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CPC Photocatalytic Reactor in Presence of Immobilized TiO_2 and Photocatalytic Activity

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Abstract

In this present work, compound parabolic collector (CPC) combined with tubular reactors was designed to accept both directly incident and reflected light. The light collecting of CPC reflecter was analysed via light reflection modeling. Titanium isopropoxide was used as a precursor to prepare immobilized titanium dioxide on the borosilicate beads which was used as supporter. The coated beads were prepared via dip coating technique. The photocatalytic activity of immobilized TiO_2 was performed to decolorize the Rhodamine B dye solution under solar irradiation. UV-Vis spectrophotometer was used to characterize the degradation of rhodamine B dye solution and to analyse the photocatalytic performance. The analysis of reflecting on CPC reflector indicates that all incidents are reflected to reactor tube according to the defined concentration ratio as equal one. The photodegradation of rhodamine B dye solution under solar irradiation is clearly observed by over 90% in presence of immobilized TiO_2 on glass beads.

Keywords: titanium dioxide, compound parabolic collector, dip coating, photacatalytic activity, photoreactor

1. Introduction

In waste water treatment there are sever a methods such as Fenton-based processes [1], UV-based processes [2] and Photo catalytic processes [3]. The alternative way for wastewater treatment is photo catalytic processes was known as one of the most effective methods for waste water treatment based on advance oxidation processes (AOPs) to generate the high lyre active radicals [4]. There are two types of solar reactor that generally used for photo catalytic degradation including concentrating and non-concentrating solar reactors [2]. In case of non-concentrating solar reactors are more effective in photo catalytic degradation in term of waste water treatment compared to concentrating solar reactor meanwhile in case of concentrating solar reactors more effective for energy generation due to high capability solar absorption for example parabolic trough collector, solar dish collector and array of heliostats field collector [5].

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Compound parabolic collector (CPC) is non-concentrating solar collector that ideally accept all incident rays which were passed through aperture with in acceptance angle, then collect to the receiver by reflector [6]. The design of CPC to be maximally collect incident rays can be designed in different ways depend on absorber or receiver shape such as flat absorber, fin absorber, invert-vee absorber and tubular absorber.

Titanium dioxide (TiO_2) is an interesting semiconductor material which use as photocatalyst in photocatalytic processes for wastewater treatment. There are three structure of TiO_2 such as anatase, rutile and brookite, each of them has its own photocatalytic properties due to differential in electronic properties. Anatase structure of TiO_2 was well known for high effective for photocatalytic properties meanwhile the mixed phase between anatase and rutile structure in proper fraction can be enhance the photocatalytic performance [4]. The use of photocatalyst in solar reactors can be used as suspension or immobilized onto supporters. The need of separation or filtration step is required in case of suspension cause to time consuming and complicate system. While, the immobilization of photocatalyst on solid inert material as a supporter such as transparent glass and porous supporter will overcome these drawback [7, 8]. There are various methods were used to prepare the TiO_2 immobilized onto the substrate or supporter. For instance, thermal evaporation [9], chemical vapour deposition [10], sputtering [11], pulsed laser deposition [12], spin-coating [13] and dip-coating [14]. Among them dipcoating technique is uncomplicated technique, adjustable, low energy consumption, non-thermal process and large production [14, 15].

This paper has been focused on the design of CPC to maxim ally collect the solar radiations for wastewater treatment and photocatalytic of TiO_2 as a photocatalyst which was immobilized on the glass beads. The preparation of immobilized TiO_2 were employed via sol-gel dipcoating technique. The photocatalytic activity of coated glass beads were investigated to decolorization of Rhodamine B dye solution under solar light irradiation

2. Experimental

2.1 Geometry of compound parabolic collector

The compound parabolic collector (CPC) is one of non-concentrating solar reactor type which acceptable all incident rays without the need of solar tracking system. CPC is able to collect both direct and diffuse radiation to be transmitted to the cylindrical or tubular absorber by CPC reflector plate at the back of receiver. Therefore, the CPC was designed based on two mainly parameters, the radius of absorber tube R and the acceptance angle of incident rays$2\theta_a$ which related to the width of aperture of the CPC as shown in Figure 1. The concentration ratio is defined as the ratio of the area of aperture ($\boldsymbol{a}$) to the area of the absorber or receiver ($\boldsymbol{a}'$) [16, 17] as shown in Eq. (1).

