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Parametric study on Tesla valve with reverse flow for hydrogen decompression

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ABSTRACT

Recharge mileage is of great importance for a hydrogen fuel cell electric vehicle. High pressure hydrogen storage can increase the recharge mileage significantly. Before hydrogen flows into the fuel cell, a decompression process is necessary. To overcome the seal of the piping system and realize the decompression, Tesla valve can be well used, since it is a type of check valve without moving parts, and when there is a reverse flow, large pressure drop appears between the inlet and outlet. In order to obtain a better pressure drop performance for a Tesla valve, in this paper, the structural parameters including the hydraulic diameter, the valve angle, and the inner curve radius are investigated for a large range of inlet velocities. The results indicate that a small hydraulic diameter and small inner curve radius but large valve angle can provide a higher pressure drop under a large inlet velocity, while the pressure drop under different structural parameters barely changes under a small inlet velocity (less than 100 m/s). Besides, there is a low-pressure zone behind the outlet of the bend channel, which should be paid attention. This work can be referred by the further applications of Tesla valves in hydrogen fuel cell electric vehicles for hydrogen decompression.

Introduction

Due to serious environmental pollutions of traditional fossil energy, sustainable and clean energy witnessed a rapid development in last decades. Hydrogen is one of the typical clean energy and it is paid many attentions to its production and utilization. In recent years, hydrogen fuel cell electric vehicles attract many researchers to lay their efforts on them. For instance, Hwang [1] carried out an overall study of hydrogen pathways for fuel cell vehicle applications. Larsson et al. [2] and Ahmadi et al. [3] discussed the application of hydrogen fuel cell vehicles in the Swedish and Canada respectively. Fernández et al. [4] mainly developed a novel approach of a battery powered electric vehicle, which contains a hydrogen fuel-cell-based range extender system. Meanwhile, Xu et al. [5] and Sulaiman et al. [6] both paid attention to the energy management system of the fuel cell hybrid electric vehicle.

As common sense, the recharge mileage of a vehicle is one of the most key parameters. In order to improve the recharge mileage, high pressure hydrogen storage is necessary like 35/70 MPa. However, decompress the hydrogen to a specific pressure fast and safely, which is suitable for hydrogen fuel cell, is very important. There are several types of research works also about this issue. For instance, Yamabe et al. [7,8] and Gerland et al. [9] investigated some nanoscale phenomena during high pressure hydrogen decompression, while Koga et al. [10] mainly observed the failure of a rubber O-ring

