-to hexa-brominated diphenyl ethers in water using solid-phase microextraction. Journal of Chromatography A, 1124(1-2), 157-166.

[26] Huang, C., Zeng, Y., Cao, Y., Zhu, C., Ren, Z., Liu, Y. E., ... & Mai, B. (2021). Mechanistic aspects regarding the ultraviolet degradation of polychlorinated biphenyls in different media: insights from carbon and chlorine isotope fractionation. Environmental Science & Technology, 55(11), 7731-7740.

[27] Tashkandi, N. Y., Albukhari, S. M., & Ismail, A. A. (2022). Mesoporous TiO2 enhanced by anchoring Mn3O4 for highly efficient photocatalyst toward photo-oxidation of ciprofloxacin. Optical Materials, 127, 112274.

[28] Türk, O. K., Adalar, G., Yazici Guvenc, S., Can-Güven, E., Varank, G., & Demir, A. (2022). Photodegradation of oxytetracycline by UV-assisted persulfate and percarbonate processes: kinetics, influencing factors, anion effect, and radical species. Environmental Science and Pollution Research, 1-15.

[29] Motamedi, M., Yerushalmi, L., Haghighat, F., & Chen, Z. (2022). A critical review of water contamination by polybrominated diphenyl ethers (PBDE) and main degradation techniques. Journal of Environmental Chemical Engineering, 108196.

[30] Karimi, F., Rezaei-Savadkouhi, N., Uçar, M., Aygun, A., Tiri, R. N. E., Meydan, I., ... & Sen, F. (2022). Efficient green photocatalyst of silver-based palladium nanoparticles for methyle orange photodegradation, investigation of lipid peroxidation inhibition, antimicrobial, and antioxidant activity. Food and Chemical Toxicology, 169, 113406.