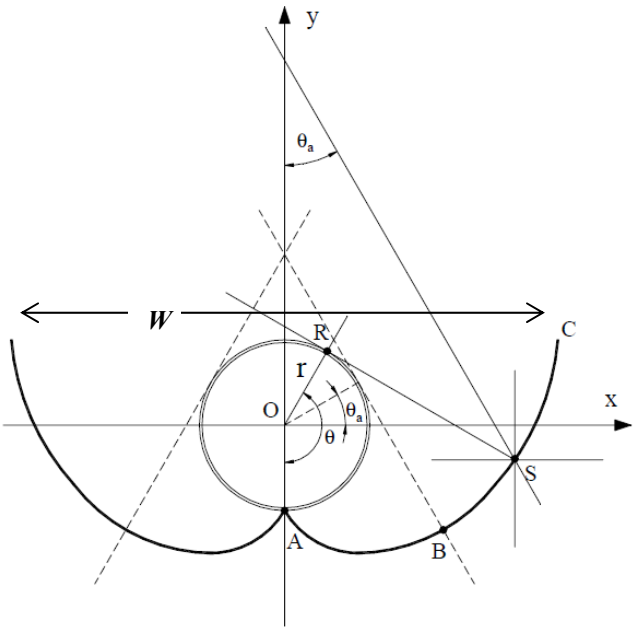

Figure 1. Cross section sketch of the CPC collector

$$\boldsymbol{CR} = \frac{\boldsymbol{a}}{\boldsymbol{a'}} = \frac{\boldsymbol{n'}}{\boldsymbol{n}\,\boldsymbol{sin}(\boldsymbol{\theta})} = \frac{\boldsymbol{W}}{\boldsymbol{2\pi r}} = \frac{\boldsymbol{1}}{\boldsymbol{sin}(\boldsymbol{\theta_a})} \tag{1}$$

Where W is the width of aperture, r is radius of tubular absorber and $\theta_a$is the acceptance half angle. The involute of CPC parabolic curve can be calculated follow Eq. (2).

$$\boldsymbol{I}(\boldsymbol{\theta}) \begin{cases} \boldsymbol{r\theta} \text{ for} |\boldsymbol{\theta}| \leq \boldsymbol{\theta_a} + \frac{\boldsymbol{\pi}}{\boldsymbol{2}} \\ \boldsymbol{r}\left(\frac{\boldsymbol{\theta}+\boldsymbol{\theta_a}+\frac{\boldsymbol{\pi}}{\boldsymbol{2}}-\boldsymbol{\cos}(\boldsymbol{\theta}-\boldsymbol{\theta_a})}{\boldsymbol{1}+\boldsymbol{\sin}(\boldsymbol{\theta}-\boldsymbol{\theta_a})}\right) \text{ for} \boldsymbol{\theta_a} + \frac{\boldsymbol{\pi}}{\boldsymbol{2}} \leq \boldsymbol{\theta} \leq \frac{\boldsymbol{3\pi}}{\boldsymbol{2}} - \boldsymbol{\theta_a} \end{cases} \tag{2}$$

Where $I(\theta)$ is the distance from tangent point at tubular absorber to reflector or the magnitude of segment RS, then the CPC curve will be coincident with segment $I(\theta)$ at point S [6, 18].

2.2 Design of compound parabolic collector

The design of CPC reactor in this paper was use dacrylic tubular absorber with dimensions about 50 mm as a receiver, the aluminum was used as the CPC reflectors.

