Degradation mechanism of hydrodynamic cavitation reactor

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Hydrodynamic cavitation is a promising technology in the degradation of the residual antibiotics which can exist in the environment for long periods as they are chemically stable.This study reviews the application of hydrodynamic cavitation to the residual antibiotics treatment.Varied methods for degrading antibiotics,bubble dynamics models coupled with chemical reactions,experiment setup,and cavitation generators are evaluated.A novel self-excited cavitation reactor which can produce pulse and cavitation using the fluid characteristic is proposed.Compared with traditional hydrodynamic cavitation generator, the self-excited pulsed cavitation jet generator has a longer hydraulic detention time,faster bubble collapse,more hydroxyl radical production,better treatment effect,and wider application prospects.Simple design,high energy efficiency,and no secondary pollution contribute to the great potential of self-excited cavitation reactor in wastewater treatment.

Key Words: *hydrodynamic cavitation, hydroxyl radicals, pulsed cavitation generator, degradation rate, antibiotics*

1. INTRODUCTION

The antibiotics,which has been utilized for more than 70 years,can be used not only against human and animal bacterial infections but also as additives for animal growth[1].While the residual antibiotics can exist in the environment for long periods as they are chemically stable and not easy for biodegradation.They may result in the generation of antibiotics resistance genes (ARGs) as well as antibiotics resistance bacteria (ARB),even causing microbial resistance by horizontal gene transfer among pathogen organisms which may infect humans[2].

The traditional treatment strategies in the world include Physical treatment[3-5] (coagulation-sedimentation method,adsorption method, membrane separation method, etc.),Chemical treatment[6-9](ozone oxidation method,Fenton oxidation method, photocatalytic oxidation method, electric-chemical oxidation method, etc.),and biological treatment[10,11](activated sludge method, biological contact oxidation method,anaerobic sludge bed method, etc.).Adsorption is a mature method as physical treatment but the regeneration of adsorbent is difficult[12].Chemical treatment require high investment and advanced equipment, and tend to bring about secondary pollution for the addition of chemical agent.Biological treatment is not a useful method for antibiotics for its inherent antibacterial property.Reverse osmosis and nanofiltration can remove the antibiotics from wastewater effectively,while the high running cost and membrane pollution restrict their widely application.Electrocatalytic oxidation technology with high efficiency and no secondary pollution property,consumes a lot of energy[13,14].Hence, a kind of simple, energy saving, high efficiency, environmentally friendly technology for treatment of antibiotics in wastewater is urgent and attractive.

Hydrodynamic cavitation(HC),as an advanced oxidation process with advantages of simple reactor design and no secondary pollution,becomes a hotspot for scholars from all over the world,but the low efficiency and high energy consumption hinder the industrial application of HC.

In this review,the hydrodynamic cavitation to the residual antibiotics treatment is studied.A novel hydrodynamic cavitation device called self-excited cavitation reactor is proposed.Different aspects self-excited cavitation reactor for wastewater treatment are evaluated.The emphasis is focused on both the related theoretical development and the experiment design and optimization.Some important contributions are incorporated,and their advantages and disadvantages are also compared.Some useful recommendations for both antibiotics degradation and self-excited application are proposed to benefit the industrial application.

2. HYDRODYNAMIC CAVITATION DEVICE

2.1 Traditional hydrodynamic generators

Hydrodynamic cavitation is a special advanced oxidation technology that has been used in wastewater treatment for about 20 years.The collapse of the bubble can provide a very extreme environment with high temperature(1,000~10,000K),and high-pressure(100-5,000bar) as well as high-speed micro-jet,the water molecules trapped in the bubble will be decomposed into high reactive free radicals such as HO •, H •, HOO •, HO_2 •, H_2O_2 etc.[15].Among the free radicals, HO • has extremely powerful oxidizability which can degrade the majority of organic pollutants with chain reaction,and decompose the organic pollutants into CO_2, H_2O,and minerals non-selectively without secondary pollution.

According to the academic papers published, the research hotspots could be summarized into three aspects.

(1) Operational parameters optimization

Operational parameters play important roles on the effect of hydrodynamic cavitation.Generally,these parameters include the inlet pressure,the temperature,the pH,the initial pollutant concentration and the initial radius of nuclei.

