Optimisation of system parameters for the removal of Metformin in a photocatalytic reactor employing TiO2

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Abstract: There is strong evidence that presence of emerging contaminants in environment including pharmaceutical compounds at very dilute concentration have deteriorating effects on various species. In general the concentration of these pollutants detected in environment ranges between ng/L to μg/L, but their concentration is elevated (mg/L) in the point sources including pharmaceutical industrial effluent. In India, highest concentration of Ciproflaxin (31 mg/L) was reported in the effluent from a generic medicine production centre in Hyderabad. To improve the removal of these emerging contaminants, pre-treatment of the highly concentrated pharmaceutical wastewater can be done before it is let into a domestic waste water treatment plant. In this work, treatment of synthetic pharmaceutical industry effluent containing critical pharmaceutical contaminants (PC) Metformin employing a photocatalytic system was investigated. Chosen factors include concentrations of contaminants (50 – 100 mg/L), TiO2 dosage (500 – 1000 mg/L) and reaction time (10- 30 min). MINITAB software was employed to perform the standard regression analysis and the corresponding second-order polynomial equation was constructed between the chosen response (contaminant removal) and the three factors.

Keywords: Pharmaceutical Contaminants; Metformin; Photocatalysis; Response surface methodology.

1. Introduction:

Literature indicates that presence of emerging contaminants in various environmental matrices at very low concentration have negative effects on different species [1]. These pollutants including pharmaceutical contaminants are typically detected in the water environment in the concentration range between ng/L to μg/L [2]. But these pharmaceutical contaminants are detected at higher concentration (mg/L) from the industrial effluents . In India, highest concentration of Ciproflaxin (31 mg/L) was reported by Larsson et al [3] in the effluent from a generic medicine production centre in Hyderabad. To manage the negative impact of these emerging contaminants economically, pre-treatment of the industrial effluent can be done well before the effluent discharge into a municipal waste water treatment plant [4]. Among the various treatment techniques Advanced oxidation process (AOP) is found to have improved efficiency in the removal of these emerging contaminants [5,6]. In this work, treatment of synthetic pharmaceutical industry effluent containing critical pharmaceutical contaminants (PC) Metformin (MTF) employing a photocatalytic system was investigated.

A survey was conducted in the city of Coimbatore, and it was found that predominant hospitals are letting their waste water without any pretreatment into the domestic wastewater system. In a work by Chinnaiyan et al.[7], MTF was found to be significant emerging contaminants for Indian environment. Hence, in this work, Metformin was selected as the contaminant. Metformin HCl (C4H12ClN5) is the most commonly prescribed medicine for Type 2 diabetics. It has a molecular weight of 165.6 g/mol and is readily soluble in water (106 mg/L).
The rationale of this study is to examine the appropriateness of heterogeneous photocatalytic system incorporating UV/ TiO$_2$ as a pre-treatment option for treating the simulated pharmaceutical wastewater containing Metformin HCl. The influence of Metformin concentration, catalyst concentration, and reaction time on the elimination of the contaminant was studied employing the design of experiment (DoE) method.

2. Materials and Methods

2.1. Reagents
All chemicals are of laboratory grade purity and are purchased from local vendor.

2.2. Experimental design
Design of experiment employing response surface methodology was used to perform standard regression analysis. The three factors chosen are initial contaminant concentration ($X_1$), TiO$_2$ concentration ($X_2$), and reaction time ($X_3$). Metformin removal was chosen as the response. The levels of the factors considered are shown in Table 1. Regression analysis was performed using MINITAB software.

| Factor                        | Levels used, actual (Coded) |
|-------------------------------|-----------------------------|
|                               | Low (-1)      | Medium (0) | High (+1)  |
| $X_1$ = Contaminant concentration (mg/L) | 50            | 75         | 100        |
| $X_2$ = TiO$_2$ concentration (mg/L)       | 500           | 750        | 1000       |
| $X_3$ = Reaction time (min)             | 10            | 20         | 30         |

2.3. Photocatalytic systems
Experiments were conducted employing the photoreactor procured from M/s Heber Scientific, Chennai. The reactor configuration is shown in Fig 1. UV radiation (365 nm) was emitted for the degradation of Metformin.

2.4. Analysis
The concentration of Metformin was measured using UV-VIS spectrometer by calibrating with known standards. For measuring the absorbance the detector was set at 254 nm.
3. Results and Discussion

3.1. MTF removal
The experimental results of the DoE are shown in Table 2. Regression analysis was performed using the results and equation obtained is presented in Eqn 1. The removal of MTF varied between 49 and 81% for the different combination of the chosen three factors. The results are comparable to earlier studies on other contaminants [8].

