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OPTIMIZATION OF PHARMACEUTICAL WASTEWATER TREATMENT BY BIOSORPTION USING GENETIC ALGORITHM

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Abstract

Purpose of the study: Optimizing the process of pharmaceutical wastewater treatment by biosorption using a genetic algorithm.

Methodology: The main steps followed were, determination of the wavelength at maximum absorbance (λ_{max}), drawing the calibration curve between the absorbance and the concentration of diclofenac sodium, designing the experiment using Design-Expert software, finding the percentage removal of diclofenac sodium for each run, obtaining the model equation of the analysis, finding the optimized condition using genetic algorithm in MATLAB software, running the experiment at the optimized conditions and analyzing the results.

Main Findings: The technique used in the optimizing process was effective, in which the percentage removal was obtained as 8.73% at the optimized conditions. It was equivalent to 3.43 mg removal / g of activated carbon.

Applications of this study: This technique can be applied in different industries especially the chemical and pharmaceutical industries.

Novelty/Originality of this study: Using genetic algorithm in order to find the optimized condition of removing diclofenac sodium based on a set of data.

Keywords: *Pharmaceutical Waste Water, Optimization, Absorbance, Adsorption, Genetic Algorithm, Diclofenac Sodium.*

INTRODUCTION

Wastewater can be defined as the water that has been used and contains suspended or dissolved waste materials (UNESCO, 2017). There are different sources of wastewater, such as industries, homes, restaurants, etc. Referring to the World Water Development Report of the United Nations in 2017, around 80% of global wastewater dumped into the environment without any treatment. Moreover, it was found that around 1.8 billion people use drinking water that contains pollutants (UN Water, 2017). Using water that contains pollutants can negatively affect the health, environment, and economy (UNESCO, 2017).

In chemical and pharmaceutical manufacturing industries, different products are manufactured using large amounts of chemicals, materials, and substances. Water is an essential material that is mostly used in the production process. Generally, wastewater streams obtained from production processes contain different nutrients, toxins, and some organic contaminants (Water World, 2012). According to statistics, it was reported that about half of pharmaceutical wastewater generated by pharmaceutical industries are disposed of without any treatment. The presence of pharmaceutical compounds in the environment has negative effects such as development in the aquatic environment of antibiotic-resistance microbes and retarding nitrate oxidation and potential for increased toxicity of chemical combinations and metabolites (Gadipelly, 2014).

Pharmaceutical wastewater treatment is the process of converting wastewater that contains pharmaceutical compounds and other pollutants into an effluent that can be used in the same process or can be used for another purpose (Tanks, 2015). It is a significant process, which helps to reduce pollution by removing organic and inorganic matter. In addition, it helps to maintain a clean and healthy environment, human health, and the biotic and abiotic systems (CEHI, 2015).

Activated carbon is defined as a highly porous adsorptive medium, which has a complex structure and mainly contains carbon atoms. It is commonly used as an adsorbent in t adsorption process in which the atoms, particles, ions, and molecules are attached to the surface of adsorbent material. A large surface area is offered by activated carbon because of its porosity. For this reason, activated carbon is commonly used in adsorption processes. Mainly, activated carbon is available in two different forms, which are granular and powder (Ecologix Environmental Systems, LLC, 2018).

This research aimed to optimize the process of pharmaceutical wastewater treatment by biosorption using a genetic algorithm. The main objectives of this study were preparing and analyzing a water sample with diclofenac sodium, designing the experiment using design-expert software (V.11), removing the diclofenac sodium using commercial activated carbon, and optimizing the process using the genetic algorithm by MATLAB.

LITERATURE REVIEW

Referring to a study conducted in 2017 to find the efficiency of activated carbon used in wastewater treatment by determining the maximum removal of COD, BOD, turbidity, and pH from the wastewater sample. The results show that the efficient and the most accurate results were obtained at 4% of activated carbon (Agrawal, Vairagade, & Kedar, 2017). Another study was conducted to develop an effective treatment system for efficient pharmaceutical residue removal (PhR's) by operating UASB and MBR reactors. According to the researchers, this system had an overall elimination rate between 92.4 to 99%. In addition, the total removal of all the pollution parameters in the effluent of the UASB-MBR system ranged from 94 to 99% (Abdel-Shafy & Mansour, 2017).

