

Photocatalytic performance analysis of Degussa P25 under various laboratory conditions

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Abstract: Photoactive semiconductor nanomaterials are the most emerging area of research for both solar photovoltaic and photocatalytic applications. Among the different photoactive materials Degussa P25 is one of the best and commercialized semiconductor material for photocatalytic applications. Degussa P25 is a mixed phase (Anatase and Rutile) heterojunction photocatalyst with superior photocatalytic performance under UV irradiation. Material engineering along with optimization of catalyst loading, radiation intensity and reaction temperature plays a vital role for improving the photocatalytic performance of any semiconductor photoactive material. In the current study the effect of catalyst loading, radiation intensity and temperature on photocatalytic performance of Degussa P25 under UV irradiation has been systematically investigated. The results reveal that high catalyst loading can reduce the photocatalytic performance of Degussa P25 rather than increasing. The increase in the radiation intensity can improve the photocatalytic performance of Degussa P25. Additionally, the increase in the reaction temperature showed an improved photocatalytic performance under UV irradiation. However more detailed analysis is needed for better understanding. This study reveals the necessity of optimization of the catalyst loading, reaction temperature and radiation intensity for efficient photocatalytic performance of Degussa P25.

1. Introduction

Green energy production and environmental remediation are the two vibrant areas of research for the current paradigm. Among various renewable energy technologies solar energy has attained much attention for sustainable energy production and green environmental remediation due to its favorable impacts. Solar energy can be utilized in different ways such as solar thermal, solar photovoltaics and solar photocatalysis [1-3]. Among them solar photocatalysis is the most emerging technology for both energy production and environmental remediation in a self-sustainable manner. Photocatalysis process needs further improvement for commercialization of this technology in a wide spectrum.

The performance of the solar photocatalyst is the vital component of the photocatalysis process and which can be improved by engineering the semiconductor photoactive material by increasing the absorbance of material to visible spectra, reducing the charge carrier recombination and increasing the effective surface area. Among different photocatalysts Degussa P25 is the most widely accepted commercial Titania photocatalyst for various applications under UV irradiation. Degussa P25 is mixed phase photocatalyst with 80 % anatase phase and 20% rutile phase. It has a band gap of 3.2 and 3.0 eV for both anatase and rutile phase respectively with an effective surface area of 50 m²/gm [4-6].

Many researchers have attempted to improve the photocatalytic performance of Degussa P25 further by doping, sensitization and preparing its composites [7-9]. H. Znad et al. reported the study of photocatalytic activity of modified Degussa P25 doped with sulfur showed commendable visible



photocatalytic performance [7]. Neil Bowering et al. reported the photocatalytic activity of silver modified Degussa P25 materials for the decomposition and reduction of nitric oxide [8]. Hao Zhang et al. reported the P25-graphene composite photocatalyst possessed great absorptivity of dyes with extended light absorption range, and efficient charge separation properties simultaneously [9].

Along with material engineering the optimization of catalyst loading, radiation intensity and reaction temperature etc. plays a crucial role to optimize the photocatalytic performance of photocatalyst. M.A. Behnajady et al. reported the effects of experimental parameters such as, catalyst loading, initial dye concentration, light intensity, and pH on the extent of photodegradation of dye [10]. Kavita Kabra et al. reported the effects of various laboratory parameters such as p^H , light intensity, dissolved oxygen, etc. on photocatalytic performance of photocatalyst [11].

Preparation of efficient photocatalyst process is sophisticated and energy consuming and excess catalyst loading may lead to decrease in photon absorption [12]. Considering the above optimization of catalyst loading is vital in photocatalysis. Photocatalysis process is photon driven process thus the wavelength and intensity of the radiation may play a significant role in photocatalytic performance. Moreover, in solar photocatalysis process the reaction temperature is a function of type of reactor type and radiation. Based on the above, current work investigate the effect of catalyst loading, radiation intensity and reaction temperature on the photocatalytic performance of Degussa P25 in detail.

2. Experimental

2.1 Materials

Degussa P25 and Methylene Blue (MB) were obtained from Sigma Aldrich and Merck (India). The solutions were prepared by dissolving appropriate amount of MB in Millipore water before each experiment.

