



## Treatability and Kinetic Analysis of BPA-containing Wastewater by Catalytic Ozone Processes Using ZnSO<sub>4</sub> and ZnO Catalysts

N. Pinar Tanatti

Department of Environmental Protection Technologies, Sakarya University of Applied Sciences, Sakarya 54100, Turkey

### ABSTRACT

BPA (Bisphenol-A) is an organic colorless crystalline synthetic compound with the chemical formula of (CH<sub>3</sub>)<sub>2</sub>C-(C<sub>6</sub>H<sub>4</sub>-OH)<sub>2</sub>. The chemical structure of BPA consists of two methyl functional groups which are connected by a bridge to the phenol rings. The purpose of this study is to investigate the treatability of containing BPA wastewater using by homogeneous (ZnSO<sub>4</sub> catalyst) and heterogeneous (ZnO catalyst) catalytic ozone processes (COPs). The BPA removals of ZnO catalyst COP method and ZnSO<sub>4</sub> catalyst COP methods were compared and using the ZnO catalyst COP process gave better results than the ZnSO<sub>4</sub> catalyst COP process. For the BPA removals, the experimental parameters including pH, catalysts dose, ozone dose, and reaction time parameters were optimized by changing one parameter at a time. As a result of 12.5 min of ZnSO<sub>4</sub> oxidation, 94.16% of BPA removal was achieved under the optimum conditions (pH 6.32, 1 mg/L ZnSO<sub>4</sub> dose, 2400 mg/L O<sub>3</sub> dose). However, under optimum conditions (pH 6.32, 50 mg/L ZnO dose, 2400 mg/L O<sub>3</sub> dose, 20 min reaction time), the BPA removals have been obtained as 98.52%. The second-order kinetic model has been found to be the most suitable model for both processes and the regression coefficients (R<sup>2</sup>) have been found as 0.999 and 0.9979 for ZnSO<sub>4</sub> and ZnO catalysts COPs, respectively. The reaction rate constants (k) have also been calculated as 0.0939 L.mg<sup>-1</sup>.min<sup>-1</sup> and 0.0509 L.mg<sup>-1</sup>.min<sup>-1</sup> for BPA in homogeneous and heterogeneous COPs, respectively.

### ARTICLE HISTORY

Received 5 February 2021  
Accepted 27 June 2021

### KEYWORDS

BPA; catalytic ozone process;  
ZnSO<sub>4</sub>; ZnO; kinetic  
modeling

### Introduction

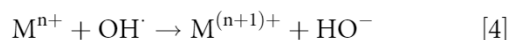
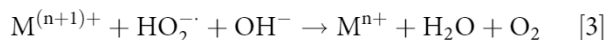
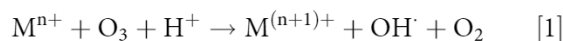
Bisphenol A (BPA), one of the most widely used industrial chemicals, is an endocrine-disrupting chemical (Wan et al. 2020). Bisphenols have emerged as alarming contaminants in recent years due to widespread human exposure and toxicity, including estrogenicity, cytotoxicity, genotoxicity, and carcinogenicity (Xue and Kannan 2019). BPA is used in different products such as polycarbonate plastic, epoxy resin, cans, toothpaste, thermal receipts, food packaging, and personal care products (Sanchis, Coscollaa, and Yusaa 2019). Large amounts of BPA have been released into the environment due to its high production and widespread use (Nie et al. 2019). Therefore, the presence of BPA has been detected in waters, soils, and sediments, and it has been determined that it seriously threatens public health. Commonly, BPA originating from industrial use is discharged into sewage and reaches wastewater treatment plants (Yan et al. 2019). Therefore, treatment studies of wastewater containing BPA have become crucial. Biological and enzymatic, adsorption (Supong et al. 2019), membrane (Pan et al. 2019), Photo-electrochemical (Silva-Castro et al. 2017), electro-Fenton (Chmaysem, Taha, and H), and

photocatalytic oxidation (Davididou et al. 2017; Vela et al. 2018) methods have been used for BPA treatment.

Advanced oxidation processes (AOPs) are among the most effective methods for removing organic pollutants. AOPs are based on mineralizing various toxic organic compounds to produce highly oxidizing free radicals such as hydroxyl radicals (Mohamadi et al. 2020). Recent studies on catalytic ozonation processes (COP), one of the AOPs methods, have been attracting the attention. The addition of a catalyst to the ozonation process effectively improves the ozone utilization efficiency and increases the decomposition of ozone to form hydroxyl radicals (OH·) with strong oxidative stability (Shahmahdi et al. 2020). Besides, the use of catalysts, the low solubility and stability of ozone in water, and the slow reaction with organic compounds can eliminate ozonation limitations with the help of catalysts (He et al. 2020; Mohamadi et al. 2020). COPs have categorized as homogeneous and heterogeneous catalytic ozonation according to the catalysts used (Asgari et al. 2020). Metal/transition metal ions such as Mn<sup>2+</sup>, Fe<sup>3+</sup>, Co<sup>2+</sup>, Cu<sup>2+</sup> and Zn<sup>2+</sup> to dissolving metal cations in homogeneous catalytic ozonation are used as catalysts. Therefore, metal oxides and bimetallic/

polymetallic oxides such as MgO, CeO<sub>2</sub>, TiO<sub>2</sub>, ZnO, Co<sub>3</sub>O<sub>4</sub> to solid catalysts are used in heterogeneous catalytic ozonation (Bilinska et al. 2020). Reaction mechanisms are defined according to the type of COPs.

