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EXPERIMENTAL STUDY ON THE PERFORMANCE OF A 100 W PEM FUEL CELL UNDER THE INFLUENCE OF HYDROGEN PRESSURE

ESTUDO EXPERIMENTAL SOBRE O DESEMPENHO DE UMA CÉLULA DE COMBUSTÍVEL PEM DE 100 W SOB A INFLUÊNCIA DA PRESSÃO DE HIDROGÊNIO

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Abstract

PEM fuel cells are a clean, efficient, and low-emission energy source. However, the system performance is highly dependent on operating conditions, especially the inlet pressure. This study focused on a 100W PEMFC fuel cell system operating under a 1Ω resistive load, allowing a current of approximately 8A. Experiments were performed at pressure levels of 0; 0.25; 0.5; 0.75 and 1bar. Parameters such as voltage, current, pressure, and hydrogen flow were measured, processed, and analyzed to evaluate the impact of pressure changes on system performance. The results showed that the inlet hydrogen pressure strongly affected the performance and stability of the 100W PEM cell. At 0.25 bar, the performance was highest but fluctuated greatly, while at 0.5–0.75bar, the performance decreased slightly but the operation was more stable. In particular, at 0.75bar the system maintains stable current and voltage, suitable for continuous exploitation and safer than other levels.

Keywords: Proton Exchange Membrane Fuel Cell (PEMFC). Water and Heat Management in PEMFC. Hydrogen Discharge. Hydrogen Safety. Hydrogen Gas.

Resumo

As células a combustível PEM são uma fonte de energia limpa, eficiente e de baixa emissão. No entanto, o desempenho do sistema depende muito das condições de operação, especialmente da pressão de entrada. Este estudo focou em um sistema de célula a combustível PEMFC de 100 W operando sob uma carga resistiva de 1 Ω, permitindo uma corrente de aproximadamente 8 A. Os experimentos foram realizados em níveis de pressão de 0; 0,25; 0,5; 0,75 e 1 bar. Parâmetros como tensão, corrente, pressão e fluxo de hidrogênio foram medidos, processados e analisados para avaliar o impacto das mudanças de pressão no desempenho do sistema. Os resultados mostraram que a pressão de hidrogênio na entrada afetou fortemente o desempenho e a estabilidade da célula PEM de 100 W. A 0,25 bar, o desempenho foi o mais alto, mas apresentou grandes flutuações, enquanto entre 0,5 e 0,75 bar, o desempenho diminuiu ligeiramente, mas a operação foi mais estável. Em particular, a 0,75 bar, o sistema mantém corrente e tensão estáveis, adequadas para exploração contínua e mais seguras do que em outros níveis.

Palavras-chave: *Célula a Combustível de Membrana de Troca de Prótons (PEMFC). Gerenciamento de Água e Calor em PEMFC. Descarga de Hidrogênio. Segurança do Hidrogênio. Gás Hidrogênio.*

