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The Characteristics and The Performance of Dual Air Supply Polymer Electrolyte Membrane Fuel Cell

고분자 전해질막 연료전지의 공기 중간 주입 시 특성 및 성능

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기계항공공학부

윤 채 영

Abstract

The characteristics and the performance of dual air supply polymer electrolyte membrane fuel cell

Chae Young Yun

Mechanical and Aerospace Engineering

The Graduate School

Seoul National University

After industrialization, environmental pollution and global warming become more crucial than before to living things and people on earth. So researchers focus on developing eco-friendly, renewable energy. Polymer electrolyte membrane fuel cell (PEMFC) is regarded as one of the promising power generator. PEMFC generates electricity by reaction of hydrogen and oxygen. So PEMFC produces water and heat after reaction, that doesn’t make pollutant like sulfur oxide (SOx) and nitrogen oxide (NOx). PEMFC has also other charming advantages, High efficiency, high power density and operation at low temperature.

But there are some problems to be solved for commercialization and popularization of PEMFC like Water management, flow distribution, high cost of Pt-catalyst, etc.

If flow doesn’t distribute uniformly inside fuel cell, it cannot show high performance. In addition, un-uniform gas distribution can cause unstable operation of fuel cell and durability problem. So many researchers make studies on flow distribution inside fuel cell.

In this study, dual air supply concept was applied to fuel cell to enhance the performance of fuel cell by improving flow distribution.
For dual air supply fuel cell, an additional air inlet port was added to normal fuel cell. Through this additional air inlet port and main air inlet, air can be divided and supplied to fuel cell. When experiments were conducted using dual air supply fuel cell, it is necessary to air flow ratio through main and an additional air inlet. So, experiments were carried out first on various air flow ratio conditions. After that, operating characteristics of dual air supply fuel cell was investigated. Stoichiometric ratio of air and relative humidity of air were selected in each experiment, operating characteristics of dual air supply fuel cell was figured out.

Also, Stability characteristics and EIS measurement were investigated. As written before, Voltage fluctuation was analyzed on various air flow ratio conditions, then results were compared that of normal fuel cell.

Lastly, EIS measurement was conducted on various air flow ratio. Reactance and resistance value could be gained. Using that, performance difference in each various air flow ratio conditions was analyzed.

Keywords: Polymer electrolyte membrane fuel cell, Dual air supply, Flow distribution, Parallel channel
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Nomenclatures

PEMFC	*Polymer electrolyte membrane fuel cell*
GDL	*Gas diffusion layer*
RH	*Relative humidity [%]*
SR	*Stoichiometric ratio*
V	*Voltage [V]*
T	*Temperature [^{o}C]*
EIS	*Electrochemical impedance spectroscopy*

Chapter 1. Introduction

1.1 Background of the study

As consumption of fossil fuel is increasing all over the world, climate change and global warming is important issue in environmental problem. Greenhouse gases cause global warming. Concentration of greenhouse gas on earth increased a lot after industrialization, greenhouse gas is also increasing nowadays. In addition, consumption of fossil fuel causes the environmental pollution and destruction of ecosystem. Fine dust, that is prevalent in korea nowadays, can be made by consumption of fossil fuel,

Electricity or electric power is produced by using fossil fuel in power plant or IC engine in case of automobile. So, the depletion of fossil fuel can cause lack of energy in various applications for human being. To solve these problems, many research activities on renewable energy are conducted. In the twenty-first century, polymer electrolyte membrane fuel cell (PEMFC) is considered to be a promising technology for clean and efficient power generation. The PEMFC has several advantages over the conventional power generation systems like low operation temperature, fast start-ups and high power density. So, fuel cell can replace a range of power supplies from batteries to internal combustion engines from home heating to mobile phone chargers and cars. However, there are some problems to replace other power supplies with fuel cell. To replace power supplies with fuel cell, it is necessary to enhance the performance of fuel cell. There are many factors that influence the performance of fuel cell like flow distribution in flow channel, water management, etc. If flow doesn’t distribute uniformly in the fuel cell, fuel cell can’t generate high current, stability of the fuel cell can drop. Also, that can cause degradation that leads to durability problem.

So, many kinds of flow structure were made and applied to fuel cell to improve flow distribution. parallel, serpentine, pin type, interdigitated, pin or mesh, cascade, etc. another approach to solve this problem is to design header part of the fuel cell, or manifold of fuel cell stack.

Flooding phenomenon can occur especially in high current density region. In that region, huge amount of water can block gas diffusion layer (GDL) and flow channel. That causes performance drop and durability problem also. To resolve that, effective purge method using air or hydrogen and controlling operating parameters like stoichiometric ratio (SR) or relative humidity (RH) of gas were investigated by researchers. Flow structure design mentioned above also can be a solution because water goes through flow channel. So effective design of flow channel for water to go out well is important.

In this study, we suggest dual air supply fuel cell that has one additional air inlet on fuel cell. We found some activation area that flow can’t distribute uniformly in parallel channel fuel cell, an additional air inlet was applied to Dual air supply fuel cell can distribute air more uniformly than normal fuel cell in parallel channel. Experiments are conducted on various conditions using dual air supply fuel cell. First, optimal main to secondary air flow ratio was founded for dual air supply fuel cell.

Experiment was conducted on various conditions like various air SR and RH to check operating characteristics of dual air supply. And then, stability and electrochemical impedance spectroscopy (EIS) measurement were carried out also.