The following reactions have been substantiated in the homogeneous catalytic ozonation process.



Three mechanisms can be seen in heterogeneous catalytic ozonation. (i) O<sub>3</sub> is adsorbed on the catalyst and generates free radicals, (ii) organic compounds are adsorbed to the catalyst and then decomposed by the O<sub>3</sub> molecule or other types, (iii) O<sub>3</sub> and organic matter are simultaneously adsorbed to the catalyst and the reaction takes place (Wang and Chen 2020).

In this study, BPA removal in synthetic water containing BPA by catalytic ozonation methods (COPs) has been investigated. Homogeneous and heterogeneous catalytic ozonation processes have been studied as COPs. ZnSO<sub>4</sub> has been used as a catalyst in homogeneous catalytic ozonation, while ZnO has been used as a catalyst in heterogeneous catalytic ozonation. The parameters of pH, O<sub>3</sub> dose, catalyst dose and reaction time on the BPA removals have been studied for both processes. Also, kinetic model analyzes were performed for both processes depending on the reaction time.

## Materials and methods

### Materials

Acros Organics brand (97%) BPA was used to prepare a synthetic Bisphenol A sample. MERCK brand hydrochloric acid (HCl) and sodium hydroxide (NaOH) have been used in the pH adjustment of the solution. Merck brand zinc sulfate (ZnSO<sub>4</sub>) and zinc oxide (ZnO) have been used as catalysts. BPA concentrations were measured with a Shimadzu brand UV-VIS 1700 spectrophotometer. pH measurements have been performed by Hanna instruments brand pH meter. Mtops brand magnetic stirrer has been used in the reactor. Sabo Elektronik's SL-10 model ozone generator has been used as the generator for O<sub>3</sub> gas production.

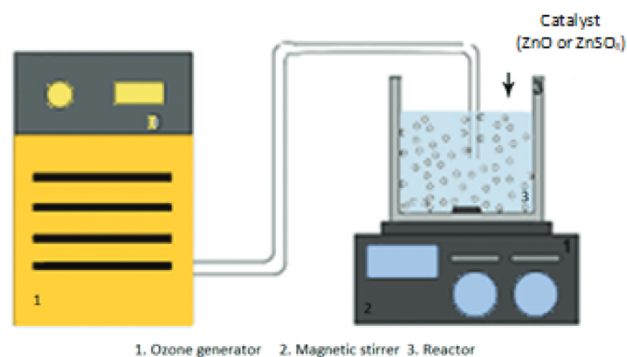


Figure 1. COP experimental setup.

### Synthetic BPA sample preparation and measurement

A synthetic BPA sample with an initial concentration ( $C_{0BPA}$ ) of 10 mg/L has been used in this study. Spectrum scanning has been performed to measure the BPA concentrations in the spectrophotometer and it was observed that a peak has been occurred at 278 nm. BPA samples between 0.5 mg/L and 25 mg/L have been prepared for calibration and the calibration curve has been constituted by taking measurements at 278 nm. Equation (5) has been obtained from the calibration curve.

$$BPA(mg/L) = \frac{0,0129}{ABS} \quad [5]$$

### Reactor design

The reactor design of the COP process used in the study is shown in Figure 1. As shown in Figure 1, the COP has consisted of an ozone generator with a maximum capacity of 0.3 g/h, a magnetic stirrer and a 300 mL glass reactor. Experiments were carried out with a sample volume of 100 mL.

In the experiments, the ozone dose was applied to the system intermittently and the ozone dosage has been calculated by multiplying the generator capacity by the time which is given to the system during catalytic oxidation and divided to the total volume of the solution.

The applied ozone dosage calculation has been done as (Van Leeuwen 2015):

$$\begin{aligned} & \text{Applied ozone dosage} \left( \frac{mg}{L} \right) \\ &= \frac{\text{Ozone rate}(mg/h) \times \text{Application time}(h)}{\text{Sample volume}(L)} \quad [6] \end{aligned}$$

In the ozone dosage optimization, five different ozonation processes were followed. The total ozonation was 10 minutes and ozone amount was changed in every

**Table 1.** The ozone dose and ozone feed time.

| Ozone feed timing (min/5 min) | 1:5 | 2:5  | 3:5  | 4:5  | 5:5  |
|-------------------------------|-----|------|------|------|------|
| Ozone dose (mg/L)             | 600 | 1200 | 1800 | 2400 | 3000 |

5 minutes. The ozonation was started applying 1 minute in the first experiment, 2 minutes in the second, 3 minutes in the third, 4 minutes in the fourth and 5 minutes in the last process. The ozonation timing is given in detail in Table 1.