In 2014 a study was conducted on using UV Spectrophotometric method in analyzing different brands of diclofenac sodium such as Dicloran, Artifin, Defnac, and Voltral. The aim of the research was to create an effective spectrophotometric technique for diclofenac sodium assay. The analysis was based on the ultraviolet absorbance, which was in the case of diclofenac sodium 276 nm. It was found that UV Spectrophotometric analysis of diclofenac sodium is a simple, precise, accurate, economical, and selective method. In addition, this method can be used to analyze diclofenac sodium effectively (Naveed & Qamar, 2014). According to a study conducted on the determination of pharmaceutical compounds in surface and underground water by solid-phase extraction-liquid chromatography. The aim of this study was to analyze and extract four different pharmaceutical residues (Diclofenac, Chloroquine, Paracetamol, and Ciprofloxacin HCl) using solid-phase extraction followed by high-performance liquid chromatography. The results were showing that the highest concentration among the four pharmaceuticals was Diclofenac and the least concentration was Ciplofaxcin HCl (James, Anyakora, & Tolulope, 2014).

Dikran and Mahmood had conducted research in 2015 to determine the conditions at which the maximum absorption of diclofenac sodium was obtained using spectrophotometric analysis. In addition, different parameters were controlled to determine the maximum absorption of diclofenac sodium by applying two optimization methods, which were, univariate and simplex method. It was recommended to measure the absorbance immediately after a constant time interval after dilution (Dikran & Mahmood, 2015). In 2017, a group of researchers had conducted a study on the determination of vitamin C using different spectrophotometric methods. The aim of this research was to determine the presence of vitamin C (ascorbic acid) via complex formation with gold using UV-VIS Spectrophotometry and Atomic Absorption Spectrophotometry (AAS). The results showing high accuracy for both techniques (Saeed, Al-kadumi, & Ali, 2017).

Referring to a study conducted on the determination of diclofenac sodium using a simple and sensitive spectrophotometric method. The aim of the research was to develop a simple and sensitive spectrophotometric method to determine the diclofenac sodium compound in pure form and in pharmaceutical preparations. In this research, different parameters were studied to optimize the spectrophotometric analysis of diclofenac sodium. It was observed that the relation between the concentration of NQS and absorbance was a direct proportion. In addition, it was noticed that the maximum absorbance was obtained when the pH value was greater than eight. Also, it was found that the reaction was not affected by increasing the temperature (Rashid, Bakir, & Baban, 2016). Another research was conducted on removal of pharmaceuticals from municipal wastewater by adsorption onto pyrolyzed pulp mill sludge. It was conducted to extract various pharmaceutical compounds from municipal wastewater through adsorption using charcoal. In this research, the adsorption process was done to extract different pharmaceuticals from the secondary effluent that was collected from the STP, as well as from the ultrapure water. In all cases, the target pharmaceutical adsorption equilibrium was achieved within 200 minutes. The kinetic constant K_2 decreased from salicylic acid > diclofenac > ibuprofen > acetaminophen, both from ultrapure water and from the STP secondary effluent (Coimbra, Calisto, Ferreira, Esteves, & Otero, 2015).

In 2012, a group of researchers had conducted a study on the removal of diclofenac sodium from aqueous solution by Isabel grape bagasse. This research aimed to determine Isabel grape bagasse's morphological and chemical characteristics and describe diclofenac sodium (DCF) adsorption from aqueous solutions by this biomass. In this research, diclofenac sodium was chosen among different pharmaceuticals because it is commonly found in aquatic environments. In addition, various research and statistics show that the percentage removal of diclofenac sodium during wastewater treatment processes typically ranges from 21% to 40%, which explains the presence of this pharmaceutical in different countries' surface water, groundwater and even drinking water. The results show that using grape bagasse to adsorb pharmaceutical compounds rather than using granular activated carbon has some advantages, such as negligible commercial value because they are waste products of productive processes.

