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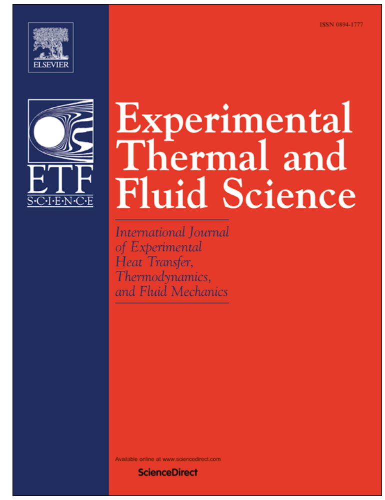

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ABSTRACT

Cavitating jet has been widely used in underground drilling to enhance the rock erosion efficiency. In this circumstance, the high ambient pressure directly influences the bubble traveling process and cavitation impact pressure. To quantitatively assess the erosion intensity of the cavitating jet under the high ambient pressure conditions, a combined numerical and experimental investigation was conducted. A convergent-divergent nozzle was chosen to generate the cavitating jet in a closed test cell. A bubble transportation model was used to simulate the bubble traveling in the water jet through the nozzle and investigate the effects of ambient pressure and flow rate on the transportation efficiency. Pitting analysis with specimen 7075 aluminum alloy was performed to measure the magnitude and distribution of the cavitation impact pressure at different standoff distances. The results reveal the dynamic bubble traveling process and shed light on the cavitation impact field. The bubble transportation capability of the cavitating jet depends on the jet velocity. Given certain ambient pressure and nozzle size, the flow rate must be larger than a certain threshold value for allowing the bubbles to be transported out before collapsing inside the nozzle. The magnitude of cavitation impact pressure is of the order of 1 GPa and shows little dependence on standoff distance. However, the overall impact rate and the distribution pattern are significantly influenced by the standoff distance. It is concluded that the variation of the erosion intensity of cavitating jet correlates more closely with the change of the impact rate than with the absolute impact magnitude.

1. Introduction

Cavitation refers to the formation of bubbles in a liquid when the local static pressure in the fluid drops below the saturated vapor pressure [1]. The collapse of cavitation bubbles produces high-speed micro-jets and emits shock waves. Hsiao et al. [2] estimated the peak collapse pressure to be 1.3 GPa, while Flint and Suslick [3] found the peak temperature to be about 5075 K. The concentrated energy in short duration from the catastrophic cavitation collapse may cause severe material erosion. As a result, there have been numerous studies on the mechanism of cavitation erosion and the method for erosion prevention. Conversely, the collapse energy can be utilized in some cases such as underground drilling, where a high-speed water jet is used to trigger cavitation to increase the rock breaking efficiency. However, when the fluid-filled well is extended to be hundreds of meters deep, the hydrostatic pressure at the bottom of the well is very large. For cavitation bubbles that are developed in the water jet at the well's bottom hole, the high ambient pressure influences the bubble dynamics and the ultimate erosion efficiency. Therefore, cavitation inception, transportation, and collapse under high ambient pressure conditions deserve to be studied.

To trigger cavitation under high ambient pressure, Johnson et al. [4] proposed a self-resonating nozzle that modulates the jet to form discrete ring vortices at the shear layer. The enhanced pressure drop in the center of the vortex core facilitates the inception of cavitation. Based on their work, many studies have been conducted subsequently to investigate the flow characteristics and optimize the nozzle for further improving the jet's erosion intensity. Li et al. [5, 6] designed series of the organ pipe nozzles and Helmholtz nozzles, and experimentally demonstrated that for cavitating jet produced by the self-resonating nozzles, the pressure fluctuation amplitude increased by 24%-37% and erosion rate was enhanced by 31.2% compared with the conventional water jet issued from a cone nozzle. Liao et al. [7] noticed a change of decline rate of the jet impact pressure and rock-breaking efficiency when the ambient pressure is larger than a certain value. Without discussing the detailed flow structures of the cavitating jet, they assumed that the suppression on cavitation by the elevated ambient pressure was responsible for the reduced rock erosion efficiency. Li et al. [8] studied the influence of nozzle's inner surface roughness on the jet's erosion intensity and concluded that there exists an optimum roughness value depending on the inlet pressure. Li et al. [9] also found that the area discontinuity has a large influence on the axial pressure fluctuation and investigated the effect of the feeding pipe diameter under various pump pressures [10]. In these studies, there was no first-hand knowledge about the cavitation impact pressure, which is the key to analyzing the variation of erosion intensity while changing nozzle structural and hydraulic parameters. As a result, only qualitative discussions have been done by assuming various interactions between the solid boundary and flow field, while the physical characteristics of the cavitation impact field were not revealed.

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