Under 3.0 bar inlet pressure for 10 mg/L initial concentration of RhB solution at 40 °C operating temperature in the presence of Fe3+-doped TiO_2 with 0.05:1.00 M ratio of Fe and Ti,the best HC degradation ratio can be obtained (91.11%)[16].Optimum conditions for the maximum cell disruption using HC were cavitation device orifice over venturi, time (180 min),pressure (5 bar),and solid load (0.45% w/v)[17].The maximum bacterial disinfection and COD reduction were obtained using CN5 reactor operated at 5 bar pump discharge pressure and the extent of reduction was found to be 59.17% and 52% respectively[18]. Although all these researches use the venturi cavitation device,different geometries and configurations require various optimum conditions due to diverse removal mechanisms[19] .

Meanwhile,even for the same pollutant,different cavitation devices require different operational parameters.Based on venturi HC device,the optimal operation parameters in HC was obtained: initial concentration of 30 μmol·L−1, inlet pressure of 0.4 MPa,temperature of 25 °C[20].The hybrid scheme treatment based on HC by using Ecowirl reactor (20℃, 2.0 bar, pH 2.0 or 4.0) and NaOCl (minimal dose 0.5 mg·L-1) was found to be the most energy efficient and environmental friendly method to treat wastewater containing RhB[21].For orifice plates, the highest cavitational yield can be obtained at pH 3 and initial dye concentration of 10 mg·L-1.Also,an increase in the inlet pressure would lead to an increase in the extent of decolorization (ED)[22].

As a result,we need to adjust the operational parameters according to specific cavitation device and specific pollutants.

(2) Coupled with other advanced oxidation processes

In situ generation of Fenton reagents can induce an advanced Fenton process(AFP) which can enhance the effect of the used catalyst in the HC process.Using a pilot scale hydrodynamic cavitation reactor, with iron metal blades as the heterogeneous catalyst,for catalytic decontamination of unsymmetrical demethylhydrazine (UDMH) wastewater,the highest cavitation yield can be obtained at pH 3 and initial UDMH concentration of 10 mg/l.In addition,the optimum value of 3 bar was determined for the downstream pressure that resulted to 98.6% degradation of UDMH after 120 min of processing time[23].In the work of removing p-nitrophenol,two different cavitating devices viz. orifice plate and venturi have been used.Effect of different operating parameters such as initial concentration (5 g/l and 10 g/l),inlet pressure (over a range 5.7-42.6 psi) and pH (over a range 2-8) on the extent of removal has been investigated.In conventional Fenton process two loadings of $FeSO_4$, 0.5 g/l and 1 g/l were investigated and three ratios of $FeSO_4$:H_2O_2 viz. 1:5, 1:7.5 and 1:10 were used.Removal observed with venturi was higher than with orifice plate in combination with Fenton chemistry.For 5 g/l initial concentration of p-nitrophenol,maximum removal of 63.2% was observed whereas for 10 g/l solution it was 56.2%[24] .

In general,coupled with AOP technologies can bring higer efficiency and wider degradation extent.While complicated operatating parameters and secondary polluants bring about new problems.

(3) Exploration of novel cavitation generator

Generally,the cavitation generators can be classified into two categories,the linear cavitation and the rotating cavitation.Linear cavitation is conventional includes venturi tube generator, orifice plate generator, liquid whistle reactor et al.

Petkovšek et al. proposed a novel rotating cavitation generator shown in Fig.1 which uses the opposite movements of two shear layers to generate shear cavitation[25].This kind of cavitation generator has larger cavitation volume,rapid pressure recovery and lower pressure loss compared to the linear cavitation device.Ranade et al. disclosed a novel vortex-based cavitation device for effluent treatment which offered cavitational yield that was 3 to 8 times better (milligrams of pollutant degraded per Joule) compared to that from the orifice plate[26].

