ABSTRACT: In developing a proton exchange membrane fuel cell, a high current density is encountered, thus requiring a novel flow field with great drainage performance. Our previous study proposed a novel compound flow field called an active drainage flow field with three inlets, which has an excellent output and drainage performance. Furthermore, the influence of muti-inlet reactant gas allocation on the three inlets is discussed in this study. The results showed that the small mass flow in the active drainage (AD) channel causes a waste of active area, while the large mass flow in the AD channel causes under-ribs convection. Considering the output and drainage performance, the 15% AD mass flow case shows the best performance under the high relative humidity investigation.

1. INTRODUCTION

A proton exchange membrane fuel cell (PEMFC) has high power density, low operating temperature, virtually zero emissions, and other advantages, making it one of the most promising energy conversion devices for the future.\textsuperscript{1−3} Because the power of a PEMFC is highly affected by water content in the membrane,\textsuperscript{4,5} a flow field with excellent water manageability is necessary.

Researchers have designed and evaluated various enhanced convective flow fields, and the results showed that enhanced convective flow fields could effectively drain water from porous electrodes and improve the current density.\textsuperscript{6−10} Baz et al.\textsuperscript{11} established a comprehensive three-dimensional two-phase mathematical model. The results show that the modified flow field model significantly improves the output performance, enhances under-rib convection mass transport through the gas diffusion layer, improves the reactant distribution on the surface of the catalyst layer, and decreases the water flooding effect in the gas diffusion layer−catalyst layer interface. Lee et al.\textsuperscript{12} proposed a new cathode flow field to enhance the water-retaining capability under the condition of excessive dry air supply. The simulation results show that the new cathode flow field design has better water retention performance than the traditional cathode flow field design (parallel flow channel configuration). Zeroual et al.\textsuperscript{13} studied the effect of inlet pressure and size of the channel on PEMFC performance by numerical simulation. It has been found that the mass transfer characteristics of the PEMFC are affected by inlet pressure and flow fields. Lee et al.\textsuperscript{14} designed a new multi-inlet flow field; results showed that the new design has a higher O\textsubscript{2} concentration and a more uniform water distribution. Therefore, a multi-inlet flow field can be developed for higher cell performance.

In our previous study, an active drainage flow field (ADFF) was proposed.\textsuperscript{15} The results revealed that the drainage performance of an ADFF is better than that of a conventional serpentine flow field (CSFF) and that the combination that the ADFF is taken as the anode while retaining the CSFF at the cathode (S-AD configuration) have better drainage performance and output performance than others. The under-rib flow occurred with a great pressure difference between the inlet and active drainage channels. The multi-inlet reactant gas allocation has a significant influence on the mass transfer characteristics of the flow field. Therefore, it is essential to study the effect of multi-inlet reactant gas allocation on ADFF PEMFC performance.

2. MODEL DESCRIPTION

2.1. Model Domain. The modeling domain consists of the bipolar plate (BP), channels, gas diffusion layer (GDL), microporous layer (MPL), catalyst layers (CL), and the membrane (mem) at the anode and cathode, as shown in Figure 1. The width of channels, width of ribs, and depth of
channels are all set to 1.0 mm. The remaining geometric parameters are shown in Table 1.

| parameters         | value  | units |
|--------------------|--------|-------|
| active area        | 250    | mm^2  |
| thickness of GDLs  | 0.2    | mm    |
| thickness of MPLs  | 0.05   | mm    |
| thickness of CLs   | 0.01   | mm    |
| thickness of membrane | 0.0508 | mm    |

Figure 2 shows the three-dimensional simplified schematic diagram of the ADFF. The inlet channels are interdigitated structures distributed on both sides. The outlet channel is a serpentine distributed between the inlet channels. Because of the dead-end characteristic of the interdigitated flow field, the reactant gas in the inlet channel has to reach the AD channel through an under-rib flow, which enhances the forced convection.