1.2 Literature review

Uniform flow distribution is important for the performance and stability of fuel cell, many kinds of flow channels are used for uniform flow distribution. Manso et al. [1] studied the influence of the different geometric parameters of the flow channels on the overall performance of a PEMFC. They introduced various kind of flow field, serpentine, parallel, interdigitated, pin or mesh and cascade, then investigated characteristics of each flow field. Barreras et al. [2] conducted experiments and numerical simulation studies on flow distribution in parallel channel. Experiment was conducted by visualizing fluid in fuel cell. In that experiment, fluid velocity is relatively low in the middle and slightly below that region. Similar tendency was shown in simulation results. Hontanon et al. [3] studied the gas flow distribution system of a PEM fuel cell using numerical simulations. Two types of flow distributors were investigated: a grooved plate with parallel channels and a porous material. In addition to study of unit cell, Studies about flow distribution on fuel cell stacks are also conducted [4, 5]. Using stack model, the sensitivity of stack performance to operating conditions and design parameters was investigated. In particular, performance under uniform, single anomaly, and random parameter distributions was investigated.

To improve performance of fuel cell, many researchers do research activity about that [6]. Higier et al. [7] measured current density directly under the land and channel using serpentine flow fields PEMFC. They analyzed characteristics of serpentine flow fields more detail, and compared experimental results over the land and channel separately. Guo et al. [8] enhanced PEMFC performance by employing hydrophilic porous carbon plate as a water transport plate. They achieved the water balance by virtue of its humidification and water drainage functions.

Hirano et al. [9] improved fuel cell performance by minimizing the Pt loading in the electrode without causing a loss in performance. With only a sputtered Pt layer in the electrode, a high level of cathode performance was obtained. Saha et al. [10] used 3-D composite electrode consisting of Pt nanoparticles supported on nitrogen –doped carbon nanotubes for PEMFC. That electrodes have a broader electrochemical surface area than the Pt/carbon nanotube electrodes as well as higher single cell performance in a PEMFC.

Fuel cell system consists of some components, air blower, humidifier, etc. It is necessary to increase total efficiency of fuel cell system for commercialization. So many research activities are conducted on various ways to increase efficiency of fuel cell system. Zhao et al. [11] analyzed hybrid power system using organic rankine cycle to enhance fuel cell system efficiency by using waste heat from PEMFC. Buchi et al. [12] studied PEMFC without external humidification component to eliminate gas humidification subsystem because it is a burden in the fuel cell system regarding weight and parasitic power.

Water management is one of the important issue to be solved in PEMFC. Huge amount of water can be produced especially in high current density region and that water can block gas diffusion area and flow channel. That causes low performance and durability. One additional effect by applying dual air supply concept is to control water adequately in PEMFC. Hussaini et al. [13] studied cathode parallel channel flooding in PEMFC by visualization and quantification. They changed relative humidity and stoichiometric ratio in some range that represent typical operating conditions for automotive applications. The impact of flooding is presented in terms of measurable parameters like two-phase pressure drop coefficient and voltage loss. Chen et al. [14] introduced a segmented model for investigating water transport in a PEMFC. A single cell consisting of 15 interconnected segments is modeled. That model was used for analyzing water content in the membrane, water accumulation in the gas diffusion layer. Chen et al. [15] studied water distribution in a PEMFC using neutron radiography. Neutron radiography has been used for visualization and measurement for liquid water in a working PEMFC. They found the relationship among operating parameters like relative humidity and stoichiometric ratio and water distribution in PEMFC. Jiao et al. [16] analyzed liquid water transport in straight micro parallel channels with manifolds for cathode side of PEMFC. A numerical investigation of air and water flow in micro parallel channels with PEMFC stack inlet and outlet manifolds for the cathode was conducted using computational fluid dynamics (CFD).

One objective of this study is to show better performance when dual air supply is applied to parallel channel fuel cell than that of normal fuel cell. By doing so, dual air supply fuel cell system can reduce parasitic power of air blower, because it can be decreased when dual air supply fuel cell performs better than normal fuel cell in parallel channel, although the amount of the air supplied to dual air supply fuel cell is smaller than that of normal fuel cell. So, dual air supply fuel cell can improve efficiency of fuel cell system.

1.3 Objectives and scopes

One objective of this study is to improve fuel cell performance by applying dual air supply fuel cell. Using dual air supply fuel cell, it is expected to solve problems like flow distribution, flooding phenomenon. To check which problem can be solved by dual air supply fuel cell, experiments were conducted on various operating conditions.

In chapter two, Experimental set up and single fuel cell used for dual air supply were introduced. Fuel cell system should be modified for dual air supply fuel cell, some components like humidifier, mass flow controller were added to fuel cell system station. Structure of bipolar plate that I designed for dual air supply fuel cell was also introduced. So the difference between normal and dual air supply bipolar plate can be seen.

In chapter three, operating characteristics of dual air supply fuel cell were shown. To confirm operating characteristics of dual air supply fuel cell, experiments were conducted on various operating conditions. Main to secondary air flow ratio, stoichiometric ratio (SR), relative humidity (RH) of air were selected as a main variable in each experiment, respectively.

In chapter four, other characteristics of dual air supply fuel cell was investigated. Analysis of stability characteristics and electrochemical impedance spectroscopy (EIS) measurement were conducted. To find adequate air flow ratio condition for the best stability, experiments were conducted on various air flow ratio conditions. To check voltage fluctuation in each case, same current was loaded to fuel cell for the same time. Then results were compared each other.

EIS measurement was carried out on low, middle, high current density region, 6, 12 and 18 A. On each current condition, EIS measurement was conducted on various air flow ratio to analyze performance difference as air flow ratio varies.

In chapter five, experimental results were summarized as a conclusion.

Chapter 2. Experimental setup and unit cell for dual air supply

2.1 Introduction

Fig. 2.1 shows schematic diagram of experimental setup using dual air supply fuel cell. This experimental system consists of various components. An electric loader was used to load current and voltage to the fuel cell, Bubblers are used to humidify hydrogen and air supplied to the fuel cell. Fig. 2.2 shows electronic loader that was used for the following experiments. MFC (Mass Flow Controller) control mass flow rate of air and hydrogen. Water generated in fuel cell goes to water trap through fuel cell outlet.

Fig. 2.3 shows impedance meter. That was used to measure reactance and resistance of fuel cell. EIS measurement was conducted using impedance meter.

