射流泵式空化发生器流动机理及其杀菌应用研究

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摘要：射流泵式空化发生器是一种基于射流泵的工作原理，将孔板空化与文丘里管空化的特点相结合，利用高速射流卷吸低速流体在低压环境下诱发剧烈漩涡空化的新型空化发生器。本研究对射流泵式空化发生器的全流动工况外特性和内部空化流动特性进行了研究，建立了外特性参数变化与内部流动规律之间的关联关系，最后利用射流泵式空化发生器对大肠杆菌细胞进行了空化处理实验。按照空化发生的机制和操作工况，射流泵式空化发生器的空化阶段可以分为两大类，即大流量比空化阶段、小流量比和负流量比空化阶段。在大流量比阶段，空化发生于喷嘴射流的剪切层内并随主流向下游进一步发展，随着出口压力下降，依次出现空化初生阶段、空化发展阶段、不稳定的极限空化阶段以及稳定的极限空化阶段。其中，在不稳定极限空化阶段，空化云在喉管内往复振荡。在稳定极限空化阶段，空化云延伸至扩散管并保持相对稳定的状态。在小流量比和负流量比空化阶段，随着流量比的减小，出口压力增大，射流发展被严重限制。其空化区域从喉管进口附近逐渐向上游移动，并依次出现回流停滞型空化阶段以及反向输运空化阶段。此时，面积比对空化的发生发展至关重要。当面积比较大时，空化只能发展至回流停滞型空化阶段。空化杀菌结果表明，射流泵式空化发生器的空化流动对大肠杆菌具有良好的灭杀效果。随着出口压力的提高，杀菌效率也逐渐增大。杀菌率随着处理时间呈现先缓慢增大后迅速增大再趋于平缓的规律，表明射流泵式空化发生器空化处理大肠杆菌存在损伤累计效应。另外，不同初始浓度下杀菌率变化情况基本相似，初始浓度越低，其相对处理时间越短，灭菌效果越好。本研究对于射流泵的空化特性研究以及水力空化的应用研究具有重要的借鉴意义。

关键词：空化发生器；射流泵；空化；杀菌

Research on flow mechanism and its sterilization application of jet pump cavitation reactors

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Abstract: As a new type of cavitation reactor based on the working principle of jet pump, the jet pump cavitation reactor combines the cavitation characteristics of orifice plate and venturi tube, which the high-speed jet sucks low-speed fluid and induces severe vortex cavitation in low-pressure environment. In this paper, researches were conducted to investigate the external parameters, internal cavitation characteristics and its relationships in jet pump cavitation reactor under the whole flow conditions. Also, the experiments on the treatment of *E. coli* cells by jet pump cavitation reactor were carried out. According to the cavitation mechanism and operating conditions, the cavitation stage of jet pump cavitation reactors can be divided into two categories, namely, large flow ratio cavitation stage, low and negative flow ratio cavitation stage. In large flow ratio cavitation stage, cavitation occurs in the shear layer of the nozzle jet and develops further downstream with the mainstream. As the outlet pressure decreases, inception cavitation stage, developing cavitation stage, unstable limited cavitation stage and stable limited cavitation stage appear successively. In unstable limited cavitation stage, the cavitation cloud keeps on oscillating back and forth in the throat. In stable limited cavitation stage, the cavitation cloud develops to the diffuser and keeps stable. In low and negative flow ratio cavitation stage, as the flow ratio decreases and outlet pressure increases, the cavitation development is severely restricted. The cavitation region moves upstream from the throat gradually, then the backflow stagnation cavitation stage and the reverse transport cavitation stage appear successively. The area ratio is crucial for the occurrence and development of cavitation. Particularly, when the area ratio is large enough, cavitation can only develop to backflow stagnation cavitation stage. The results of cavitation sterilization show that the cavitation flow of jet pump cavitation reactor has a good killing effect on e. coli cells. With the increase of the outlet pressure, the bactericidal rate is also gradually enhanced. The bactericidal rate increases slowly at first, then rapidly and finally gradually with the treatment time, indicating that the cumulative damage effect of e. coli cells accounts for a major role in cavitation treatment by jet pump cavitation reactor. In addition, the change of bactericidal rate at different initial concentrations is basically similar. The lower the initial concentration, the shorter the relative treatment time, and the better the sterilization effect. This study has significant reference for hydraulic cavitation characteristics and application of jet pump.

Key words: Cavitation reactor; Jet pump; Cavitation; Sterilization