1 INTRODUCTION

During the development of proton exchange membrane fuel cells (PEMFCs), many research groups have focused on understanding the mechanisms of current distribution, heat distribution, water management, as well as optimizing design and control strategies to improve the efficiency and durability of the system. One of the pioneering works in this field was conducted by S. Park and colleagues [1], who carried out an experimental study on the simultaneous distribution of current density and temperature inside a PEMFC. By using micro-sensors to measure at multiple positions within the cell, the study revealed that non-uniform distributions are the main cause of performance degradation and reduced operational lifespan. The important contribution of this work was to provide a scientific basis for designing and optimizing flow channel structures to achieve higher uniformity during operation. The findings of S. Park and his team not only clarified the physical phenomena in PEMFCs but also paved the way for subsequent studies on channel geometry improvement and cooling methods. Continuing in this research direction, Z. Qi and colleagues [2] focused on designing high-performance PEMFC stacks without the need for complex cooling systems. Through improvements in open-cathode structure and the application of optimized materials, the team demonstrated that PEMFCs can maintain stable performance even when operating at room temperature. This represents an important direction toward reducing system costs, increasing portability, and expanding the application range of PEMFCs, especially in portable energy devices. The work of Z. Qi and colleagues shows the potential for simplified yet efficient PEMFC designs, contributing to the realization of compact, low-cost commercialization. In another approach, T. Berning and colleagues [3] used numerical modeling combined with experimental data to analyze heat distribution within PEMFCs. The results indicated that thermal gradients form due to non-uniform heat transfer in the proton exchange membrane and electrode layers, which directly affect electrochemical performance and water management capability. These findings emphasize the need to optimize flow field design and cooling systems to minimize thermal gradients, thereby improving durability and operational efficiency. The study by T. Berning and colleagues clearly demonstrates the critical role of combining numerical simulation and experiments in understanding and optimizing thermodynamic behavior in PEMFCs. In addition to studies focusing on intrinsic physical aspects, X. Li and colleagues [4] investigated the dynamic response of integrated electrical systems using PEMFCs. The authors built a test model to evaluate variations in voltage, current, and load response characteristics under different operating conditions. The results showed that the dynamic characteristics of PEMFCs significantly affect the stability of the electrical system, thus requiring coordinated control strategies to reduce fluctuations and enhance operational reliability. This work expanded the understanding of PEMFCs not only as individual cells but also as components in complex electrical systems where dynamic stability plays a crucial role. In the field of heat transfer, M. Shimpalee and colleagues [5] conducted a 3D numerical simulation study to analyze heat transfer processes and propose cooling solutions for PEMFCs. Using CFD modeling, the team investigated the effects of coolant flow rate, channel configuration, and various thermally conductive materials. The results demonstrated that applying optimal cooling strategies not only reduces thermal gradients but also maintains stable performance and extends the operational lifespan of PEMFCs. The work of M. Shimpalee and colleagues provided a comprehensive analytical framework that serves as a valuable reference for subsequent studies in PEMFC cooling system design. Complementing this direction, Y. Wang and colleagues [6] developed a self-regulating cooling solution to maintain optimal operating temperature for PEMFCs. Unlike conventional cooling systems that require complex control devices, this method is based on a self-balancing mechanism responding to load and environmental conditions. Through experiments, the group demonstrated that the self-regulating cooling system not only maintains stable temperature but also reduces control costs, increases reliability, and enhances applicability in portable devices. This study proved the feasibility of developing simplified yet efficient PEMFCs for mobile energy demands. Another notable contribution from S. Shimpalee and colleagues [7] combined both experimental and simulation approaches to analyze the performance of portable PEMFC stacks. The research team conducted power and current distribution tests and then calibrated the simulation model to reflect real operating characteristics. The results showed that portable PEMFC stacks can achieve high efficiency while maintaining stable operation. Furthermore, the developed numerical model can be used as a tool for future design optimization. This work reinforced the confidence in the practical application potential of PEMFCs in mobile energy systems. In parallel, J. Wu and colleagues [8] focused on thermal management in PEMFC systems. They proposed a thermodynamic analysis model combined with temperature control strategies to reduce thermal gradients and prevent dehydration in the proton exchange membrane. Experimental results indicated that effective thermal management significantly improves performance while increasing durability and system stability, especially in high-power applications. This study holds great practical significance as it addresses one of the key challenges in PEMFC operation—the balance between thermal and water management. Alongside thermal management, water management has also received considerable attention from researchers. L. Ma and colleagues [9] conducted a comprehensive experimental study on water management mechanisms in PEMFCs. By measuring water distribution in the membrane and flow channels under various load conditions, the authors highlighted the importance of water removal in maintaining stable performance. The study confirmed that a proper water management strategy is crucial to prevent flooding and ensure long-term cell stability. The work of L. Ma and colleagues added an important scientific foundation for the practical design and operation of PEMFCs. Finally, H. Yu and colleagues [10] proposed an adaptive coordinated control method for the gas supply system of PEMFCs. By developing a nonlinear control algorithm, the team successfully balanced gas flow and load response rapidly. Experiments showed that this approach significantly improved voltage stability, reduced oscillations during load transitions, and enhanced overall system efficiency. This represents a key contribution in the control field, demonstrating that the application of advanced control techniques is essential for improving PEMFC performance under complex real-world conditions. In the next stage of PEMFC development and optimization, many studies have focused more intensively on intelligent control strategies, thermal management, and especially water management through purge cycles. These works not only contribute to improving efficiency but also ensure long-term operational stability. First, K. Zhang and colleagues [11] developed a simulation model for water-cooled PEMFCs while applying intelligent control algorithms to maintain stable operating temperature. Their approach, based on fuzzy control combined with parameter optimization, minimized temperature deviations under varying loads. The study showed that the system not only maintained stable operation but also improved efficiency and reduced membrane degradation risk. Notably, the work of K. Zhang and colleagues confirmed the effectiveness of artificial intelligence in PEMFC management and control, opening a new direction for applying AI technologies in clean energy systems. Meanwhile, H. Xu and colleagues [12] focused on gas purge strategies for PEMFCs operating under variable loads. The authors built a model and conducted experiments to determine the optimal purge frequency and duration to prevent flooding—a major issue leading to performance loss. The results indicated that appropriate purge strategies help maintain stable voltage and extend cell lifespan, which is particularly valuable for continuous and fluctuating operations. The study of H. Xu and colleagues plays a key role in developing solutions for excess water control, enhancing PEMFC reliability in practical applications. Following this direction, Y. Zhao and colleagues [13] investigated the dynamic evolution of local current density and water–gas distribution inside PEMFCs. Using micro-sensors, the team observed detailed changes in parameters during operation. The experiments revealed that local flooding directly affects current distribution and reduces overall system performance. The work of Y. Zhao and colleagues provided deep insights into PEMFC internal mechanisms, especially regarding the interaction between current distribution and water management. Building on this, Q. Chen and colleagues [14] conducted a comprehensive analysis of gas purge strategies for PEMFCs, combining experimental and quantitative evaluation methods. They established a set of indices to compare different purge approaches and identified the optimal solution. The findings showed that applying an appropriate purge strategy not only improves performance and cell lifespan but also significantly reduces hydrogen consumption—an essential factor for enhancing system economics. The work of Q. Chen and colleagues provided a scientific foundation for balancing energy efficiency and durability in PEMFC operation. Continuing this research trend, J. Liu and colleagues [15] focused on closed-anode PEMFCs, where water flooding is more severe due to limited gas exhaust capacity. Through experiments, the group determined the optimal purge cycle ensuring long-term stability. The results indicated that when purge frequency and duration are properly adjusted, the cell can operate stably over long periods without flooding. The work of J. Liu and colleagues demonstrated that optimizing purge cycles is crucial for improving durability and practical applicability of PEMFCs. Beyond experiments, M. Bazylak and colleagues [16] combined numerical simulation and experiments to analyze liquid water transport in PEMFCs. The team developed a CFD model calibrated with experimental data, enabling accurate prediction of water distribution in channels and electrodes. The results showed that flow field design plays a critical role in water management. This work not only enhanced understanding of water transport phenomena but also proved the effectiveness of hybrid experimental–simulation approaches in PEMFC research. Meanwhile, X. Wang and colleagues [17] investigated operational stability of PEMFCs with closed-anode configurations. Experiments revealed that water and inert gas accumulation in the anode are main causes of instability and performance loss. To address this, the group proposed periodic gas purging, which improved performance and extended cell lifespan. The study by X. Wang and colleagues is significant as it provides a practical solution for improving PEMFC stability under real-world conditions. Building on this foundation, L. Yang and colleagues [18] analyzed optimal purge durations for closed-anode PEMFCs. Experimental investigations under various purge times evaluated their effects on voltage, efficiency, and cell durability. The results showed the existence of an optimal purge duration balancing water removal and hydrogen loss. The study by L. Yang and colleagues offered essential experimental evidence for designing rational purge cycles in PEMFC operation. Parallel to these experimental studies, C. Xu and colleagues [19] employed CFD simulations to analyze purge strategies in closed-anode PEMFCs. Their model simulated gas flow distribution, water accumulation, and the effects of purge frequency on performance. The simulated results agreed well with experimental data, confirming the usefulness of simulations for optimizing purge strategies, reducing testing costs, and enhancing design efficiency. The study by C. Xu and colleagues provides clear evidence for integrating numerical modeling in PEMFC operational optimization. Further refining this perspective, R. Lin and colleagues [20] performed a combined experimental and simulation study to optimize purge cycles in PEMFC systems. The team identified the most reasonable purge interval and frequency that maintain stable performance while minimizing fuel consumption. The results demonstrated the high practicality of their strategy, offering valuable guidance for long-term PEMFC operation across various applications. The work of R. Lin and colleagues directly contributed to enhancing the practical viability of PEMFCs. In parallel with the previous research directions, many scholars have focused on gas purge strategies at both the cathode and anode, as well as on special operating conditions of PEMFCs. These studies contribute to a more comprehensive research framework encompassing gas and water management, as well as optimization of efficiency and durability. Beginning this group, H. Zhou and colleagues [21] analyzed the influence of cathode purge strategies on oxygen utilization efficiency in PEMFCs. Through a series of experiments, they compared various cathode purge methods to determine how to maintain stable oxygen concentration at the electrode surface. The findings showed that selecting a suitable cathode purge strategy improves electrochemical performance and reduces oxygen deficiency losses. The study of H. Zhou and colleagues emphasized the central role of cathode management in PEMFC operation, which has often been overlooked compared to anode management. Subsequently, C. Zhang and colleagues [22] aimed to optimize PEMFC performance by adjusting operating conditions combined with purge frequency. Experimental results showed that parameters such as gas flow rate, temperature, and purge cycle directly affect voltage and cell durability. Particularly, the team demonstrated that when these factors are optimally synchronized, overall performance improves significantly while water flooding is mitigated. The study of C. Zhang and colleagues provided clear scientific evidence that optimizing operating conditions must be accompanied by appropriate purge strategies to achieve maximum efficiency. Meanwhile, Y. Kim and colleagues [23] investigated the effects of hydrogen purging on PEMFC performance and durability. Through detailed experiments, they evaluated changes in voltage, water distribution, and degradation after multiple operating cycles. The results indicated that proper hydrogen purging not only removes inert gases but also significantly reduces water flooding, thereby extending cell lifespan. The study of Y. Kim and colleagues introduced a new perspective, highlighting the importance of hydrogen management in improving PEMFC operation. Similarly, L. Sun and colleagues [24] examined the effect of purge duration on the performance of closed-anode PEMFCs under gravitational conditions. Experiments showed that if the purge duration is too short, inert gases are not fully expelled, while excessive purge time leads to unnecessary hydrogen loss. The team identified an optimal purge duration balancing performance maintenance and fuel conservation. The study of L. Sun and colleagues holds high practical significance, providing a scientific basis for selecting suitable operational parameters in real-world applications. Adding another important aspect, X. Zhu and colleagues [25] focused on purge strategies during PEMFC shutdown. Experimental studies showed that residual water in the cell can cause flooding, corrosion, and performance degradation during restart. By applying an appropriate purge cycle at shutdown, the system maintained stable startup voltage and prolonged lifespan. The study of X. Zhu and colleagues proposed a practical solution to enhance PEMFC durability during frequent on/off cycles—conditions commonly encountered in real applications. In another study, H. Gao and colleagues [26] analyzed the effects of pressure conditions on purge strategies in PEMFCs. Experimental results revealed that operating pressure directly influences water and inert gas accumulation in the anode. Adjusting the purge cycle according to pressure demonstrated the ability to maintain stable performance while reducing flooding risk. The work of H. Gao and colleagues broadened the scope of gas management research, offering a flexible approach for operating PEMFCs under different pressure conditions. Additionally, M. Chen and colleagues [27] focused on optimizing purge cycles for PEMFCs operating under variable load conditions. Combining modeling and experiments, they showed that load fluctuations strongly affect water distribution and performance. Accordingly, the team proposed load-adaptive purge strategies that improve voltage stability and prevent performance degradation. The study of M. Chen and colleagues represents an important contribution, offering a flexible and effective solution for real-world PEMFC applications. Completing this group, R. Huang and colleagues [28] analyzed and compared multiple purge methods to enhance PEMFC operational reliability. These included hydrogen purge, cathode purge, and combined purge. Experimental results showed that each method has its own advantages; however, the combined strategy provides the most comprehensive effectiveness in removing inert gases and preventing flooding. The study of R. Huang and colleagues confirmed the central role of purge strategies in improving PEMFC durability, providing important guidance for practical design and operation. From the 28 research works reviewed, it can be observed that the development of PEMFCs simultaneously depends on several key factors, including thermal management, water management, gas purge strategies, and intelligent control techniques. The studies of S. Park, Z. Qi, and T. Berning laid the foundation for understanding current and thermal distribution, establishing the basis for improvements in flow field design and cooling systems. The works of X. Li, M. Shimpalee, and Y. Wang further expanded understanding of dynamic response, numerical simulation, and self-regulating cooling solutions, emphasizing the necessity of structural optimization and thermal management.