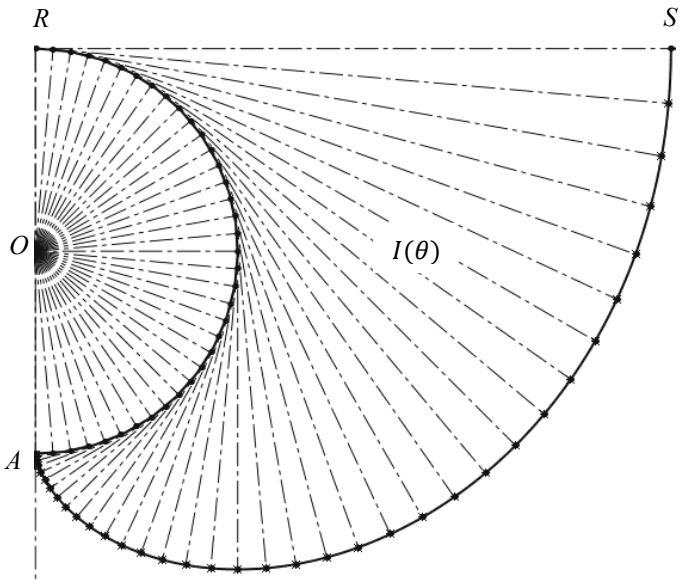

Figure 2. Cross section sketch of the CPC involute coincided with $I(\theta)$ from 0 to 180°

The CPC involute was calculated follow Eq. (2). The curve of CPC was coincided along point S of segment $I(\theta)$ at different angle in range of $\theta = 0$ to $\theta = 180^{o}$ as shown in Figure 2. The segment $\overline{RS}$ is about 78.54 at $\theta = 180^{o}$ then aperture width is about 157 mm, and the concentration ratio is approximately almost 1. The CPC curve with concentration ratio is about 1 was shown in Figure 3. The symmetry of involute parabolic curve in case of acceptance half angle (θ_a) is 90^{o}.

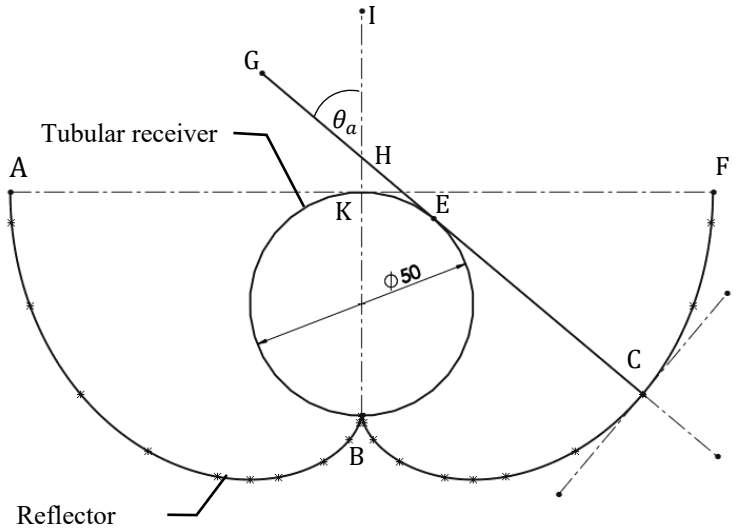

Figure 3. The sketch of symmetry parabolic curve with concentration ratio is almost 1.

2.3 Preparation of Immobilized TiO_2

Titanium isopropoxide was used as precursor to prepare TiO_2 sol by using 5 ml, 15 ml of isoproplye alcohol and 250 ml of deionized water were mixed and stirred for 24 h till gain the transparent solution. Then the cleaned borosilicate glass beads with diameter 0.6 mm were immersed in the solution for 2 min. And the coated borosilicate glass beads were dried in atmosphere at 100°C in oven for 5 min, this step was repeat for 5 times. Finally, the coated borosilicate glass beads were calcined at 400°C for 1 h in the furnace to form the anatase phase.