For dual air supply, some additional components are necessary. An additional bubbler, MFC and air supply line to humidify, control, transport air supplied to an additional air inlet. These are added to fuel cell system station.

2.2 Bipolar plate for dual air supply

For dual air supply, an additional air inlet should be added to bipolar plate and end plate of fuel cell. Fig. 2.4 shows specification of bipolar plate that I designed using Autocad for dual air supply. Main air inlet and outlet is on the same location with normal bipolar plate. But an additional inlet was added in the middle and left side of bipolar plate. Through these two different ports, air can be divided and supplied to the fuel cell. Activation area of fuel cell is 5cm x 5cm and flow type on bipolar plate is parallel.

2.3 Dual air supply fuel cell

Unit fuel cell that was used for experiments consists of membrane electrolyte assembly (MEA), gas diffusion layer (GDL), gasket, bipolar plates and end plates.

Unit fuel cells that were used for experiments are shown in Fig. 2.5, normal and dual air supply fuel cell. The difference between normal and dual air supply fuel cell can be found in Fig. 2.5. main inlet and outlet port are located on the same points of end plate, but an additional air inlet port was added to an end plate of dual air supply fuel cell. Through this port and a n additional port in a bipolar plate, air can be supplied to inside of the fuel cell.

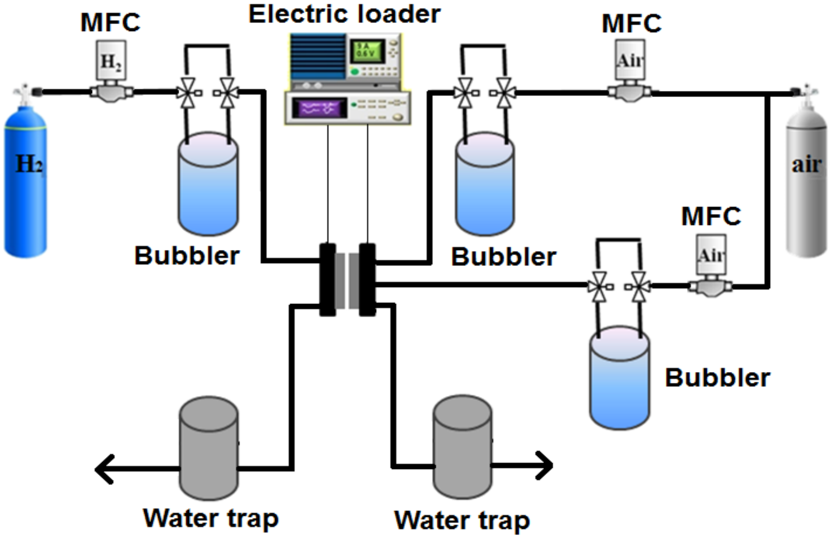
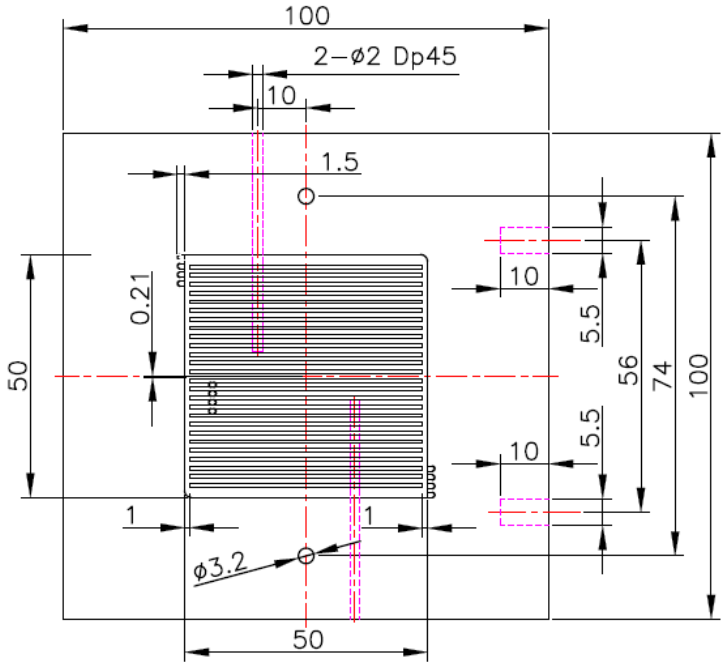


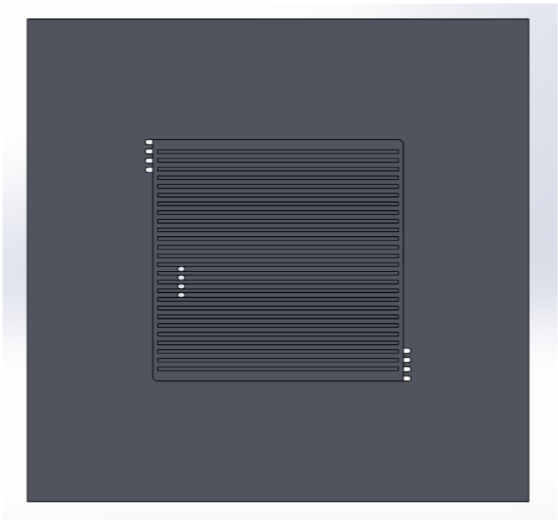
Fig. 2.1 Schematic diagram of the experimental setup

Fig. 2.2 Electric loader

Fig. 2.3 Impedance meter



(a)



(b)

Fig. 2.4 Specification of bipolar plate for dual air supply fuel cell

(a) 2D specification (b) 3D specification

(a)

(b)

Fig. 2.5 Unit fuel cell

(a) normal fuel cell (b) dual air supply fuel cell

Chapter 3. Operating characteristics of dual air supply PEMFC

3.1 Introduction

In this chapter, experiments were conducted using dual air supply fuel cell. Main variables are main to secondary air flow ratio, air stoichiometric ratio, relative humidity of air in each experiment. First, it is necessary to find optimal main to secondary air supply ratio for dual air supply fuel cell. And then, additional experiments were conducted on various air stoichiometric ratio conditions to compare the performance between normal fuel cell and dual air supply fuel cell in case of parallel channel. Lastly, non-humidified or humidified air was supplied to an additional air inlet in each case and results were compared each other.