## Results and discussion

### Effect of pH on BPA removal

One of the most important factors affecting the degradation of pollutants in catalytic ozonation is pH because radical reactions gain importance due to the effect of pH. A chain reaction takes place by the decomposition of ozone, which produces hydroxyl radicals ( $\text{OH}\cdot$ ) as non-selective oxidants. In this way, it has been determined that it reacts with ozone (Javadi et al. 2018; Polat, Balci, and Özbelge 2015).

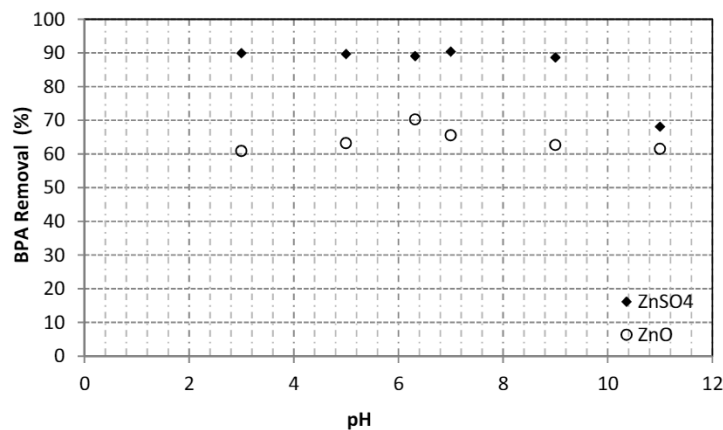
While investigating the effect of pH on BPA removal, studies have been carried out at pH 3, 5, 6.32, 7, 9 and 11 values. pH is the pH value of the wastewater containing 6.32 BPA. In the wastewater with an initial BPA concentration of 10 mg/L, a dose of 50 mg/L  $\text{ZnSO}_4$  and ZnO, 1200 mg/L ozone dose and 10 min reaction times have been studied for both processes. Figure 2 shows that the effect of pH on the BPA removal with COP.

As shown in Figure 2, pH does not have a great effect on BPA removals. BPA removals in alkaline conditions are at their lowest. In homogeneous COP, the highest BPA removal has been obtained at pH 7 and the removal

has been found to be 90.37% at this pH. However, the initial pH value of the wastewater containing BPA is 6.32 and the removal at this value has been found to be 89.05%. The highest removal of BPA has been established 70.24% at pH 6.32 in ZnO catalyst COP. The appropriate pH value has determined to be pH 6.32 for both catalytic ozonation processes. In the  $\text{ZnSO}_4$  catalyzed oxidation process, the BPA removal is higher than the ZnO catalyzed oxidation process. The activity of a catalyst depends on its active sites available. the active catalytic sites have been determined based on catalytic activities during COP processes at neutral initial pH (Chen et al. 2019).

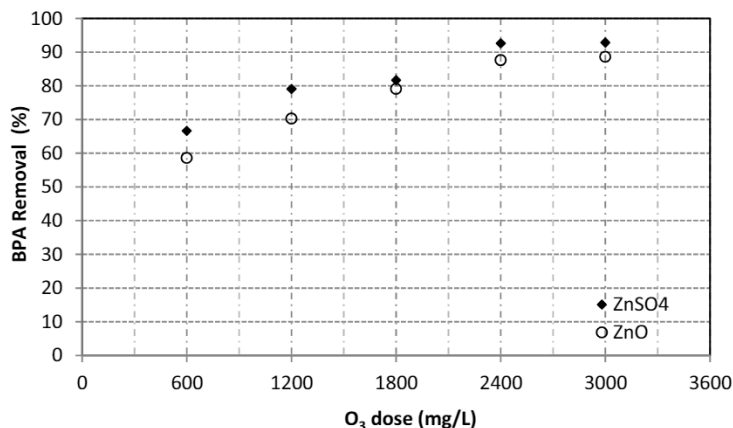
### Effect of $\text{O}_3$ dose on BPA removal

