

Comparative Study of Removal of Organic Pollutant from Waste Water by Using Advance Oxidation Techniques

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Abstract

The food processing industry is one of the largest generators of high-strength wastewater characterized by large amount of organic pollutants, suspended solids, oils, fats, carbohydrates, and proteins. The effluents typically exhibit high chemical oxygen demand (COD) and biological oxygen demand (BOD) along with significant fluctuations in pH and turbidity due to variations in raw materials and processing operations. Conventional biological treatment methods are often ineffective for complete degradation of recalcitrant organic compounds present in these effluents. Therefore, advanced treatment approaches are required to ensure effective pollutant removal, compliance with environmental regulations and the protection of water resources. Photocatalytic and photo-ozonation are efficient methods for removal of organic pollutant from wastewater. However, these processes have some limitations, for example photocatalytic due to limited light penetration in turbid effluent while photo-ozonation is constrained by the high energy requirement for ozone generation. This study evaluates the performance of TiO_2 nanoparticles in real food industry wastewater to remove organic pollutant by using combination of Advanced Oxidation Techniques (AOP) like photocatalytic and photo-ozonation with a removal of organic pollutant efficiency, process optimization and ecotoxicological impacts. The combined approach was employed to systematically analyze the effect of pH, effect of dose, effect of concentration with an analytical method like Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Dissolved oxygen(DO). Through combined AOP method 90% efficiency achieved with sustainable approach. The model equation study was studied with Minitab software for finding error between experimental and predicted results.

1. Introduction

The increasing water pollution by industries like textile (Khataee et al. 2011), pharmaceutical (Paumo et al. 2021), cosmetics (Titchou et al. 2021), food industry (Li and Li 2001), agriculture (Wani and Kumar 2018) etc are great concern problems which creates a problem for environment and human health (Titchou et al. 2021). It also decreases the life of aquatic organisms (Ang Li, Carolien Kroeze, Taher Kahil 2019). Out of these food industries are considered as major partner for water pollution because they are more water consumer for cooling process,, sanitizing and cleaning purposes which produces severe health and environmental issues (Abdel-fatah and A 2023). Diverse range of organic pollutants, largely categorized persistent organic pollutant (POP) are generated by food industries. There are number of techniques available for wastewater treatment such as coagulation, adsorption, filtration etc. but these methods are having some disadvantages to remove organic and inorganic pollutants. The advanced oxidation techniques (AOP) (Admane and Marathe 2024) understood the drawbacks of these processes and clear the water by intermediary action of extremely reactive species hydroxyl radical (OH) which can oxidise and mineralise producing ecologically friendly gases like CO_2 and inorganic gases. (Kaswan and Kaur 2023). The goal of the AOP methods for wastewater treatment is the reduction of the toxicity and chemical contaminants to such extent that the wastewater can be reintroduced into the receiving streams (Glaze, Kang, and Chapin 1987).

The AOP techniques includes UV radiation, ozone, electrochemical and Fenton methods (Khader et al. 2024). Overall all AOP methods used, in photocatalytic method, to enhance radical formation and hydrogen peroxide UV radiation involves (Hübner et al. 2024). In ozonation process ozone radical which is very powerful oxidant react directly with pollutant or decompose it into hydroxyl radical to increase its treatment efficiency (Sievers 2011). Fenton based process, use of iron catalyst in acidic conditions with hydrogen peroxide generate hydrogen radical. If efficiency of process still increase then add UV light in the process which is called as Photo-Fenton process (Grosser et al. 2025). In electrochemical reaction, a used of electrochemical reactor or specialized anode made for generation of radicals directly on the surface of water (Zhang et al. 2024). For breaking down non-biodegradable, toxic and persistent pollutant, AOP is primarily used method for wastewater. The advantage of these process is that it will create small footprint and eliminate the need of secondary sludge (Arimi et al. 2020).

The research is focussed on comparative application of AOP techniques for removal of organic pollutant from food industry wastewater by photocatalytic and photo ozonation method. It has comparative results of both the processes by varying parameters like agitation speed, solid loading, pH and time. The results are analysed on Biological Oxygen demand (BOD), Chemical Oxygen Demand (COD), Total dissolved solid (TDS) and pH. The results are best fitted and optimised parameter are useful for further experimentation. The increasing interest in water reuse and more stringent regulations regarding water pollution are currently accelerating the implementation of AOPs at full-scale. Since AOPs were first defined in 1987, the field has witnessed a rapid development both in theory and in application (Chuan et al. 2021).