Subsequently, the series of studies from H. Xu and colleagues to R. Lin and colleagues clarified the crucial role of gas purge strategies in maintaining stable performance and extending the lifetime of fuel cells. In particular, the works of Y. Zhao and colleagues, M. Bazylak and colleagues, and C. Xu and colleagues emphasized the strength of combining numerical simulation with experimental approaches to gain deep insight into operational mechanisms and design optimization. Finally, the research groups from [21–28], represented by H. Zhou and colleagues, C. Zhang and colleagues, Y. Kim and colleagues, together with R. Huang and colleagues, expanded the research framework by analyzing the effects of the cathode, hydrogen, pressure, variable loads, and even shutdown cycles. These results demonstrate that a comprehensive management strategy—integrating thermal management, water management, and flexible purge control—is the key to bringing PEMFC technology closer to long-term practical applications. Thus, all the aforementioned studies together form an interconnected knowledge system, spanning from fundamental understanding to applied solutions, from numerical simulation to experimental validation, and from structural design to control strategies. This report affirms that the sustainable and efficient development of PEMFCs requires the coordinated integration of multiple disciplines: materials science, mechanical design, numerical modeling, control engineering, and operational optimization. The contributions of international research groups not only drive scientific advancement but also bring PEMFCs closer to real-world applications in clean, mobile, and sustainable energy systems. This study provides a foundation for developing a deep learning–based training approach for fuel cell systems under varying pressures, aiming to propose control strategies for the efficient utilization of hydrogen across different load conditions.

2 EXPERIMENTAL SETUP

2.1 Experimental model of a 100 W PEM fuel cell system under the influence of inlet pressure

The experimental setup is illustrated in Figure 1. All experiments were conducted using a 100W PEM fuel cell (H100, Horizon Fuel Cell Technologies, Singapore) with an active area of 22.5cm². Hydrogen gas was supplied from a compressed H_2 cylinder through a gas pressure regulator (Regulator Hydrogen Gas, TANAKA Brand, Japan). The pressure regulator allowed adjustment of the inlet pressure in the range of 0–1bar to investigate its effect on energy conversion efficiency. Pressurized air (Airtac Brand, Taiwan) and a hydrogen flow meter (M-20SLPM-D/5M, Alicat Scientific Inc., USA) were also integrated into the system. In this setup, the original controller of the fuel cell stack was replaced by a laboratory microcontroller unit (MCU) to control the 100W fan speed and perform the anode purging process. The operating parameters were monitored using a temperature sensor (RS20K-C, SULINKIOT, China), a pressure sensor (ES-P300, Electesla, China), as well as voltage and current sensors. The output electrical power was connected to a 1Ω resistive load to maintain a load current of approximately 8 A. All measurement signals, including pressure, flow rate, voltage, current, and temperature, were collected through the MCU-based control system and transmitted to a computer for real-time visualization in MATLAB Simulink. The integration of the schematic diagram and the experimental model enabled quantitative evaluation of the effect of inlet pressure on operational efficiency while enhancing the safety and reliability of the PEM fuel cell system.

Figure 1

Schematic diagram of the experimental setup for monitoring the effect of inlet pressure levels on the PEM fuel cell system.