When the ozone concentration in the water containing the pollutant increases, the mass transfer driving force increases and the production of ozone-derived free radicals (such as  $\text{OH}\cdot$ ) increases (Hu et al. 2016). Therefore, oxidant dose has a significant effect on the breakdown of organic compounds (Xie et al. 2019). While the effect of ozone dose on BPA removal has been examined, pH 6.32, 50 mg/L  $\text{ZnSO}_4$ , and ZnO dose and 10 min reaction time have been studied. Figure 3 shows the effect of ozone dose on BPA removals in COPs. Ozone doses were studied at values between 600 mg/L and 3000 mg/L in COPs. Increasing the ozone dose has increased the BPA removal in both processes. However, between 2400 mg/L ozone dose and 3000 mg/L ozone dose, the BPA removal increase is less than 1% for both processes. BPA removal has been determined 66.64% at 600 mg/L ozone dose in  $\text{ZnSO}_4$  catalyst COP, while it has found 92.82% at 3000 mg/L ozone dose. In ZnO catalyst COP,



**Figure 2.** The effect of pH on the BPA removal ( $C_{0,BPA} = 10$  mg/L;  $\text{ZnSO}_4$  dose = 50 mg/L; ZnO dose = 50 mg/L;  $\text{O}_3$  dose = 1200 mg/L;  $t = 10$  min).





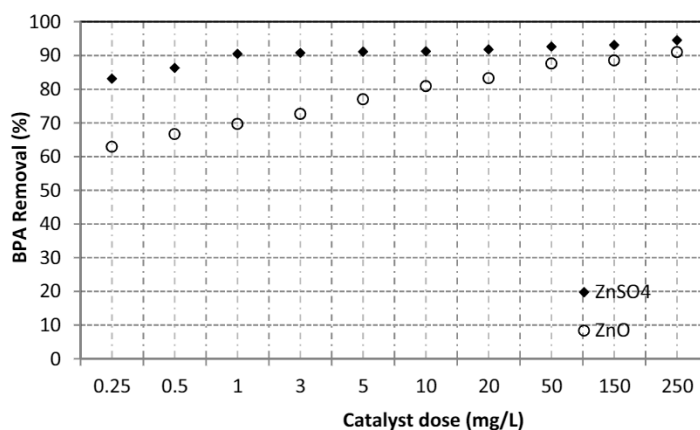
**Figure 3.** The effect of O<sub>3</sub> dose on the BPA removal ( $C_{0,BPA} = 10$  mg/L; pH = 6.32; ZnSO<sub>4</sub> dose = 50 mg/L; ZnO dose = 50 mg/L; t = 10 min).

BPA removals have been found 58.57% at 600 mg/L g/h ozone dose, 87.62% at 2400 mg/L ozone dose and 88.57% at 3000 mg/L ozone dose. The optimum ozone dose for the effect of the ozone dose on the BPA removal was determined as 2400 mg/L for both processes.

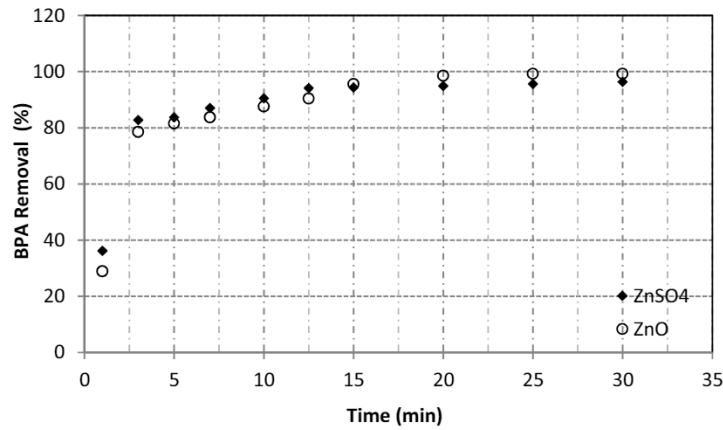
#### Effect of catalyst dose (ZnSO<sub>4</sub> and ZnO) on BPA removal

In general, organic matter removal increases with the increasing amount of catalyst. Because the catalyst provides active sites for catalytic reactions between water, ozone, and organic compounds (Li et al. 2018). It is more effective in the decomposition of ozone by increasing the surface area and increasing reactive regions with the increase of the catalyst dose (Hu et al. 2016). The effect of the catalyst dose on the BPA removal in ZnSO<sub>4</sub> catalyst and ZnO catalyst COPs have been determined by studying at pH 6.32, 2400 mg/L ozone dose and

10 min reaction time. ZnSO<sub>4</sub> and ZnO catalyst doses between 0.25 mg/L and 250 mg/L have been studied. Figure 4 shows the effects of ZnSO<sub>4</sub> and ZnO catalysts on BPA removal. The BPA removal in ZnSO<sub>4</sub> catalyst COP has been confirmed 83.13% at 0.25 mg/L ZnSO<sub>4</sub> dose and 94.54% at 250 mg/L ZnSO<sub>4</sub> dose. While BPA removals increase rapidly up to 1 mg/L ZnSO<sub>4</sub> dose, there is a slow increase in BPA removal after 1 mg/L ZnSO<sub>4</sub> dose. Therefore, the dose of ZnSO<sub>4</sub> has been determined as 1 mg/L in ZnSO<sub>4</sub> catalyst (homogeneous) COP. In ZnO catalyst (heterogeneous) COP, the BPA removal was established at 62.89% at a dose of 0.25 mg/L ZnO, while it was 90.97% at a dose of 250 mg/L ZnO. When Figure 4 is examined, there is a high increase in BPA removals up to 50 mg/L ZnO dose. The increase in removals decreases after the 50 mg/L ZnO dose. At a dose of 50 mg/L ZnO, the BPA removal has obtained 87.61%. The optimum ZnO dose in ZnO catalyst COP has been determined as 50 mg/L.