2. Materials and Methods

The experimentation was carried out with wastewater collected from nearby industry around Alandi (D) Pune. The water was analysed for different parameters like pH, TDS, BOD, COD etc. the required chemicals were purchased from sigma Aldrich with AR grade. The removal efficiency of wastewater was calculated by using formula (Lopez et al. 2022)

$$\eta \text{ (\%)} = \frac{(C_0 - C)}{C_0} \text{-----(2.1)}$$

Where,

C_0 – Initial Concentration (BOD/COD)

C - Final concentration after treatment

3. Results and Discussion

3.1 Effect of Time

The removal efficiency of organic matter from food industry wastewater was studied for time parameter for both photocatalytic and photo ozonation method.

The results are shown in Fig. 3.1. The figure illustrates that removal efficiency increases with increase in time for both the methods. During initial time lower efficiency occurs because of insufficient generation of reactive species like hydroxyl ions ($\text{OH}^\cdot$). As the reaction time increases BOD and COD removal efficiency was also increased because large number of hydroxyl ions were available for oxidation process (Khan et al. 2023). The study shows that more BOD and COD removal occurs at photo ozonation than photocatalytic method because of synergetic effect of hydroxyl radical generation and oxidation process.

3.2 Effect of Solid Loading

The experiment was performed for studied of effect of solid loading (1 gm, 2gm, 3gm, 4gm) was studied for both the processes.

Figure 3.2 illustrates that as solid loading increases from 1 to 3 gm removal efficiency increases because more active sites are available for oxidation process but as solid loading dose increases to 4 gm the removal efficiency decreases because of reduced light penetration due to increased turbidity (Zahoor et al. 2026).

3.3 Effect of pH

The experiment was performed at different pH (2,4,6 and 8) for both the process.

The results are shown in Fig. 3.3. From the figure it is concluded that the best results are shown at pH 6. This is because of the reason that at pH 6 catalyst surface is almost neutral and provide highest degradation efficiency for organic pollutant. While at acidic pH, surface is acidic which repels the positively charged organic pollutant and opposite effect will be observed in basic pH.

3.4 Effect of Agitation speed

The experiment was performed at different agitation speed (300, 500, 700, 900 RPM) for degradation of organic pollutant from food industry wastewater for both photocatalytic and photo zonation method.

The results are shown in Fig. 3.4. The graph shown that as agitation speed increases degradation increases. Upto 700 RPM the expected result was observed because of enhanced mass transfer, catalyst dispersion and ozone dissolution, after that though agitation speed increases it decreases.

4. Data Analysis

The Minitab software system was used to analysed the experimental data (Antony 2023). It provides robust techniques for data interpretation, modelling and optimization of parameters like solid loading, reaction time (Raina, Roy, and Bharadvaja 2020). Minitab serves as an efficient platform for transforming experimental data into meaningful insights, enabling accurate modelling, optimization and validation of advanced oxidation processes in wastewater treatment. (Madondo and Rathilal 2022). Experimental studies were conducted to investigate the degradation of organic pollutant from food industry wastewater. The model equation for time, pH, agitation speed and solid loading are as follows in Table 4.1

Table 4.1
Regression equation and experimental analysis of parameters:

Parameters	BOD after Photo-catalysis (mg/L)	BOD after Photo-ozonation (mg/L)	COD after Photo-catalysis (mg/L)	COD after Photo-ozonation (mg/L)
Effect of Time (Hr)				
Regression Equation	$-14.33 + 37.52 \text{ Time (hr)} - 3.963 \text{ Time (hr)} * \text{Time (hr)}$	$3.04 + 33.53 \text{ Time (hr)} - 3.618 \text{ Time (hr)} * \text{Time (hr)}$	$-9.50 + 29.00 \text{ Time (hr)} - 2.500 \text{ Time (hr)} * \text{Time (hr)}$	$3.50 + 3.125 \text{ Time (hr)} - 0.000121 \text{ Time (hr)} * \text{Time (hr)}$
R ² Experimental	98.88	99.88	99.85	99.93
R ² modelling	97.76	99.76	99.71	99.86
Effect of Solid Loading (gm)				
Regression Equation	$-0.10 + 42.69 \text{ Catalyst Dosage (g)} - 6.03 \text{ Catalyst Dosage (g)} * \text{Catalyst Dosage (g)}$	$-11.25 + 44.25 \text{ Catalyst Dosage (g)} - 6.25 \text{ Catalyst Dosage (g)} * \text{Catalyst Dosage (g)}$	$9.55 + 40.76 \text{ Catalyst Dosage (g)} - 6.030 \text{ Catalyst Dosage (g)} * \text{Catalyst Dosage (g)}$	$-3.13 + 6.25 \text{ Catalyst Dosage (g)} - 0.000121 \text{ Catalyst Dosage (g)} * \text{Catalyst Dosage (g)}$
R ² Experimental	98.89	98.89	99.84	99.99
R ² modelling	98.67	96.67	99.51	97.52
Effect of pH				
Regression Equation	$-12.2 + 25.93 \text{ pH} - 2.110 \text{ pH} * \text{pH}$	$26.6 + 28.47 \text{ pH} - 2.266 \text{ pH} * \text{pH}$	$-4.9 + 25.93 \text{ pH} - 2.110 \text{ pH} * \text{pH}$	$-23.1 + 2.110 \text{ pH} * \text{pH}$
R ² Experimental	96.27	97.27	96.27	98.63
R ² modelling	88.81	91.8	88.81	95.89
Effect of Agitation speed (RPM)				
Regression Equation	$-2.8 + 0.1746 \text{ RPM} - 0.000096 \text{ RPM} * \text{RPM}$	$-27.2 + 0.2300 \text{ RPM} - 0.000141 \text{ RPM} * \text{RPM}$	$2.56 + 0.1905 \text{ RPM} - 0.000121 \text{ RPM} * \text{RPM}$	$-18.7 + 0.1905 \text{ RPM} - 0.000121 \text{ RPM} * \text{RPM}$
R ² Experimental	95.99	98.28	99.1	97.52
R ² modelling	87.96	94.85	97.3	92.57

The experimental and validated results are perfectly matched. Figure 4.1a, Fig. 4.1b, Fig. 4.1c and Fig. 4.1d indicates that operating conditions evaluated through experimentation are mapped with model results also. From modelling study, we can conclude that photo-ozonation is the best method than photocatalytic method.

Conclusion

The present study evaluated the effect of time and solid loading parameter for both photo ozonation and photo catalytic method. The results were clearly explained that both the parameters have significant influence of both the parameters on both the processes. In reaction time parameter as time increases BOD and COD removal efficiency for both processes increases. While as solid loading increase BOD COD removal efficiency also increase but after that though solid loading increase it decreases because of problems in light penetration and more turbidity. It also concluded that photo ozonation has significant higher removal efficiency than photo catalytic method because of UV light and more hydroxyl radicals. Overall, the study highlights the importance of optimizing operational parameters such as reaction time and catalyst loading to achieve maximum efficiency. These findings provide valuable insights for the design and scale up of advanced oxidation processes for wastewater treatment applications.

Declarations

Author Contribution

Shraddha Admane contributed to the investigation, methodology, visualization, data curation, and preparation of the original draft. Bhaskar Wabhitkar contributed to conceptualization, methodology, supervision, and writing—review and editing. Both authors reviewed and approved the final version of the manuscript.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figures