2.2 Photocatalytic Test

The photocatalytic performance of Degussa P25 were performed in an indigenous batch mode photocatalytic reactor using methylene blue (MB) as probe pollutant. The radiation source was a UV lamp obtained from Philips with a power of 15W and wavelength of 254 nm. The photocatalytic experiments were performed under different conditions such as different catalyst loading, radiation intensity and reaction temperature. The experiments were carried out by simultaneous exposure of the blank solution along with Degussa P-25 having 60 ml of MB of 0.015mM concentration. The solutions were kept in dark for 1 hr before exposing them to the UV irradiation to ensure adsorption-desorption equilibrium. To study the role of catalyst loading of Degussa P25 on photocatalytic performance, the experiments were performed at different catalyst loading such as 0.25, 0.50, 0.75 and 1.00 gm/l. During this experiment the reaction temperature was maintained at 30°C along with the radiation intensity of 7.4 W/m². The role of radiation intensity on photocatalytic performance of Degussa P25 were investigated under different radiation intensities such as 1.5, 3.4 and 7.4 W/m² at a reaction temperature of 30°C along with the catalyst loading of 0.50 gm/l. The intensity of the UV light source was adjusted by changing the position of the source. The light intensity was measured by a radiometer (International Light Technologies ILT 2400 with a UV detector 005). Moreover, the effect of reaction temperature on photocatalytic performance of Degussa P25 was investigated at different temperature such as 30, 45, 60 and 75°C at a catalyst loading of 0.50 gm/l and radiation intensity of 3.4 W/m². Throughout the experiments the volume and concentration of MB was kept same as outlined above. The sampling was done in every 10 min of exposure throughout experiments. The spectral responses of the centrifuged sample solution were checked at the wavelength of the 667nm in UV-Visible spectrophotometer (Agilent Technologies, India).

3. Result and Discussion

3.1 Catalyst Loading

Preparation of efficient semiconductor photocatalyst requires sophisticated experimental set up which is costly and energy consuming. Considering the above optimization of catalyst loading is a vital component in economic and efficient photocatalysis process. The photocatalytic performance of Degussa P25 were performed at different catalyst loading such as 0.25, 0.50, 0.75 and 1.00 gm/l under constant reaction temperature and radiation intensity for 60 min. The variation of MB concentration with time is shown in Figure 1a. For determining the photocatalytic performance of Degussa P25, degradation kinetics and photonic efficiency has been employed. The rate constant of Degussa P25 for the degradation of MB has been calculated by plotting $\ln(C/C_0) = -kt$, as shown in Figure 1b where C_0 is the initial concentration, C is the final concentration and k is kinetic rate constant assuming the degradation of MB follows pseudo-1st-order kinetics [13]. Degussa P25 showed superior photocatalytic performance at all catalyst loading and the rate constant was maximum for the catalyst loading of 0.75 gm/l. Further increase in the catalyst loading reduced the performance of Degussa P25 instead of increasing the performance. On careful examination of the rate constants reveals that the optimum catalyst loading for the photocatalysis employed using Degussa P25 is 0.50 gm/l and not much significant improvement in the photocatalytic performance is observed for higher catalyst loading. For the comparative analysis of the performance of the heterogeneous photocatalysts on the radiation intensity and the irradiation spectrum, photonic efficiency plays a significant role and were calculated [13]. The rate constants and the photonic efficiency values of Degussa P25 are given in Table 1 and are comparable with the earlier report [14]. However, it may be noted that the photonic efficiency is also dependent on the type and design of the reactor as well. So only the relative values are significant. Thus, the optimized catalyst loading for MB degradation is 0.5 gm/L. Many authors have reported that, above certain concentration of loading, increase in turbidity of the solution reduces the light transmission through the solution. Thus no further reacting molecules are available for adsorption; hence additional catalysts are not useful for the catalytic activity [15].

