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A novel device for hazardous substances degradation based on double-cavitating-jets impingement: Parameters optimization and efficiency assessment

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HIGHLIGHTS

- A novel two-cavitating-jets impinging device for hazardous substances degradation.
- Synergetic effect of two-cavitating-jets impingement and Fenton chemistry.
- Significant RB removal from aqueous solution during 2 h treatment.
- Advantages of reducing demand of H_2O_2 and increasing treatment efficiency.

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ABSTRACT

Hydrodynamic cavitation is an effective advanced oxidation process. But sometimes it cannot obtain satisfactory treatment efficiency by using hydrodynamic cavitation individually, so it is necessary to introduce intensive methods. Based on double-cavitating-jets impingement, this paper presents a novel device that has advantages of strong heat and mass transfer and efficient chemical reactions. Based on the device, a series of experimental investigations on degradation of a basic dye, i.e. Rhodamine B were carried out. Significant Rhodamine B removal from aqueous solution was observed during 2 h treatment and the degradation reaction conformed to pseudo-first-order kinetics. The synergetic effects between double-cavitating-jets impingement and Fenton chemistry on simultaneous degradation of Rhodamine B were confirmed. Both single-variable experiments and orthogonal experiments were carried out to study the effects of initial hydrogen peroxide, ferrous sulfate and Rhodamine B concentrations and the optimum conditions were found out. Effects of jet inlet pressure in the range of 6–12 MPa and solution pH value in the range of 2–8 were also investigated. The cavitation yield was evaluated to assess the energy efficiency. The present treatment scheme showed advantages in terms of reducing the demand of hydrogen peroxide concentration and enhancing the treatment efficiency in large scale operation.

1. Introduction

Effluents coming from dyeing and printing industry usually contain high levels of dye components. These components are photolytically stable, bio-refractory and resistant to chemical oxidation [1,2]. Generally, treatment methods as adsorption by activated carbon, coagulation by a chemical agent, or reverse osmosis are applied to such effluents [3]. Nevertheless, these are non-destructive methods and merely transfer contaminants from water to sludge. So there is a need to develop more environmentally friendly methods. With ability to effectively eliminate hazardous substances in wastewater, the advanced oxidation processes[1] (AOPs) have increasingly aroused people's attention [4]. The AOPs are characterized by releasing of highly oxidizing hydroxyl radicals (•OH), which can attack organic pollutants via adding to the aromatic ring or double bond, and abstracting electron or hydrogen [5].

Cavitation has been implemented as an AOP for wastewater treatment by many previous researchers [6–12]. It is a pressure-

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[1] Advanced oxidation processes (AOPs).

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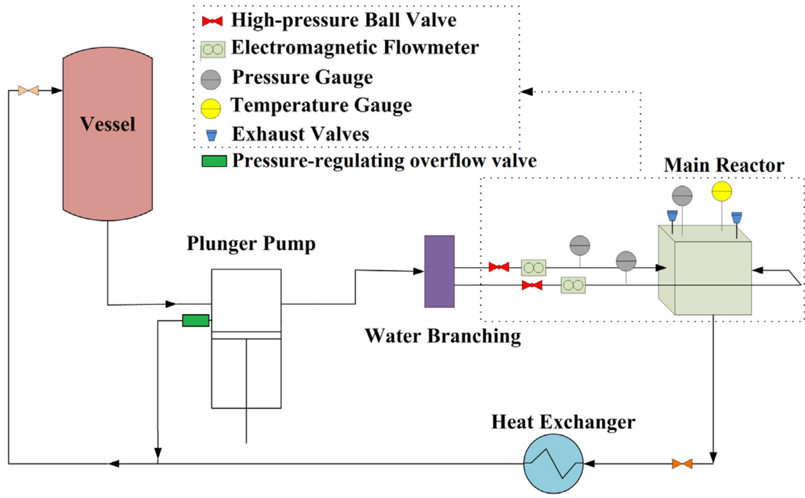

Fig. 1. Schematic representation of the experimental setup.