2.2. Numerical Procedures. The software Fluent 18.2 was used for the simulation in this study. The hydrogen and oxygen molar concentration in the section at the center of the flow channel (x = 25 mm) is used to verify the grid independence. The midpoints of the junction line between the flow channels and the gas diffusion layers are taken at the anode and cathode sides of the section, that is, the midpoints of the corresponding anode inlet flow channel, anode outlet flow channel, cathode inlet flow channel, and cathode outlet flow channel. The coordinates of the four points are (25,47,0.285), (25,49,0.285), (25,47,−0.285), and (25,49,−0.285), respectively. The specific location is shown in Figure 3. The line segments of points A, B, C, and D are divided into 4 equal parts, 8 equal parts, and 16 equal parts, respectively.
equal parts, respectively, that is, the total numbers of grids corresponding to the model are 2,080,000, 4,160,000, and 8,320,000, respectively. The molar concentrations of hydrogen and oxygen are compared at four points under different grid numbers, as shown in Figure 4. It can be seen from the figure that when the number of grids is increased from 2,080,000 to 8,320,000, with the increase of the number of grids, the molar concentrations of the four points changes very little, all within 2%. It can be considered that the number of grids of 2,080,000 has reached grid independence. The PEM fuel cell module of the Fluent software was used for the simulation. The calculation process first discretizes the coupled and nonlinear equations using the finite volume method and the SIMPLE algorithm for pressure–velocity coupling.

### 2.3. Model Assumptions
The fuel cell operates under a steady-state condition. The gases in the PEMFC (H₂, O₂, and N₂) are considered ideal and cannot dissolve in water. The porous electrodes are isotropic and homogeneous, with the same characteristic parameters in the same layer. Constant temperature boundary conditions are applied in the PEMFC outer surfaces, and the contact resistance is ignored. The effects of gravity are also ignored in the multicomponent transfer and reaction processes. The fluid flow was assumed to be laminar.

### 2.4. Boundary Conditions
The mass flow of hydrogen and oxygen required for fuel cell operation is obtained by the following equations:

![Figure 5. AD flow field PEMFC and testing equipment: (a) the bipolar plate of the CSFF, (b) bipolar plate of the ADFF, (c) assembly of the PEMFC, and (d) the FCT-6KW fuel-cell testing system.](https://doi.org/10.1021/acsomega.1c04649)
\[ \dot{M}_H = \lambda \cdot K_e^H I \]  
(1)

\[ \dot{M}_O = \lambda \cdot K_e^O I \]  
(2)

where \( \lambda \) is the excess coefficient, \( K_e^H \) is the electrochemical equivalent of hydrogen \((1.05 \times 10^{-8} \text{ kg A}^{-1} \text{s}^{-1})\), and \( K_e^O \) is the electrochemical equivalent of oxygen \((8.29 \times 10^{-8} \text{ kg A}^{-1} \text{s}^{-1})\).

\[ I = i \cdot A \]  
(3)

where \( i \) is the current density and \( A \) is the active area.

Tables 2 and 3 show the electrochemical and operation parameters, respectively.

**2.5. Governing Equation.** A steady-state, two-phase, three-dimensional model was employed with the governing equation given as follows:

**Continuity equation:**

\[ \frac{\partial (\varepsilon \rho u)}{\partial t} + \nabla \cdot (\varepsilon \rho u) = S_m \]  
(4)

where \( \varepsilon \) is the porosity of porous media and \( S_m \) is the mass source terms, computed according to the boundary.

\[ S_m = 0 \]  
(5)

\[ S_m \text{ in the channel, GDL, and MPL:} \]

\[ S_m = 0 \]

\[ S_m \text{ in the anode CL:} \]

\[ S_m = S_{H_2} = -\frac{M_{H_2}}{2F} \]  
(6)

\[ S_m \text{ in the cathode CL:} \]

\[ S_m = S_{O_2} + S_{H_2O} = \frac{M_{H_2O}}{4F} - \frac{M_{O_2}}{4F} \]  
(7)

where \( M_{H_2}, M_{O_2}, \) and \( M_{H_2O} \) are the molar fractions of hydrogen, oxygen, and water, respectively, and \( F \) is the Faraday constant.