| Contaminant Conc. (mg/L) | T,IO₂ (mg/l) | Time (min) | MTF removal (%) |
|--------------------------|--------------|------------|-----------------|
| 75                       | 750          | 20         | 62              |
| 75                       | 750          | 20         | 53              |
| 100                      | 500          | 30         | 68              |
| 75                       | 750          | 10         | 59              |
| 75                       | 750          | 20         | 68              |
| 50                       | 500          | 10         | 49              |
| 75                       | 1000         | 20         | 58              |
| 75                       | 500          | 20         | 61              |
| 75                       | 750          | 20         | 67              |
| 50                       | 750          | 20         | 63              |
| 75                       | 750          | 30         | 69              |
| 100                      | 750          | 20         | 64              |
| 100                      | 1000         | 30         | 81              |
| 50                       | 1000         | 10         | 57              |
| 100                      | 1000         | 10         | 71              |
| 100                      | 500          | 10         | 59              |
| 50                       | 500          | 30         | 63              |
| 50                       | 1000         | 30         | 69              |
| 75                       | 750          | 20         | 59              |
| 75                       | 750          | 20         | 62              |

Equation 1:

\[
MTF\ \text{Removal} = 46.6 - 0.440 \times \text{Contaminant Conc (mg/l)} + 0.0436 \times T,IO₂ (mg/l) \\
- 0.20 \times \text{Time (min)} + 0.0034 \times \text{Contaminant Conc (mg/l)} \times \text{Contaminant Conc (mg/l)} \\
+ 0.0264 \times \text{Time (min)} \times \text{Time (min)} + 0.0002 \times \text{Contaminant Conc (mg/l)} \times T,IO₂ (mg/l) \\
- 0.0035 \times \text{Contaminant Conc (mg/l)} \times \text{Time (min)}
\]

3.2. Response surface plot
To study the interaction between the factors considered, response surface plot (RSP) were generated (Figs 2 a to c ) from the model equations.

Figure 2a Response surface for MTF removal for change in MTF and TiO₂
Analysing the response surface plot (Fig 2a), it was found that there is a strong interaction between the factors MTF concentration and TiO$_2$ with respect to the response MTF removal. For the same initial concentration, the MTF removal increases as photocatalyst concentration increases. Maximum removal of around 70% was observed when the TiO$_2$ concentration was 1000 mg/L.

![Figure 2b](image)

**Figure 2b** Response surface for MTF removal for change in MTF and Time

Analysing the response surface plot (Fig 2b), it was found that there is a strong interaction between the factors MTF concentration and timewith respect to the response MTF removal. For the same initial concentration, the MTF removal increases as time increases. Maximum removal of around 78% was observed when the reaction time was maintained at 30 min.

![Figure 2c](image)

**Figure 2c** Response surface for MTF removal for change in TiO$_2$ and Time

Analysing the response surface plot (Fig 2c), it was found that there is a strong interaction between the factors TiO$_2$ and timewith respect to the response MTF removal. The removal is found to increase as the TiO$_2$ increases. Similar trend is observed for the factor time and maximum removal of 70% was observed at a reaction period of 30 min.

4. Conclusion
The synthetic pharmaceutical wastewater containing Metformin was pre treated using UV/ TiO$_2$ heterogeneous photocatalytic system. Influence of initial Metformin concentration, time and TiO$_2$ concentration was studied using response surface methodology. Standard regression analysis was performed and a model was created between MTF removal and the three chosen factors. Analysing the response surface plots it was found the MTF removal was influenced by all the chosen three factors. Maximum removal of 78% was observed at a reaction period of 30 min and when the TiO$_2$ concentration is at 1000 mg/L, indicating that the heterogeneous photocatalytic system can be suitably employed for the pre treatment of the pharmaceutical effluent.
Reference

[1] Daughton, C., 2004. PPCPs in the Environment: Future Research - Beginning with the End Always in Mind. In K Kümmерer, ed. Pharmaceuticals in the Environment. Springer, pp. 463–495.

[2] Hughes, S.R., Kay, P. & Brown, L.E., 2013. Global Synthesis and Critical Evaluation of Pharmaceutical Data Sets Collected from River Systems. Environmental Science & Technology, 47(Critical Review), pp.661–677.

[3] Larsson, D.G.J., de Pedro, C. & Paxeus, N., 2007. Effluent from drug manufactures contains extremely high levels of pharmaceuticals. Journal of Hazardous Materials, 148(3), pp.751–755. Available at: 10.1016/j.jhazmat.2007.07.008.

[4] Chong, M.N. & Jin, B., 2012. Photocatalytic treatment of high concentration carbamazepine in synthetic hospital wastewater. Journal of Hazardous Materials, 199-200(2010), pp.135–142. Available at: http://dx.doi.org/10.1016/j.jhazmat.2011.10.067.

[5] Pereira, V., Linden, K. & Weinberg, H., 2007. Evaluation of UV irradiation for photolytic and oxidative degradation of pharmaceutical compounds in water. Water Res, 41, pp.4413–23.

[6] Trovó, A. et al., 2011. Degradation of the antibiotic amoxicillin by photo-Fenton process—chemical and toxicological assessment. Water Res, 45, pp.1394–02.

[7] Chinnaian, P. et al., 2018. Pharmaceutical products as emerging contaminant in water : relevance for developing nations and identification of critical compounds for Indian environment. Environ Monit Assess, 190(288). Available at: https://doi.org/10.1007/s10661-018-6672-9.

[8] Jung, Y.J. et al., 2012. Removal of amoxicillin by UV and UV/H2O2 processes. Science of the Total Environment, 420, pp.160–167. Available at: http://dx.doi.org/10.1016/j.scitotenv.2011.12.011.