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Review Paper

Numerical Investigation of Water Droplet Flow in the Cathode Channel of a PEM Fuel Cell with Transversal Blocked Flow Channel

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1. ABSTRACT

In this paper, the motion of water droplets inside a cathode gas channel of a polymer membrane fuel cell with transverse channel blocking is investigated numerically, biphasically, and two-dimensionally. 24 different blocked geometries are studied and the effect of the different block lengths (Wr) and the position of the block across the channel (λ) upon velocity and pressure contours, the shape of streamlines and droplet deformation is investigated and droplet discharge time, instant pressure drop, mean pressure drop, and instant and mean water coverage ratio are calculated. The results show that the channel becomes blocked and clogged for some geometries and in other cases where the droplet crosses the block, the discharge time decreases and the instant and average pressure drop and water coverage ratio increase by placing the barrier. According to the obtained results, the greatest decrease in discharge time (if there is no restriction in pressure supply) is for Wr=1.66 and λ=0.3. Also, the lowest instant pressure drop and water coverage ratio occur for Wr=0.66 and λ=0.3.

Keywords: Polymer Membrane Fuel Cell, Cathode Channel, Channel Block, Pressure Drop, Coverage Ratio, Water Management

2. INTRODUCTION

Fuel cells are electrochemical devices that directly convert the chemical energy resulting from the reaction of fuel and oxidizer into electricity and heat. Among the different types of fuel cells, the polymer membrane fuel cell can be widely used due to its high efficiency, suitable and low operating temperature, no pollution and short start-up time, and it is a suitable source of energy conversion in the future. The efficiency of fuel cells can reach a significant amount of 60% in the conversion of electrical energy, as well as a total amount of 80% in the combined heat and power generation with more than 90% reduction of the main pollutants [1]. Polymer membrane fuel cells work at relatively low temperatures, around 80°C. [1]. The presence of water in the polymer fuel cell membrane is necessary for the membrane to carry out ion conduction from the anode to the cathode. Proper management of water droplets produced in the cathode channel is an important factor to maintain the high performance of the polymer membrane fuel cell.

In this article, the process of water discharge in the cathode channel of parallel type with a rectangular barrier across the channel and in a partially blocked state is investigated and compared with the channel without barrier using two-phase simulation and the volume of fluid method. Also, the effect of changing the length of the barrier and changing the location of the barrier across the channel on water management parameters such as pressure, velocity, discharge time and water coverage ratio is investigated.

3. MATERIALS AND METHODS

Two-dimensional, unsteady and two-phase modelling of water management inside the cathode channel with a square cross-section along with initial and boundary conditions is expressed in this section.

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3.1. Geometry and modelling

The computational field is shown schematically in a typical channel (without a block) in Figure 1 (a) and the channel with a block in Figure 1 (b).

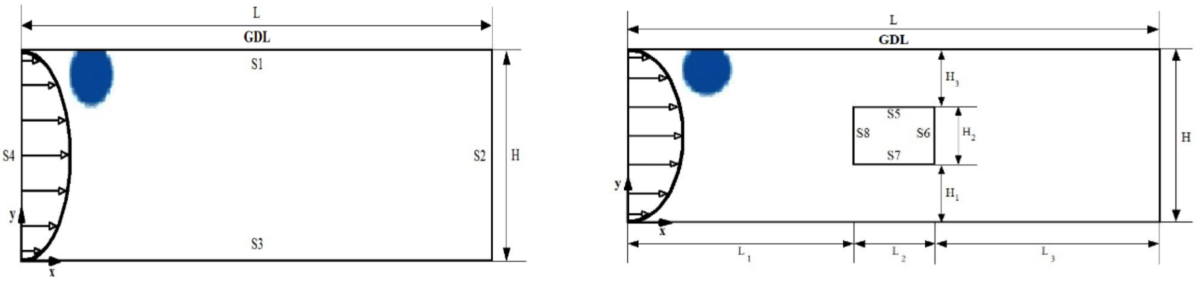
The geometric characteristics of the channel are given in Table 1, which is designed by adapting the general geometric plan of the channel presented by Perng et al. [2].

In this research, the changes in the length of the block and the location of the block across the channel are defined and changed by two parameters Wr and λ respectively, as follows:

$$\mathrm{Wr} = \frac{L_2}{H} \quad (1)$$

$$\lambda = \frac{H_3}{H} \quad (2)$$

Where L_2 is the length of the block and H_3 is the distance between the top of the block (S_5) and the wall of the channel (S_1).



(a) (b)

Figure 1. The computational field (a) without block (b) with block [2]

Table 1. Geometric characteristics of the channel

Parameters	Values (mm)
Channel Length (L)	10
Channel Height (H)	0.5
Distance between the block and top wall (H_3)	0.3

3.2. Governing equations and boundary conditions

The common assumptions in the modelling of droplet movement in the gas channel are given in reference [3]. The governing equations in modelling are: the mass conservation equation, the momentum conservation equation (Navier-Stokes) and the volume of fluid equation (VOF) used to model the interface between water droplets and gas flow. The flow of phases is assumed to be laminar and incompressible

In this paper, the density and dynamic viscosity used in the simulations are 998.2 kgm^{-3} and 0.001003 $kgm^{-1}s^{-1}$ for water and 1.225 kgm^{-3} and 1.78×10^{-5} $kgm^{-1}s^{-1}$ for air. The coefficient of surface tension between the water and air is 0.0719 Nm^{-1} and the acceleration of gravity is considered to be 9.81 ms^{-2}. Also, the initial velocity condition is zero. The simulations are performed at the maximum velocity of 5.7ms^{-1} (U_{max}) at the inlet. This maximum velocity has been obtained using the maximum Reynolds number (344.101) given in a study by Ashrafi et al. [4]. This Reynolds number is in the range of laminar flow.