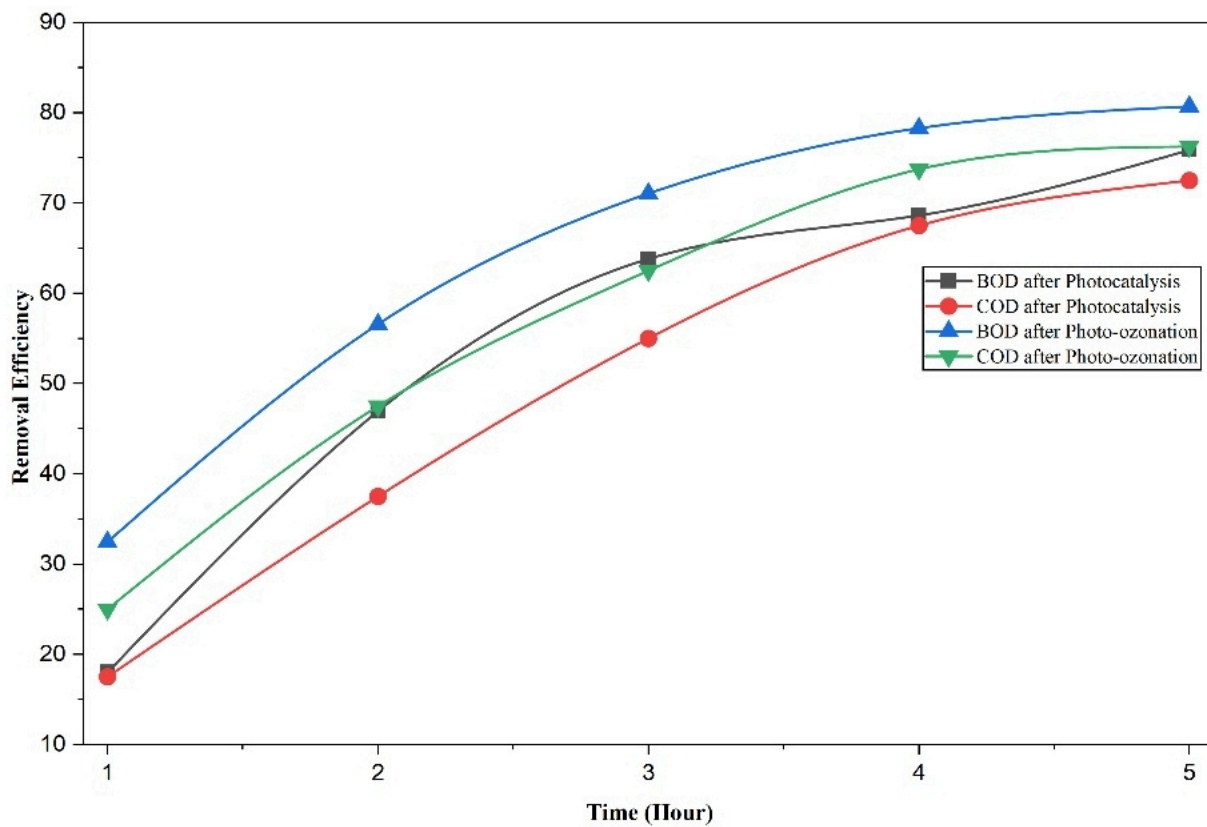


Figure 1

3.1 Effect of time for Photo ozonation and photocatalytic method

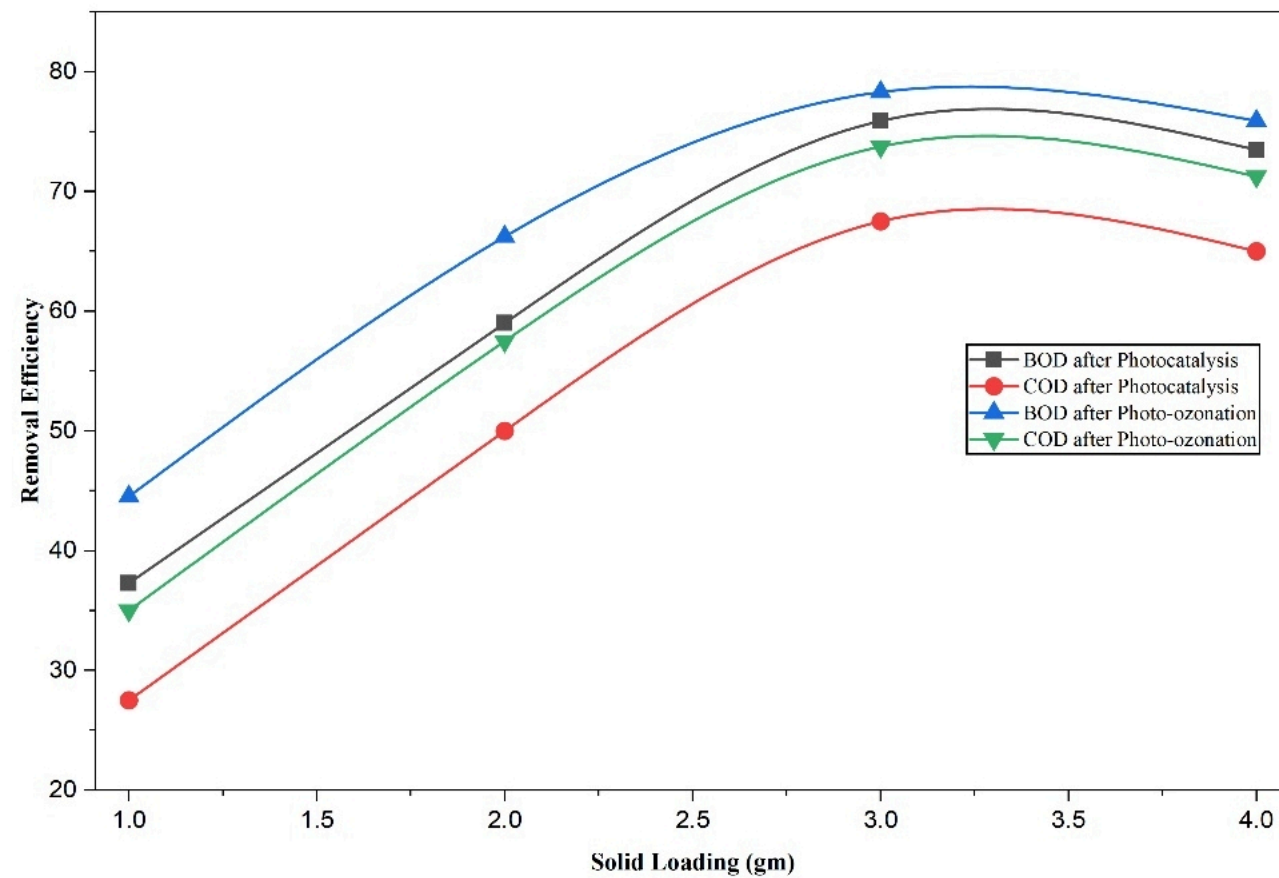


Figure 2

3.2 Effect of solid loading for photocatalytic and photo ozonation method