3.2 Performance comparison on various air supply ratio

The objective of this experiment is to find optimal main to secondary air flow ratio. Experiments were carried out on various air flow ratio, performances were compared to find optimal main to secondary air flow ratio in which fuel cell performs the best.

3.2.1 Experimental conditions

Experimental conditions are presented in Table 3.1. SR of hydrogen and air were 1.5, 2.0, respectively. Temperature of fuel cell was set to 65℃. RH of air to the main inlet is 100%, and RH of air to an additional inlet was different in each case, 0 and 100%. Main to secondary air flow ratio varied from 100:0 to 30:70. In case of air flow ratio 100:0, number 100 means air flow ratio supplied to the main air inlet, and second number 0 means air flow ratio supplied to an additional air inlet.

3.2.2 I-V curve comparison

Fuel cell performance on various air flow ratio were shown in Fig 3.1 and Fig 3.2. Fig 3.1 represents supplying non-humidified air to an additional inlet case and Fig. 3.2 shows supplying humidified air to an additional inlet case. Humidified air was supplied to the main air inlet in both cases. Secondary air flow ratio increased from 0 to 70.

Fig 3.1 shows that fuel cell performance increases as the amount of the air supplied to an additional air inlet to certain air flow ratio. Fuel cell shows the best performance when main to secondary air flow ratio is 50:50 and 40:60. While secondary air flow ratio increased above 70, performance started to decrease compared with that of air flow ratio 40:60 case.

Similar tendency can be seen in Fig. 3.2, supplying humidified air to an additional air inlet case.

3.2.3 I-P curve comparison

Fig 3.3 and Fig 3.4 shows I-P curve comparison, non-humidified or humidified air was supplied to an additional air inlet, respectively. Same tendency can be seen in these two results, electric power increases as the amount of the air supplied to an additional air inlet mounts up to certain value. When main to secondary air flow ratio was 40:60, dual air supply fuel cell showed the highest power while that power value was compared to that of normal fuel cell.

Table 3.1 Operating value of the experiment for various air flow ratio conditions

Operating parameter	Value
SR of hydrogen	1.5
SR of air	2.0
Temperature [^{o}C]	65
Relative humidity of hydrogen	100
Relative humidity of air to main inlet [%]	100
Relative humidity of air to additional inlet [%]	0/100
Main to secondary air flow ratio	100:0~30:70

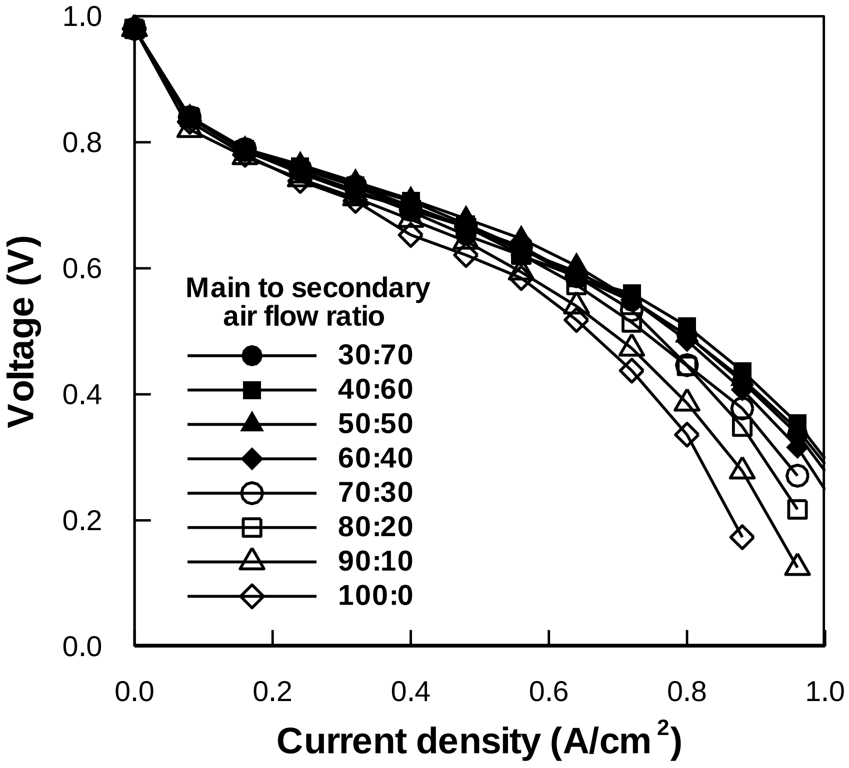


Fig. 3.1 I-V curve comparison for supplying non-humidified air to an additional air inlet case

