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Degradation of formaldehyde using ZnO powder as photocatalyst

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ABSTRACT

In the present study, commercially available Metal Oxide powder was used for the degradation of Formaldehyde in an aqueous phase. The Photocatalysis oxidation was favored at neutral pH. The effect of catalyst concentration, operating temperature, and the stirring effect was studied. The reflector was used in order to increase the impact of UV light for Photocatalysis process. For 500 mg/L concentration of Formaldehyde in an aqueous phase, degradation was observed and the catalyst was recycled using physical separation method and reused. Similar results were observed in the recycled catalyst.

***Keywords*:** *Formaldehyde, Metal oxide, UV light, Reflector, Photocatalysis.*

1. INTRODUCTION

Industrial effluent contains a diversity of impurities and therefore its treatment constitutes a special task. Textile and chemical industries are the major sources of water pollution. The polluted water affects the aquatic animals and degrade the quality of water and make it unfit for human consumption. So it is necessary to treat all the wastewater from the industries to be treated before discharging into water body.[1]

Normally for treatment of wastewater chemical effluent treatment plant is highly recommendable as it economical and easy to operate. But when microorganisms are used for the degradation of organic compounds in the Chemical effluent treatment plant there are certain chemicals that are toxic to the microorganisms. Formaldehyde is highly toxic and if its concentration increases above 300mg/l, the survival of microorganisms gets difficult. Formaldehyde is listed as carcinogenic under International Agency for Research on Cancer (IARC). There are almost 45 chemicals listed under it out of which formaldehyde is one of the most toxic. Formaldehyde is used in the manufacturing of resin and in the textile industry. It is also used as a disinfectant. Formaldehyde is commercially available in 37% w/w solution generally termed Formalin. Apart from being carcinogenic Formaldehyde on physical contact can cause skin irritation. So it is very necessary to degrade Formaldehyde.[1]

Degradation of Formaldehyde in aqueous solution has always been a tough task. Very less research has been carried out on the degradation of Formaldehyde in aqueous solution in comparison to gaseous formaldehyde. In recent time advanced oxidation process is highly recommended for degradation of organic compounds due to ease of operation and very efficient in removing toxic compounds present in wastewater and it is getting a lot of appraisals. On degradation, volatile organic compounds are broken into smaller molecules like water and carbon dioxide. Photocatalytic oxidation of molecules in order to degrade them into small molecules has gained a lot of attention in past few years due to its efficiency and better results. Photocatalysis is a process in which a semiconductor acts a catalyst in the presence of light which results in moving of electrons from valence band to conductance band which further reacts with oxygen and water molecules to form ozone and·OH, radical which have a higher potential of oxidation and reduction of the organic compounds.[3-4]

There are many photocatalyst that is used for the degradation of organic compounds such as TiO_2, $Fe2O_3$, ZnO, $ZnFe_2O_4$ but Zinc Oxide is recommended due to various reasons. It has a low band gap of 3.37 eV. Zinc Oxide is inexpensive and easily available. It is non-toxic in nature. Zinc Oxide provides high activity rate.[3] Normally nanoparticles are used as photocatalyst in order to get high surface to volume ratio but nanoparticles are very costly to be used on large scale and its recovery is also very expensive so in this study efforts are made to use the commercially available Zinc Oxide powder as photocatalyst for the degradation of Formaldehyde present in aqueous solution. The effect of operating temperature, catalyst concentration, stirring has been studied and the results are demonstrated.

2. EXPERIMENT SET-UP

2.1 Chemicals

Zinc Oxide powder was directly purchased from Finar Chemicals. Formaldehyde solution of 37% w/w containing 15% w/w methanol was purchased and used to make the feed solution having a concentration of 0.05% w/w Formaldehyde.

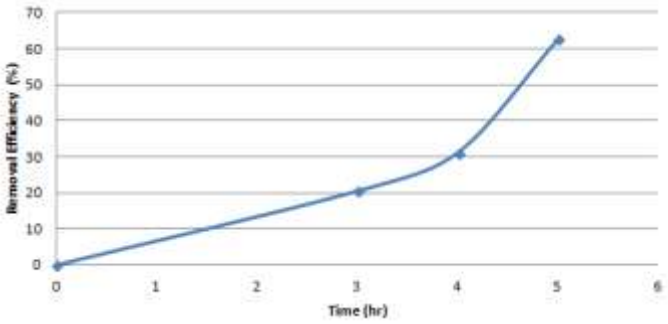
2.2 Reactor

Normally for a photocatalytic reaction a glass photocatalytic reactor with a magnetic stirrer and UV light placed in the center is used. Here as Zinc Oxide powder is used proper stirring is required which is not obtained using the normal photocatalytic reactor. So a new photocatalytic reactor was designed. A glass vessel having operating L/D ratio of 2.09 was used as it is a gas-liquid reaction as air is going to be purged. Air is purged using a deep tube and a glass baffle was used to get proper stirring. The stirrer was designed having 1- cowl blade attached at the bottom with 3 6-bladed pitched blades and was used to atomize the air purged and getting proper mixing. The reflector was made into a hollow cylinder and was placed around the set-up in order to increase the impact of UV light as it has high optical reflectivity.[2]