**Momentum equation:**

\[ \frac{\partial (\varepsilon \rho u)}{\partial t} + \nabla \cdot (\varepsilon \rho u u) = -\varepsilon VP + \nabla \cdot (\varepsilon \rho u \nabla \phi) + S_u \]  
(8)

The expansion of the steady-state equation of eq 8 in the \( x, y, \) and \( z \) axes:

\[ u \frac{\partial (\varepsilon \rho u)}{\partial x} + v \frac{\partial (\varepsilon \rho u)}{\partial y} + w \frac{\partial (\varepsilon \rho u)}{\partial w} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left( \varepsilon \mu \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left( \varepsilon \mu \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z} \left( \varepsilon \mu \frac{\partial u}{\partial z} \right) \]

\[ + S_u \]  
(9)

\[ u \frac{\partial (\varepsilon \rho v)}{\partial x} + v \frac{\partial (\varepsilon \rho v)}{\partial y} + w \frac{\partial (\varepsilon \rho v)}{\partial w} = -\frac{\partial p}{\partial y} + \frac{\partial}{\partial x} \left( \varepsilon \mu \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y} \left( \varepsilon \mu \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial z} \left( \varepsilon \mu \frac{\partial v}{\partial z} \right) \]

\[ + S_v \]  
(10)

\[ u \left( \frac{\partial (\varepsilon \rho w)}{\partial x} \right) + v \left( \frac{\partial (\varepsilon \rho w)}{\partial y} \right) + w \left( \frac{\partial (\varepsilon \rho w)}{\partial w} \right) = -\frac{\partial p}{\partial z} + \frac{\partial}{\partial x} \left( \varepsilon \mu \frac{\partial w}{\partial x} \right) + \frac{\partial}{\partial y} \left( \varepsilon \mu \frac{\partial w}{\partial y} \right) + \frac{\partial}{\partial z} \left( \varepsilon \mu \frac{\partial w}{\partial z} \right) \]

\[ + S_w \]  
(11)

\[ S_m \text{ in the channel:} \]

\[ S_m = 0 \]  
(12)

In the GDL and MPL, the source term of eq 8 can be reduced to Darcy’s law:

\[ S_u = -\frac{K}{\mu} \nabla P \]  
(13)

where \( P \) (Pa) is the pressure, \( \mu \) (mPa s) is the fluid’s dynamic viscosity, and \( K \) is the permeability coefficient.

**Energy conservation equation:**

\[ \frac{\partial (\varepsilon \rho c T)}{\partial t} + \nabla \cdot (\varepsilon \rho c u T) = -\varepsilon \kappa \nabla^2 T + S_{\text{C}} \]  
(14)

**Species conservation equation:**

\[ \frac{\partial (\varepsilon \rho c_k)}{\partial t} + \nabla \cdot (\varepsilon \rho c_k u) = -\varepsilon \kappa \nabla^2 c_k + S_{c_k} \]  
(15)

where \( e \) is the species concentration, \( D_{k_{\text{eff}}} \) is the species effective diffusion coefficient, and \( S_{c_k} \) is the species source term.

In the diffusion layer of porous media, eq 15 can be reduced to Fick’s theorem.

\[ q_{j,k} = -D_{k_{\text{eff}}} \frac{\partial c_k}{\partial y} \]  
(16)

\[ D_{k_{\text{eff}}} = \varepsilon (1 - s) \rho F \]  
(17)

where \( q_{j,k} \) (kg/m²s) is the diffusion flux of component \( k \) in the \( y \) direction, \( D_k \) (m²/s) is the mass diffusivity of component \( k \) in porous media, \( s \) is the saturation of liquid water, \( D_k^0 \) (m²/s) is the mass diffusivity of component \( k \) at pressure \( P_0 \) and temperature \( T_0 \), \( P \) (Pa) is pressure, \( T \) (K) is temperature, and \( y \) is the pressure factor.

The conservation equations for the electronic and ionic charges:

\[ \nabla \cdot (\varepsilon_k \kappa_{k_{\text{eff}}} \nabla \phi_k) + S_{\phi_k} = 0 \]  
(18)

\[ \nabla \cdot (\varepsilon_m \kappa_{m_{\text{eff}}} \nabla \phi_m) + S_{\phi_m} = 0 \]  
(19)

where \( \kappa_{k_{\text{eff}}} (S/m) \) is the solid-phase electrical conductivity, \( \kappa_{m_{\text{eff}}} (S/m) \) is the membrane electrical conductivity, \( \phi_k \) (V) is the solid-phase electrical potential, \( \phi_m \) (V) is the membrane electrical potential, \( S_{\phi_k} \) is the source terms of electronic current, and \( S_{\phi_m} \) is the source terms of ionic current.