However, it is not applicable for industrial-scale applications (Antunes, et al., 2012). In 2015, Akter, Zaman, and Muhit had conducted a study on pharmaceutical wastewater treatment. In addition, they had studied the efficiency of effluent treatment plants (ETP) in the context of Bangladesh. This research aims to investigate the scenario of wastewater treatment in the pharmaceutical industries of Bangladesh. In this research, ETP was studied because the industries which use ETP usually discharge their effluent to nearby water bodies after the treatment. It was found that the treated water did not meet the standard characteristics of drinking water. However, it was meeting the standard characteristics of the discharge water. It can be concluded that the treated water cannot be used as drinking water. However, it can be used safely for low-end applications like gardening, irrigation, etc. (Zaman & Akter, 2015).

METHODOLOGY

Determination of the Wavelength at Maximum Absorbance (λ_{max})

According to Usman Armaya'u, for determining the wavelength at the maximum absorbance for any compound using a UV-Vis spectrophotometer, a solution with the known concentration of the desired compound must be prepared and the absorbance should be measured at different wavelengths from ultra-violet to visible regions. The wavelength at which the maximum absorbance obtained is defined as λ_{max}(Armaya'u, 2019).

Therefore, the phosphate buffer solution of 6.8 pH value was prepared by mixing a specific amount of 0.2M sodium di-hydrogen ortho-phosphate and 0.2M sodium hydroxide solutions and diluted with distilled water so it can be detected in UV-Vis spectrophotometer. The pH value was maintained at 6.8 using a buffer solution. Then, the first stock solution was prepared by dissolving drug tablets that contain a known amount of diclofenac sodium in a specific amount of the prepared phosphate buffer solution. After that, the second stock solution was prepared by measuring a small amount of the first stock solution and mixing it with a specific amount of phosphate buffer solution. Next, the solution was filtered using a clean filter paper to avoid the presence of any solid particles. Then, the standard solution of 15 ppm was prepared by adding a specific amount of the prepared second stock solution and mixing it with phosphate buffer solution. Next, the maximum absorbance was determined by analyzing the prepared standard solution using a UV-Vis spectrophotometer by measuring the absorbance of the sample at different wavelengths ranged between 260-280nm. A sample of phosphate buffer solution was used as a reference in this analysis. Then, a graph was plotted between the absorbance (y-axis) and the wavelength (x-axis) to find the wavelength at which the maximum absorbance was determined (Chan, 2015).

Drawing the Calibration Curve between the Absorbance and the Concentration of Diclofenac Sodium

For this step, different standard solutions with known concentrations were prepared by adding a specific amount of the second stock solution with a phosphate buffer solution. Then, the absorbance was measured for each of the prepared samples at the wavelength of the maximum absorbance using a UV-Vis spectrophotometer. After that, a calibration curve was plotted between the absorbance (y-axis) and the concentration of diclofenac sodium (x-axis) (Schoolworkhelper Editorial Team, 2019).

Designing the Experiment using Design-Expert Software

In this stage, the experiment of removing diclofenac sodium was designed using design-expert software in which the factors were studied by varying the value of each factor, and the relation was determined between these factors and the response (%removal). The following table shows the parameters that were studied in this research and their levels. Then, a table was obtained from the software, which shows the number of runs that must be conducted as well as the conditions of each run.

Table 1: Parameters Studied in this Research

Parameters	Levels		
Initial Concentration of Diclofenac Sodium(ppm)	3	15	21
Adsorption Time (min)	10	20	30
Amount of Activated Carbon (grams)	0.04	0.07	0.2

Finding the Percentage Removal of Diclofenac Sodium for Each Run

For determining the percentage removal of diclofenac sodium of each run, the adsorption experiments were conducted using activated carbon as adsorbent at the given conditions in the software. The absorbance was measured of each sample before and after adsorption. Then, the concentration was found using the plotted calibration curve. Shaking was required in this process to increase the adsorption of diclofenac sodium and to provide the same shaking speed for all prepared samples. The samples were filtered using clean filter papers before measuring the final absorbance. Then the percentage removal was calculated for each run using the following formula (Scientific Research Publishing Inc., 2015).

$$\%Removal = \frac{Initial\ Concentration(ppm) - Final\ Concentration(ppm)}{Initial\ Concentration(ppm)} \times 100$$

Obtaining the Model Equation of the Analysis

The table was filled with the calculated percentage removal of each run and directly the model equation was found from the analysis tap in design-expert software. In addition, different graphs and tables obtained from the software were studied and analyzed, such as studying the effect of the individual parameters on the percentage removal, studying the 3D surface plots from design-expert software, etc.