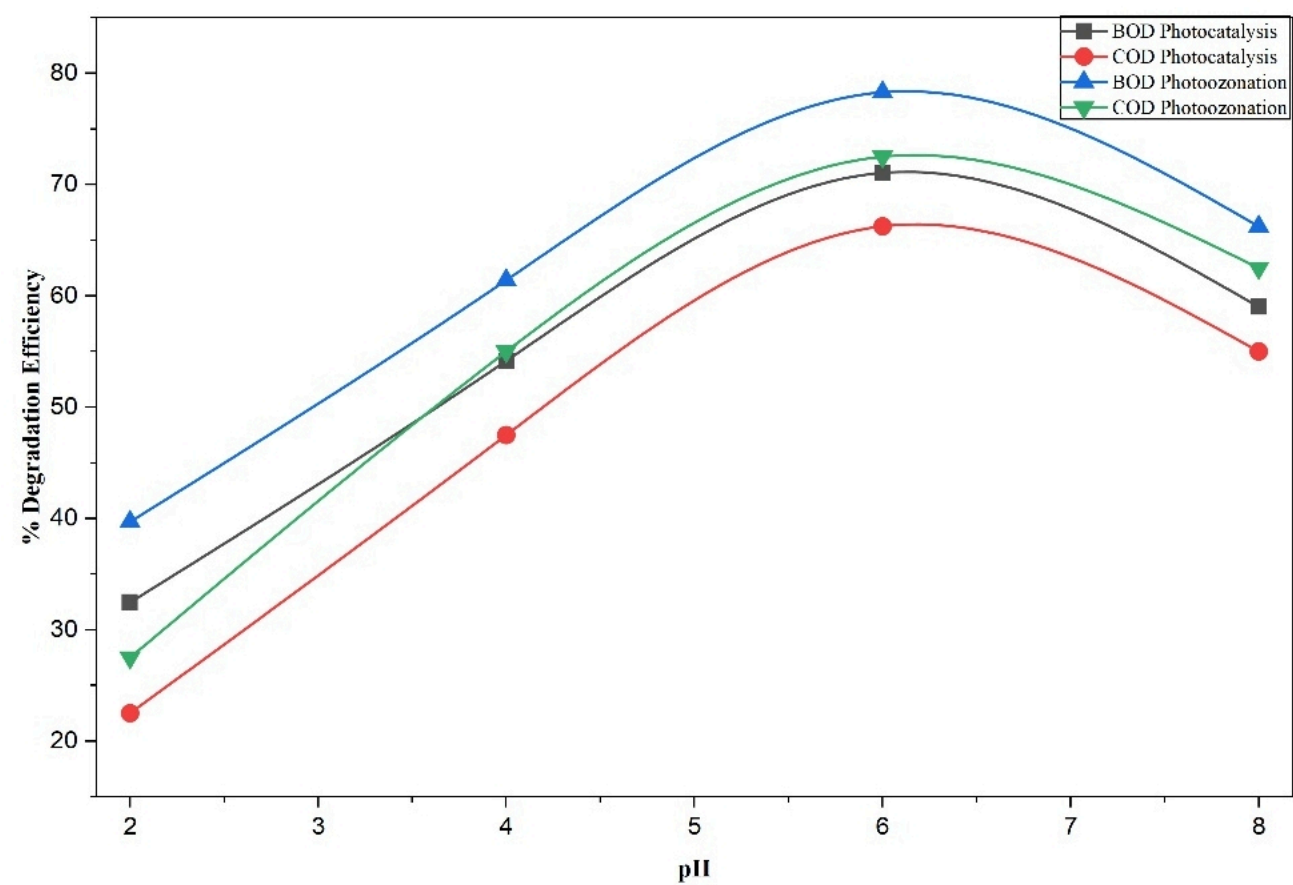


Figure 3

3.3 Effect of pH for photocatalytic and photo ozonation method

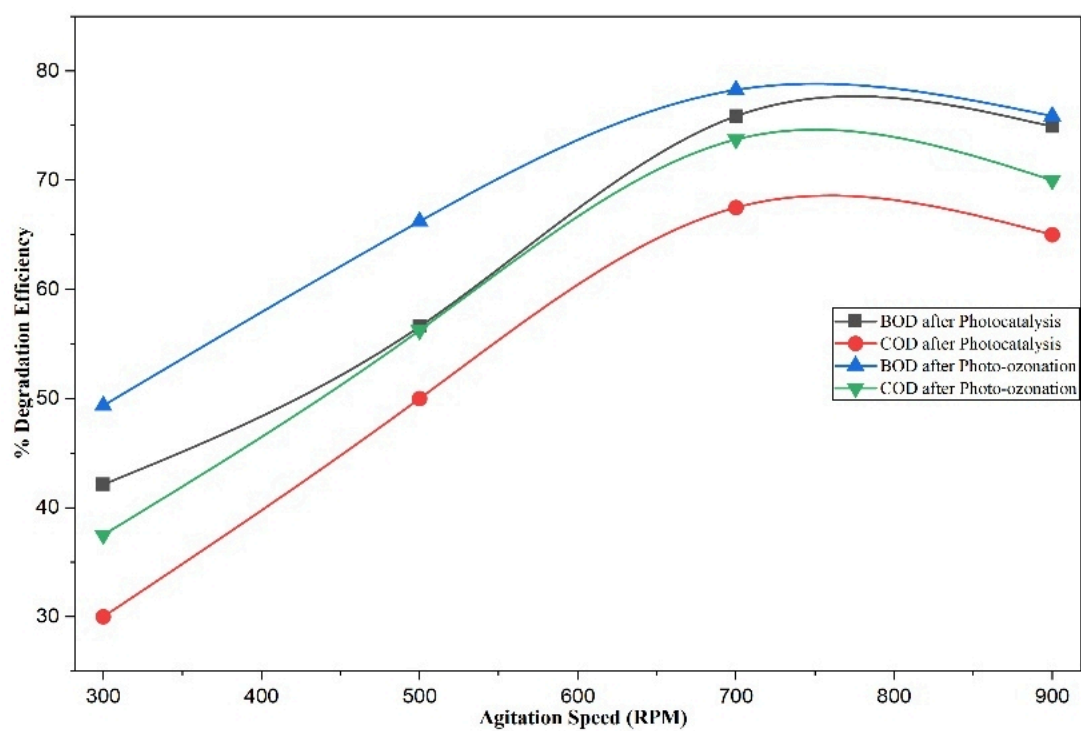


Figure 4

3.4 Effect of Agitation speed for photocatalytic and photo ozonation method

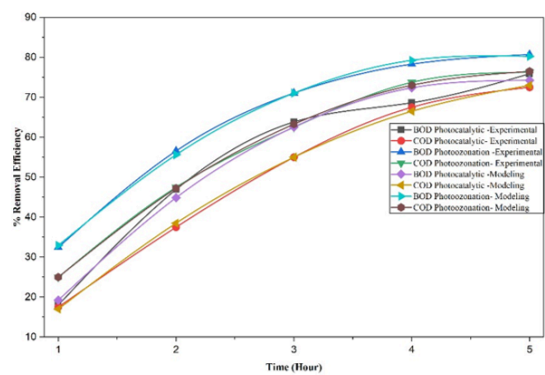