3.3. Validation

In this section, the discharge time for inlet velocities (U_{max}) of 5 ms^{-1}, 10 ms^{-1} and 15 ms^{-1} are compared with the experimental results of research by Ashrafi et al. [4] and the results are presented in Table 2.

Table 2. Laboratory results, results of Ansys Fluent software and corresponding error for different input velocities

Air inlet velocity (ms^{-1})	Droplet discharge times (μs)		Error ٪
	Experimental results	Numerical results	
5	1.13	10.5	7.8
10	1.71	1.84	7.4
15	7.60	8.72	12.8

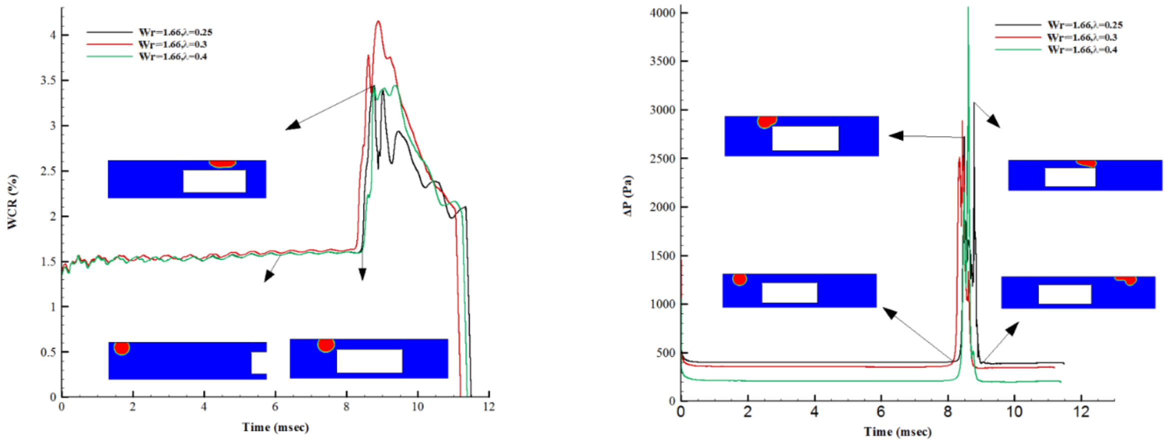
As is shown, the lowest error is 7.4% and the highest error is 12.8%, which shows a good agreement between the two sets of data.

4. RESULTS AND DISCUSSION

In this paper, 24 different geometries for the block are modelled and the effects of changes in the length of the block (Wr) and its position across the channel (λ) on the velocity and pressure contours, streamlines and the droplet shape have been investigated. The droplet discharge time, instant and average pressure drop and the instant and average water coverage ratio have been calculated in this study.

a. Investigating the effect of the location of the block across the channel

The water coverage ratio and presure drop in terms of time in the channel blocked by the barrier with the ratio of Wr=1.66 and λ=0.25, 0.3 and 0.4 are shown in Figure 2. The position of the drop in the channel with the λ=0.25 is also presented for times 6.15, 8.43 and 8.76 msec and 8.18, 8.49, 8.8 and 9.06 msec in Figures 2(a) and 2(b), respectively.



(a) (b)

Figure 2. (a) Water coverage ratio, (b) pressure drop, in terms of time at Wr=1.66 and λ=0.25, 0.3 and 0.4

As shown in Figure 2 (b), the pressure reduces along the channel in the direction of the flow and this indicates that the pressure gradient (dp/dx) along the channel is negative. It can also be shown that the pressure inside the droplet is higher than outside it, which is due to the surface tension forces at the interface between the droplet surface and the air. Unlike the channel without a block, the pressure changes with the movement of the drop along the channel, especially when the drop reaches the block and when the drop leaves the block.

5. CONCLUSION

In this paper, the water drop movement inside the polymer membrane fuel cell cathode channel along with the transverse block in different geometries (24 different geometries) has been numerically investigated. The main results obtained are:

- The presence of a block in the channel reduces the drop discharge time from 21.30% to 26.71%.
- The presence of a block increases the average pressure drop from 177.16% to 488.46% in the channel.
- In the cathode channel, when the drop reaches the block and is placed between the block and the top wall of the channel, the WCR increases, so it is better to make a more water-repellent surface in this part of the channel.
- Increasing the length of the block increases the pressure drop at constant λ.
- For λ smaller than 0.25, blockage occurs in the channel, and it is better to use λ=0.3 to avoid the unstable performance of the fuel cell.
- In general, blocking the channel with a block transversely does not have a significant effect on the average value of WCR.
- The best block ratio, if there is no restriction in providing the pressure drop, is related to the ratio of Wr=1.66 and λ=0.3, which a corresponding discharge time is 11.20 msec.
- The best block geometry is for Wr=0.66 and λ=0.3 according to instant pressure drop and water coverage ratio.
- For the management of the water inside the cathode channel of the fuel cell in real conditions, it is necessary to get the water to drop out faster to avoid blocking and disrupting the working process of the fuel cell. Also, checking the pressure drop to choose a system suitable for pumping and not having temporary pressure fluctuations is very important for the stable operation of the fuel cell.

6. REFERENCES

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