related process and usually occurs when local pressure falls below the vapor pressure corresponding to liquid temperature. In case of acoustic cavitation, the local pressure fluctuation is caused by acoustic waves. While hydrodynamic cavitation occurs when liquid passes through constricting-diverging structures, such as throttling valve, orifice plate, and venturi. In the constriction region, the pressure decreases with the increased flow velocity and cavitation bubbles form. Subsequently, in the downstream region of constriction, the pressure is subjected to a recovery with the expansion of cross-sectional area, which leads to bubble collapse. Due to the violent compression of the internal gas during bubble collapse process, extreme environment (temperature 1000–10000 K, pressure 100–5000 bar [13,14]) is formed inside the bubble. The dissociation of water molecules and a series of chain reactions are excited in the extreme environment, giving rise to the formation of •OH [15]. Compared with acoustic cavitation, hydrodynamic cavitation has higher energy efficiency and allows for easier realization of scale-up applications [16].

Hydrodynamic cavitation has shown promising application potential for wastewater treatment, but sometimes it cannot obtain satisfactory treatment efficiency by using hydrodynamic cavitation individually [6,17]. In these situations, the intensifying methods can be introduced to enhance the efficiency and reliability of wastewater treatment systems based on hydrodynamic cavitation technique. The jets impinging technique, which was proposed by Elperin [18], is widely applied to the field of heat and mass transfer. With the capacity to decompose toxic substances and purify sewages, it has also received attention in environmental protection industry in recent years [19–21]. But to our knowledge, the combined utilization of hydrodynamic cavitation and jets impinging technique is very rare. Including hydrodynamic cavitation in the impinging jets has several important advantages in wastewater treatment: the collision, extrusion and shearing stress generated by jets impingement will divide cavitation bubbles into micro bubbles, and this will increase the bubble surface area and accelerate the reactions at the bubble surface; the severe turbulence in the impact zone will promotes cavitation inception, resulting in a secondary cavitation zone; high frequency pressure pulses caused by cavitation bubble collapse will strengthen the micro-mixing and enhance the impinging energy, leading to more efficient impingement and higher chemical reaction rate.

By making use of double-cavitating-jets impingement, an innovative device was developed in this work. The device provides strong heat and mass transfer and efficient chemical reactions. To determine its applicability in wastewater treatment, a series of experimental investigations on degradation of a basic dye, i.e. Rhodamine B[2] (RB), were carried out. Effects of hydrogen peroxide, ferrous sulfate and initial RB concentrations, jet inlet pressure and solution pH were also investigated and the optimum conditions were assessed. The cavitation yield of was evaluated assess the energy efficiency. The results showed that the present treatment scheme showed advantages in terms of reducing the demand of hydrogen peroxide concentration, weakening the coalescing effects between cavitation bubbles, and enhancing the treatment efficiency in large scale operation.

2. Materials and methods

2.1. Materials

RB (Analytical grade), Hydrogen peroxide (30%, chemical reagent grade), Ferrous sulfate (Analytical grade), Sulfuric acid (Analytical grade), and Sodium hydroxide (Flake, Analytical grade) were purchased from Sinopharm Chemical Reagent Beijing Co., Ltd. Purified water was used throughout all experiments.

2.2. Experimental set-up

Fig. 1 depicts the experimental setup. It is a closed circulation loop, which consists of a water containing vessel of 50 L volume, a plunger pump of 5.5 kW power rating and two pipelines: the main line and the bypass line. Water is drawn from the vessel by the plunger pump and flow into the main line after being pressurized to desired values by adjusting the pressure-regulating valve in the bypass line. The water in the main line then branches into two lines. Each line installs a high-pressure ball valve, an electromagnetic flow meter, a pressure gauge and a nozzle with convergent-divergent structure. Water undergoes cavitation process inside each nozzle and flow out of the nozzle in the form of high-speed cavitating jets, and then two jets impinge in the center of the main reactor chamber, where the pollutant degradation reaction mainly takes place. The schematics of the main reactor chamber and the dimensions of the nozzle are shown in Fig. 2. A fixed distance of 15 mm between the two nozzle's outlets was adopted throughout the experiments in this paper. Water flows back to the vessel through a heat exchanger to control its temperature.

[2] Rhodamine B (RB).