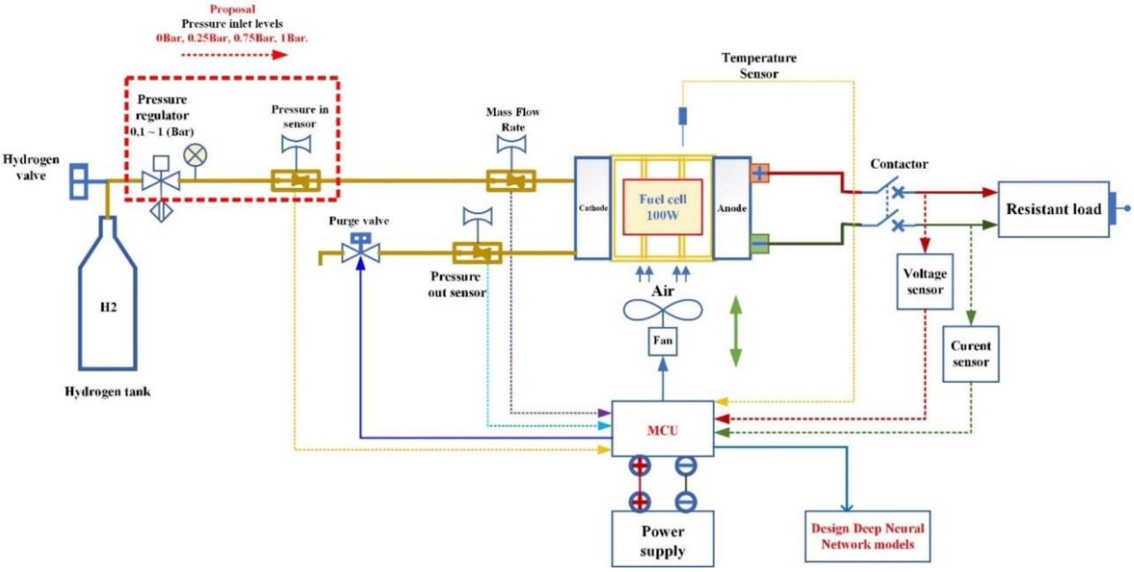
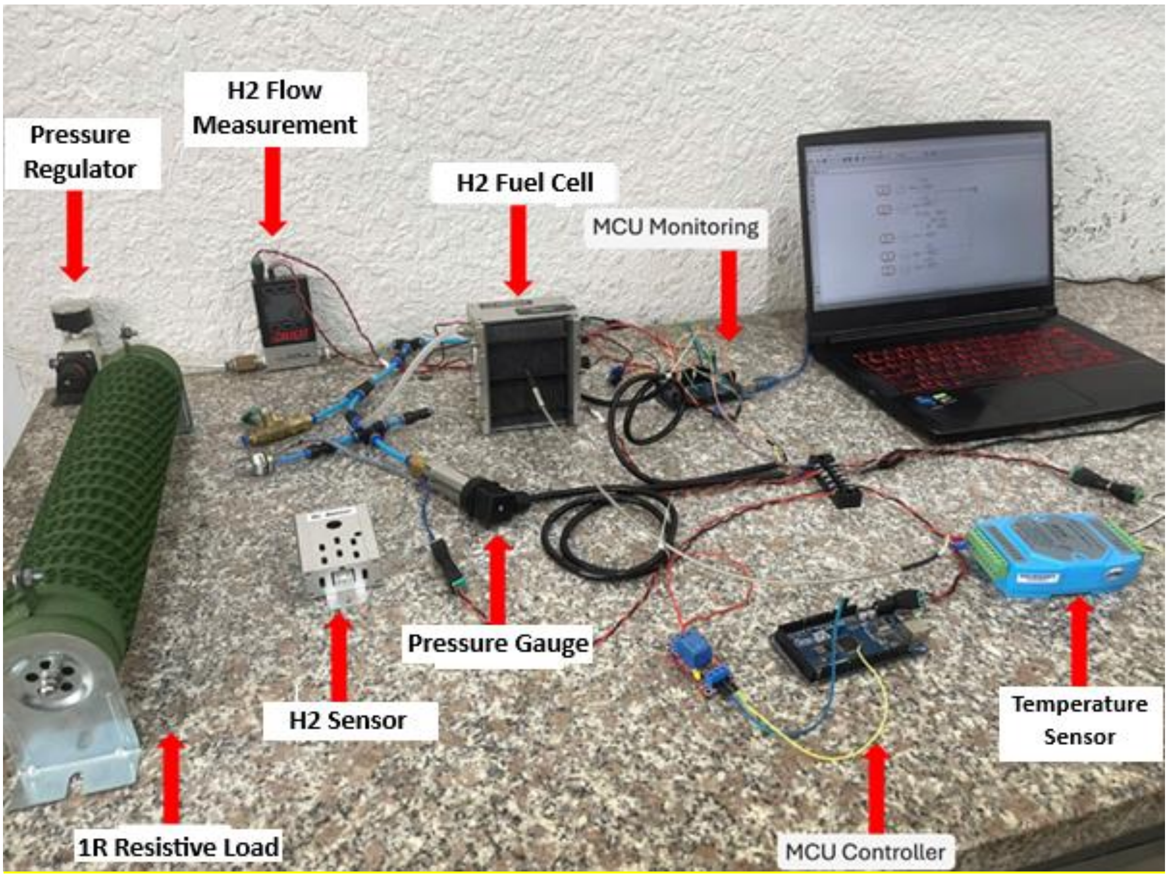


Figure 2 illustrates the experimental model designed to systematically measure key operational parameters, including electrical current, voltage, system pressure, and hydrogen flow rate. This setup enables precise data acquisition for analyzing the performance and behavior of the fuel cell under controlled conditions, facilitating a comprehensive evaluation of system efficiency and operational dynamics.

Figure 2

Experimental system model simulating the fuel cell.



2.2 Methodology of the experiment

First, the fuel cell system was operated under no-load conditions at 0.5bar until the open-circuit voltage (OCV) stabilized. Subsequently, the fuel cell was tested at different pressure levels—0 bar, 0.25bar, 0.5bar, 0.75 bar, and 1bar—for 20 minutes under varying load conditions. During the experiments, electrical current, voltage, system pressure, and hydrogen consumption were measured to evaluate the operational efficiency of the system. The efficiency of the fuel cell system is calculated using the following formula:

$$\eta(t)=\frac{P_{out}(t)}{m_{H_2}(t).LHV_{H_2}} \qquad (1)$$

Where:

- $\eta(t)$: Efficiency
- $P_{out}(t)$: Electrical output power at time t (W). Usually measured directly as $P_{out} = V(t). I(t)$ (V: voltage (V); I: current (A)).
- $m_{H2}(t)$: Hydrogen mass flow rate (kg/s) at time t. (Preferably measured using a mass flow meter). $m_{H2}(t)$
- LHV_{H2}: Lower heating value of hydrogen.

