THE COMPARISON OF SOLAR PHOTOCATALYTIC CASCADE REACTOR WITH ROTATING DRUM REACTOR ON SIMULTANEOUS REDUCTION Cr(VI) AND DEGRADATION PHENOL

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ABSTRACT

The simultaneous reduction of heavy metal Cr(VI) and degradation of organic compound was conducted in two solar photocatalytic reactors, cascade reactor and rotating drum reactor. Both of reactors were pilot scale which solar light as photon source. In this experiment used catalyst TiO₂ from P25 Degussa that was immobilized by spin coating method at stainless steel plate surface. This experiment has compared the performance of reactors into treat the mixed of Cr (VI) and phenol with initial concentration 10 ppm and 20 ppm within 10 liters solution. The experiment results showed the performance of rotating drum reactor was better than cascade reactor. The conversion of both Cr(VI) and phenol for Rotating Drum reactor at initial concentration 10 ppm, were obtained 99.89% and 100%, and then for cascade reactor was obtained 86.27% and 82.65%.

Keywords: Solar light, Cr(VI), phenol, photocatalytic, TiO₂, Cascade Reactor, Rotating Drum reactor

I. INTRODUCTION

The presence of heavy metal like Cr(VI) and organic waste like phenol in aquatic bodies have been known to cause environmental problems. The major source of Cr(VI) and phenol is the improper discharge of various industrial wastewater [1]. Among them the potential source of Cr(VI) include lather tanning, paints, dyes, photographic materials, steel alloy cement industries and mining [2]. The potential sources of phenol are polymers, plastics, pulps, papers and organic pesticides. Some chemical industries produce both Cr(VI) and phenol together in acid condition such as Ni/Cr electroplating and latter tanning industry.

Chromium is widely used in industry and has resulted in a tremendous contamination [3-5]. Cr(VI) and Cr(III) are the primary oxidation states found in the environment. The concentration of Cr(VI) has been regulated because Cr(VI) mutagenic and carcinogenic and can inflict many health problems [4]. On the other hand, Cr(III) is readily precipitated and sorbed on a variety of inorganic and organic substrates at neutral or alkaline pH [6]. Cr(III) is 100 times lower in toxicity than Cr(VI) [2,5]. Therefore Cr(VI) is usually reduced to Cr(III) in order to minimize environmental pollution. Several methods have been used for treating the Cr(VI) such as chemical precipitation, reverse osmosis, foam flotation, electrolysis, ion exchange, adsorption, etc. However, most of these methods require either high energy and/or large quantities of chemicals [2].

Phenol is one of organic substrate that uses in many industries. Phenols in the environment are major aquatic pollutant because they are quite toxic. In certain concentration, phenols can cause physiologist attack to fishes and disturb microorganism activities in nitrification process. Phenols can also create bad effect for human being include heart and kidney attack, stress tension and death. The minimum range concentration of phenols required
in environment is 0.1-11 mg/l and in drinking water is not more than 0.002 mg/l. Several methods have been used for destructing phenols such as biologist method using microorganism, air stripping method, adsorption method using activated carbon. However, photocatalytic method is the best among of them due to it is economistic and only needs small amount of energy [7].

Simultaneous wastewater treatment has been developed nowadays by many researchers [6,8-10]. This system was identified can improves the conversion of each waste in the mixed system. Schrank reported that the presence of organic compound (including phenol and derivatives) might act as hole scavenger and promoted the photocatalytic reduction of Cr(VI) by electrons. This could be happened because the oxidation of phenol consumes photo-excited holes promptly and efficiently, attenuating electron-hole recombination and promoting photocatalytic Cr(VI) reduction on TiO$_2$ [3].

Matthews [11] reported the use of suspended TiO$_2$ in a solar illuminated tubular reactor to degrade a variety of organic materials. This type of reactor usually utilizes TiO$_2$ particles whose diameter is usually less than 1 µm. Thus the removal of suspended catalyst particles from the treated water would be costly and laborious. The need for a separation system to recover the catalysts leads to the conclusion that scaling up such design may be difficult. Hence, more attention has been recently paid to the development of supported TiO$_2$ reactors, where the catalyst is retained within the reactor itself [12-15]. Goslich [16], wyness [17] and Scalfani [18] investigated solar powered fixed bed reactors, in which organic containing solutions flow across single flat plates coated TiO$_2$ catalysts. The reactions taking place in these reactors may, however, be constrained by mass transfer limitations due to laminar flow conditions [16,17]. Toyoda [14] and Zhang[15] developed bench scale solar rotating drum reactor. This reactor can reduce mass transfer limitation. Chan [13] developed cascade reactor which 9 plates. It was demonstrated that the back flow and turbulence resulting from the novel cascade reactor design can reduce mass transfer limitations and the “water fall” effect can also enhance oxygen transfer to the solution. In this study, a pilot scale cascade reactor and a pilot scale rotating drum reactor were developed. The performance of these reactor were compared for reducing Cr(VI) and degrade phenol simultaneous

II. MATERIAL AND METHODS

Ten 316 stainless steel flat plates were arranged in a cascade configuration in the solar powered photocatalytic reactor. The plates were coated with TiO$_2$ catalysts (Degussa P25) using spin coating method previously described [19]. The area of each plate exposed to solar light was 15 cm x 30 cm. The total mass of catalysts that immobilized on these surfaces plates was 1.58 gram. A solution of a known concentration of phenol (Merck) was introduced by an overflow to the liquid reservoir and flowed down across the cascade as a thin film. A centrifugal pump was used to circulate the solution back to the liquid reservoir. Rotating drum reactor has five 316 stainless steel drums. The surfaces of drums were coated with TiO$_2$ catalyst (Degussa P25). The total area of drums exposed to solar light was 8796.46 cm$^2$ with total mass of catalyst was 2.19 gram. There is no circulating the solution at this reactor. The mixing of solution was generated by rotating drums.