The Butler–Volmer equation:
Figure 6. Contours of current density at the interface between the cathode MPL and CL when the operating voltage is 0.3 V: (a) 5% AD mass flow, (b) 10% AD mass flow, (c) 15% AD mass flow, (d) 20% AD mass flow, (e) 25% AD mass flow, and (f) 30% AD mass flow.
where $j_{i}^\text{ref}$ (A/cm$^2$) is the reference exchange current density, $c_i$ is the species molar concentration, $c_{i,\text{ref}}$ is the reference species molar concentration, $\gamma$ is the concentration index, $\alpha$ is the coefficient of transmission, and $\eta$ (V) is the overpotential.

Formation and transport equation of liquid water:

\[
\frac{\rho \cdot \partial \varepsilon}{\partial t} + \nabla \cdot \varepsilon = - \frac{\partial (\rho \varepsilon \rho _W \dot{\varepsilon})}{\partial t}.
\]  

where $r_w$ is the condensation rate of water, $c_i$ is the constant, $p_w$ (Pa) is the water vapor pressure, $p_{sat}$ (Pa) is the water vapor saturation pressure, and $\rho_1$ (g/cm$^3$) is the density of liquid water.

3. EXPERIMENT SETUP

The conventional serpentine flow field (CSFF) and ADFF are designed and processed on a flexible graphite plate (Figure 5a,b). The active area of the PEMFC is 25 cm$^2$ (50 mm $\times$ 50 mm), the width of channels is 1 mm, the depth of channels is 1 mm, and the width of ribs is 1 mm. The GDL, MPL, CL, and mem thicknesses are 0.2, 0.05, 0.01, and 0.0508 mm, respectively. Nekson Power Technology Co., Ltd. constructed the membrane electrode assembly. The contact resistance between the bipolar and collector plates was reduced by coating the collector plate with gold. The S-AD configuration showed outstanding performance in the previous study. Therefore, the PEMFC with the S-AD configuration is assembled (Figure 5c).

The FCT-6KW fuel cell testing system (Nekson Power Technology Co., Ltd.) monitored and controlled the mass flow rate, temperature, humidity, and load of the PEMFC, as shown in Figure 5d. Tables 4 and 5 show the operating parameters. The polarization curve of the cell was evaluated after reaching a steady state. The current controlled the polarization curve; the current was increased by 2.5 A for each step and maintained for 2 min.

4. RESULTS AND DISCUSSION

4.1. Current Density Distributions. Current density is one of the essential parameters to ascertain the output performance and stability directly related to the rate of reaction. Figure 6 shows the contours of current density at the interface between the cathode CL and MPL when the operating voltage is 0.3 V. In these different AD mass flow rate scenarios, similar current density distributions were observed. However, the 5% AD mass flow case exhibited the least current density in the AD channel.
Because of the small mass flow inlet, the 5% AD mass flow case showed similar characteristics to the conventional interdigitated flow field. At the same time, the less reactant gas causes a low current density in the AD channel, especially at the end of channels marked in Figure 6. As shown in Figure 6b,c, the region near the AD inlet shows an abnormal low current density. The partially enlarged detail is shown in Figure 7. In the 10% AD mass flow case, the pressure difference between the AD channel and adjacent channels was relatively small; thus, the forced convection phenomenon is weak, and the current density is low. The most significant pressure difference is close to the inlet and the high current density region in the conventional interdigitated flow field. However, there is extra pressure in the AD channel, and the high current density occurs in the middle and rear of the activated area (marked area in Figure 6b,c) of the PEMFC. As the mass flow of the active drainage channel increased from 10 to 15%, the oxygen concentration in the middle and rear of the activation area increases, resulting in the increase of current density. Therefore, the homogeneity of the current density and output performance of the ADFF are excellent. With the increase of AD mass flow, the pressure of the AD channel near the inlet is higher than adjacent channels when the AD mass flow is more than 15%, causing reversed forced convection, i.e., the reactant gas reaches the inlet channels from the AD channel through the under-rib flow. Although the reversed forced convection increases the current density near the AD inlet, this phenomenon may cause the water to accumulate in the interdigitated inlet channel, which is adverse to the stability and performance of the PEMFC. Overall, the most significant performance case study is the 15% AD mass flow.