Finding the Optimized Condition using Genetic Algorithm in MATLAB Software

The model equation obtained from design-expert software was used in the genetic algorithm in MATLAB to determine the optimized condition.

Running the Experiment at the Optimized Conditions and Analyzing the Results

Finally, the experiment was conducted at the obtained conditions after optimization to ensure that the process is designed perfectly. Then, the percentage of removal was calculated for the optimized condition.

RESULTS AND DISCUSSION

The following graph shows the relation obtained between the absorbance of diclofenac sodium and the wavelength. It can be noticed that the maximum absorbance was found when the wavelength was 270nm.

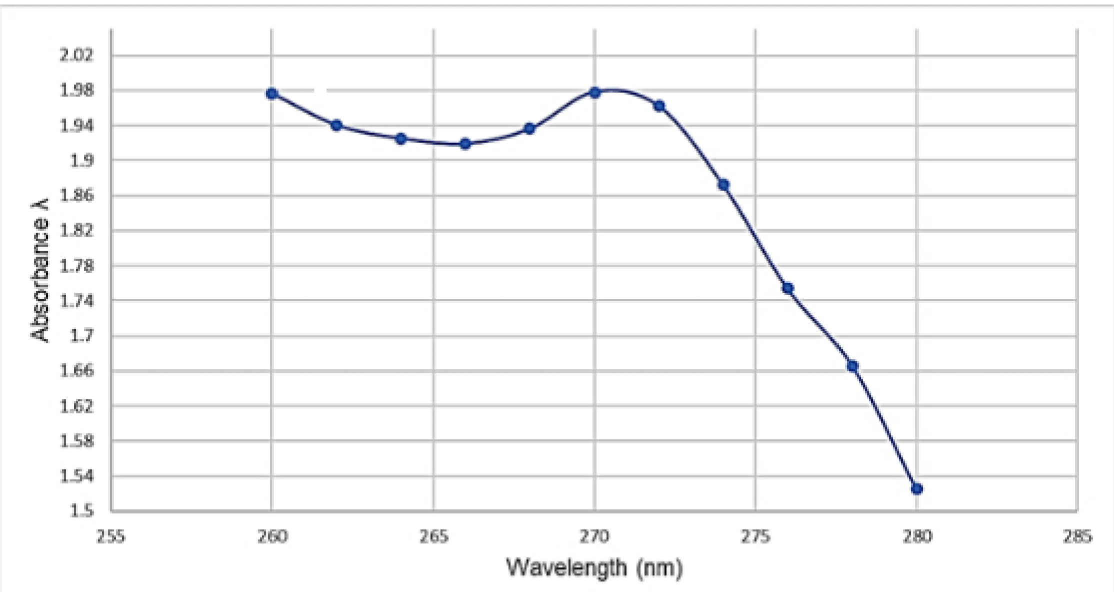

Figure 1: Absorbance vs. Wavelength

According to Beer-Lambert law, a linear relationship was found between the absorbance and the concentration of diclofenac sodium as showing below.