There are many reflectors that can be used for required purpose like stainless steel, mild steel, Mirror, Aluminum etc. out of which Aluminum was used as reflector due to its high optical reflectivity and it is economical and easy to operate while Stainless steel and mild steel contain carbon which oxidizes in presence of UV light and form black spots and for mirror it is expensive and it's handling is difficult. Thus Aluminum was used as reflector. [2]

2.3 Experiment procedure and analysis

For the experiment the glass vessel with operating L/D ratio of 2.09 was filled with the feed solution having formaldehyde concentration of 0.05%. Zinc Oxide powder was added to the feed and the stirring was started. Air was purged using a deep tube by an air compressor. The operating temperature was raised to 55^0C. The UV-light used was 6W-240 nm tube placed to start Photocatalysis. The reaction was carried on for 5 hours. The samples were collected at 3 hour, 4 hour and finally at 5 hour that are plotted in Graph 1. Chemical oxygen demand and pH of the samples were checked. The degradation of formaldehyde was determined by difference in chemical oxygen demand between initial and final sample according to the standard methods for examination of wastewater. The chemical oxygen demand of the final output was decreased by 62.56% in respect to the initial feed.



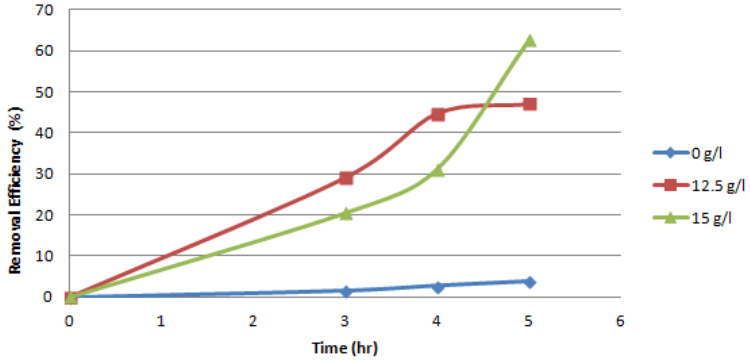
Graph 1: Photocatalytic oxidation of 500mg/l formaldehyde in aqueous phase

3. COMPARATIVE STUDY

Comparative study was performed to observe the role of each parameter like catalyst concentration, catalyst recycling, operating temperature and stirring involved in the photocatalytic oxidation of formaldehyde.

3.1 The effect of catalyst concentration

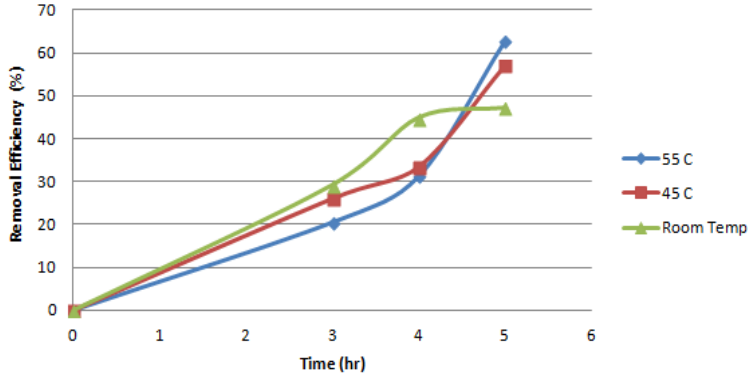
For evaluating the effect of the catalyst concentration on the degradation of formaldehyde in aqueous form, the concentration of Zinc Oxide was varied to optimize it in such a way that the concentration of formaldehyde gets into the limit and is economically feasible. Increasing the concentration of Zinc Oxide for the same concentration of formaldehyde the degradation increased. Increasing Zinc Oxide concentration from 0 g/l to 15 g/l the percentage degradation of formaldehyde increased from 3.8% to 62.56% as shown in Graph 2. On using 15 g/l Zinc oxide concentration for degradation of formaldehyde having concentration 0.05% w/w the final COD was 292 ppm that is lower than the required limit of 300 ppm. Thus using 15 g/l is feasible as the requirement is fulfilled by it. On further increasing the catalyst concentration the degradation would increase but it will increase the operating cost and that won't be economically feasible.