3. Results and Discussion

3.1 Analytical of CPC reflector

The CPC curve can be plotted in term of point position from x and y axis in rectangular axis system which was described via x and y as follow Eq. (3). The plotting of CPC curve based on x and y axis was shown in Figure 4.

$$x = r\sin(\theta) - I_{(\theta)}\cos(\theta)$$
$$y = -r\cos(\theta) - I_{(\theta)}\sin(\theta) \quad (3)$$

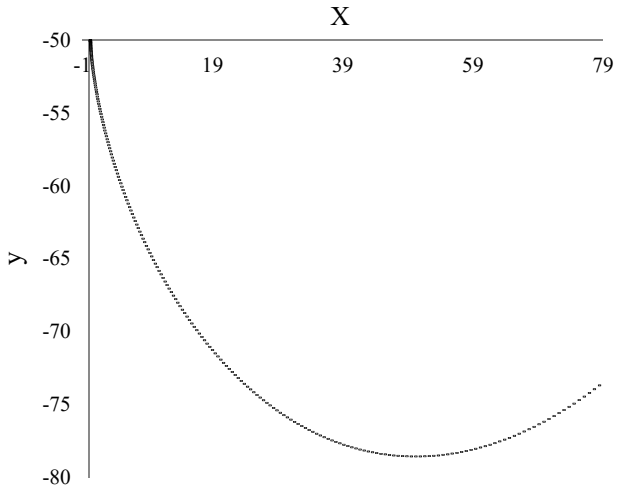

Figure 4. Plotting of half CPC curve.

The modeling of reflection of the incident ray sat different angle of incident on the surface of CPC reflector as shown in Figure5. This schematic show that the angle of incident rays within acceptance angle ($2\theta_{a_{max}}$) can be collected by reflector then reflect to the receiver. Consider incident rays from direction C would be reflected at the surface of CPC curve to tubular absorber at point B, and in the same case for incident ray from direction E, H and K. Thus in this case all of accepted incoming rays which were reflected along involutes NQ would be collected to the receiver as describe by law of reflection.

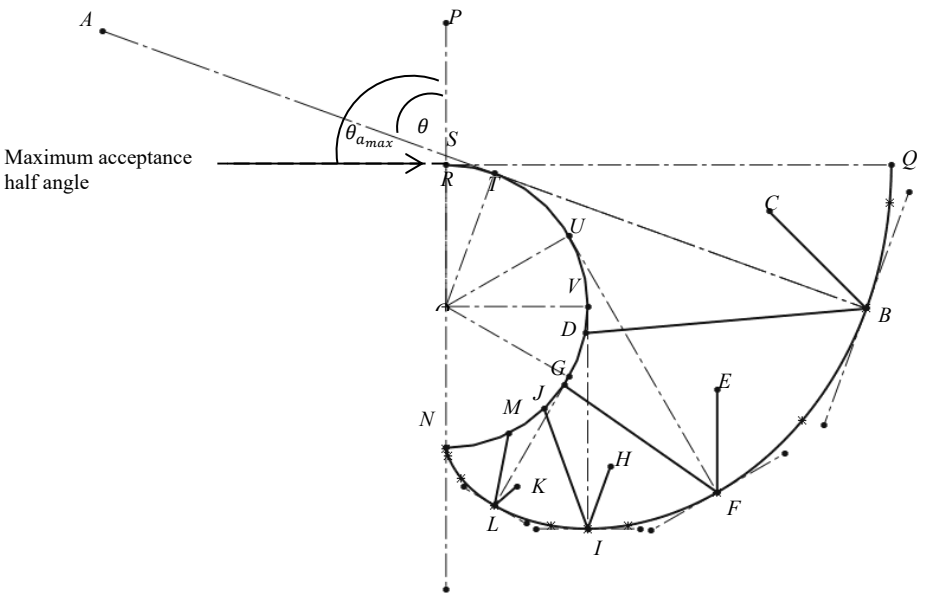

Figure 5. Cross section sketch of incident reflection on CPC surface with acceptance angle is 90°.

