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Comparison of effectiveness of acoustic and hydrodynamic cavitation in combined treatment schemes for degradation of dye wastewaters

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ABSTRACT

Cavitation has shown promising applications but individually it cannot prove to be an energy efficient approach for wastewater treatment. The present study reports the use of combined treatment strategies based on cavitation and different oxidizing agents (H_2O_2, $Na_2S_2O_8$ and NaOCl). Decolorization of two biorefractory dye pollutants viz. orange acid-II (OA-II) and brilliant green (BG) has been investigated as model systems for comparison of the effectiveness of cavitating conditions generated by acoustic and hydrodynamic modes. The optimum conditions for temperature, pH and power dissipation in the case of acoustic cavitation and inlet pressure in the case of hydrodynamic cavitation have been established initially. At the optimum operating conditions, the effect of combination of different oxidizing agents has been examined with an objective of obtaining the maximum decolorization. Basic extent of decolorization due to the use of oxidizing agents has also been quantified by performing experiments in the absence of cavitating conditions. The obtained results for cavitational yields indicate that the decolorization is most efficient for the combination of hydrodynamic cavitation and chemical oxidation as compared to chemical oxidation and acoustic cavitation based combination for both the dye effluents.

1. Introduction

Textile and paper industry is one of the largest water consuming and water polluting industry as large amount of dyes are likely to be discharged into waste streams. Significant quantum of water is consumed for the preparation, dyeing, washing and rinsing stages of reactive dyeing processes. The textile/paper industry and consequently its wastewater have been increasing exponentially with the ever increasing demands. If these wastewaters are discharged to the environment without any treatment, these dyes can remain in the environment for an extended period of time due to their high stability to light and temperature. The presence of even very low concentrations of dyes in effluent is highly undesirable. Depending on the exposure time and dye concentration, dyes can have acute and/or chronic effects on exposed organisms. They also affect the absorption and reflection of sunlight through water, reduce oxygen solubility and threaten the photosynthetic activity of aquatic plants and algae. The effect in reduction in the oxygen levels interferes with the growth of bacteria such that they become inefficient in biologically degrading impurities in the water and hence risk the food chain. These reasons make the effective elimination of reactive dyes from effluents of textile industries very important before release into the environment [1].

Wastewater from textile, paper and some other industries contain residual dyes, which are not readily biodegradable, and also hard to treat because of their overall high biological and chemical oxygen demands due to presence of heavy metals, phenolic compounds, chlorides, etc. [2]. There are many types of dyes and different dyeing manufacture processes, making difficult that only a single treatment process satisfactorily meets the treatment requirements in all situations [3]. In earlier years, chemical oxidation treatment was the most commonly used approach for dye decolorization with requirement of low quantities of oxidant and hence considered to be economical. Various types of oxidants including chlorine, hydrogen peroxide, ozone and chlorine dioxide can be used for color removal from wastewater. Chlorine in the form of sodium hypochlorite has long been used for bleaching of textile wastewater. Water-soluble dyes such as reactive, acid, direct and metal complex dyes are decolorized readily by hypochlorite, but water-insoluble disperse and vat dyes are resistant to decolorization by this process. Although the use of chlorine gas is a cost effective, its use causes unavoidable side reactions, producing organochlorine compounds including toxic trihalomethane. Hydrogen peroxide alone is not effective for decolorization of dye effluent at normal conditions. Also the time of treatment with chemical or biological methods may be quite high and total mineralization of the effluent stream may not be possible. Existing waste water treatment methods such as adsorption on activated

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carbon, extraction, and chemical oxidation suffer from limitations such as limited applicability, low efficiency, and transfer of dyes from the liquid to the solid phase causing secondary pollution and requiring further treatment (e.g. activated sludge process) and formation of toxic by-products etc. [3], thus imparting the need of research into alternative treatment techniques such as advanced oxidation processes (AOPs) or cavitational reactors either applied alone or in combination with AOP [4]. Cavitation can be described as the formation of nuclei, growth and collapse of bubbles in liquid, releasing large magnitudes of energy [4,5]. The collapse of the bubbles induces localized supercritical conditions [6] i.e. high temperature and high pressure (few thousand atmospheric pressure and few thousands Kelvin temperature). The local effects of cavitation include generation of free radicals, hot spots and intense turbulence coupled with liquid circulation currents; the conditions being quite favorable for oxidation of pollutants. During cavitational bubble collapse, H_2O undergoes thermal dissociation within the vapor phase to give hydroxyl radical and hydrogen atoms. In water and wastewater treatment applications, organic pollutants may be destroyed either in the cavitation bubble itself by pyrolytic decomposition (if the compounds are hydrophobic), at the interfacial sheath between the gaseous bubble and the surrounding liquid or in the bulk solution via oxidative degradation by hydroxyl radicals.

