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Research paper

The flow downstream of a bifurcation of a flow channel for uniform flow distribution via cascade flow channel bifurcations

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HIGHLIGHTS

- Fundamental issues for uniform flow distribution are addressed.
- Uniform flow distribution is via cascade bifurcation of flow channels.
- Show effect of dimensions of bifurcation zone to downstream velocity profiles.
- Show good designs of bifurcation zone for obtaining symmetric velocity profiles.

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ABSTRACT

Uniform flow distribution is an important and fundamental issue to miscellaneous devices. The present work studied the details of flow in a channel with a fundamental structure—a symmetric bifurcation of one flow channel into two sub-channels. The structure is designated to split one flow into two streams of even flow rate. Key geometric design factors of the flow channel are investigated regarding the effect to the development of a symmetric velocity profile after the flow channel bifurcation, as the symmetric velocity profile is critical to the even split of the flow into two streams in the next stage of flow channel bifurcation. The study is based on both two-dimensional and three-dimensional CFD analyses. Both laminar and turbulent flows are investigated. Commercial CFD software ANSYS FLUENT® was used. The numerical treatment of convection terms in governing equations was based on the QUICK scheme, and the SIMPLE algorithm was used to treat the coupling of pressure and velocity fields. The obtained results are of great significance to the design of flow distributors using cascade flow channel bifurcations.

1. Introduction

Uniform flow distribution is required in many engineering devices and circumstances, with ubiquitous examples, such as in many piping systems [1,2], chemical reactors [3,4], solar thermal collectors [5], plate-type heat exchangers and reactors [6,7], heat sinks for cooling of electronic devices [8–10], air conditioning systems [11], and nuclear reactors [12], etc. In biological area, study showed that uniform flow distribution is helpful to the reduction of flow resistances in vascular system [13]. In modern agricultural irrigation systems, uniform flow distribution provides the maximum production at minimum use of water [14]. Uniform flow distribution is also important for fuel cells that require uniform electrochemical reactions for high energy conversion efficiency [15–19]. It is generally known from all the above applications that uniform flow distribution is often advantageous in providing better heat transfer, temperature control, and low pressure loss, which is translated into less pumping power, as well as minimization of flow-related vibrations, noise, thermal and flow stresses, and corrosions due to bad flow uniformity. Consequently, these benefits contribute to higher reliability and durability of flow-involved facilities and devices.

While many configurations of manifolds and flow distributors have been proposed by researchers for uniform flow distribution [18,19], a relatively standardized flow channel design [20] is of particularly interest in this work. As shown in Fig. 1 the standardized flow channel design is based on a fundamental structure of symmetric bifurcation of a flow channel. The advantage of this symmetric bifurcation of a flow channel is that the structure can be standardized and thus can be easily duplicated in a cascade manner to construct a large number of distributed flow streams. The cascade flow channel bifurcation can further be evolved to form

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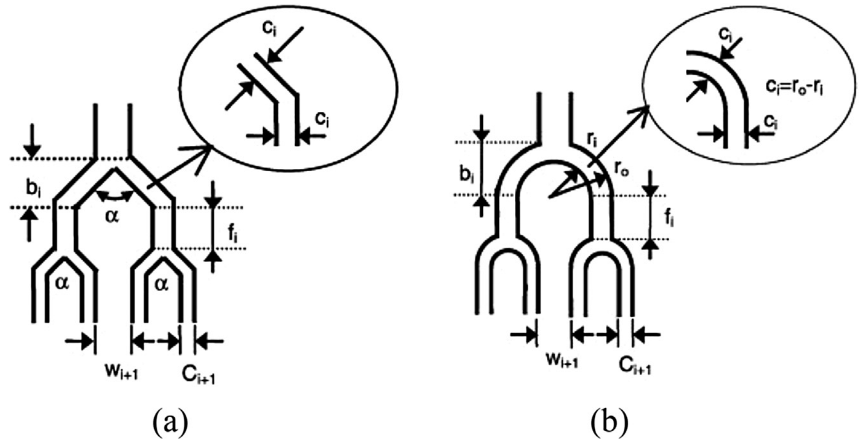

Fig. 1. Basic flow channel bifurcation structures [23]. (a) Tree-bifurcation; (b) Circular-bifurcation.

arrays of flow distributions as shown in Fig. 2, where the channel bifurcation angle$\alpha = 180°$, for which the definition is shown in Fig. 1(a). Configurations of manifolds for a planar domain flow distribution (2-D) are common in planar type fuel cells, plate-type heat exchangers and reactors [6,7,21,22]. Manifolds for a flow distribution to arrayed channels (3-D in Fig. 2(b)) with better uniformity are generally required for nuclear reactors, and various flow-bed reactors.