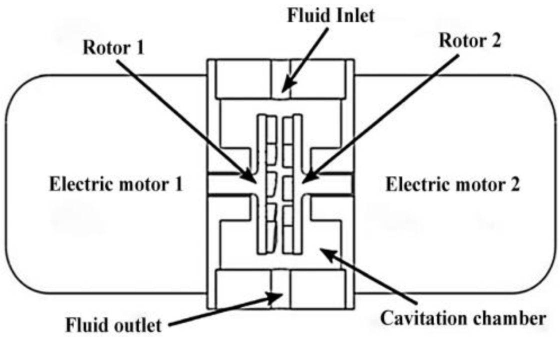

Figure.1 Rotating cavitation generator

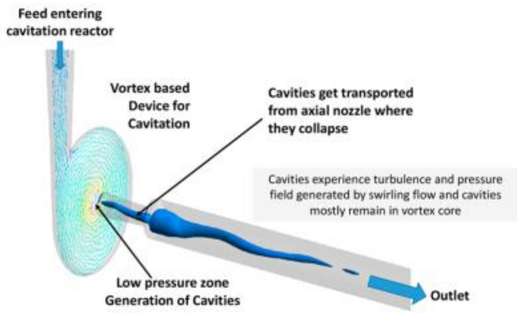

Figure.2 Vortes diode cavitation generator

2.2 Self-excited cavitation reactor

Self-excited cavitation reactor is a novel cavitation generator.Using the unique chamber structure and related operating parameters,this device can change the continuous energy into pulsed one and improve the hitting force significantly[27].As a result,it offers more violent collapse to the bubbles and generate more hydroxyl radicals and improve the degradation rate of the antibiotics or any other refractory organic pollutants.

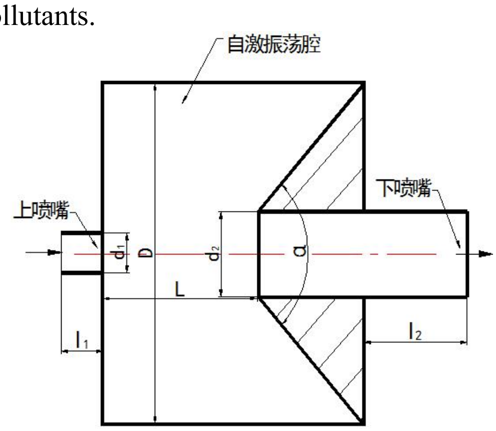

Figure.3 The structure of self-excited cavitation reactor

The working process of the self-excited cavitation reactor can be divided into two stages:energy storage and energy release as is shown in Fig.4.The simulated formation of the cavity is shown in Fig.5.

The self-excited cavitation generating technology is promising for its high efficiency, simple design and no by-products.While the modelling of the inception,growth, movement and collapse of the bubble is a big challenge.

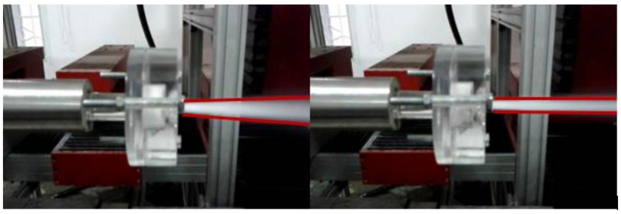

Figure.4 Working process of self-excited cavitation reactor

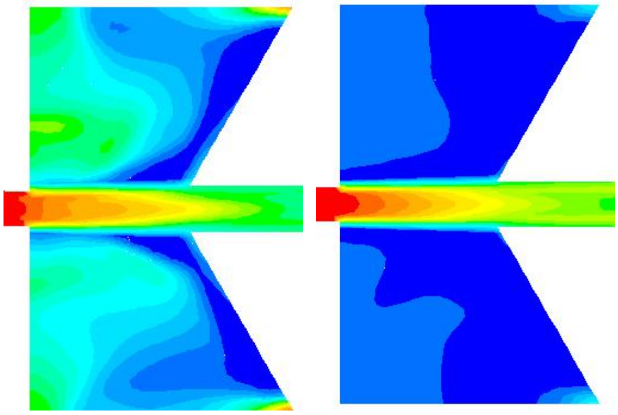

Figure.5 The formation of cavity in the chamber

Table1 the advantage of self-excited cavitation reactor

	Energy consumption	hydraulic detention time	bubble collapse speed	hydroxyl radical production
self-excited reactor	less	long	fast	more
traditional hydrodynamic generators	more	short	slow	less

3. CONCLUSION

Hydrodynamic cavitation is a promising technology for refractory organic wastewater treatment as it can provide a very special environment with high temperature and high pressure and generate hydroxyl radicals with strong oxidation.In the present proposal,we review the conventional cavitation generator and rotating cavitation generator,compare the pros and cons of every kind of the device.Thereafter,we propose a novel pulsed cavitation generator,illustrate the working principle,list the advantages and point out the challenge of modelling.

ACKNOWLEDGMENTS

This work was financially supported by “S cience and Technology Research Project of Hub ei Provincial Department of Education(Q2017110 7)”.

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