**Figure 4.** The effect of catalyst dose on BPA removal ( $C_{0,BPA} = 10$  mg/L; pH = 6.32; O<sub>3</sub> dose = 2400 mg/L; t = 10 min).



**Figure 5.** The effect of reaction time on the BPA removal ( $C_{o,BPA} = 10$  mg/L; pH = 6.32;  $O_3$  dose = 2400 mg/L;  $ZnSO_4$  dose = 1 mg/L; ZnO dose = 50 mg/L).

### Effect of reaction time on BPA removal

The effect of reaction time on BPA removal with COPs has been studied for up to 30 min at pH 6.32, 2400 mg/L ozone dose, 1 mg/L  $ZnSO_4$  dose and 50 mg/L ZnO dose. Figure 5 shows the effect of reaction time on BPA removal. As seen from Figure 5, as the reaction time increases in COPs, BPA removals have increased, but after a certain period of time, the increase in removals has become very small. In  $ZnSO_4$  catalyst (homogeneous) COP, the efficiency of BPA removal in the 1<sup>st</sup> min has been seen 36.20% and 96.35% in the 30<sup>th</sup> min. It has found to be 94.16% at 12.5<sup>th</sup> min. The increase in BPA removals after 12.5 min is about 0.5%. Therefore, the reaction time has been determined as 12.5 min at the COP using  $ZnSO_4$  catalyst. In ZnO catalyst (heterogeneous) COP, the BPA removal has obtained in the 1<sup>st</sup> min 28.89% and 99.26% in the 30<sup>th</sup> min. The increase in removals after 20 min in COP using ZnO catalyst was about 0.7%. The BPA removal at 20 min has obtained 98.52%. For this reason, the reaction time in heterogeneous COP has been specified as 20 min. In the study using Al catalyst, BPA removal was procured as 90% at 4.5 ppm ozone dose in 10 min reaction time (Keykavoos et al. 2013).

Comparing  $ZnSO_4$  and ZnO catalysts COPs depending on the reaction time, the BPA removals in ZnO catalyst COP have been made higher when the reaction time increases. The amount of BPA remaining in the system at the end of 30 min has was 0.365 mg/L in COP using  $ZnSO_4$  catalyst, and with COP using ZnO catalyst 0.074 mg/L was obtained. With homogeneous and heterogeneous COP at the BPA concentrations selected, optimum reaction times have been found to be 0.584 mg/L and 0.148 mg/L, respectively. When both processes are examined, it is clear that the more effective

treatment method on BPA removal is ZnO catalyst (heterogeneous) COP.

### Kinetic analysis of BPA removal efficiencies

By using experimental data, reaction rate constants ( $k$ ) and regression coefficients ( $R^2$ ) are determined by kinetic modeling (Kaur et al. 2020). In the study, four different kinetic models are discussed for  $ZnSO_4$  catalyst (homogeneous) and ZnO catalyst (heterogeneous) COP processes. The equations of the examined kinetic Models are given below.

First-order kinetic:  $\ln \frac{C_0}{C} = k.t$  [7] (Javadi et al. 2018)

Second-order kinetic:  $\frac{1}{C} - \frac{1}{C_0} = k.t$  [8] (Thalman et al. 2014)

Pseudo-first-order kinetic:  $\ln[C_e - C(t)] = \ln C_e - k.t$  [9] (Simonin 2016)

Pseudo-second-order kinetic:  $\frac{t}{C} = \frac{1}{k_2.C_e^2} + \frac{1}{C_e}.t$  [10] (Titchou et al. 2020)