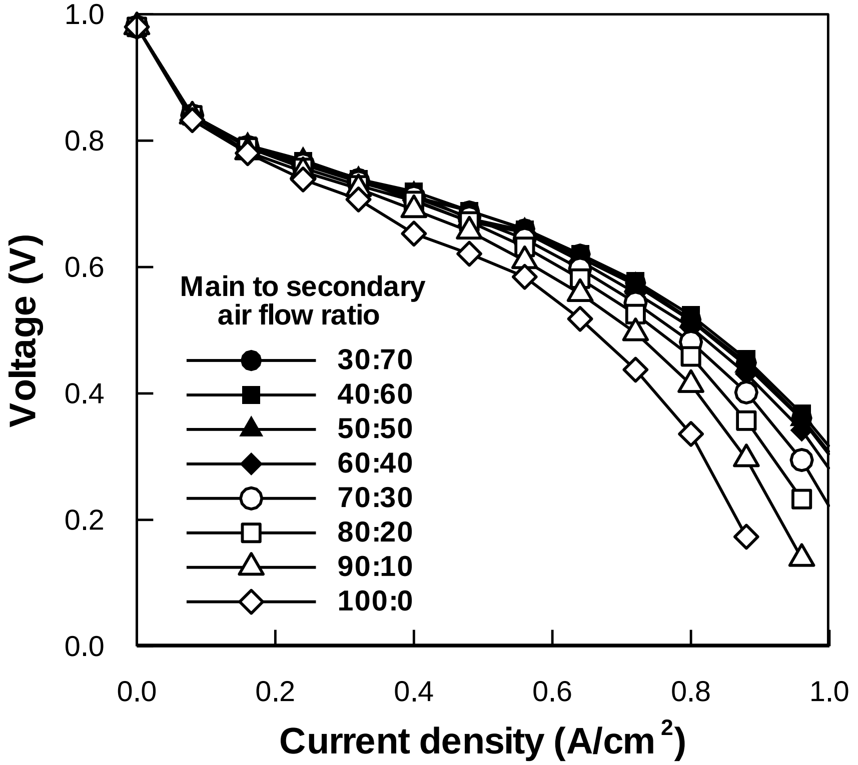


Fig. 3.2 I-V curve comparison for supplying humidified air to an additional air inlet case

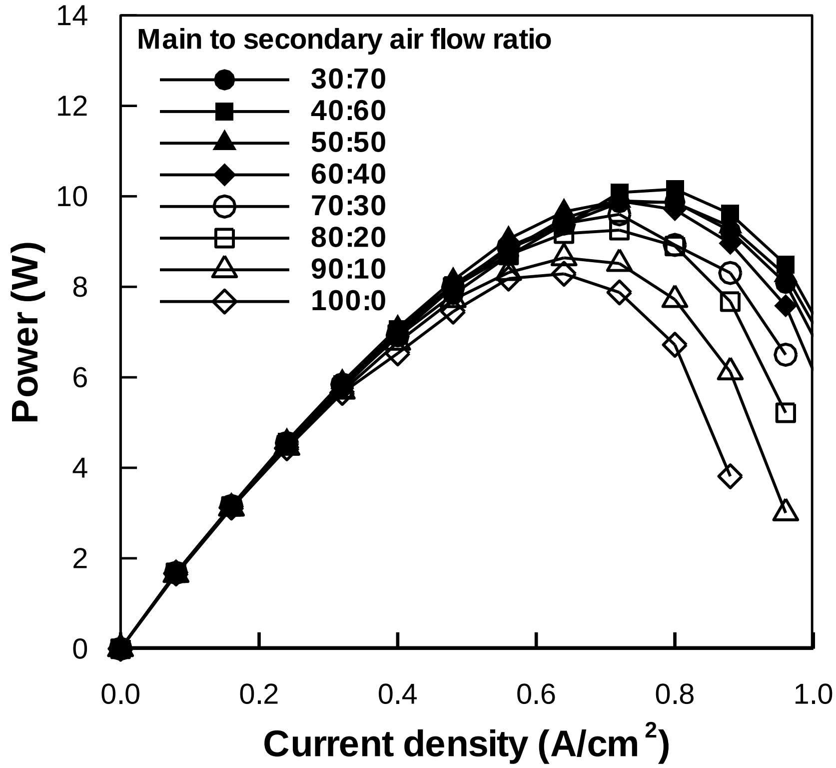


Fig. 3.3 I-P curve comparison for supplying non-humidified air to an additional air inlet case

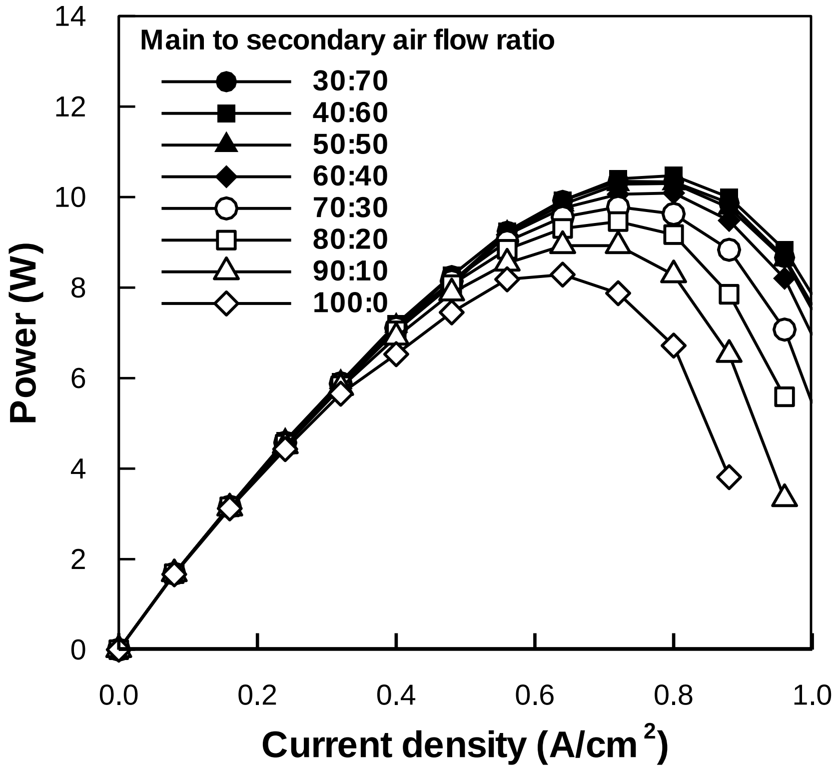


Fig. 3.4 I-P curve comparison for supplying humidified air to an additional air inlet case

3.3 Performance comparison on various air stoichiometric ratio conditions

In this section, objective of this experiment is performance comparison between normal and dual air supply fuel cell on the same and different air stoichiometric ratio conditions. Normal and dual air supply fuel cell were performed on various air stoichiometric ratio conditions and performances were compared.

