Ultrasonics Sonochemistry 27 (2015) 592–601

Contents lists available at ScienceDirect

Ultrasonics Sonochemistry

journal homepage: www.elsevier.com/locate/ultson

Synergistic degradation of chitosan by impinging stream and jet cavitation

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ARTICLE INFO

Article history:
Received 28 October 2014
Received in revised form 19 March 2015
Accepted 17 April 2015
Available online 23 April 2015

Keywords:
Chitosan
Degradation
Impinging stream
Jet cavitation
Synergistic effect

ABSTRACT

Chitosan degradation was investigated using a combination of jet cavitation and impinging stream. Different operating parameters such as the initial concentration (1–5 g L^{-1}), initial pH (3.2–4.8), solution temperature (30, 40, 50, 60, and 70 °C), inlet pressure (0.1–0.45 MPa), and treatment time (0–120 min) were optimized to achieve the maximum degradation of chitosan. After the optimization of jet cavitation parameters, chitosan degradation was carried out using venturi tubes of different structures (the fluidic generator). The efficiency of the jet cavitation degradation was improved significantly by combining with impinging stream. The structures of the degradation products were characterized by Fourier-transform infrared spectroscopy and X-ray diffraction. This study has conclusively established that a combination of jet cavitation and impinging stream can be effectively used for the complete degradation of chitosan.

1. Introduction

Chitosan, β-(1,4)-2-amino-2-deoxy-D-glucose, is a natural polymer and can be easily derived by the *N*-deacetylation of chitin(β-(1,4)-2-acetamido-2-deoxy-D-glucose) with alkali [1]. When the *N*-deacetylation of chitin reaches approximately 50% (depending on the origin of the polymer), the resulting product becomes soluble in an aqueous acidic media and named as chitosan [2]. Because of the hydroxyl and amino groups in chitosan, it has superior chemical activity. Studies show that molecular weight has a significant impact on the properties of chitosan. There are tremendous differences between chitosans with different molecular weights. Moreover, only when the molecular weight of chitosan is reduced to a certain degree, unique functions can be obtained [3]. Thus, reducing the molecular size of chitosan without altering its chemical structure is of great significance.

Hydrodynamic cavitation is a new chemical-intensive way, by which cavities can be formed due to the pressure variation in the flow of a liquid, caused by a change in the flow area of a part such as venturi tube and orifice plate [4]. When a liquid passes through a constriction such as a venturi tube, the pressure at the gular of the venturi tube equals to or falls below the vapor pressure of the liquid, forming the vaporous cavities. With further lowering of the pressure, the cavities continue to grow and reach their maximum size at the lowest pressure; subsequently, when the liquid jet expands and reduces the flow velocity, the pressure recovers, resulting in the collapse of the earlier formed cavities [5]. Hydrodynamic cavitation generates localized transient high temperatures (~10,000 K), high pressure (~1000 atm), and high-speed microjets, and diverse extremely complex physicochemical effects [6]. Studies show that hydrodynamic cavitation can be used for the degradation of organic compounds [7–12]. Currently, hydrodynamic cavitation mainly includes swirling cavitation and jet cavitation based on orifice plate or venturi tube. In our previous study, good results were achieved when using jet cavitation for chitosan degradation [13].

Impinging stream (IS) is another novel chemical-intensive technology. As a scientific concept, IS technology was put forward by Elperin [14] for the first time, aimed at strengthening phase transfer between gas and solid-phase systems. Scholars from various countries have carried out extensive research on IS technology because of its superior and potential applications. The IS concept gradually extended to a liquid continuous phase. Yuan Wu defined IS as follows [15]: ISs are flow configuration in which two continuous steams with certain momentum fluxes, with or without dispersed phase(s), flowing along opposite directions, vertical to the bisection across the impinging point, impinge against each other. Liquid-continuous ISs (LIS) have the following major features: micromixing and pressure fluctuation. A strong micromixing increases the probability of molecular collision. Pressure fluctuations change the energy and distribution of molecules; a part of the molecules acquire more energy and thus favors the kinetics. This effect is beneficial to chitosan degradation.

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http://dx.doi.org/10.1016/j.ultsonch.2015.04.019
1350-4177/

Based on the characteristics of jet cavitation and IS, a cavitation IS coupled technology was used in this study to strengthen the hydrodynamic cavitation reaction process of chitosan degradation. The effects of initial concentrations, initial pH, solution temperature, inlet pressure, and treatment time were evaluated by a single-factor method under different structural parameters of venturi tubes. Then, chitosan degradation using venturi tubes of different structures was studied.

2. Experimental

2.1. Materials

Chitosan was purchased from Kabo Industrial Co., Ltd. (Shanghai, China). The degree of deacetylation and viscosity-average molecular weight of the commercial chitosan used in this study were determined experimentally. All other chemicals including acetic acid (CH_3COOH), sodium acetate trihydrate ($CH_3COONa{\cdot}3H_2O$) were of analytical reagent grade and used as received without further purification.