3.2 Photocatalyticactivity of immobilized TiO_2

Photocatalytic activity of immobilized TiO_2 was evaluated to decolorize the rhodamine B dye solution as model pollutant. The immobilized TiO_2 on borosilicate glass beads were carefully packed into 480 mm of reactor tube with diameter 50 mm for three tubes, composed with aluminium sheets as CPC reflectors. The experiment were performed under solar irradiation for 3 h. The solution was withdrawn every 30 min to be monitored by UV-Visible spectrophotometer. Photodegradation of rhodamine B was evaluated follow the equation (4). The photodegradation of rhodamine B in presence of immobilized TiO_2 which were supported on borosilicate glass beadsunder sunlight is shown in Figure 6. The result illustrated slightly in the decolorization of rhodamine B under sun light irradiation in case of no beads due to its photoreaction. In case of uncoated beads indicated that the degradation of rhodamine B is slower compare to the case of no beads since the light obstruction of glass beads for photoreaction. And the degradation show excellent in case of the presence of immobilized TiO_2 on glass beads due to photocatalytic properties of TiO_2, which were excited by photon energy from solar irradiation resulting to generate the separation of electron (e^-) and hole (h^+) on the surface to be form the highly reactive radicals which were decomposed the organic pollutant.

$$\boldsymbol{Degradation} = \frac{\boldsymbol{C_o - C_t}}{\boldsymbol{C_o}} \quad (4)$$

Where $\boldsymbol{C_0}$ is initial concentration of dye solution and $\boldsymbol{C_t}$is concentration of dye solution at time $\boldsymbol{t}$

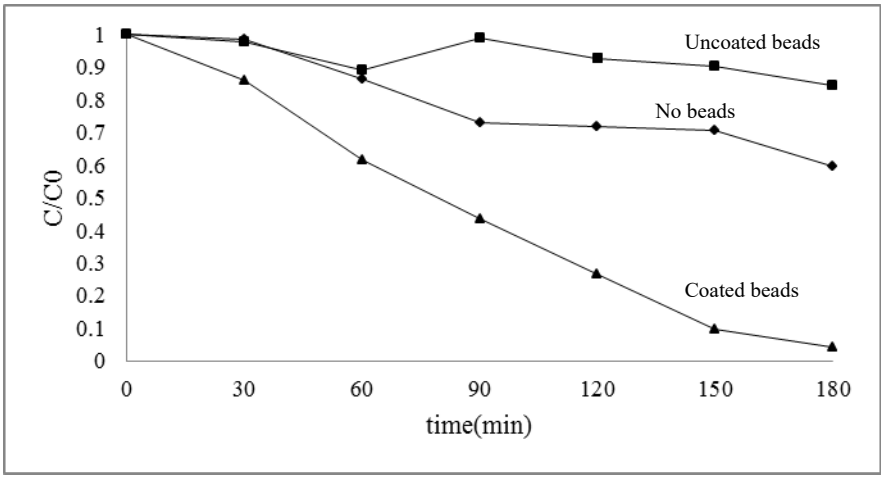

Figure 6. Photocatalyticactivity of immobilized TiO_2undersun light irradiation.

4. Conclusions

The solar reactor for wastewater treatment was composed by compound parabolic collectors (CPC) which were designed with acceptance angle is 90º and the concentration ratio is about 1. Resulting to all accepted incident rays at angle of incident in range of 0°-180° would be collected then reflect to tubular receiver. The photodegradation of rhodamine B in presence of uncoated beads show slower compare to no beads due to light obscure in dye solution meanwhile the photodegradation show higher in case of coated glass beads since the photocatalytic behavior of TiO_2.

5. Acknowledgement

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