Application and Advancements in Sonochemistry and Cavitation-A Review

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Abstract:

The research on sonochemistry and cavitation is finding increasing importance in the field of process intensification. The research has been reported in order to synthesize various products like nanomaterials by using this technique. Also the research has been reported in order to study the effects of various parameters like frequency, intensity (acoustic pressure), solvent, bubbled gas, external parameter (temperature, pressure) on cavitation and bubble collapse. This review presents the summery of the research carried out in this field with respect to affecting parameters, applications and modelling.

Keywords:

Bubbles, collapse, hydrodynamic cavitation, ultrasound

Introduction

Sonochemistry is the application of ultrasound to chemical reactions and processes. The origin of sonochemical effects in liquids is the phenomenon of acoustic cavitation. This cavity is called cavitation bubble as this process is called cavitation and the point where it starts cavitation threshold. The bubble formed responds to the sound waves by expanding and contracting. Stable and transient are two types of cavitation. Frequency, intensity (acoustic pressure), solvent, bubbled gas, external parameter (temperature, pressure) are few parameters affecting the size, life time and fate of a cavitation bubble. It has been experimentally shown that the cavitational collapse creates drastic conditions inside the medium for an extremely short time: temperatures of 2000-5000 K and pressures up to 1800 atm inside the collapsing cavity. Chemistry, materials and life sciences as well as medicine are few areas where ultrasound has found wide applications. The present review aims at presenting the work carried out in this field. The research was reported on the application of sonochemistry and cavitation in synthesis of various products, also various models were proposed by the investigators for discussing the reaction and phenomenon of collapse of bubbles.

Research on Sonochemistry and Cavitation

Gogate et.al. have presented theoretical studies on application of cavitations for wastewater treatment (1). The focus was to intensify the disinfection by using combination of cavitations and electrochemical chlorination, ozonation. The increase in water treatment ability because of combination of above processes was considered as a result of increase in hydroxyl radicals, increased ozone contact and decreased mass transfer resistance. The reactor completely removed the need of chemical biocides and scale inhibitors. It also plays vital role in altering flow ability of treated water in positive way. Kratochvíl et. al. carried out the research in order to quantify the effect of cavitation ultrasound generated by descaling tool (2). Chloroform–water mixture was used as dodimeter. During exposure to the ultrasound the liberated chloride ions react with hydroxyl ions. With increasing exposure time, more hydrochloric acid was formed and pH decreased. The amount of product formed was found to exponentially proportional to the exposure time. The reaction occurred was first order in nature. Application of sonochemistry for preparation of metal oxide was studied by Shrivastava et.al (3). The metal oxides are important ingredient in surface applications. They dissolved the surfactant in a minimum amount of ethanol in a 100-mL sonication flask. The precursor was added with further addition of water. Sonication was carried out for three hours. It was observed that the sonochemical way reduces the time considerably.

Hydrodynamic cavitation was used for disinfection of bacteria by Karamah and Sunarko (4). Orifice plate and venturi injector type of contactors were used for the purpose. The orifice plate gave better result than ventury. It was observed that for the initial concentration of 106 CFU/mL, the value of C/Co of orifice plate at 60 minutes was smaller. Also it was found that for the initial concentration of 105 CFU/mL and 104 CFU/mL, the C/Co value was reached faster for orifice plate than for the venturi injector. The ultrasound induced cavitation was used for synthesis of nanoparticles by Theerdhala et.al (5). Cavitation induces the collapse of micro bubbles, which provide extreme synthesis conditions, in terms of temperature of the order of 5000 K. Metals, alloys, their composite forms can be synthesized by using this technique and since synthesis time is very short, they are obtained on nano-levels.

The studies on sonochemical and hydrodynamic cavitation reactors for laccase/hydrogen peroxide cotton bleaching was carried out by Gonçalves et.al(6).They tried to develop a novel and environmental-friendly technology for cotton bleaching with reduced processing costs. They observed that the use of medium frequency ultrasound (850 kHz, 120 W) improved the cotton bleaching using a combined laccase–hydrogen process. Also it was observed that ultrasound power was beneficial to the cotton bleaching by the combined laccase/hydrogen peroxide process. Ashokkumar et.al. studied acoustic cavitation in detail (7).They discussed the application of hydrodynamic cavitation as new approach to ultrasonic processing. They also developed mathematical model for rotary disintegrator. High noise level was one of the problems in this application, which was overcome by constructing noise proof case around the equipment. Wang et.al. carried out investigation on sonochemical degradation in aqueous solution of methyl violet (8). They studied influence of the initial concentrations, reaction temperature and the pH of medium on the ultrasonic decomposition of methyl violet. It was observed that the concentrations of methyl violet in aqueous solution decreased exponentially with sonication time, indicating first-order kinetics. Also with increase in initial concentration degradation rate constant decreased. It was also observed that the ultrasonic degradation rate was almost invariable at the temperature 20-40°C.The degradation coefficient was higher in acidic conditions than neutral conditions and it was minimum in basic conditions. Raman et.al. obtained linear acoustic pressure field by olving the homogenous Helmholtz equation using FEMLAB package (COMSOL Multi-physics 3.2b) (9). Cavity cluster approach was used to calculate collapse pressure of transient cavitation bubble. The ultrasound intensity distribution was calculated from the pressure field distribution. They showed that incorrectly modelling the out-of-plane wave number could lead to erroneous results. Their simulation results suggested a sinusoidal pressure field inside the sonoreactor instead of exponential decay behaviour as obtained by other workers.

