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Novel wedge structured rotating disk photocatalytic reactor for post-treatment of actual textile wastewater

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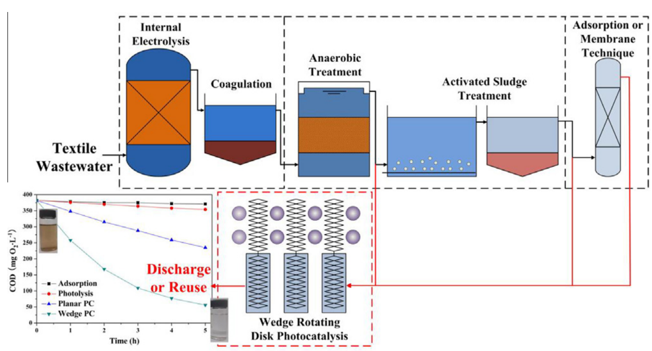
HIGHLIGHTS

- Actual textile wastewaters were post treated using a wedge rotating disk PC reactor.
- Wedge disk exhibited much higher COD removal efficiency than planar disk.
- Both the large surface area and multiple reflections played important role.
- The inhibition caused by inorganic anions could be weakened by wedge structure.
- PEC process could further improve COD removal without adding extra electrolyte.

GRAPHICAL ABSTRACT



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ABSTRACT

A wedge structured rotating disk photocatalytic (PC) reactor was used for post-treatment of actual textile wastewater collected after activated sludge treatment. Compared with a conventional planar disk, the wedge structured disk had larger surface area and exhibited better light utilization efficiency. Treatment conditions such as pH and rotating speed were optimized. The COD content in effluent was reduced from 380 $mgO_2\,L^{-1}$ to 109 and 56 $mgO_2\,L^{-1}$ respectively after 3 h and 5 h treatment at pH 6.0 and rotating speed of 20 rpm. The effect of anions (NO_3^-, SO_4^{2-} and Cl^-) in actual textile wastewater on treatment was investigated. Benefit from high light utilization efficiency, the wedge rotating disk reactor could compensate COD removal inhibition caused by anions. A 1.5 V voltage was also applied to perform photoelectrocatalysis process to further improve the performance, and no additional electrolyte was needed. COD in effluent was reduced to as low as 75 $mgO_2\,L^{-1}$ after 3 h treatment. In addition, this reactor was used to treat other water samples including the actual textile wastewaters collected before activated sludge treatment (initial COD of 880 $mgO_2\,L^{-1}$) and after activated carbon adsorption post-treatment (initial COD of 108 $mgO_2\,L^{-1}$). Experimental results suggested that wedge structured rotating disk photocatalysis process was stable, efficient and worth further scale-up investigation.

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1. Introduction

It is estimated that more than 15% of the world dye production, about 400-ton per day, is released into natural environment during

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synthesis, processing and use [1]. Textile industry, one of the largest industrial sectors in coastal areas of Southeastern China, generates large amount of wastewaters daily. Because such wastewater usually contains organic and inorganic compounds including dyes, pigments, oils, surfactants and sizing agents, it has to be treated before discharge. Fig. 1 shows a typical process for treatment of industrial textile wastewater, which includes initial physicochemical treatment such as iron-carbon internal electrolysis and coagulation, then followed by biological processes such as anaerobic and activated sludge treatment. Chemical oxygen demand (COD) can be reduced from more than 10,000 $mgO_2\,L^{-1}$ in raw water to less than 500 $mgO_2\,L^{-1}$ in effluent. Although post-treatment process like activated carbon adsorption or membrane technique would be employed to further reduce COD to less than 100 $mgO_2\,L^{-1}$ [2,3], the resulted effluent can hardly be reused because the residual COD leads to microorganisms and algae growth in water body. In addition, replacement of adsorbent or membrane is not convenient and disposal of waste adsorbent or concentrated water generated in membrane treatment is expensive. Development of new textile wastewater post-treatment method thus is highly demanded.

TiO_2 photocatalysis (PC) is a promising wastewater treatment technique using oxidizing power provided by hydroxyl radicals ($^{\cdot}OH$) and superoxides radical ($O_2^{\cdot-}$). So far, this technique has been applied to various actual systems including textile wastewater [4,5], papermaking wastewater [6,7], olive mill wastewater [8–10], petroleum refinery wastewater [11] and hospital wastewater [12]. However, this method has limitation in current format. For example, it is only effective for treating low concentration wastewater because more energy and much longer time are needed for higher concentration. Considering the fact that there are significant amount of non-biodegradable compounds existing in actual wastewaters, TiO_2 photocatalysis after biological process for post-treatment of actual wastewater is feasible [13–15].