3 RESEARCH RESULTS

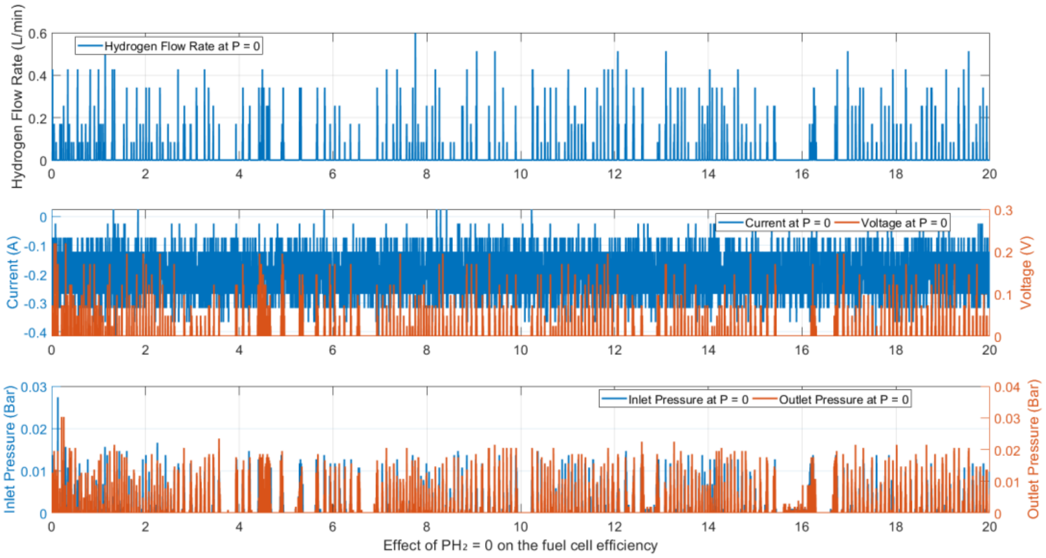
The experimental results for evaluating the system efficiency under the influence of pressure regulation show that the hydrogen fuel cell system is significantly affected by the pressure levels of 0 bar, 0.25bar, 0.5bar, 0.75bar, and 1bar. The efficiency of the hydrogen fuel cell system was assessed under these different pressure conditions.

3.1 Effect of 0bar pressure on the hydrogen fuel cell system

Figure 3 shows the hydrogen flow rate, current, voltage, and input/output pressures of the fuel cell system with a 1Ω resistive load connected. The results indicate that at the initial stage, when the load is applied, the system exhibits large fluctuations in hydrogen flow, current, and voltage due to the near-zero input pressure, which is insufficient to maintain a stable operating state. Voltage drops to low values (0.05–0.3V), current fluctuates between –0.4 and 0A, and hydrogen flow varies significantly from 0 to 0.6L/min, demonstrating irregular electrochemical reactions. Both input and output pressures remain very low (below 0.1bar), with the output pressure consistently lower than the input, indicating pressure losses during gas delivery. The analysis also shows that at 0 bar input pressure, hydrogen flow decreases and fluctuates strongly, causing voltage and current instability. Conversely, when input pressure is increased, hydrogen supply becomes more stable, current maintains higher levels (with smaller fluctuations around a stable negative value), and voltage varies less, thereby improving fuel cell system efficiency. Mechanistically, input pressure directly affects hydrogen diffusion to the anode catalyst surface. At low pressure, local fuel starvation occurs, interrupting the electrochemical reaction and reducing voltage and current. As pressure increases, diffusion improves, redox reactions proceed more uniformly, and voltage and current stabilize. However, pressures above the optimal level may increase hydrogen consumption or cause mechanical losses without further performance improvement. Therefore, selecting and controlling the appropriate input pressure is crucial for the stability and energy conversion efficiency of the fuel cell system. In conclusion, Figure 3 demonstrates that input pressure plays a decisive role in fuel cell stability and performance: at too low a pressure, the system cannot maintain stable voltage and current, whereas at an appropriately controlled pressure, hydrogen is adequately supplied, enabling the system to operate more stably and efficiently.

Figure 3

Diagram of current, voltage, input pressure, output pressure, and hydrogen consumption of the fuel cell at an input pressure of 0bar.

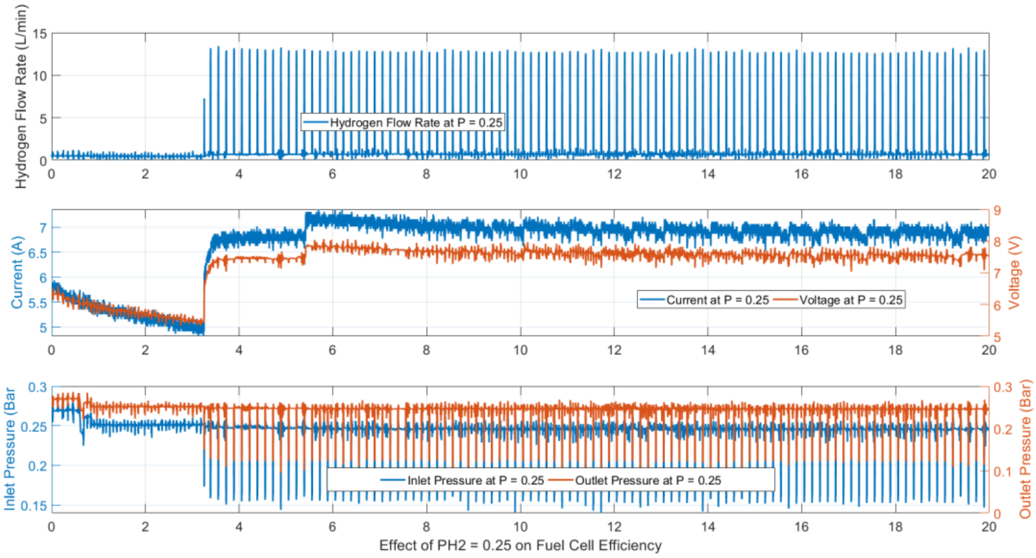


3.2 Effect of 0.25bar pressure on the hydrogen fuel cell system

Figure 4 shows the hydrogen flow rate, current, voltage, input pressure, and output pressure of the fuel cell system with a 1Ω resistive load connected at an input pressure of 0.25bar. The results indicate that the hydrogen flow rate begins to increase significantly after the third minute, fluctuating cyclically between 10–15L/min while stabilizing around 0.6–0.8L/min, reflecting a continuous fuel supply for the electrochemical reaction. The current gradually rises from approximately 5A to above 7A and remains stable throughout the process, while the voltage is maintained at a high level, oscillating around 7–8V. The input pressure stays around 0.25bar with minor fluctuations, and the output pressure is lower but varies synchronously with the input, indicating some pressure loss within acceptable limits. These results demonstrate that the system operates stably, hydrogen is supplied consistently, and the fuel cell achieves high energy conversion efficiency. Mechanistically, maintaining an input pressure of 0.25bar ensures continuous and effective diffusion of hydrogen to the anode, stabilizing the redox reaction, reducing fluctuations in operational parameters, and enhancing overall system stability. The conclusion from Figure 4 is that the fuel cell system operates reliably at an input pressure of 0.25bar, with hydrogen flow rate, current, and voltage remaining high and stable, ensuring good energy conversion performance.