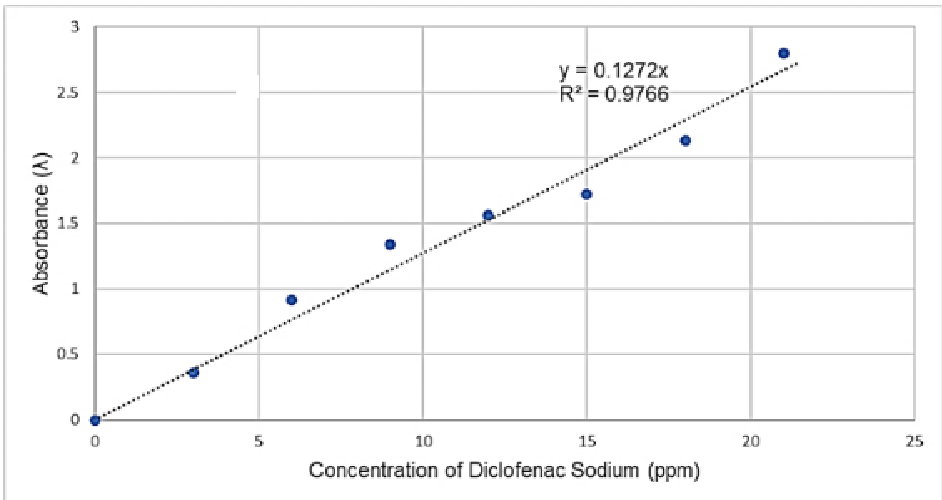

Figure 2: Absorbance vs. Concentration of Diclofenac Sodium

Then, the percentage of removal was found for each run and the table was filled with the calculated percentage removal. The maximum removal was obtained at the fourth experiment in which it was determined as 15.28%. However, the minimum removal of diclofenac sodium was obtained at run 22, in which the percentage removal was calculated as 1.36%.

The quantity adsorbed by a unit mass of an adsorbent at equilibrium was calculated for the fourth run by the following formula (Nsami & Mbadcam, 2013). It was found that each one gram of activated carbon can adsorb 292 µg of diclofenac sodium.

$$Q_e = \frac{C_o - C_t}{m} V$$

$$Q_e = \left(\frac{20.22 - 17.13}{0.2}\right) \times 20$$

$$= 292\ \mu g\ diclofenac\ sodium/\ g\ activated\ carbon$$

Table 2: Percentage Removal of Diclofenac Sodium

Run	Initial Concentration (ppm)	Time (min)	Amount of Activated Carbon (grams)	Initial Absorbance	Final Absorbance
1	3	10	0.2	0.368	0.337
2	3	10	0.07	0.370	0.353
3	15	20	0.04	1.846	1.700
4	21	30	0.2	2.584	2.189
5	15	20	0.2	1.851	1.640
6	15	10	0.04	1.845	1.759
7	15	10	0.07	1.848	1.702
8	21	10	0.07	2.583	2.333
9	21	20	0.07	2.588	2.259
10	21	10	0.04	2.581	2.379
11	15	30	0.2	1.847	1.616
12	21	10	0.2	2.585	2.318
13	3	30	0.04	0.371	0.348
14	21	20	0.2	2.585	2.243
15	15	30	0.04	1.851	1.642
16	3	30	0.07	0.371	0.335
17	21	30	0.07	2.583	2.241
18	3	20	0.2	0.367	0.326
19	3	20	0.04	0.371	0.354
20	15	10	0.2	1.848	1.688
21	15	30	0.07	1.848	1.616
22	3	10	0.04	0.369	0.364
23	3	30	0.2	0.370	0.328
24	21	20	0.04	2.588	2.365
25	21	30	0.04	2.584	2.339
26	15	20	0.07	1.848	1.640
27	3	20	0.07	0.369	0.339

The following graph shows the relationship between the actual and the predicted values of each run experiment. It can be noticed that the points were close to the fitted diagonal line, which indicates that the actual values were almost close to the predicted values. Therefore, the readings obtained seemed to provide an adequate fit.

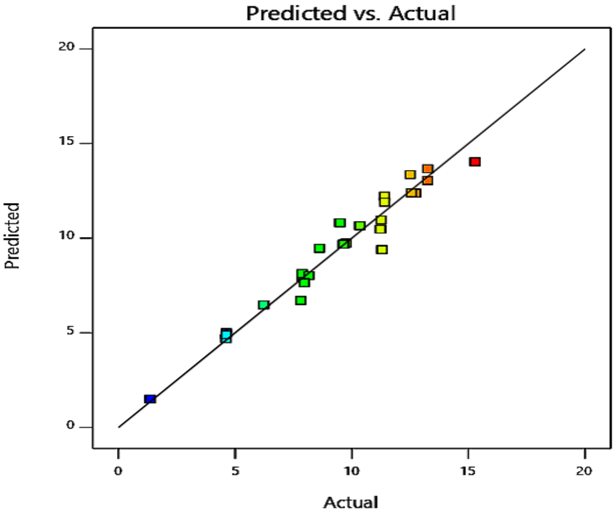

Figure 3: Predicted vs. Actual

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The following 3D surface plots showing the effect of the studied parameters, which are the initial concentration, the contact time, and the amount of activated carbon used on the percentage removal. The red areas showing the maximum removal percentage.