Development of novel reactor to reduce light loss during PC process is a practical approach to improve PC reaction rate and is crucial for actual wastewater post-treatment. Pilot plants with double-skin sheet photoreactors (DSSRs) and compound parabolic collector photoreactors (CPCRs) were built in Germany and Spain to treat bio-treated wastewater and pesticide bottle washing wastewater [16,17]. These two types of reactor utilized both the direct and diffuse portion of solar radiation. Separation of suspension TiO_2 from treated water, however, was needed in these two plants. Immobilization of TiO_2 on different substrates is a method of choice to avoid separation. Fig. 2 demonstrates three types of TiO_2 immobilization in PC water treatment process. Fig. 2(a) shows a planar substrate inserting in water solution, in which part of incident light lost because of reflection on solution and substrate surface. Meanwhile, significant amount of transmission light would be also lost due to solution absorption (Beer–Lambert law). This is especially significant when solution concentration is high and light path length is long. In order to reduce light loss caused by solution absorption, a thin film PC reactor (Fig. 2(b)) can be used, in which a thin layer of aqueous solution covers the surface of immobilized photocatalyst during PC reaction. Various kinds of thin film PC reactors were developed in the past few years, which include rotating disk reactor [18–20], rotating drum reactor [21,22], spinning disk reactor [23,24] and inclined plate reactor [25]. These reactors have been proven to be effective for treating wastewater containing high concentration pollutants. A pilot plant with two thin film fixed bed reactors were built in Tunisia using solar energy to treat textile wastewater [26]. In order to further improve light utilization efficiency, voltage is usually applied to perform photoelectrocatalytic (PEC) oxidation to prevent rapid recombination of photo generated electron and holes [27,28]. In this design, loss of irradiation power still occurs on the surface of the planar disk through light reflection. The third type of immobilization (Fig. 2(c)) uses wedge or pyramid surface structure to enlarge surface area and enhance light utilization through multiple light reflections. PC reaction rate for actual wastewater post-treatment can be further improved.

So far, limited research has been done to treat actual textile wastewater by using photocatalysis. It is mainly because the composition of textile wastewater is complicated and salinity is high. In this work, we explored the feasibility of post-treatment of actual textile wastewater using a wedge structured rotating disk PC reactor under UV irradiation. Following three research questions are addressed: (a) if wedge rotating disk photocatalysis is capable to reduce COD level in effluent to meet the discharge or reuse standards in a reasonable time frame; (b) if high concentration inorganic anions in wastewater would significantly influence PC performance, and (c) considering energy consumption, if it is worth further scaling-up this technique for real water treatment.

2. Materials and methods

2.1. Materials and reagents

Titanium disk plate (99.6% purity, diameter 75 mm, thickness 12 mm) was purchased from Shanghai Hongtai Metal Production Co. Ltd. (Shanghai, China) and employed as the substrate for TiO_2 film coating. Tetrabutyl titanate (Sinopharm Chemical Reagent Co. Ltd., China) was used as the precursor for preparing TiO_2 colloidal suspensions. Rhodamine B and Methyl Orange (Shanghai Jiaying

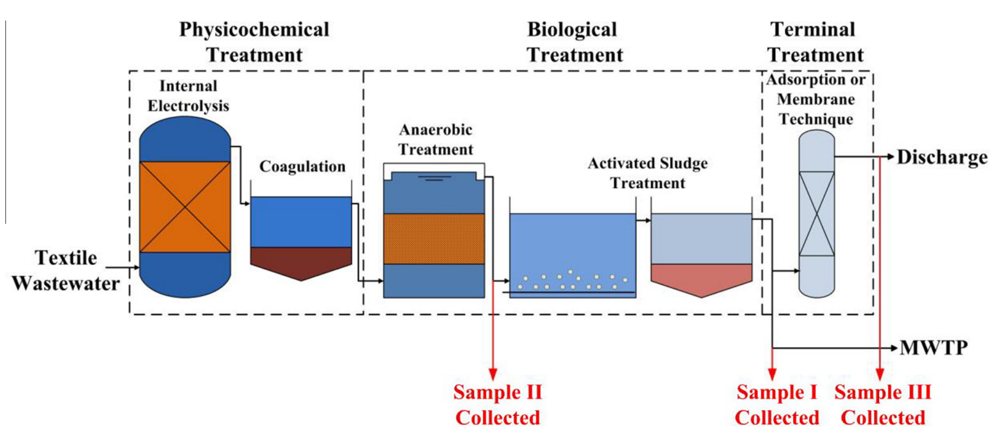

Fig. 1. Process flow chart of actual textile wastewater treatment in plant.

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