Figure 4

Diagram of current, voltage, input pressure, output pressure, and hydrogen consumption of the fuel cell at an input pressure of 0.25bar.

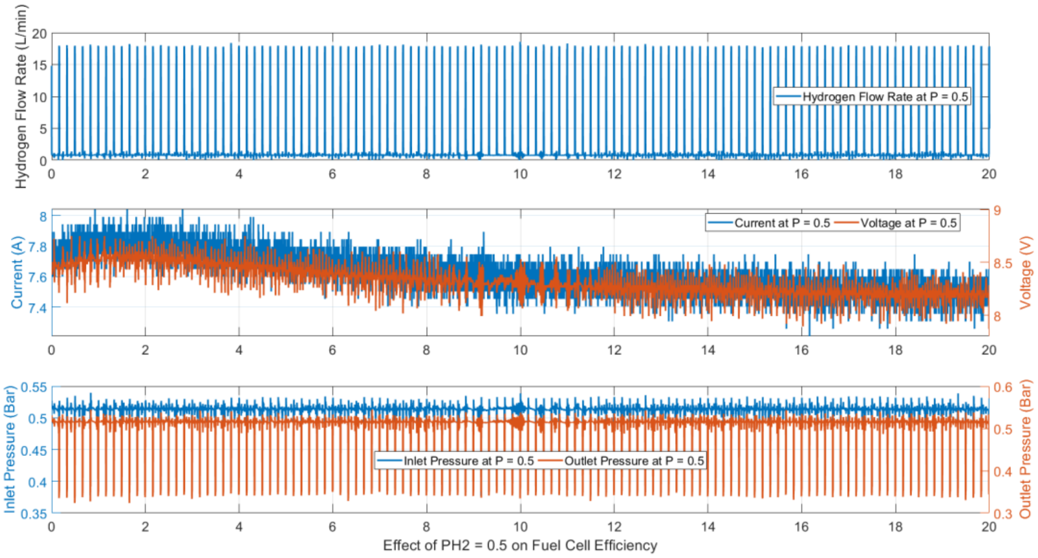


3.3 The Effect of an input pressure of 0.5bar on the hydrogen fuel cell system

Figure 5 shows the hydrogen flow rate, current, voltage, inlet pressure, and outlet pressure of the fuel cell system with a 1Ω resistive load connected under an input pressure of 0.5bar. The results indicate that the hydrogen flow oscillates within a 0–20L/min range and stabilizes at 0.8–1L/min, reflecting a continuous fuel supply with periodic regulation. The current remains stable around 7.4–8A, while the voltage stays high, fluctuating around 8–8.5V. The inlet pressure is maintained near 0.5bar with minor fluctuations, and the outlet pressure is lower (around 0.45bar) but varies synchronously with the inlet, indicating some pressure loss within allowable limits. These results demonstrate that the system operates stably at 0.5bar, with consistent hydrogen supply and high energy conversion efficiency. Mechanistically, maintaining the inlet pressure at 0.5bar promotes effective hydrogen diffusion to the anode, ensuring stable redox reactions, reducing current and voltage fluctuations, and enhancing overall system stability. The conclusion from Figure 5 indicates that an inlet pressure of 0.5bar allows the fuel cell to operate stably, with hydrogen flow, current, and voltage maintained at high levels, ensuring good energy conversion efficiency.

Figure 5

Diagram of current, voltage, inlet pressure, outlet pressure, and hydrogen consumption of the fuel cell at an inlet pressure of 0.5 bar.

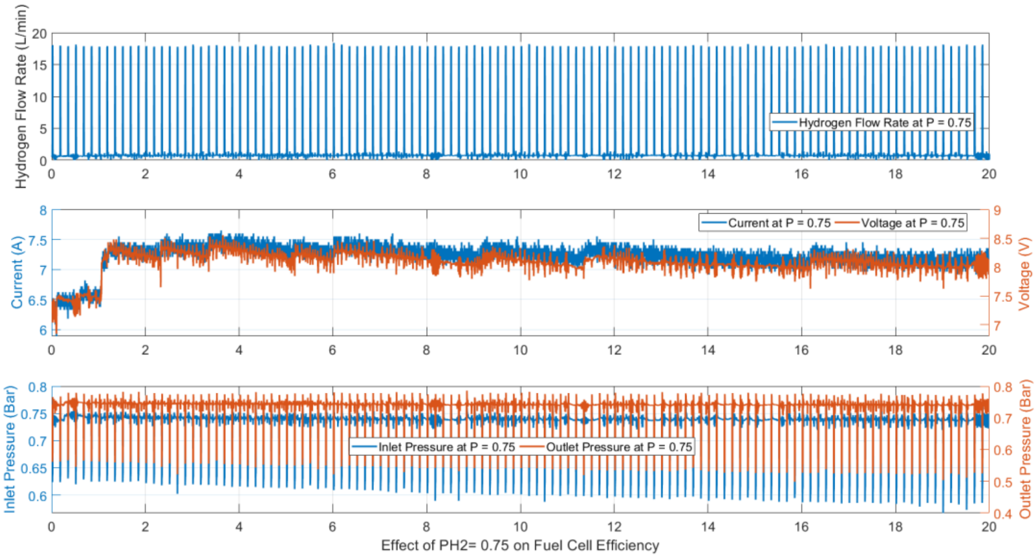


3.4 Effect of pressure at 0.75bar on hydrogen fuel cell system

Figure 6 shows the hydrogen flow rate, current, voltage, input pressure, and output pressure of the fuel cell system when a 1Ω resistive load is connected under an input pressure of 0.75bar. The results indicate that the hydrogen flow oscillates periodically between 0–20L/min, reflecting a continuous but clearly pulsed fuel supply. The current remains stable around 7–7.5A, while the voltage stays high, fluctuating near 8 V. The input pressure is maintained around 0.65–0.75 bar, and the output pressure is slightly higher (around 0.7–0.8bar) but varies synchronously with the input pressure, indicating pressure fluctuations during fuel supply. These results demonstrate that the system still operates stably at 0.75bar, with hydrogen supplied consistently and energy conversion efficiency maintained. Mechanistically, when the input pressure increases to 0.75bar, hydrogen diffusion to the cathode improves, resulting in high current and stable voltage around 8V. However, the fluctuations in flow and pressure also reflect the impact of the pressure regulation mode on fuel supply characteristics, which may cause minor oscillations in efficiency. The conclusion from Figure 6 indicates that an input pressure of 0.75bar enables the fuel cell to operate efficiently, with current and voltage maintained at high and stable levels, ensuring good energy conversion efficiency, although some fluctuations in hydrogen supply still exist.

