Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 2, Number 14; April-June, 2015 pp. 1246-1248

http://www.krishisanskriti.org/jbaer.html

Design of a Photoreactor for the Treatment of Wastewater

Ankit Kumar[1], Priyanka Padmanabhan[2], Sudipta Dasgupta[3], Vrati Mittal[4], Ravi Vadgama[5] and Leena V Bora[6]

[1,2,3,4,5,6]Affiliated to Institute of Technology, Nirma University, Ahmedabad

Abstract—*Photocatalysis is an upcoming area in the commercial usage of solar energy. Also, there is an impending issue of water shortage throughput the world. This project aims to combine both these issues and find answers to the raised questions. India, being a tropical country receives solar radiations in abundance. Moreover, there are a large number of industries that release wastewater in huge quantities. Treating these water to make them fit for further usage and not just for the compliance of pollution norms will address the problem of water shortage to a large extent. But, treating the water requires costly infrastructure and skilled man force. The objective of this project is to use the naturally available solar radiations for the treatment of wastewater to a certain degree wherein the treated water can be used for various other purposes. This project aims to design a photoreactor that complies with the requirements and proves to be better than a simple batch reactor, i.e., a beaker. The reactor we designed is working as we expected and the results are compared with a standard batch reactor (i.e. beaker). We found that the color reduction in the reactor is greater than that of a beaker. The better result in reactor may be because of two major reasons. Firstly the surface area for the reaction is increased in the reactor and secondly, the thin film of the fluid increases mass transfer rate of oxygen from atmosphere to the fluid. Mass transfer data are difficult to predict and requires rigorous calculations thus we have compared the reaction kinetics of both the reactor and the beaker. And also an expression for time has been derived for the desired conversion.*

Keywords: *Photocatalysis, Design, Photoreactor, Solar energy*

1. INTRODUCTION

India, being a tropical country has abundant solar energy throughout the year. Moreover, to satisfy the needs of a growing population, there are huge number of industries that are being set-up. India's potential and the supporting environment is improving really fast has an estimated 7 billion dollars capital equity involved in the sector. It is predicted that once the growth phase begins, solar projects will get larger with some approaching 100 MW.

2. REQUIRED CHARACTERISTICS OF THE REACTOR

The following are the features required in the photoreactor to be designed:-

- Maximum contact between light, catalyst, wastewater and air
- Maximum turbulence in the system
- Providing a residence time of about 10-15 minutes with/without recycling
- Increase in temperature is not the objective
- Effective regeneration and recycling of the process fluids should be attained

3. CATALYST LIMITATIONS

We needed to use a catalyst which can be activated by the visible spectrum of sunlight, so we were going to use Ag_2CO_3 catalyst. But by doing some experiments we found that the catalyst has a limitation that it sticks to the solid surfaces and it makes the use of a pump very difficult, so it was needed that the pump be eliminated from the system. But the reaction is slow and to provide enough time, recycling was necessary. To recycle the fluid, we must overcome the gravitational force acting on the fluid. To overcome this, we used the rotational speed of the plate itself for liquid to go up. This was achieved by using pipes which are inclined in the direction of rotation so that liquid can lift up through the tubes (See fig. 1).

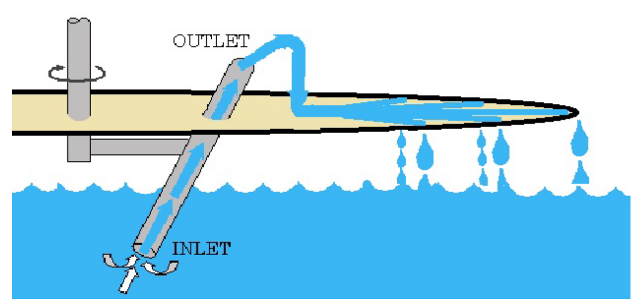

Fig. 1: Recirculation System

4. FABRICATED REACTOR

4.1 MOC

The reactor is made up of Acrylic. Acrylic has been chosen as the material of construction because it is cheaper than glass (although glass would give better transparency and thus better results) and easy to handle (cutting and molding).

4.2 Dimensions

Reactor has been fabricated for approximately 1 liter volume. Volume was decided as per the amount of catalyst available. The dimensions of reactor for the desired volume are calculated so that we can get maximum output. Stepwise explanation of mechanical design is as follow:

- Minimum height we needed in the reactor was around 1 inch, so for given volume (1lit) we calculated the reactor diameter.Reactor Dia. (D) = $(V/\Pi)^{1/2}$ and selected the standard diameter available (24cm).
- Plate diameter (Dp) was calculated by reducing a clearance from the reactor diameter. Dp=24-2*2 Dp=20cm
- For better stirring the impeller diameter (in our case impeller is replaced with the pipes , thus pipe circle diameter is taken as the impeller diameter) must be in the range of 1/4 to 1/3 of the vessel diameter i.e. D. Thus, pipe circle diameter (Dc) = 1/4 * D = 6cm
- Height of vanes above the plate and the baffle height was selected as per the previous experience and thus height of the reactor wall was also decided such that water do not get thrown away during the operation.

Fig. 2: (a) Reactor, (b) Baffles configuration, (c) Vanes configuration above the plate, (d) Pipe circle diameter, (e) Pipes for water recirculation

5. EXPERIMENT

Experiment was carried out to compare the performance of the designed reactor with an ordinary batch reactor (i.e. beaker). 1 liter Dyed water (Reactive Red 2) with 20ppm concentration was taken in both reactor and the beaker and color reduction was studied as a function of time. An equal amount (0.11gm) of Ag_2CO_3 catalyst was added to both and kept in dark for 30 minutes to eliminate the absorbance effects. Now, the reactor and beaker were kept in sunlight at the same time and samples were collected at different time intervals. Maximum numbers of parameters in both the reactors are kept constant like temperature, volume, catalyst amount, dye concentration, sunlight intensity and rpm.