However, the green areas showing the minimum percentage removal of diclofenac sodium. In addition, it was noticed that a linear relationship obtained between the initial concentration and the time of contact, and the percentage removal. However, the relationship between the activated carbon used and the removal is showing a curve, in which at equilibrium the maximum removal can be obtained. Then, after increasing the amount of activated carbon used, no change was found in the removal of diclofenac sodium.

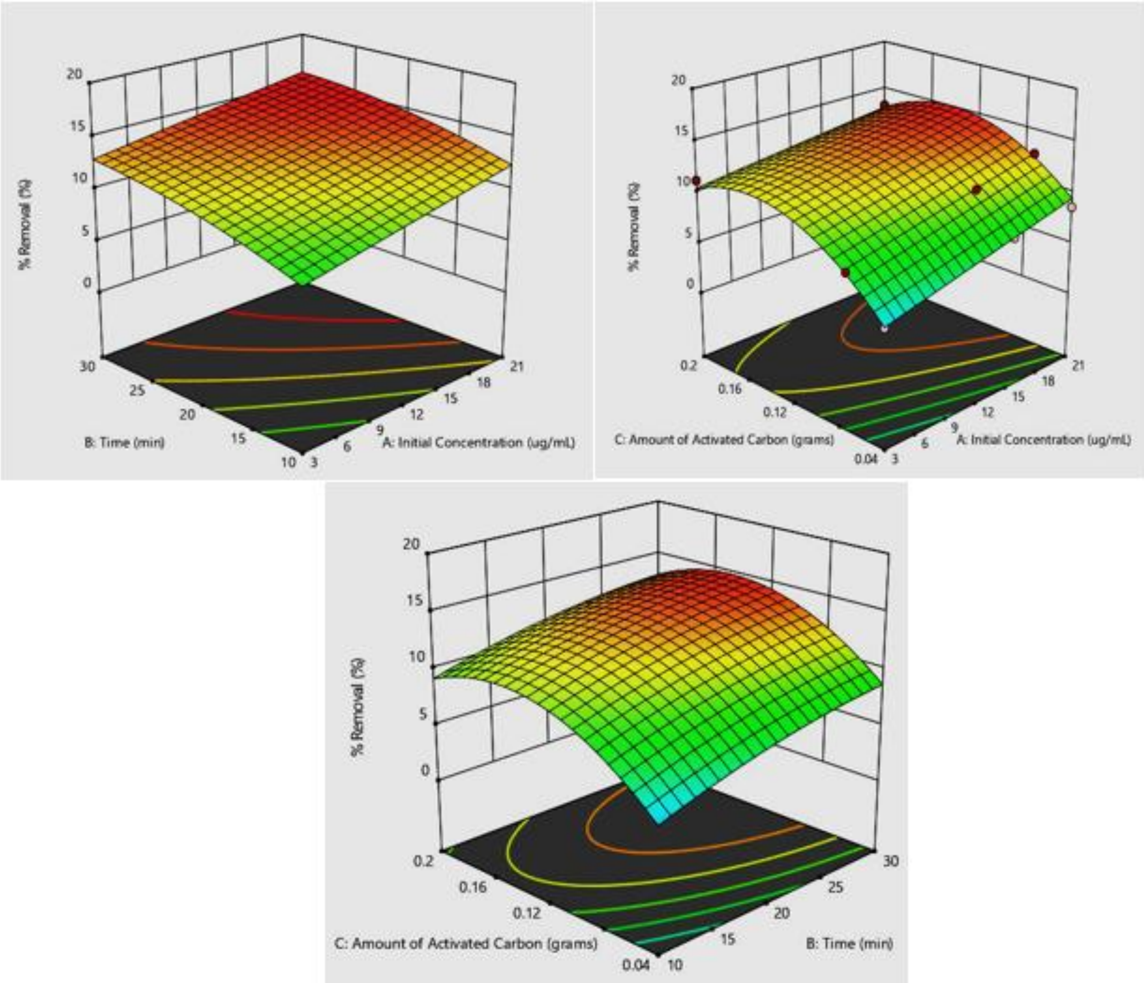

Figure 4: 3D surface plots showing the effect of the studied parameters on the percentage removal

The model equation that was obtained from design-expert software is showing below, in which the equation was used in the genetic algorithm to obtain the optimized condition.