Fig. 4.1: Comparative analysis of photocatalytic and photo-ozonation method (a)

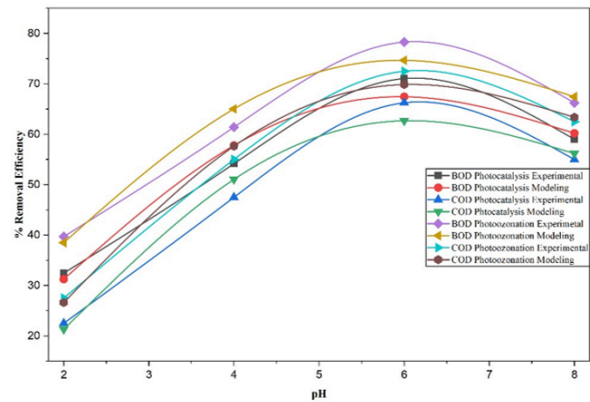


Fig. 4.1: Comparative analysis of photocatalytic and photo-ozonation method (c)

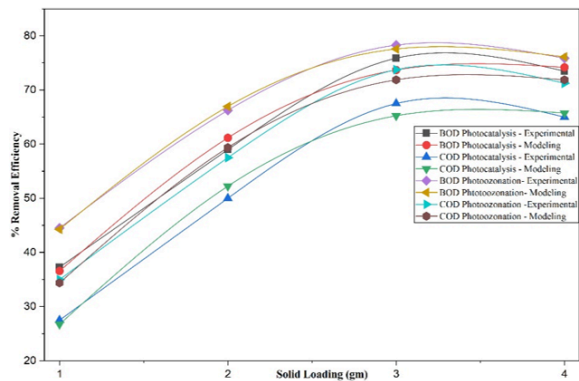


Fig. 4.1: Comparative analysis of photocatalytic and photo-ozonation method (b)

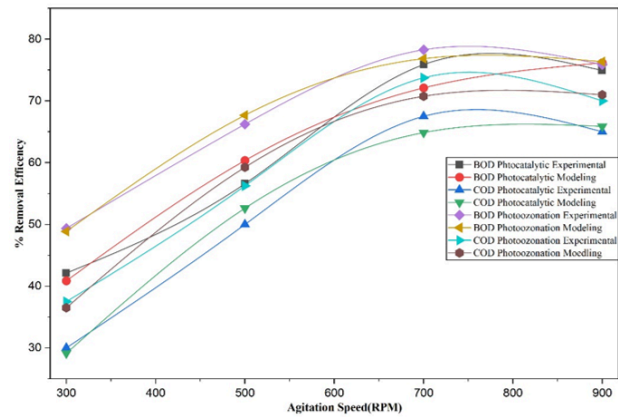


Fig. 4.1: Comparative analysis of photocatalytic and photo-ozonation method (d)

Figure 5

See image above for figure legend.