Cavitational reactors have shown considerable promise for wastewater treatment due to advantages like, low processing time and higher extent of degradation but have not been significantly successful at commercial scale installations due to much higher costs of treatment. An effective way has been to combine cavitation with chemical oxidation giving benefits of possibly lower energy requirements and lower chemical use. Objective of the present work is to investigate the application of cavitation in combination with chemical oxidation for dye wastewater treatment and compare the effectiveness of two modes of cavitation viz. acoustic cavitation and hydrodynamic cavitation. In acoustic cavitation [7], the pressure variations in the liquid required for achieving different stages of cavitation phenomena are brought about using sound waves, usually ultrasound (16 kHz–1 MHz) whereas in the hydrodynamic mode [8], cavitation is produced by pressure variations obtained using geometry of the system creating velocity variation. The work has investigated the decolorization of two commercially important dye (orange acid II and brilliant green) containing wastewaters. Orange acid II is a classical example of azo dyes whereas brilliant green is a typical cationic dye with significantly toxic properties.

Azo dyes constitute the largest class of dyes and are widely used in a variety of industries from textile to cosmetics. The chromophore structure of azo dyes is made of two aryl rings connected through an azo, —N=N—, bridge. The color of the dye is due to azo (—N=N—) chromophore. Decolorization would occur from the breakdown of azo group [9]. The exact structure of the orange acid II has been given in Fig. 1. Orange acid II is chemically described as 2-hydroxy-1-napthylazobenzene sulfonic acid sodium salt ($HOC_{10}H_6N{=}NC_6H_4SO_3Na$) with λ_{max} of 485 nm and molecular weight of 350.

The second dye used in the investigation is triphenyl nitrogen containing cationic dye (brilliant green). The use of brilliant green (BG) dye has been banned in many countries due to its carcinogenic nature [2]. It appears as minute golden crystals. It is used as a dye to color synthetic fibers and silk biological stain, dermatological agent, veterinary medicine, and as an additive to poultry feed to inhibit propagation of mold, intestinal parasites and fungus. It is also extensively used in textile dying and paper printing [10]. It is considered highly toxic for humans and animals because it can cause permanent injury to eyes. It also causes irritation to the respiratory tract that leads to cough and shortness of breath. It can cause irritation to the gastrointestinal tract, which also results in nausea, vomiting and diarrhea in human beings. The exact structure of the brilliant green dye has also been given in Fig. 1. Brilliant green is chemically described as ammonium, 4-(p-diethylamino)-alpha-(phenylbenzylidene) ($C_{27}H_{34}N_2O_4S$) with λ_{max} of 625 nm and molecular weight of 482.

2. Materials and methods

2.1. Materials

Orange acid II (OA-II) (C.I. number 15510; 350.33 g/mol) and brilliant green (BG) (Malachite green, $C_{27}H_{33}N_2HO_4S$, C.I. number 42040) dyes were obtained from Dyes Technology Department of the Institute locally. Stock solutions of orange acid-II and brilliant green dye were prepared in distilled water. Distilled water was obtained from distilled water plant procured from Millipore. For each experimental run 0.1 M H_2SO_4 and 0.1 M NaOH were used to adjust the initial pH of the dye solution. H_2SO_4, NaOH and the oxidizing agents like hydrogen peroxide (H_2O_2), sodium persulfate ($Na_2S_2O_8$), sodium hypochlorite (NaOCl) were obtained from S.D. Fine Chem. Ltd., Mumbai, India. All the chemicals were used as received from the suppliers.

2.2. Experimental setup

2.2.1. Acoustic cavitation

In the case of experiments related to acoustic cavitation, experiments were performed using ultrasonic horn, which was procured from Dakshin India Ltd., Mumbai. Ultrasonic horn was operated at

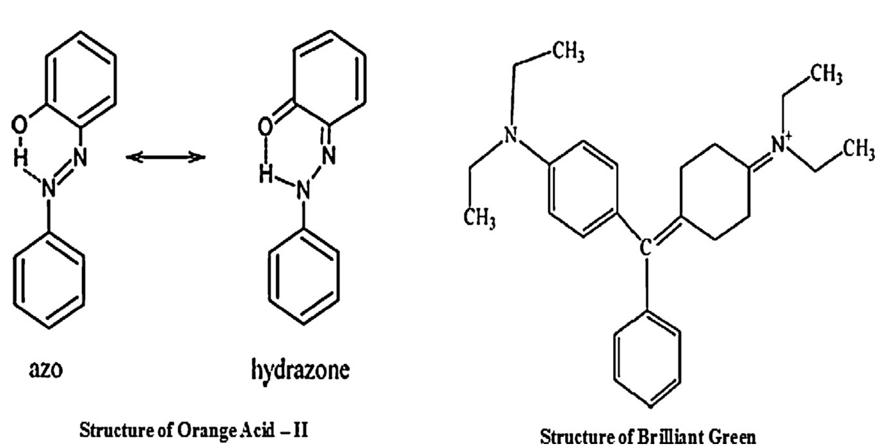

Fig. 1. Structures of the dyes.