3.3.1 Experimental conditions

Experimental conditions are shown in Table 3.2. SR of hydrogen was same, 1.5 in normal and dual air supply fuel cell. Main variable in this experiment is SR of air. That varied from 1.5 to 3.0 in normal and dual air supply fuel cell.

3.3.2 I-V performance on various air SR conditions

Experiments were carried out on various air SR conditions, that result can be seen from Fig. 3.5 to Fig. 3.6. Fig 3.5 shows performance comparison when air SR was 1.5, 2.0, Fig 3.6 represents performance comparison in different air SR conditions, in case air SR was 2.5, 3.0. In these two experimental results, dual air supply fuel cell always performed better than normal fuel cell, when air SR was the same in each fuel cell.

Experimental results conducted on different air SR conditions can be compared also. Comparison of Performance of dual air supply fuel cell when air SR is 1.5 and that of normal fuel cell when air SR was 2.0 can be done in Fig. 3.5. Smaller amount of the air was supplied to dual air supply fuel cell than normal fuel cell, but dual air supply fuel cell showed better performance than normal fuel cell.

In Fig 3.6, It can be found out that dual air supply fuel cell higher performance than normal fuel cell when total amount of the air supplied to the fuel cell was the same. We can check that comparing two results, dual air supply fuel cell performance when air SR was 3.0, normal fuel cell performance when air SR was 3.0. The performance comparison can be investigated on different air SR case also. Performance of dual air supply fuel cell when air SR was 2.5 showed higher voltage than that of normal fuel cell when air SR was 3.0. So, dual air supply fuel cell performs better than normal fuel cell in parallel channel. In terms of fuel cell system, parasitic power of air blower can be decreased when dual air supply fuel cell is applied because smaller amount of the air was necessary to dual air supply fuel cell than normal fuel cell.

Table 3.2 Operating value of the experiment for different air SR conditions

Operating parameter	Value
SR of hydrogen	1.5
SR of air (normal fuel cell)	1.5/2.0/2.5/3.0
SR of air (dual air supply fuel cell)	1.5/2.0/2.5/3.0
Temperature [^{o}C]	65
Relative humidity of hydrogen [%]	100
Relative humidity of air [%]	100
Main to secondary air flow ratio	100:0/40:60

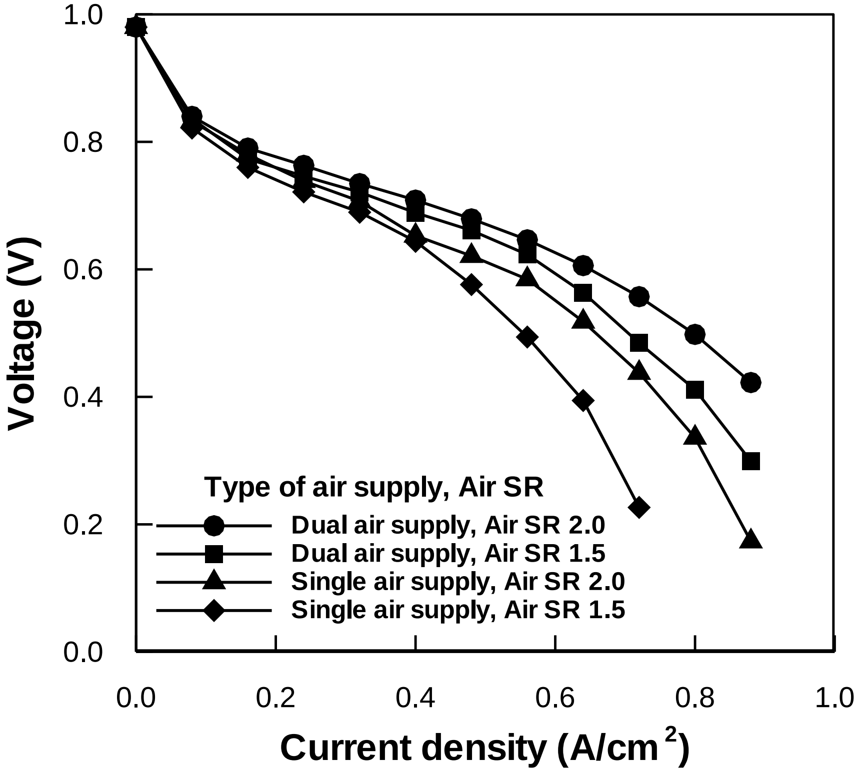


Fig. 3.5 I-V curve comparison using normal and dual air supply fuel cell when air SR was 1.5 and 2.0