Final Equation in Terms of Actual Factors

% Removal	=
-10.40046	
+0.355400	* Initial Concentration
+0.544964	* Time
+181.61679	* Amount of Activated Carbon
-0.002437	* Initial Concentration * Time
-0.765260	* Initial Concentration * Amount of Activated Carbon
-0.224846	* Time * Amount of Activated Carbon
-0.000453	* Initial Concentration²
-0.006994	* Time²
-577.65313	* Amount of Activated Carbon²

Figure 5: Model Equation Obtained from Design-expert Software

Then, the following table shows the optimized conditions, the experiment was conducted and the reults were analyzed. The percentage of removal was calculated for the optimized condition as 8.73%. It can be said that the conditions obtained from the genetic algorithm were not giving the maximum removal of diclofenac sodium the reason behind this is the difference between the two software programs used in this research. However, the percentage found in between the range obtained from the previous experiments. In addition, it can be considered as the optimized condition, in which the initial concentration of diclofenac sodium was less than 3 ppm. In addition, the time of adsorption was less than 30 minutes, and the amount of activated carbon used as an adsorbent is less than 0.007 grams. Therefore, less initial concentration, less contact time, and less amount of adsorbent can give 8.73% removal which can be considered as the best conditions for the removal of diclofenac sodium.

Table 2: Optimized Condition Readings

Initial Absorbance	Actual Initial Concentration (ppm)	Time (min)	Amount of Activated Carbon (grams)	Final Absorbance	Final Concentration (ppm)	%Removal (%)
0.319	2.51	25.5	0.064	0.291	2.29	8.73

CONCLUSION

In conclusion, this research was conducted to optimize the process of pharmaceutical wastewater treatment by biosorption using a genetic algorithm. The main objectives of this project were achieved, in which a water sample that contains diclofenac sodium were prepared and analyzed. Then, the experiment was designed using design-expert software (V.11). After that, the diclofenac sodium was removed using commercial activated carbon. Finally, the process was optimized using the genetic algorithm by MATLAB, and the experiment was conducted based on the obtained conditions, and the percentage removal was calculated.

LIMITATION AND STUDY FORWARD

No study covers all aspects of the research problem. Therefore, it is recommended to use large volume glassware in preparing samples that have the same concentration. In addition, it is recommended to prepare two samples of each run experiment to reduce the errors that can happen while preparing samples. For the future work, different pharmaceutical compounds must be analyzed using this technique to support the study and the technique used in pharmaceutical wastewater treatment.

CONFLICT OF INTEREST AND ETHICAL STANDARDS

The authors declare that there exists no conflict of interest with the current organization and no unethical practices followed during the study. (Like plagiarism, animal testing, human testing, etc)

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REFERENCES

1. Abdel-Shafy, H., & Mansour, M. (2017). Treatment of Pharmaceutical Industrial Wastewater via Anaerobic /Aerobic System for Unrestricted Reuse. Indian Journal of Scientific & Industrial Research, 76, 119-127.
2. Agrawal, V., Vairagade, V., & Kedar, A. (2017). Activated Carbon as Adsorbent In Advance Treatement of Wastewater. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 14(4), 36-40. Retrieved 2019. https://doi.org/10.9790/1684-1404023640
3. Antunes, M., Esteves, V., Guégan, R., Crespo, J., Fernandes, A., & Giovanela, M. (2012). Removal of diclofenac sodium from aqueous solution by Isabel grape bagasse. Chemical Engineering Journal, 192, 114–121. https://doi.org/10.1016/j.cej.2012.03.062
4. Armaya'u, U. (2019). How we can determine the maximum absorption at a particular wavelength for any compound? Retrieved January 15th, 2020, from https://www.researchgate.net/post/How_we_can_determine_the_maximum_absorption_at_a_particular_wavelength_for_any_compound.
5. CEHI. (2015). WHY TREAT WASTEWATER? Retrieved May 5, 2019, from http://www.cep.unep.org/issues/wastewater.PDF.
6. Chan, A. (2015). What is wavelength vs. absorbance? Retrieved January 20th, 2020, from https://www.quora.com/What-is-wavelength-vs-absorbance.