4.2. Pressure Distributions. Table 6 shows the simulation results of the pressure drop of gas distribution in the AD flow field when the operating voltage is 0.3 V. AD mass flows have a direct effect on pressure distribution. Figure 8 shows the pressure contours at the interface between the cathode flow field and GDL when the operating voltage is 0.3 V. There is a significant pressure difference between interdigitated inlet channels and AD channels, causing forced convolutions. However, different AD mass flows cause different phenomena at the start of the flow field. On the one hand, a small AD mass flow leads to insufficient driving force, and water is difficult to discharge from the flow field. On the other hand, a high AD mass flow leads to the transfer of reaction gas from the AD channel to the interdigitated inlet channel, which is a dead-end channel. The study with the 15% AD mass flow showed a small pressure difference at the start of the flow field and sufficient drainage force.

4.3. Relative Humidity Distribution. Figure 9a shows the contour of relative humidity at the interface between the cathode flow field and GDL when the operating voltage is 0.3 V. Similar to the contours of current density, high relative humidity occurs in the region under the ribs where the current density is high. Figure 9b shows the relative humidity curve of the imaginary line, which is marked in Figure 9a. In the upper half, the relative humidity in the AD channel is higher than that in the inlet channels. This indicates that the water in inlet channels flows into the AD channel, verifying the active drainage mechanism. Additionally, the relative humidity under the ribs in the lower half is high, with notable differences in drainage performance in these cases. Although the current density of the 15% AD mass flow case is the highest in this region, it showed the lowest relative humidity because of the excellent drainage performance.

4.4. Experimental Results of the Polarization Curve. According to the previous study, we have validated that the experimental data of the ADFF are consistent with the numerical results. In this paper, exploring the best reactant gas allocations of the S-AD configuration through experiments is our goal. The experiment on different reactant gas allocations of the S-AD configuration was conducted. Figure 10 shows the polarization curve of the experimental results. The performance difference in the low current density region is not obvious. However, with the increase in current density, the reaction produces more water, leading to significant differences in the various cases.

In the 5% AD mass flow case, water flooding occurs when the current density is more than 1.2 A/cm². Combined with the simulation results of pressure, the water flooding region may occur in the lower half of the AD channel. Unlike the conventional interdigitated flow field, the AD channel is surrounded by inlet interdigitated channels, with different flow directions on both sides of the AD channel. In addition, the gas in the AD channel has a low flow force. Therefore, it is difficult to drain the water in the lower half of the AD channel.

In the 25 and 30% AD mass flow cases, the water flooding condition also occurred when the current density was more than 1.2 A/cm². This condition occurred earlier in the 33.3% AD mass flow case. Combined with the pressure simulation results, the flooding region can be said to occur in the upper half of ribs and inlet channels because of the reversed forced convection. Similar to the numerical simulation results, the performance of the 15% AD mass flow case is the best among these cases, with excellent output performance and stability.

5. CONCLUSIONS

The effect of inlet gas allocations on mass transfer and output performance of an ADFF PEMFC is studied. The ADFF generated a stable pressure difference between adjacent flow channels. Additionally, the numerical simulation and experimental results show substantial differences in characteristics among different gas allocations. The small AD mass flow rate causes water flooding in the lower half of the ADFF because of the inadequate drainage force. In contrast, the large AD mass flow rate caused forced convection and low output performance because of the small pressure difference between the AD and inlet channels. The reversed forced convection occurs in the upper half of the ADFF. The region where reversed forced convection occurred is prone to flooding because of the dead-end characteristic of the interdigitated inlet channels. Considering the output and drainage performance, the 15% AD mass flow case is the best among these experimental cases under the high relative humidity investigation.
Figure 8. Contours of pressure at the interface between the cathode flow field and GDL when the operating voltage is 0.3 V: (a) 5% AD mass flow, (b) 10% AD mass flow, (c) 15% AD mass flow, (d) 20% AD mass flow, (e) 25% AD mass flow, and (f) 30% AD mass flow.
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Notes
The authors declare no competing financial interest.