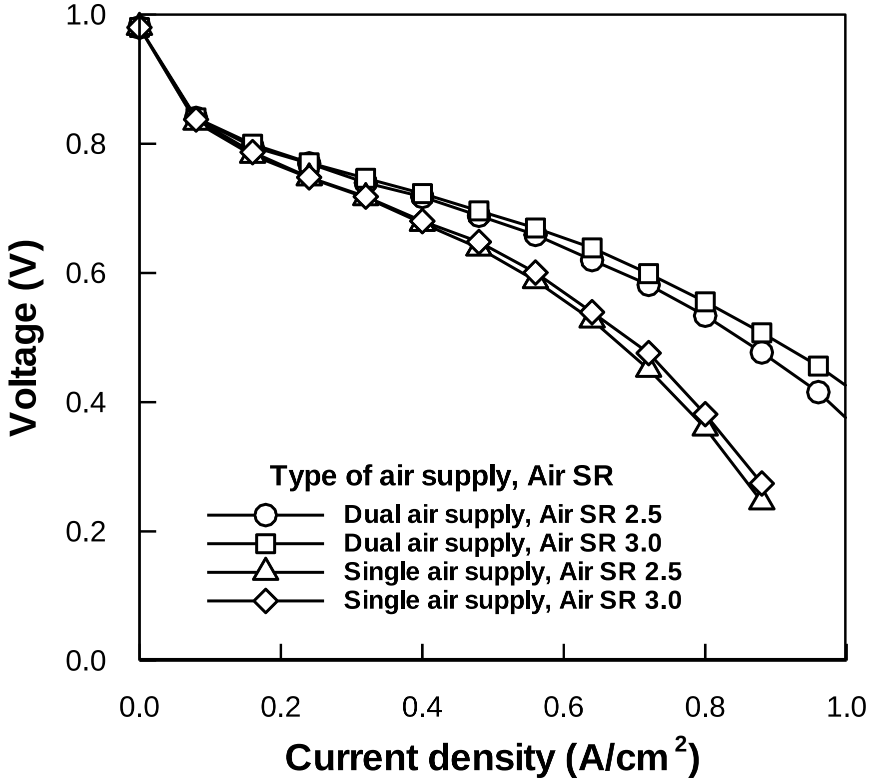


Fig. 3.6 I-V curve comparison using normal and dual air supply fuel cell when air SR was 2.5 and 3.0

3.4 Performance measurement on supplying non-humidified or humidified air to an additional inlet

When we applied dual air supply concept to fuel cell, that concept would be effective to solve flow distribution and flooding phenomenon problem. Objective of this experiment is to check which problem can be solved more effectively through dual air supply fuel cell. If fuel cell shows better performance when non-humidified air was supplied to an additional air inlet than supplying humidified air to an additional air inlet case, it can be concluded that dual air supply fuel cell is more effective to solve flooding phenomenon than flow distribution problem. Because flooding phenomenon is caused by water, supplying non-humidified air is more effective to push water inside the fuel cell than humidified air. Second, when supplying humidified air to an additional air inlet shows better performance, it can be summarized that dual air supply fuel cell is more effective to solve flow distribution problem than flooding phenomenon. Because supplying humidified air to fuel cell shows better performance than supplying non-humidified air to fuel cell when flow distribution problem exist in fuel cell.

3.4.1 Experimental conditions

Table 3.3 presents conditions of operating parameters of this experiment. Stoichiometric ratio of hydrogen and air, temperature, relative humidity of hydrogen was constant in this experiment. Non-humidified air or humidified air was supplied to an additional air inlet of dual air supply fuel cell in each case, while humidified air was supplied to main air inlet. Then performances were compared on various air flow ratio conditions.

3.4.2 Experimental results

Experimental results can be seen from Fig. 3.7 to Fig. 3.11. Fig. 3.7 shows performance curves when air flow ratio was 90:10 and 80:20. In these two air flow ratio cases, fuel cell showed better performance when humidified air was supplied to an additional air inlet than when non-humidified air was supplied to an additional air inlet. Similar results can be seen in Fig. 3.8, Supplying humidified air to an additional air inlet shows better performance than supplying non-humidified air to an additional air inlet when air flow ratio is 70:30, 60:40 case also. In other figures, Fig. 3.10 and Fig 3.11, same tendency can be seen. Supplying humidified air to an additional air inlet shows better performance than supplying non-humidified air to an additional air inlet. In conclusion, dual air supply fuel cell is more effective to solve flow distribution problem than flooding phenomenon in parallel channel.

Table 3.3 Operating value of the experiment for different air RH conditions

Operating parameter	Value
SR of hydrogen	1.5
SR of air	2.0
Temperature [^{o}C]	65
Relative humidity of hydrogen [%]	100
Relative humidity of air to main inlet [%]	100
Relative humidity of air to additional inlet [%]	0/100
Main to secondary air flow ratio	100:0~30:70

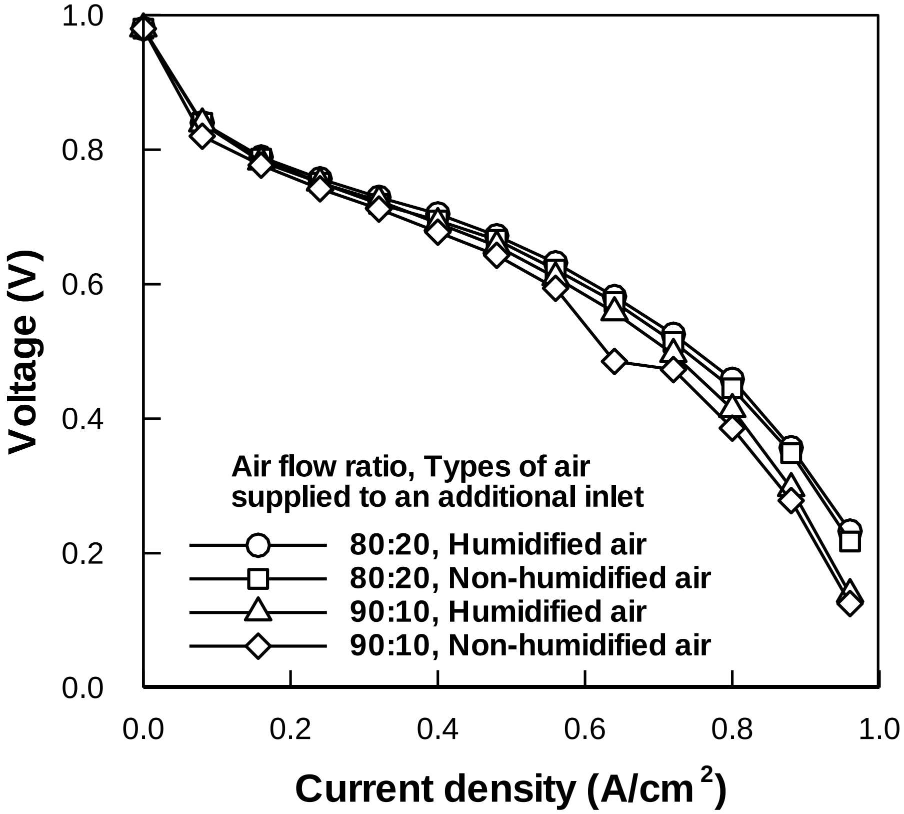


Fig. 3.7 I-V curve comparison supplying non-humidified or humidified air to an additional inlet of dual air supply fuel cell when air flow ratio was 90:10 and 80:20