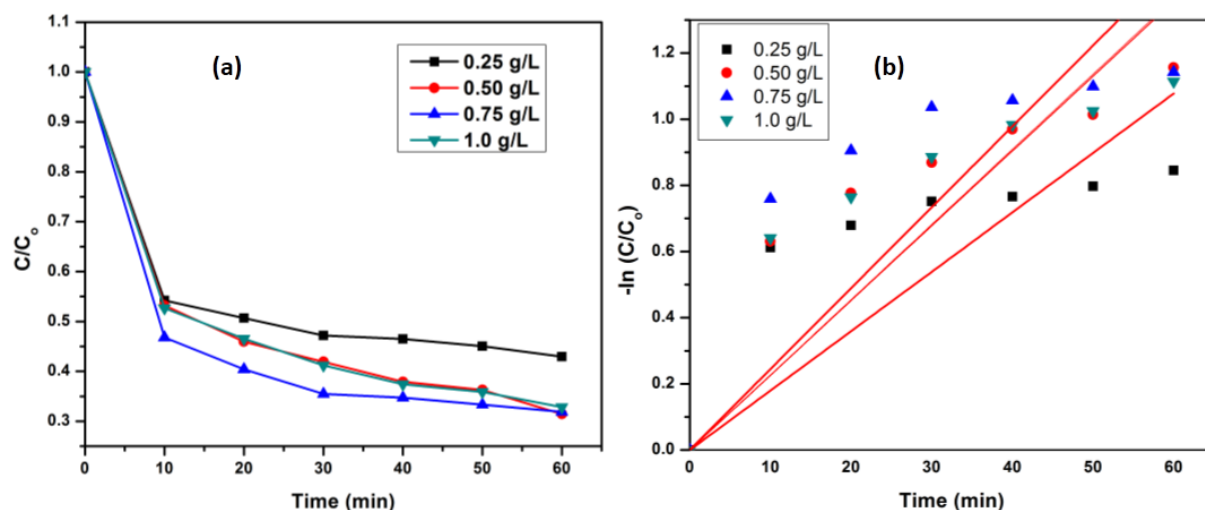


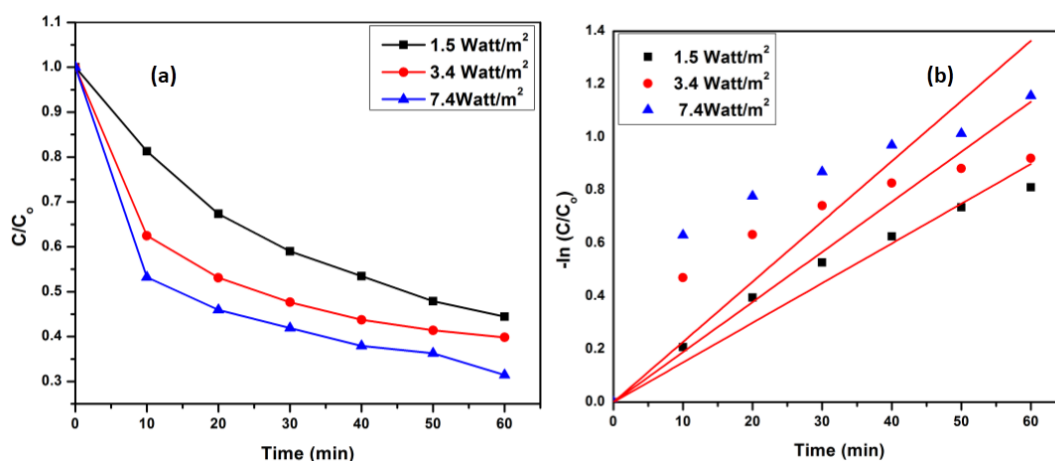
Figure 1: Degradation spectra of MB at different catalyst loading (a) and rate constant calculation spectra (b) of Degussa P25.

Table 1: Degradation rate constants and photonic efficiency of Degussa P25 under UV irradiation.

Role	Specifications	Rate constant (min ⁻¹)	Photonic Efficiency (%)
Radiation Intensity	1.5 W/m ²	0.014	0.44
	3.4 W/m ²	0.019	0.91
	7.4 W/m ²	0.023	2.28
Catalyst Loading	0.25 g/l	0.018	0.44
	0.5 g/l	0.023	0.46
	0.75 g/l	0.025	0.52
	1.00 g/l	0.022	0.47
Reaction Temperature	30°C	0.019	0.91
	45°C	0.022	1.05
	60°C	0.038	1.15
	75°C	0.066	1.26

3.2 Radiation Intensity

The wavelength and intensity of the source are the two major factors influencing the photocatalytic performance of Degussa P25. Considering the above an attempt was made to study the influence of the radiation intensity for the degradation of MB at constant reaction temperature and catalyst loading. The intensities used during the experiments were 1.5, 3.4 and 7.4 W/m². The photocatalytic performance of Degussa P25 under different intensities of the radiation were calculated in terms of rate constant and photonic efficiency. The degradation of MB with respect to radiation intensity is shown in Figure 2a and the degradation kinetics is shown in Figure 2b. Rate constant and photonic efficiency were calculated and the values are depicted in Table 1 and which is in accordance with the earlier report [14]. A direct proportionality is found between the incident radiation intensity and the degradation, rate constant and photonic efficiency of the sample. In this test, it is evident that the rate of degradation increases with increase radiation intensity and which is accordance with the earlier report [12]. It is observed that the rate constant along with photonic efficiency has been increased monotonically with increase in radiation intensity. This increase in the rate constant and photonic efficiency at higher radiation intensity can be attributed to the increased photon absorption resulting in the generation of more hydroxyl radicals which leads to the enhanced oxidation of MB.