Whereas the above concept of flow channel bifurcation gives great flexibility for one to construct uniform flow distributors of different functional requirement, the fundamental part of uniform flow distribution is the flow channel bifurcation structure as shown in Fig. 3. Therefore, a comprehensive study to the flow in and downstream of the channel bifurcation zone becomes fundamentally important. A good design of the channel bifurcation zone should allow the flow to quickly develop a symmetric velocity profile after the upper-stage bifurcation of flow channel. This is because that a symmetric velocity profile is important for the flow to be evenly split into two equal sub-streams by the next-stage bifurcation of flow channels.

In order for the flow to develop a symmetric velocity profile one can simply make the channel sufficiently long (with a large L as shown in Fig. 3). However, in practical application, it is often desired that the symmetric velocity profile is developed in a short distance along the main flow direction between two stages of flow channel bifurcations, which therefore can minimize the space for the flow distribution. As a result, it is necessary to examine and study other effects, such as fillet/corners of the bending zone of the flow channel, as well as the lateral length (W as shown in Fig. 3) of a flow channel from after the bifurcation to the bending. The results are to be presented in the following sections.

2. Configurations of the flow channel bifurcations

As discussed above, if we want to split one stream of flow into two even flow streams relying on the bifurcation of the flow channel, what directly influencing the uniformity of the flow distribution is the symmetry of the upstream flow velocity profile. If an incoming flow has a non-symmetric velocity profile, it will be bifurcated into two downstream flows with different flow rates. In order to prevent the possibility of generating non-symmetric velocity profile right upstream of a channel bifurcation, we have to ensure that the velocity profile in downstream channel after any flow channel bifurcation must be as symmetric as possible in a short length.

A Tee-shape bifurcation structure with bifurcation angle α(as given in Fig. 1(a)) of 180° is interested in this study for its short bifurcation zone along the main flow direction. This paper investigated three major factors that affect the downstream flow symmetry—the channel bending/turning curvature or the shape of the fillet, the ratio of W/D_2, and the length L of the downstream channel after bending/turning. As shown in Fig. 3, W is the distance between the centerlines of the upstream and downstream channels due to one bifurcation; L presents the length for the re-

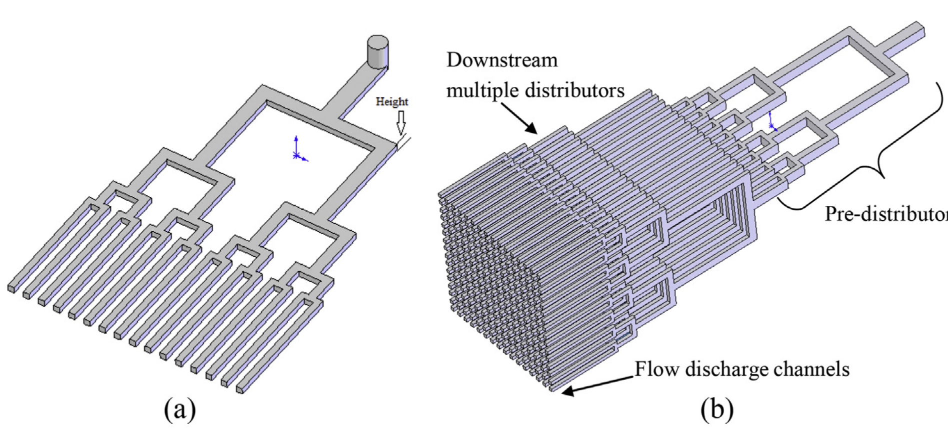

Fig. 2. Examples of 2-D and 3-D flow distribution configured from the basic channel bifurcation structure [23]. (a) 2-D; (b) 3-D.