Graph 2: Effect of catalyst concentration on aqueous phase containing 500mg/l formaldehyde

3.2 The effect of operating Temperature

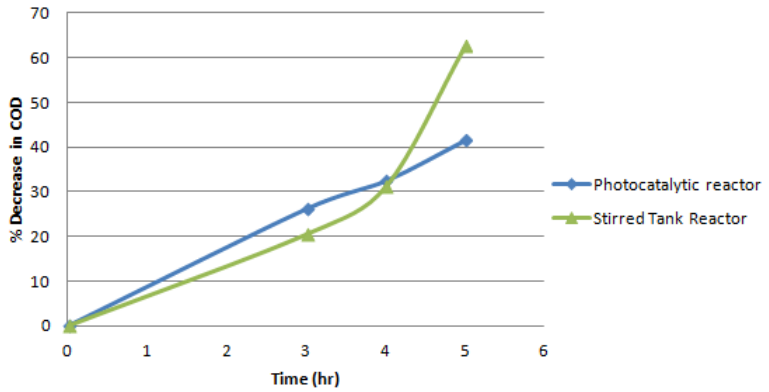
For the evaluation of the effect of operating temperature on the photocatalytic degradation of formaldehyde, the experiments were carried out at a different temperature to find the optimum temperature. Increasing the operating temperature from room temperature to 55^0C the percentage degradation of formaldehyde increased from 47.14% to 62.56% as shown in graph 3. At operating temperature of 55^0C, the requirement was fulfilled and the concentration of formaldehyde was decreased to 292 mg/l.



Graph 3: Effect of operating Temperature on aqueous phase containing 500mg/l formaldehyde

3.3 The effect of Stirring

Stirring is a very important parameter affecting the photocatalytic oxidation of formaldehyde. To optimize the stirring and for better mixing different stirrer were used. A comparative study was studied between the stirring effect of the magnetic stirrer in the normally used photocatalytic reactor and the stirrer in the stirred tank reactor. By using magnetic stirrer in the photocatalytic reactor the percentage degradation of formaldehyde obtained was 41.51% and on using stirred tank reactor for photocatalytic degradation 62.56% degradation was obtained. The result is plotted in graph-4

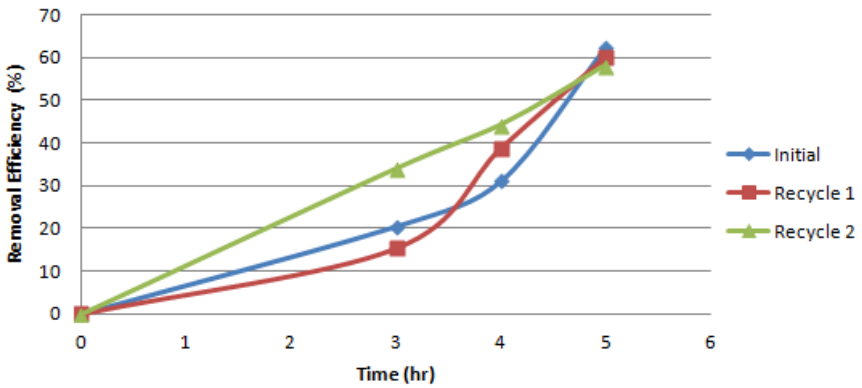


Graph 4: Effect of Stirring on aqueous phase containing 500mg/l formaldehyde

4. CATALYST RECYCLING

Recycling of catalyst is very necessary for any process as it makes the process economical. It is one of the major benefits of using zinc oxide powder as a photocatalyst. In nanoparticles as the particle size is in nanoscale it is very difficult to recycle it nanofiltration has to be used which makes the process complex and expensive. While in Zinc oxide powder the particles are comparatively bigger due to which it gets easily settled down and due to this filtration is not required which reduces the operation and cost and the liquid can be easily decanted and the catalyst can be used again. In the same manner, the catalyst was recycled three times and the photocatalytic activity the catalyst was found almost same for all the three experiments. The results are plotted in graph-5.

From the trend seen in the results of degradation of formaldehyde carried out using recycled catalyst, it can be seen that the activity of the catalyst remains almost the same and it still can be recycled few more times.



Graph 5: Use of a recycled catalyst for photocatalytic degradation of Formaldehyde in the aqueous phase

5. CONCLUSION

Zinc Oxide irradiated by UV light was used for photocatalytic degradation of formaldehyde in the aqueous phase. Required COD removal was obtained using stirred tank reactor along with reflector at 55^0C for 5 hours for an initial formaldehyde concentration of 500 mg/l. The catalyst was recycled using physical separation technique and reused. So finally it can be concluded from the series of experiment that Zinc Oxide powder can be effective for photocatalytic degradation of formaldehyde in the aqueous phase.

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