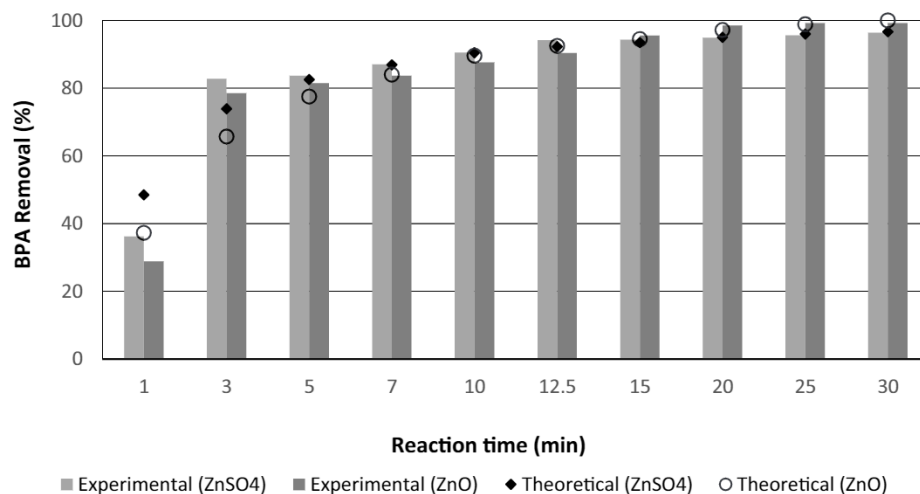
where  $C_0$ : Initial BPA concentration (mg/L),  $C$ : Final BPA concentration (mg/L),  $t$ : Reaction time (min),  $C_e$ : Concentration coefficient (mg/L),  $k$ : Reaction rate constant,  $k_2$ : Mean mass transport coefficient (L/min).

The values of  $k$  and  $R^2$  resulting from four different kinetic models for homogeneous and heterogeneous COP are given in Table 2. As seen from Table 2, the highest  $R^2$  values for both methods have been obtained

**Table 2.**  $R^2$  and  $k$  values as per kinetic models in COPs.

| Kinetic model           | ZnSO <sub>4</sub> catalyst |        | ZnO catalyst |        |
|-------------------------|----------------------------|--------|--------------|--------|
|                         | $R^2$                      | $k$    | $R^2$        | $k$    |
| First order*            | 0.97586                    | 0.0783 | 0.9512       | 0.1558 |
| second order**          | 0.9574                     | 0.0858 | 0.8522       | 0.5148 |
| Pseudo first order***   | 0.9066                     | 0.164  | 0.6454       | 0.5645 |
| Pseudo second order**** | 0.9990                     | 0.0939 | 0.9979       | 0.0509 |

First order\*  $k$  unit: 1/min, second order\*\* $k$  unit: L.mg<sup>-1</sup>.min<sup>-1</sup>, Pseudo first order\*\*\*  $k$  unit: mg/L. min<sup>-1</sup>Pseudo second order\*\*\*\*  $k$  unit: L.mg<sup>-1</sup>.min<sup>-1</sup>.



**Figure 6.** Theoretical and experimental BPA removal efficiency as pseudo second-order order kinetics.

in the pseudo-second-order kinetic model. Therefore, the model suitable for both processes is the pseudo-second-order kinetic model. In the homogeneous COP using ZnSO<sub>4</sub> catalyst, the  $k$  value has been obtained 0.0939 L.mg<sup>-1</sup>.min<sup>-1</sup> and the  $R^2$  value has been obtained 0.999. In heterogeneous COP using ZnO catalyst,  $k$  and values have been found as 0.0509 and 0.9979 L.mg<sup>-1</sup>.min<sup>-1</sup>, respectively.

The BPA removals for COPs using ZnSO<sub>4</sub> and ZnO catalysts have been calculated using the constants obtained with the pseudo-second-order kinetic model. Figure 6 shows the BPA removals calculated with pseudo-second-order kinetic model and the BPA removals obtained from the experimental results. In Figure 6, it is seen that the experimental results and the theoretically calculated results are close to each other. With increasing reaction time, BPA removals increase. Moreover, the increase in removal has been decreasing after 12.5 min in homogeneous COP and 20 min in heterogeneous COP.

## Conclusions

Two different catalytic oxidation processes have been used on the containing BPA wastewater treatment. The optimum conditions for catalytic ozonation with ZnSO<sub>4</sub> catalyst process have determined as pH 6.32, 1 mg/L ZnSO<sub>4</sub> dose, 2400 mg/L O<sub>3</sub> dose and 12.5 min reaction time. Moreover, the optimum conditions for catalytic ozonation with ZnO catalyst process have determined as pH 6.32, 50 mg/L ZnO dose 2400 mg/L O<sub>3</sub> dose and 20 min reaction time. Therefore, under the optimum conditions, the BPA removals for using ZnSO<sub>4</sub> catalyst and using ZnO catalyst processes was obtained as 94.16% and 98.52%, respectively. The result of this study verifies that the BPA removals reached the highest

efficiency for both processes, whereas, comparing to the homogeneous (ZnSO<sub>4</sub> catalyst) COP, it has seen that heterogeneous (ZnO catalyst) COP removal efficiency is higher than the homogeneous (ZnSO<sub>4</sub> catalyst) COP.