2.2. Experimental setup

The schematic of the experimental setup for jet cavitation is shown in Fig. 1. It consists of a closed loop system, designed to draw the chitosan solution from a 10 L holding tank, transferring it into the IS and jet cavitation reactors using two centrifugal pumps, and discharging the treated solution back to the tank. The other components of the system include the control values (V_1 and V_2). The inside diameter of pipe is 6.5 mm. The flow rate of sample is $1.66 \times 10^{-4}\ m^3\ s^{-1}$.

As shown in the figure, the chitosan solution enters the IS reactor simultaneously by adjusting the control valves. It can produce a strong interaction in the IS reactor (Fig. 2(B)); then, the jet cavitation was generated in the facility using a venturi tube (Fig. 2(A)).

Because of the axial symmetry of venturi tube, only half of its section is discussed. The inlet and outlet angles mentioned below are half of the actual angle.

For a typical degradation experiment, 3 L of an aqueous solution of chitosan with the desired concentration was placed in a holding tank. The electromotor was started, and the pressure was adjusted by controlling V_1 and V_2. The operating temperature was kept constant by circulating water through the jacket. First, the effect of solution concentration on chitosan degradation was investigated with concentrations of 1, 3, 5, 7, and 10 g L^{-1}. Experiments were carried out at varying pH values of 3.2, 3.6, 4.0, 4.4, and 4.8. The effect of temperature was investigated at 30, 40, 50, 60, and 70 °C. To study the effect of inlet pressure, the inlet pressure was varied from 0.1 MPa to 0.45 MPa. Moreover, to study the effect of treatment time, the solution was treated in the experimental setup

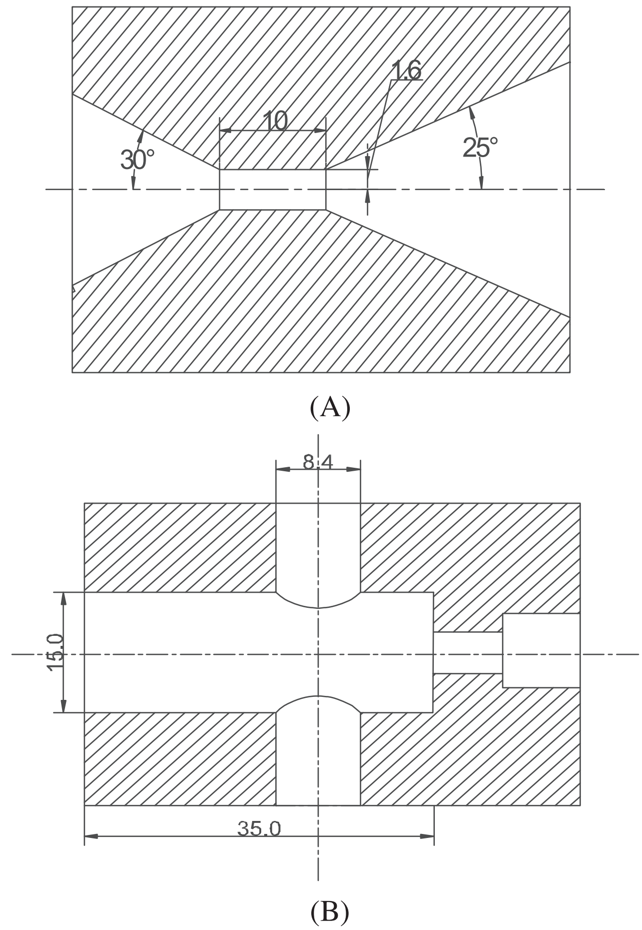

Fig. 2. Structure of venturi tube (A) and impinging stream reactor (B).

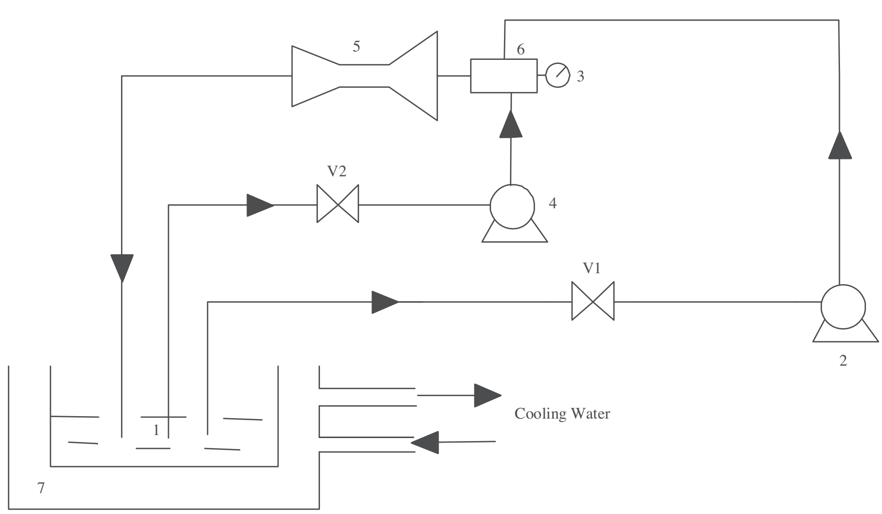

Fig. 1. Abridged general view of cavitation equipment. 1—Holding tank; 2 and 4—pump; 3—pressure gage; 5—jet cavitation reactor (venturi tube); 6—impinging stream reactor; 7—cooling water; V_1 and V_2—valves.