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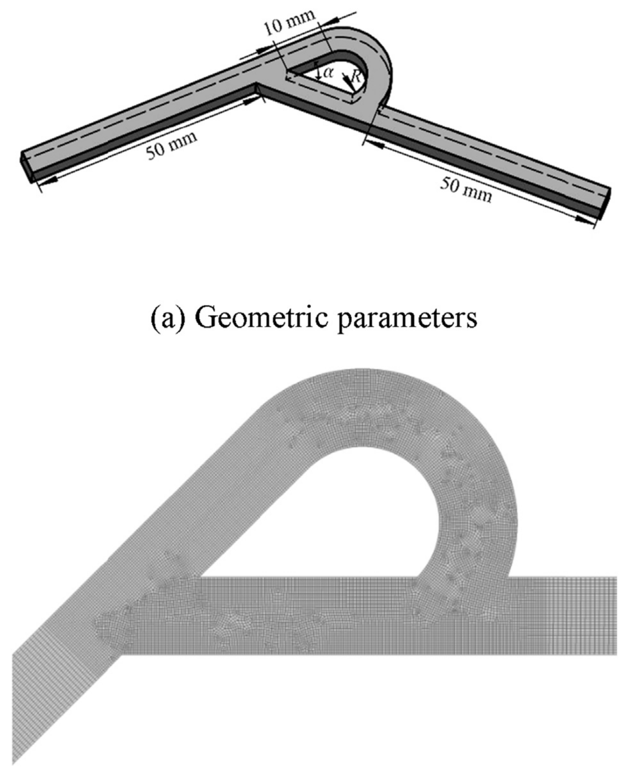
during the high pressure hydrogen decompression. Castagnet et al. [11] evaluated the swell during hydrogen sorption and decompression. At the same time, other researchers mainly paid attention to the hydrogen flow control devices, which was mainly realized by valves. For instance, Chen et al. [12] proposed a two-step high pressure reducing system for hydrogen fuel cell electric vehicle by using a pressure reducing valve. Jin et al. [13] and Qian et al. [14,15] both investigated the hydrogen flow through a multi-stage pressure reducing valve and a pilot control globe valve. Meanwhile, Amirante et al. [16,17] and Lisowski et al. [18,19] both carried out some fluid dynamic research on proportional directional valves, while Saha et al. [20] and Chattopadhyay et al. [21] paid attention to a pressure regulating valve. Specific to Tesla valves, it allows hydrogen flows in one direction easily but can produce a high pressure drop when hydrogen flows in the other direction, so it can also be applied to the situations when pressure reduction is needed. Due to without any moving parts, Tesla valves have obvious advantages when comparing with other valves, and some pioneer works have been successfully carried out in different applications. Thompson et al. [22] and de Vries et al. [23] found that Tesla-type check valve could increase the flow thermal performance under single or two-phase flow for heat pipes, and Thompson et al. [24] also found that the diodicity had a power-law relationship with the number of Tesla valve stages and valve-to-valve distance when the flow was laminar, while Wang et al. [25] investigated the geometrical parameters when there was a plate in Tesla-type micromixer to improve the mixing efficiency. Besides, Zhang et al. [26] found that high aspect ratio resulted in better performance under the same hydraulic diameter. Truong and Nguyen [27] found that the optimal values of valve angle and straight segment distance were related to flow rate and all of them took the main characteristic of Tesla valves with the forward flow and reverse flow.

As is mentioned above, there is no moving part in Tesla valve, and Tesla valves can produce high pressure drop when the hydrogen flow is reversed flow, so the demand of pressure reducing valve used together with Tesla valves can be reduced. Thus, Tesla valves can be nicely adopted for high pressure hydrogen decompression to increase safety and reduce costs. In this paper, the pressure drop of a Tesla valve in hydrogen decompression process is investigated by numerical methods. The structural parameters like the hydraulic diameter, the valve angle, and the inner curve radius are discussed to obtain a better pressure drop. The reliability of the adopted model is validated firstly, then the pressure and velocity distributions are plotted to find out the flow characteristics in a typical Tesla valve. This work is of significance for the further application of Tesla valve in hydrogen fuel cell electric vehicles, or other research works for hydrogen decompression.

Model description

Physical model

Fig. 1a shows the structure of a typical Tesla valve. Here, the hydraulic diameter D_H, the valve angle α, and the inner curve radius R are the key parameters. In this study, the inlet length, the outlet length, and the straight segment length are kept constant and their values are also shown in Fig. 1a. Besides, the values of the three investigated parameters will be given in the below section.



(a) Geometric parameters

(b) Mesh

Fig. 1 – Geometric parameters and mesh of Tesla valve.

Numerical model

In this paper, the working fluid is hydrogen gas and it is treated as a compressible Newtonian fluid. The continuity, the momentum, and the energy equations are shown in Eqs. (1)–(3).

$$\frac{\partial}{\partial x_j}(\rho u_j) = 0 \tag{1}$$

$$\frac{\partial}{\partial x_j}(\rho u_i u_j + p\delta_{ij} - \tau_{ij}) = 0 \tag{2}$$

$$\frac{\partial}{\partial x_j}\left(\rho u_j C_v T + u_j p + C_p \frac{\mu}{Pr}\frac{\partial T}{\partial x_j} - u_i \tau_{ij}\right) = 0 \tag{3}$$

where ρ is density, u is flow velocity, p is the pressure, μ is dynamic viscosity, Pr is Prandtl number, C_v and C_p are specific heat, δ_{ij} is Kronecker delta and τ_{ij} is viscous stress.

$$\tau_{ij} = \mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\mu\frac{\partial u_i}{\partial x_j}\delta_{ij} \tag{4}$$

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