## References

- Asgari, G., A. Seidmohammadi, J. Faradmal, A. Esrafil, M. N. Sepehr, and M. Jafarinia. 2020. "Optimization of Synthesis a New Composite of nano-MgO, CNT and Graphite as a Catalyst in Heterogeneous Catalytic Ozonation for the Treatment of Pesticide-laden Wastewater." *Journal of Water Process Engineering* 33:101082. doi:10.1016/j.jwpe.2019.101082.
- Bilinska, L., K. Blus, M. Foszpanczyk, M. Gmurek, and S. Ledakowicz. 2020. "Catalytic Ozonation of Textile Wastewater as a Polishing Step after Industrial Scale Electrocoagulation." *Journal of Environmental Management* 265:110502. doi:10.1016/j.jenvman.2020.110502.
- Chen, C., X. Yan, Y.Y. Xu, B.A. Yoza, X. Wang, Y. Kou, H. Ye, Q. Wang, and Q.X. Li. 2019. "Activated Petroleum Waste Sludge Biochar for Efficient Catalytic Ozonation of Refinery Wastewater." *Science of the Total Environment* 651:2631–40. doi:10.1016/j.scitotenv.2018.10.131.
- Davididou, K., E. Hale, N. Lane, E. Chatzisyneon, A. Pichavant, and J.F. Hochepped. 2017. "Photocatalytic Treatment of Saccharin and bisphenol-A in Thepresence of TiO<sub>2</sub>nanocomposites Tuned by Sn(IV)." *Catalysis Today* 287:3–9. doi:10.1016/j.cattod.2017.01.038.
- He, C., J. Wang, C. Wang, C. Zhang, P. Hou, and X. Xu. 2020. "Catalytic Ozonation of Bio-treated Coking Wastewater in Continuous Pilot- and Full-scale System: Efficiency, Catalyst Deactivation and Insitu Regeneration." *Water Research* 183:116090. doi:10.1016/j.watres.2020.116090.
- Hu, E., X. Wu, S. Shang, X. Tao, S. Jiang, and L. Gan. 2016. "Catalytic Ozonation of Simulated Textile Dyeing Wastewater Using Mesoporous Carbon Aerogel Supported Copper Oxide Catalyst." *Journal of Cleaner Production* 112:4710–18. doi:10.1016/j.jclepro.2015.06.127.