Ten liters solution was contained Cr(VI) (Merck) and phenol (Merck) with initial concentrations were 10 ppm and 20 ppm. The pH solution was 2. The adjustments were made to the initial pH of the solution for all the experiments by added HCl 37% (Merck). The photoreactors performance were evaluated based on decreasing of Cr(VI) and phenol concentration. A Spectrophotometer (Labomed.Inc) was used to analyze the Cr(VI) concentration at wave lenght 398 nm and UV-VIS Spectrophotometer double beam for phenol concentration at 500 nm. A UV Light Meter Lutron (290-390nm) was used to measure the solar light intensity.

III. RESULT AND DISCUSSION

The chose of solar light as photon resource was caused by its advantages. The solar light was capable to accelerate the production rate of electron hole pairs due to it has higher UV intensity than the black light lamps. Beside that, the black lamps contributes to a large portion of the operating, capital and maintenance costs of photocatalytic reaction system because of the utility consumption and periodic replacement of the lamps [13].
These experiments were held in two days at 8:30am to 3:30pm that showed different solar light intensities. The initial concentration for first experiment was 10 ppm and the second was 20 ppm. Figure 1 shows the solar light intensity variation during two days. The average intensities for first day was 894 µW/cm² and the second was 547 µW/cm². Those data showed the weather conditions during 2 days, which were not too bright (894 µW/cm²) and cloudy (547 µW/cm²).

**Figure 2.** Reduction of Cr(VI) and degradation of phenol simultaneous at initial concentration 10 ppm with cascade reactor and rotating drum reactor.
Figure 2 and Figure 3 show that performance of rotating drum reactor was better than cascade reactor. For initial concentration 10 ppm, rotating drum reactor was obtained percent decrease of Cr(VI) and phenol were 99.89% and 100%, but Cascade reactor were 86.27% and 82.65%. It was not too bright weather with average intensities 894 \( \mu \text{W/cm}^2 \). Using rotating drum reactor after three hours, the final concentration Cr(VI) and phenol were 0.7 ppm and 0.40 ppm. This condition already reached to minimum concentration required for both Cr(VI) and fenol. But for cascade reactor after 6 hours had not reached yet minimum concentration required. The final concentration after six hours using cascade reactor was 1.51 ppm for Cr(VI) and 1.78 ppm for phenol.

Compared to cascade reactor, decreasing concentration from rotating drum reactor was higher due to configuration of this reactor was more advantage significantly, such as rotational drum speed was faster resulting optimum mixing then reducing mass transfer limitation. Beside of that solution above surface catalyst at rotating drum reactor was about 1mm while at RSB the layer solution as a thin layer film. This thin layer would cause penetrate UV at rotating drum reactor become more effective compared to cascade reactor then intensity of UV through to surface catalyst would be bigger. The UV light would promote catalyst until was generated electron and hole at surface catalis which will reduce Cr(VI) and degrade phenol. Beside UV penetration was better, oxygen diffuse at the rotating drum reactor would be easier then increasing generated hydroxyl radical.

From point of view moving phase, at rotating drum reactor as moving phase was catalyst with rotating speed 120 rpm, while at cascade reactor was waste itself with circulation speed 8.1 lts/mnt. If we compared both of them, the probability of contacting between solution, catalyst and UV light at rotating drum reactor was higher than cascade reactor.
At initial concentration 20 ppm performance of rotating drum reactor still better than cascade reactor as shown figure 4 and figure 5. In cloudy with average intensity 547µW/cm$^2$ decreasing Cr(VI) and phenol at Rotating drum reactor was 94.54% and 75.56 %. While for cascade reactor was 85.58% and 66.15%. The final concentration after six hours for both reactors had not reached yet minimum concentration required. For Rotating drum reactor, the final concentration Cr(VI) and phenol was 2.55 ppm and 5.94 ppm. For cascade reactor, the final concentration Cr(VI) and phenol was 1.18 ppm and 4.67 ppm. Out of this final concentration for both reactor possibility was caused by low intensity UV light accepted. On other hand, the intermediates were produced at this time and caused the brown effect to the catalyst. These might be caused by carbonic compounds like C=O, aromatic, C-H and C-O that deposited on the TiO2 as reported by Morawski et al[20]. But the facet showed the presence of metal like Cr, Ti and Fe were also assumed to affect the brown effect [21]. As the effects, the TiO$_2$ catalyst would be deactivated and the photon penetration would be disturbed.

**IV. CONCLUSION**

Rotating drum reactor had a good configuration and better performance to treat solution of Cr(VI) and phenol simultaneous compared to cascade reactor. In weather not too bright (average intensity was 894 µW/m$^2$), the reactor able to treat 10 liters Cr(VI) and phenol at initial concentration 10 ppm until below of final concentration required. The final concentration Cr(VI) and phenol after 3 hours was 0.47 ppm and 0.0 ppm. The conversion of both Cr(VI) and phenol for Rotating Drum reactor at initial concentration 10 ppm, were obtained 99.89% and 100%, and then for cascade reactor was obtained 86.27% and 82.65%.
ACKNOWLEDGMENT

The authors would like to thank the Ministry of Research and Technology of Indonesia through financial support under RUT XI with contract number 14/perj/Dep/III/RUT/PPKI/II/2005 and research theme: Simultaneous waste (heavy metal, organic and acid) treatment using photoreactor based Solar energy.

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