7. Coimbra, R., Calisto, V., Ferreira, C., Esteves, V., & Otero, M. (2015). Removal of pharmaceuticals from municipal wastewater by adsorption onto pyrolyzed pulp mill sludge. Arabian Journal of Chemistry, 12(4), 10-22.
8. Dikran, S., & Mahmood, R. (2015). Spectrophotometric Determination of Diclofenac sodium Using 2,4-dinitrophenylhydrazine in Pure Form and Pharmaceutical Preparations. Ibn Al-Haitham Jour. for Pure & Appl. Sci., 28(3), 129-141.
9. Ecologix Environmental Systems, LLC. (2018). Activated Carbon. Retrieved May 12, 2019, from https://www.ecologixsystems.com/product-activated-carbon/.
10. Gadipelly, C. (2014). Pharmaceutical Industry Wastewater: Review of the Technologies. Retrieved May 3, 2019, from https://grupos.unican.es/IPS/Publicaciones/2014/1.%20Gadipelly.pdf.
11. James, O., Anyakora, C., & Tolulope, B. (2014). Determination of pharmaceutical compounds in surface and underground water by solid phase extraction-liquid chromatography. Journal of Environmental Chemistry and Ecotoxicology, 6(3)(2141-226X), 20-26. https://doi.org/10.5897/JECE2013.0312
12. Naveed, S., & Qamar, F. (2014). UV spectrophotometric assay of different brands of Diclofenac sodium. Journal of Innovations in Pharmaceuticals and Biological Sciences, 1(3), 92-96. https://doi.org/10.4236/oalib.1100615
13. Nsami, J., & Mbadcam, J. (2013). The Adsorption Efficiency of Chemically Prepared Activated Carbon from Cola Nut Shells by ZnCl2 on Methylene Blue. Journal of Chemistry, 2013(469170), 1-7. Retrieved from https://www.hindawi.com/journals/jchem/2013/469170/. https://doi.org/10.1155/2013/469170
14. Rashid, Q., Bakir, M., & Baban, S. (2016). Spectrophotometric determination of Diclofenac Sodium in pure form and in the pharmaceutical preparations. Tikrit Journal of Pure Science, 21(3)(2415-1726), 76-80.
15. Saeed, A., Al-kadumi, A., & Ali, N. (2017). Determination of Vitamin C via Formation of Gold Complex Using Different Spectrophotometric Methods. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 8(4)(0975-8585), 1045-1053.
16. Schoolworkhelper Editorial Team. (2019). Beer's Law Lab Explained: Absorbance vs. Concentration. Retrieved January 20th, 2020, from https://schoolworkhelper.net/beers-law-lab-explained-absorbance-vs-concentration/.
17. Scientific Research Publishing Inc. (2015). Application of 3A Zeolite Prepared from Venezuelan Kaolin for Removal of Pb (II) from Wastewater and Its Determination by Flame Atomic Absorption Spectrometry. Retrieved January 20th, 2020, from https://www.scirp.org/html/4-2200666_37806.htm.
18. Tanks, C. (2015). Why Waste Water Treatment is So Important. Retrieved May 4, 2019, from https://www.carlowtanks.ie/why-waste-water-treatment-is-so-important/.
19. UN Water. (2017). Water Quality and Wastewater. Retrieved May 2, 2019, from http://www.unwater.org/water-facts/quality-and-wastewater/.
20. UNESCO. (2017). The United Nations World Water Development Report 2017. Retrieved May 2, 2019, from https://reliefweb.int/sites/reliefweb.int/files/resources/247153e.pdf.
21. Water World. (2012). Water Treatment: Chemical and Pharmaceutical Industries. Retrieved May 3, 2019, from https://www.waterworld.com/articles/iww/print/volume-12/issue-05/feature-editorial/water-treatment-chemical-and-pharmaceutical-industries.html.
22. Zaman, F., & Akter, S. (2015, Februery 15-17). Pharmaceutical Waste Water Treatment and the Efficiency of ETP in Context of Bangladesh. Retrieved May 20, 2019, from https://www.researchgate.net/publication/275028071_Pharmaceutical_Waste_Water_Treatment_and_The_Efficiency_Of_ETP_in_Context_Of_Bangladesh.