Figure 6

Diagram of current, voltage, input pressure, output pressure, and hydrogen consumption of the fuel cell at an input pressure of 0.75bar.

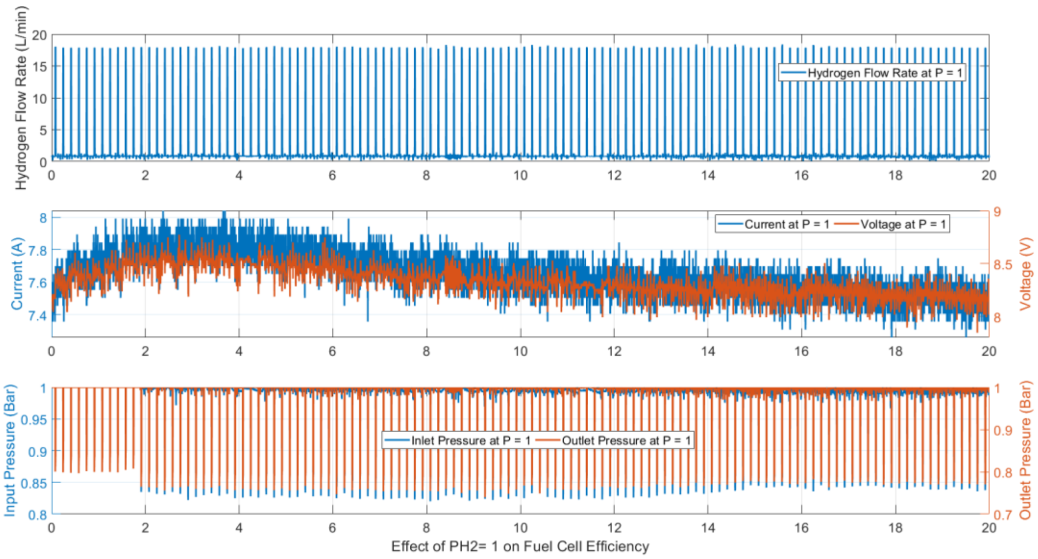


3.5 The effect of a 1bar pressure on the hydrogen fuel cell system

Figure 7 illustrates the hydrogen flow rate, current, voltage, inlet pressure, and outlet pressure of the fuel cell system when a 1Ω resistive load is connected under an inlet pressure condition of 1 bar. The hydrogen flow rate oscillates cyclically between 0 and nearly 20L/min, reflecting a continuous fuel supply with pulsatile regulation. The current remains stable around 7.5–8A, indicating reliable power generation. The voltage fluctuates around 8–8.5V and stays at a high level, showing that energy conversion efficiency is maintained. The inlet pressure varies around 0.95–1bar, while the outlet pressure is slightly lower, ranging from 0.85–0.95bar. Both pressures vary synchronously over time, reflecting fluctuations in the pressure regulation system but still maintaining a stable fuel supply process. These results demonstrate that the fuel cell system operates well at an inlet pressure of 1bar. Higher pressure facilitates hydrogen diffusion to the cathode, helping maintain stable high current and voltage. However, noticeable oscillations in flow rate and pressure reflect the influence of the pressure regulation mechanism, which may cause minor variations in fuel supply. The conclusion from Figure 7 shows that at a 1bar inlet pressure, the fuel cell system operates stably with high current and voltage, ensuring good energy conversion efficiency, although some fluctuations in hydrogen supply still occur.

Figure 7

Diagram of current, voltage, inlet pressure, outlet pressure, and hydrogen consumption of the fuel cell at an inlet pressure of 1bar.