Shestakov et. al. described the ability of sonochemical reactor for physical-chemical treatment of pure water (10). It was observed that If in reactor the phases oscillation of emitters are offset, which allows them to shape the resulting wave with the maximum amplitude, and sizes of the cavitation, areas increase too. The applicability of an external microphone and a self-sensing ultrasound transducer for cavitation detection were experimentally investigated by Bornmann et.al (11). Both the methods were suitable and easily applicable. Manoiu and Aloman carried out research on synthesizing silver nanoparticles by sonochemical methods (12).In this, silver nitrate was used and it was exposed to the ultrasound flow, leading to the microscopic bubble formation. The nanoparticles of uniform shape and size of spherical nature were obtained. Storey and Szeri explained a detailed computational model for the collapse of a single bubble (13). They took into account phase change, mass transfer, heat transfer and chemical reactions. The reduced model gave reasonable results with less complexity. The preliminary studies carried out by Duller indicated that a single cavitations pit can result from more than one cavitation event (14). They investigated the erosion effect on a thin aluminium foil. It was determined that larger single pits result from several impacts of shock waves on the same area.

A model was proposed for ultrasound propagation in liquid by Louisnard (15). Thermal diffusion in the gas and viscous friction in the liquid were calculated numerically for a single inertial bubble driven at 20 kHz and were found to be several orders of magnitude larger than the linear prediction. For the small bubbles, viscous dissipation was major cause of energy loss. Gong and Hart presented a model that combined the dynamics of bubble collapse with the chemical kinetics of a single cavitation event (16). Their model provided means for studying chemical kinetics that takes place at each stage of bubble collapse. Also the model provided means for resolving fundamental scaling relationships. The model showed that, despite its volatility, *OH* can accumulate in the vapour phase of the bubble, increasing in concentration with each oscillation. Though the model was helpful to understand the chemistry of the bubble collapse, it did not account for transport of species into solution, it also failed to provide a tool for investigating overall sonochemical reaction rates. A review was carried out on Sonochemical Treatment of Water for Chlorinated Organocompounds by González-García et.al (17).

In their review they carried out an extensive study of the influence of the initial concentration, ultrasonic intensity and frequency on the kinetics, degradation efficiency and mechanism. It was concluded that sonochemical treatment was not an efficient way of wastewater treatment for removal of organic pollutants. Yuan and He simulated spherical oscillation of an acoustically levitated gas bubble in water to elucidate the phenomenon of single-bubble son luminescence (SBSL) (18).They used a refined hydrochemical model. They assumed the bubble was spherically symmetric and is composed of mixture of noble gas, water vapour and reaction products. Nayak et.al. applied sonochemical approach for rapid growth of zinc oxide nanowalls (19).They tried sonochemical synthesis on Si, SiO2, Cr, and Ag. They immersed an Al coated Si substrate immersed into a beaker containing zinc nitrate hexahydrate and HMTA to understand the growth kinetics. They found that to grow ZnO nanowalls, an Al layer was essential. The growth on Al to the formation of $ZnAl_2O_4$ at high temperatures was attributed to vertical growth of ZnO nanowalls. Their study also showed that Al was consumed in the growth process of these ZnO nanowalls .Storey and Szeri presented a simple model that included all the physics relevant to the determination of the reaction products(20).This reduced model found to provide reasonably accurate results. It was also found that many observed behaviours in sonochemistry were reflected in a single bubble. Studies on sonochemical and high-speed optical characterization of cavitation generated by an ultrasonically oscillating dental file in root canal models were carried out by Macedo et.al. (21).Sonoluminescence (SL), sonochemiluminescence (SCL) around ultrasonically oscillating files were measured. It was observed that sonication occurred even at low power settings. Smaller bubbles contributed largely to sonochemiluminescence.

Conclusion

Sonochemistry finds wide application in synthesizing various nanomaterials, in hybrid reactors for disinfection, water treatment, and treatment of fuel components. The research on preparation of metal oxide also has been reported. Effective disinfection of bacteria by using hydrodynamic cavitation was also reported. Cavitation reactors for laccase/hydrogen peroxide cotton bleaching were found effective. The research carried out also includes mapping of cavitation events and models to describe the cavitation. It can be concluded that sonochemistry and cavitation is very important tool for intensifying various physical and chemical processes in order to render economy, reducing time and increasing product quality.

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