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REFERENCES

(1) Zhu, M.; Xie, X.; Wu, K. C.; Najimi, A. U. H.; Jiao, K. Experimental Investigation of the Effect of Membrane Water Content on PEM Fuel Cell Cold Start. J. Energy Procedia 2019, 158, 1724−1729.
(2) Pei, P.; Chen, H. Main factors affecting the lifetime of Proton Exchange Membrane fuel cells in vehicle applications: A review. J. Appl Energ 2014, 125, 60−75.
(3) Wang, Y.; Chen, K. S.; Mishler, J.; Cho, S. C.; Adroher, X. C. A review of polymer electrolyte membrane fuel cells: Technology, applications, and needs on fundamental research. J. Appl Energ 2011, 88, 981−1007.
(4) Barbir, F. PEM Fuel Cells: Theory and Practice. J. Elsevier Academic Press, 2005.
(5) Buchi, F. N.; Srinivasan, S. Operating proton exchange membrane fuel cells without external humidification of the reactant gases. J. Electrochem. Soc. 1997, 144, 2767−2772.
(6) Chen, X.; Yu, Z.; Yang, C.; Chen, Y.; Jin, C.; Ding, Y.; Li, W.; Wan, Z. Performance investigation on a novel 3D wave flow channel design for PEMFC. Int. J. Hydrogen Energy 2021, 46, 11127−11139.
(7) Shen, J.; Tu, Z.; Chan, S. H. Performance enhancement in a proton exchange membrane fuel cell with a novel 3D flow field. J. Power Sources 2020, 457, 128034.
(8) Thitakamol, V.; Therdhthiamwong, A.; Therdhthiamwong, S. Mid-baffle interdigitated flow fields for proton exchange membrane fuel cells. Int. J. Hydrogen Energy 2011, 36, 3614−3622.
(9) Wang, X. F.; Qin, Y. Z.; Wu, S. Y.; Xiang, S. G.; Zhang, J. F.; Yin, Y. Numerical and experimental investigation of baffle plate arrangement on proton exchange membrane fuel cell performance. J. Power Sources 2020, 457, 228034.
(10) Lim, K.; Vaz, N.; Lee, J.; Ju, H. Advantages and disadvantages of various cathode flow field designs for a polymer electrolyte membrane fuel cell. Int. J. Heat Mass Tran 2020, 163, 120497.
(11) Baz, F. B.; Ookawara, S.; Ahmed, M. Enhancing under-rib mass transport in proton exchange membrane fuel cells using new serpentine flow field designs. *Int. J. Hydrogen Energy* 2019, *44*, 30644–30662.

(12) Lee, J.; Gundu, M. H.; Lee, N.; Lim, K.; Lee, S. W.; Jang, S. S.; Kim, J. Y.; Ju, H. Innovative cathode flow-field design for passive air-cooled polymer electrolyte membrane (PEM) fuel cell stacks. *Int. J. Hydrogen Energy* 2020, *45*, 11704–11713.

(13) Zeroual, M.; Bouzida, S. B.; Benmoussa, H.; Bouguettaia, H. Numerical Study of the Effect of the Inlet Pressure and the Height of Gas Channel on the Distribution and Consumption of Reagents in a Fuel Cell (PEMFC). *J. Energy Procedia* 2012, *18*, 205–214.

(14) Lee, S.; Kim, T.; Park, H. Comparison of multi-inlet and serpentine channel design on water production of PEMFCs. *J. Chem. Eng. Sci* 2011, *66*, 1748–1758.

(15) Wang, Y.; Wang, L.; Ji, X.; Zhou, Y.; Wu, M. Experimental and Numerical Study of Proton Exchange Membrane Fuel Cells with a Novel Compound Flow Field. *ACS Omega* 2021, 21892.