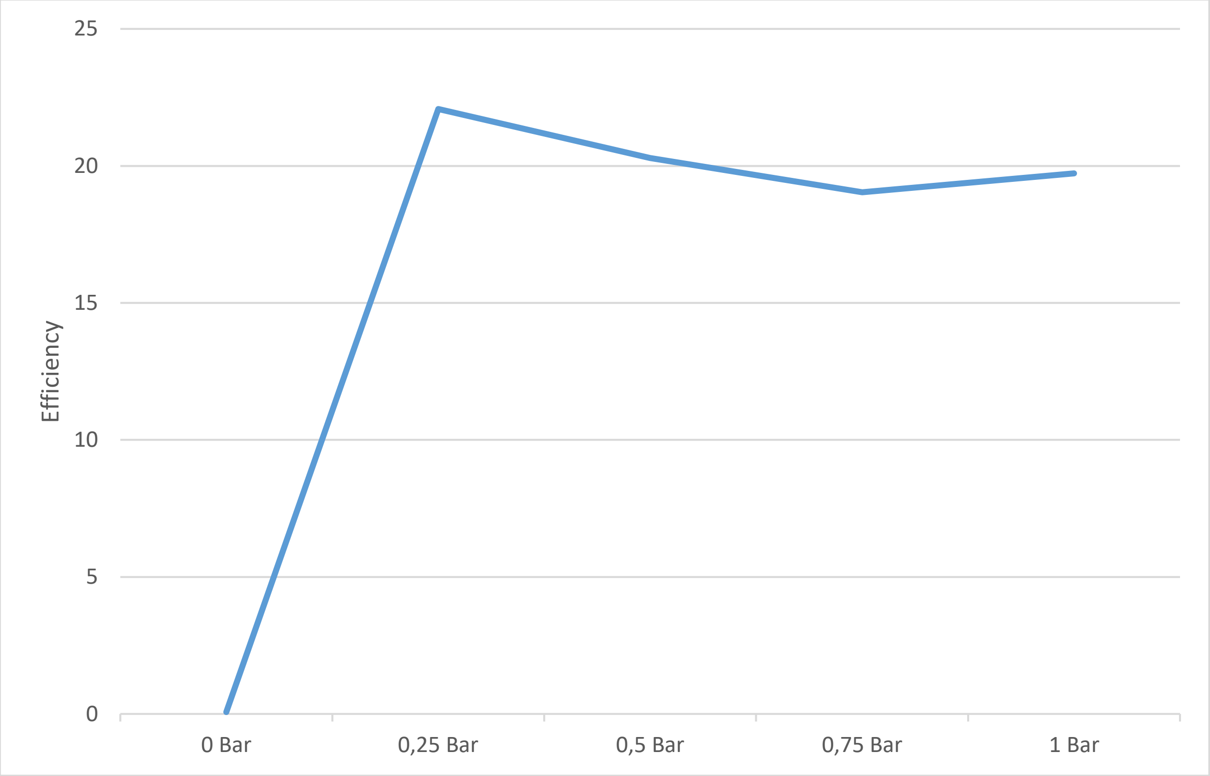


3.6 The results of the impact of hydrogen supply pressure on the efficiency of the fuel cell system

The results shown in Figure 8 illustrate the variation in the fuel cell system efficiency when operating under different hydrogen supply pressures (0bar, 0.25bar, 0.5bar, 0.75bar, and 1bar) with a 1Ω load and a rated power of 100W. It is evident that at 0bar, the efficiency is almost zero because the fuel supply is insufficient, preventing the electrochemical reaction in the cell from occurring effectively. When the pressure is increased to 0.25bar, efficiency rises sharply to its highest value (approximately 22%), indicating that this hydrogen supply condition is optimal, allowing strong electrochemical reactions and achieving the best output current and voltage. However, as the supply pressure further increases to 0.5bar, 0.75bar, and 1bar, efficiency gradually decreases to about 20.3%, 19%, and 19.6%, respectively. This decline can be attributed to excess hydrogen at higher pressures, which disrupts the fuel-to-air ratio in the reaction chamber, affecting diffusion and hydrogen utilization efficiency. Therefore, the experimental results demonstrate that hydrogen supply pressure has a direct impact on fuel cell performance: at very low pressure (0 bar), the system is nearly inoperative, at moderate pressure (0.25bar), efficiency reaches an optimal value, and at higher pressures, efficiency decreases slightly but remains relatively stable. This trend highlights the importance of selecting appropriate operating conditions, particularly hydrogen supply pressure, to maximize the performance of the fuel cell system.

Figure 8

Efficiency diagram of the PEMFC system at different hydrogen supply pressures (0bar, 0.25bar, 0.5bar, 0.75bar, and 1bar) with a 1Ω load at 100W.

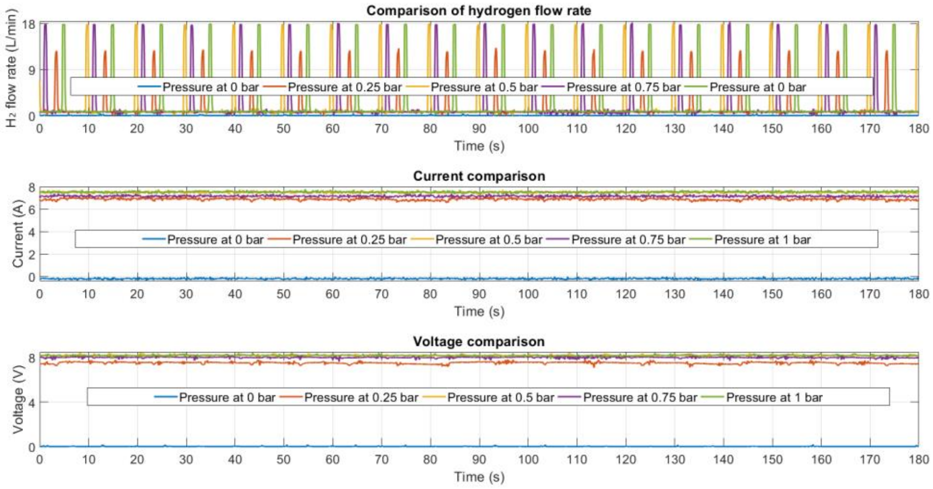


3.7 Effect of hydrogen consumption

Under normal operating conditions, the amount of hydrogen used is determined by hydrogen consumption and hydrogen purge. In this study, the hydrogen flow rate oscillated cyclically between 0 and approximately 18L/min, while the current remained stable between 6 and 8 A and the fuel cell voltage stayed stable around 7V to 8V, indicating that the system reached a normal operating state without significant fluctuations in voltage and current. Figure 9 shows that during the purge mode, the hydrogen flow exhibited short, sharp spikes up to 18L/min; however, the current and voltage barely changed, and the system continued to operate stably. Considering different pressure levels, the results indicate that at 0bar, hydrogen consumption fluctuated more with larger amplitude, while at 0.25bar, 0.5bar, 0.75bar, and 1bar, hydrogen flow became more stable and less spiky. Simultaneously, the current and voltage were higher and more stable as pressure increased, demonstrating a clear dependence between pressure and system performance. The impact of pressure on hydrogen flow, current, and voltage reflects that at low pressures, the system requires more hydrogen to maintain operation, whereas at pressures of 0.5bar and above, the system operates more stably and efficiently. This indicates that the system achieves high energy efficiency when operating within the optimal pressure range of 0.5bar or higher. In conclusion, the study shows a clear distinction between pressure levels: at low pressure, hydrogen consumption is high and fluctuating, leading to decreased current and voltage, while at higher pressures, hydrogen consumption is stable and the system maintains good voltage–current performance. Therefore, implementing a warning system when pressure drops below 0.5bar is recommended to ensure performance, safety, and the operational lifespan of the fuel cell.

Figure 9

Diagram of current, voltage, and hydrogen consumption of the fuel cell at different pressures



4 CONCLUSION

The research results show that the inlet pressure has a decisive impact on the efficiency and operational stability of the 100W PEM fuel cell system. At 0bar, the system cannot generate electricity due to a lack of hydrogen supply. When increased to 0.25bar, the efficiency reaches its highest value (≈22%), indicating that at low pressure, the system has good energy conversion capability. However, at this level, the current and voltage are not stable, and the hydrogen flow fluctuates significantly, limiting long-term operation. When increased to 0.5bar and 0.75bar, the efficiency slightly decreases (≈20% and 19%, respectively), but the system's stability improves significantly. In particular, at 0.75bar, the current remains around 7–7.5A, the voltage is stable at approximately 8V, and the inlet–outlet pressures fluctuate minimally and remain balanced, showing that the system operates stably, with low risk and suitable for continuous power exploitation. At 1bar, the efficiency slightly increases again (≈19.5%), but pressure differences and regulator fluctuations become more pronounced, posing a potential risk of fuel imbalance. Furthermore, the experiments indicate that the hydrogen input not only affects efficiency but also impacts safety and the environment. Therefore, integrating pressure sensors, flow sensors, and hydrogen sensors in the environment is necessary to monitor and automatically shut down the system when concentrations exceed the safety threshold (20%). From these results, it can be concluded that although 0.25bar provides the highest efficiency, 0.75bar represents the more optimal operating condition within the 0–1bar range, as it ensures stable power output while maintaining reliability and safety for the PEM fuel cell system.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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Authors’ Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study’s findings are fully available within the article.

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