- Husain, Q., and S. Qayyum. 2013. "Biological and Enzymatic Treatment of Bisphenol A and Other Endocrine Disrupting Compounds: A Review." *Critical Reviews in Biotechnology* 33 (3): 260–92. doi:10.3109/07388551.2012.694409
- Javadi, N.H.S., M. Baghdadi, N. Mehrdadi, and M. Mortazavi. 2018. "Removal of Benzotriazole from Secondary Municipal Wastewater Effluent by Catalytic Ozonation in the Presence of Magnetic Alumina Nanocomposite." *Journal of Environmental Chemical Engineering* 6:6421–30. doi:10.1016/j.jece.2018.09.063.
- Kaur, P., M.A. Imteaz, M. Sillanp, V.K. Sangal, and J. P. Kushwaha. 2020. "Parametric Optimization and MCR-ALS Kinetic Modeling of Electro Oxidation Process for the Treatment of Textile Wastewater." *Chemometrics and Intelligent Laboratory Systems* 203:104027. doi:10.1016/j.chemolab.2020.104027.
- Keykavoos, R., R. Mankidy, H. Ma, P. Jones, and J. Soltan. 2013. "Mineralization of Bisphenol A by Catalytic Ozonation over Alumina." *Separation and Purification Technology* 107:310–17. doi:10.1016/j.seppur.2013.01.050.
- Li, X., W. Chen, L. Ma, H. Wang, and J. Fan. 2018. "Industrial Wastewater Advanced Treatment Via Catalytic Ozonation With An Fe-based Catalyst." *Chemosphere* 195:336–43. doi:10.1016/j.chemosphere.2017.12.080.
- Mohamadi, L., E. Bazrafshan, A. Rahdar, G. Labuto, and A. R. Kamali. 2020. "Nanostructured MgO-enhanced Catalytic Ozonation of Petrochemical Wastewater." *Boletín De La Sociedad Espanola De Cerámica Y Vidrio*. inpress. doi:10.1016/j.bsecev.2020.06.002.
- Nie, M., Y. Deng, S. Nie, C. Yan, M. Ding, W. Dong, Y. Dai, and Y. Zhang. 2019. "Simultaneous Removal of Bisphenol A and Phosphate from Water by Peroxymonosulfate Combined with Calcium Hydroxide." *Chemical Engineering Journal* 369:35–45. doi:10.1016/j.cej.2019.03.046.
- Pan, Z., F. Yu, L. Li, C. Song, J. Yang, C. Wang, Y. Pan, and T. Wang. 2019. "Electrochemical Microfiltration Treatment of Bisphenol A Wastewater Using Coal-based Carbon Membrane." *Separation and Purification Technology* 227:115695. doi:10.1016/j.seppur.2019.115695.
- Polat, D., I. Balci, and T.A. Özbelge. 2015. "Catalytic Ozonation of an Industrial Textile Wastewater in a Heterogeneous Continuous Reactor." *Journal of Environmental Chemical Engineering* 3:1860–71. doi:10.1016/j.jece.2015.04.020.
- Shahmahdi, N., R. Dehghanzadeh, H. Aslani, and S. B. Shokouhi. 2020. "Performance Evaluation of Waste Iron Shavings (Fe<sub>0</sub>) for Catalytic Ozonation in Removal of Sulfamethoxazole from Municipal Wastewater Treatment Plant Effluent in a Batch Mode Pilot Plant." *Chemical Engineering Journal* 383:123093. doi:10.1016/j.cej.2019.123093.
- Silva-Castro, V., J.C. Durán-Álvarez, J. Mateos-Santiago, A. A. Flores-Caballero, L. Lartundo-Rojas, and A. Manzo-Robledo. 2017. "Photo-electrochemical and Interfacial-process Analysis of WO<sub>3</sub> Nanostructures Supported on TiO<sub>2</sub>: An Approach to BPA Oxidation." *Materials Science in Semiconductor Processing* 72:115–21. doi:10.1016/j.mssp.2017.09.014.
- Simonin, J.P. 2016. "On the Comparison of Pseudo-first Order and Pseudo-second Order Rate Laws in the Modeling of Adsorption Kinetics." *Chemical Engineering Journal* 300:254–63. doi:10.1016/j.cej.2016.04.079.
- Supong, A., P.C. Bhomick, M. Baruah, C. Pongener, U. B. Sinha, and D. Sinha. 2019. "Adsorptive Removal of Bisphenol A by Biomass Activated Carbon and Insights into the Adsorption Mechanism through Density Functional Theory Calculations." *Sustainable Chemistry and Pharmacy* 13:100159. doi:10.1016/j.scp.2019.100159.
- Thalmann, B., A. Voegelin, B. Sinnet, E. Morgenroth, and R. Kaegi. 2014. "Sulfidation Kinetics of Silver Nanoparticles Reacted with Metal Sulfides." *Environmental Science and Technology* 48 (9): 4885–92. doi:10.1021/es5003378
- Titchou, F.E., R.A. Akbour, A. Assabbane, and M. Hamdani. 2020. "Removal of Cationic Dye from Aqueous Solution Using Moroccan Pozzolana as Adsorbent: Isotherms, Kinetic Studies, and Application on Real Textile Wastewater Treatment." *Groundwater Sustainable Development* 11:100405. doi:10.1016/j.gsd.2020.100405.
- Van Leeuwen, J.H. 2015. "Proposed OSE Requirement: Measuring Ozone Dosage." *Ozone: Science & Engineering* 37 (2): 191–92. doi:10.1080/01919512.2015.1006467
- Vela, N., M. Calin, M. J. Yanez-Gascon, I. Garrido, G. Perez-Lucas, J. Fenoll, and S. Navarro. 2018. "Solar Reclamation of Wastewater Effluent Polluted with Bisphenols, Phthalates and Parabens by Photocatalytic Treatment with TiO<sub>2</sub>/Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub> at Pilot Plant Scale." *Chemosphere* 212:95–104. doi:10.1016/j.chemosphere.2018.08.069.
- Wan, D., H. Wang, I.P. Pozdnyakov, C. Wang, J. Su, Y. Zhang, Y. Zuo, D.D. Dionysiou, and Y. Chen. 2020. "Formation and Enhanced Photodegradation of Chlorinated Derivatives of Bisphenol A in Wastewater Treatment Plant Effluent." *Water Research* 184:116002. doi:10.1016/j.watres.2020.116002.
- Wang, J., and H. Chen. 2020. "Catalytic Ozonation for Water and Wastewater Treatment: Recent Advances and Perspective." *Science of the Total Environment* 704:135249.
- Xie, X., W. Zhao, Y. Hu, X. Xu, and H. Cheng. 2019. "Permanganate Oxidation and Ferric Ion Precipitation (KMnO<sub>4</sub>-Fe(iii)) Process for Treating Phenylarsenic Compounds." *Chemical Engineering Journal* 357:600–10. doi:10.1016/j.cej.2018.09.194.
- Xue, J., and K. Kannan. 2019. "Mass Flows and Removal of Eight Bisphenol Analogs, Bisphenol A Diglycidyl Ether and Its Derivatives in Two Wastewater Treatment Plants in New York State, USA." *Science of the Total Environment* 648 (2019): 442–49. doi:10.1016/j.scitotenv.2018.08.047
- Yan, Z., Y. Zhu, H. Meng, S. Wang, L. Gan, X. Li, J. Xu, and W. Zhang. 2019. "Insights into Thermodynamic Mechanisms Driving Bisphenol A (BPA) Binding to Extracellular Polymeric Substances (EPS) of Activated Sludge." *Science of the Total Environment* 677:502–10. doi:10.1016/j.scitotenv.2019.04.413.