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Analysis of vortex breakdown in an enclosed cylinder based on the energy gradient theory

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Abstract

Numerical simulation is carried out to study the phenomenon of vortex breakdown in an enclosed cylinder. The energy gradient theory is used to explain the vortex breakdown in the cylinder with consideration of centrifugal force, Coriolis force, angular momentum and azimuthal vorticity. The research results show that the large value of energy gradient function K is mainly located at the centerline and the region between the circulation vortices on both sides of the cylinder and the vortex breakdown bubbles at the centerline. It is found that the position of the local peak value of the energy gradient function K at the centerline corresponds to the location of vortex breakdown first occurrence. The position of the local peak value of K function in horizontal direction corresponds to the velocity inflection points except for the centerline. The vortex breakdown is mainly determined by the high K value at the centerline for low aspect ratio. The influence of the region of high K value between the circulation vortices on both sides of the cylinder and the vortex breakdown bubbles at the centerline becomes larger with the increase of the aspect ratio. The occurrence and development of the vortex breakdown bubble may be affected by the region of high K value between the circulation vortices on both sides of the cylinder and the vortex breakdown bubbles at the centerline for high aspect ratio.

Keywords: vortex breakdown; energy gradient theory; numerical simulation

1. Introduction

The vortex devices are widely used in chemical, biological, energy and other industries. Swirling flow is a very common and important phenomenon occurred in the vortex devices, such as centrifugal separator, bioreactor, pump, vortex flow meter, vortex mixer, agitator and so on. The flow characteristics of the swirling flow could influence the mass transfer and heat transfer, subsequently affects the chemical reaction, biochemical reactions and cell metabolism. It also plays an important role in the separation and purification of the product.

The vortex breakdown phenomena would occur in the closed cylinder driven by the bottom wall with the increase of Reynolds number. The vortex breakdown in the enclosed cylinder is easy to occur and easy to control. Therefore, it has attracted a lot of attention from researchers in recent years.

The control strategies can be applied to regulate beneficially the flow in a closed cylinder using various cross-section configurations of the closed container (Naumov et al., 2015; Yu et al., 2006), partial rotating lids (Piva et al., 2005; Yu et al., 2007; Jørgensen et al., 2010; Mununga et al., 2014), small rotating disk (Mununga et al., 2004; Tan et al., 2009), temperature gradient

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