Fig. 3: Experimental setup

5.1 Observations

Samples at different time intervals was taken and UV spectroscopy was done on these samples. Then the absorbance calculated by UV spectrometer has been converted into concentration using the calibration curve.

Table 1: Absorbance and concentration readings of samples at different time intervals

Time	Initial	After 30 minutes in dark	15 minutes in sunlight	90 minutes in sunlight	120 minutes in sunlight
Absorbance of beaker samples	0.85	0.661	0.648	0.407	0.395
Concentration in Beaker (ppm)	19.7	15.372	15.07	9.4651	9.186
Absorbance of Reactor samples	0.85	0.661	0.569	0.282	0.254
Concentration in Reactor (ppm)	19.7	15.372	13.233	6.5581	5.907

6. RESULTS AND DISCUSSION

The concentration vs. time profile for both, reactor and beaker have been developed.

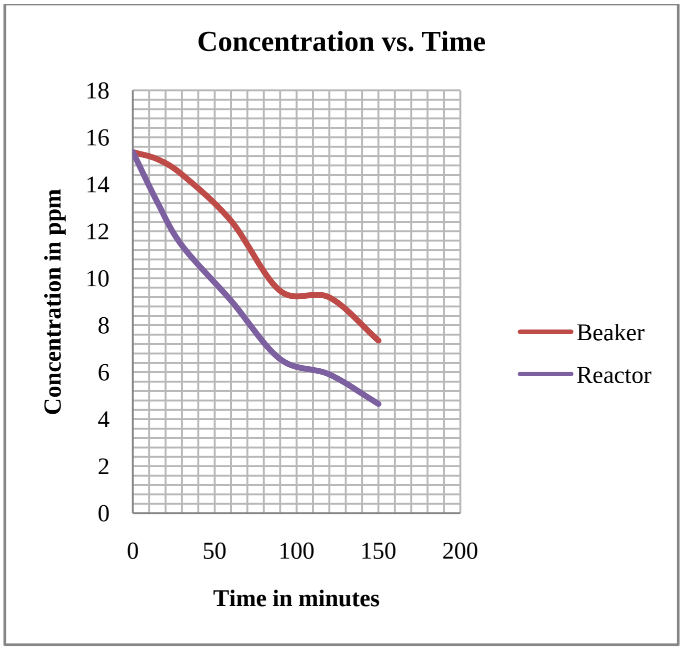

Fig. 5: Concentration vs. Time graph for both beaker and reactor

By drawing the profile we found that the color reduction in reactor is always greater than that in beaker. To find out the order or the reaction we used the integral method of analysis.

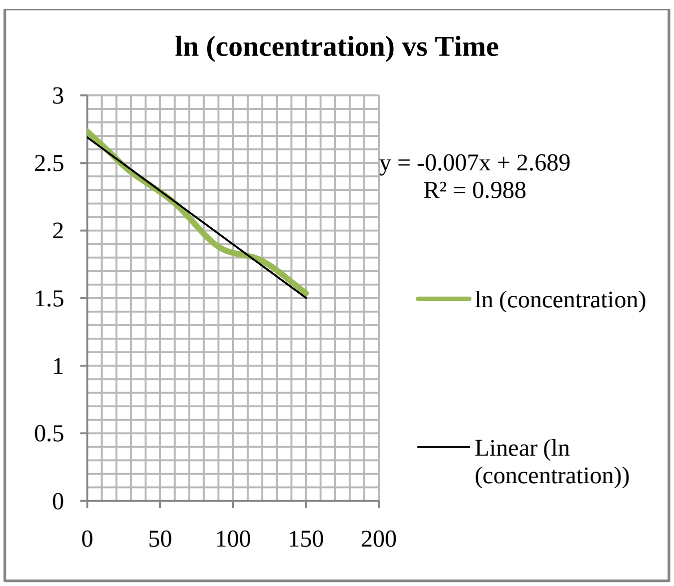

Fig. 6: ln(Concentration) vs. Time graph, first order reaction check

We found that the ln(concentration) vs. time is a better linear fit, thus the reaction is first order reaction with rate equation

$$Rate = k * C_A$$

To find out k we need the characteristic equation of a batch reactor. Integral form of a characteristic equation for first order reaction is

$$C_A = C_{A_0} e^{-kt}$$

By taking the data points at t=0 and t=120, we can calculate the value of k for both beaker and reactor. The value of k for beaker is equal to $0.00429 s^{-1}$ and for reactor it is equal to $0.00797 s^{-1}$. Now we can get the characteristic equation for the reactor and we can find out the time required for the desired conversion in the reactor.

$$t = -\frac{\ln(C/C_0)}{k}$$

7. CONCLUSION

The reactor we designed is working as we expected and the results are compared with a standard batch reactor (i.e. beaker). We found that the color reduction in the reactor is greater than that of a beaker. The better result in reactor may be because of two major reasons.Firstly the surface area for the reaction is increased in the reactor and secondly, the thin film of the fluid increases mass transfer rate of oxygen from atmosphere to the fluid. Mass transfer data are difficult to predict and requires rigorous calculations thus we have compared the reaction kinetics of both the reactor and the beaker. And also an expression for time has been derived for the desired conversion.

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[1] http://www.renewablegreenenergypower.com/solar-energy-pros-and-cons/, 12.08.2014, 22:03