**Figure 2:** Degradation spectra of MB at different radiation intensity (a) and rate constant calculation spectra (b) of Degussa P25.

3.3 Reaction Temperature

Photocatalysis process can be performed using different type of reactors and radiation. Thus, reaction temperature has a direct impact on photocatalytic performance of Degussa P25. Considering the this the effect of reaction temperature on photocatalytic degradation of MB has been studied at different reaction temperature at constant radiation intensity and catalyst loading. The experiments were performed at four different reaction temperatures (30, 45, 60 and 75°C) and the degradation of MB is shown in Figure 3a and the degradation kinetics is shown in Figure 3b. The rate constant and photonic efficiency were calculated and given in Table 2 and which are in accordance with earlier report [14]. The photonic efficiency and rate constant showed an increase with respect to increase in reaction temperature and which may be attributed to the reaction to occur at faster rate at higher reaction temperature resulting in faster degradation of MB [16]. However more detailed analysis has to be carried out to optimize the reaction temperature.

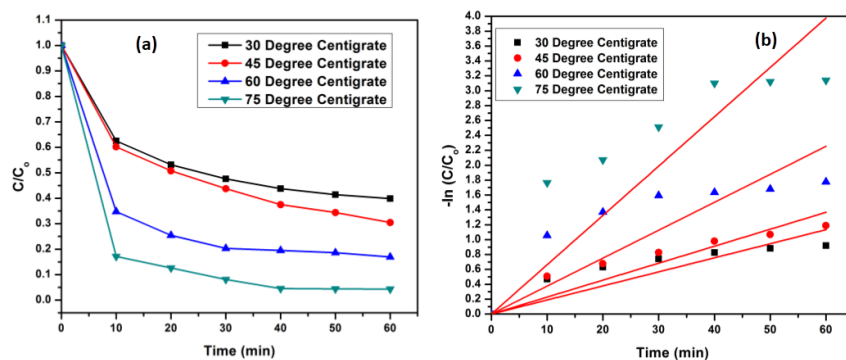


Figure 3: Degradation spectra of MB at different reaction temperature (a) and rate constant calculation spectra (b) of Degussa P25

The overall photocatalytic performance of Degussa P25 for the degradation of MB in terms of rate constant under different catalyst loading, radiation intensity and reaction temperature is given in Figure 4. The results confirm that catalyst loading optimization is vital as both excess as well as shortfall catalyst loading reduces the overall performance of the catalyst. Further the increase in radiation intensity and reaction temperature results in improved photocatalytic performance of Degussa P25. However more detailed analysis is required to optimize the same.

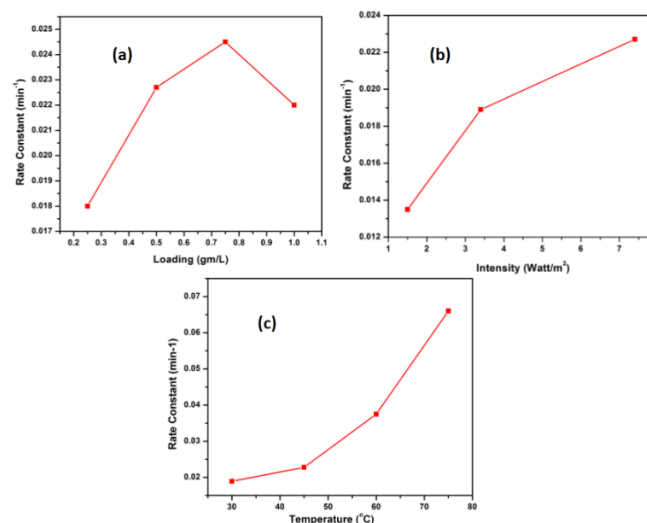


Figure 4: Variation of rate constant with catalyst loading (a) radiation intensity (b) and reaction temperature (c) of Degussa P25.

4. Conclusion

The overall photocatalytic performance of Degussa P25 has been successfully improved by optimizing the catalyst loading, radiation intensity and reaction temperature. It can be concluded that optimization of catalyst loading is crucial as both excess and shortfall catalyst loading can decrease the photocatalytic performance of Degussa P25 substantially. Moreover, the increase in radiation intensity and reaction temperature can improve the photocatalytic performance of Degussa P25 in larger extent. However more detailed analysis is required for the optimization of both radiation intensity and reaction temperature. These studies open up a new era of research on photocatalysis for the performance engineering of the photocatalysis process along with other factors.

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