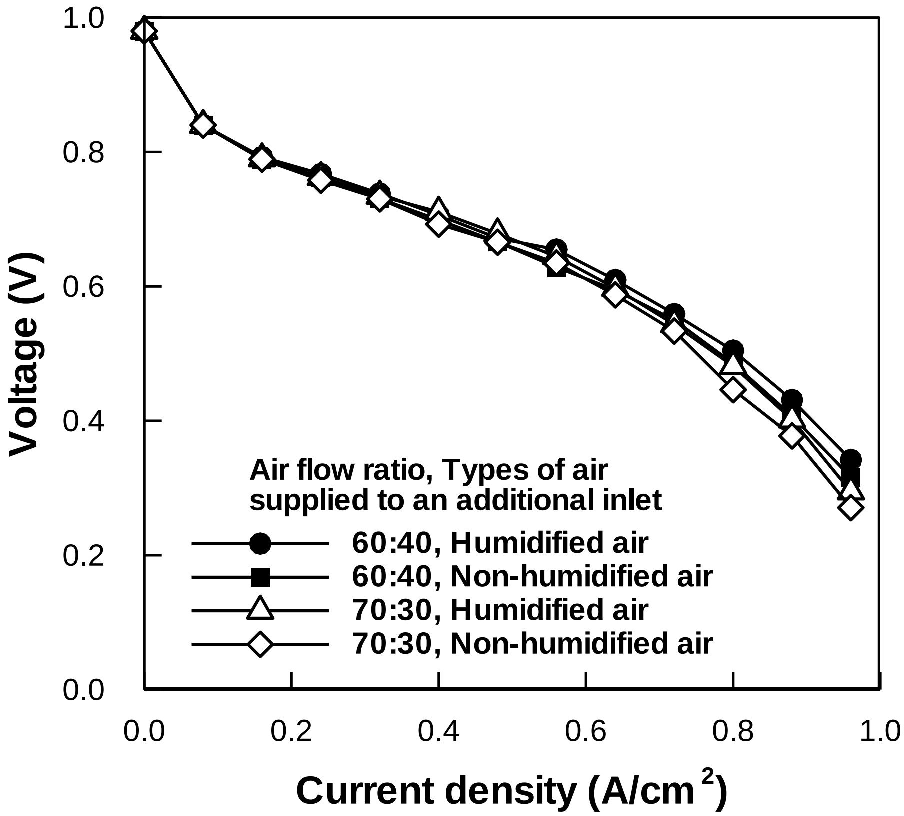


Fig. 3.8 I-V curve comparison supplying non-humidified or humidified air to an additional inlet of dual air supply fuel cell when air flow ratio was 70:30 and 60:40

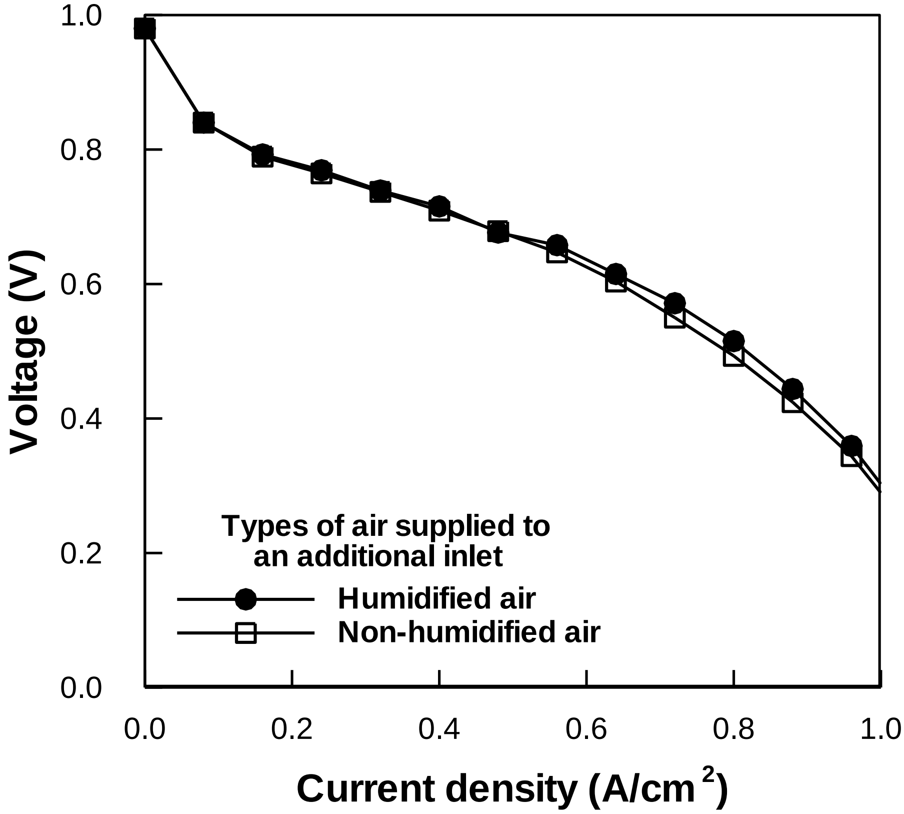


Fig. 3.9 I-V curve comparison supplying non-humidified or humidified air to an additional inlet of dual air supply fuel cell when air flow ratio was 50:50

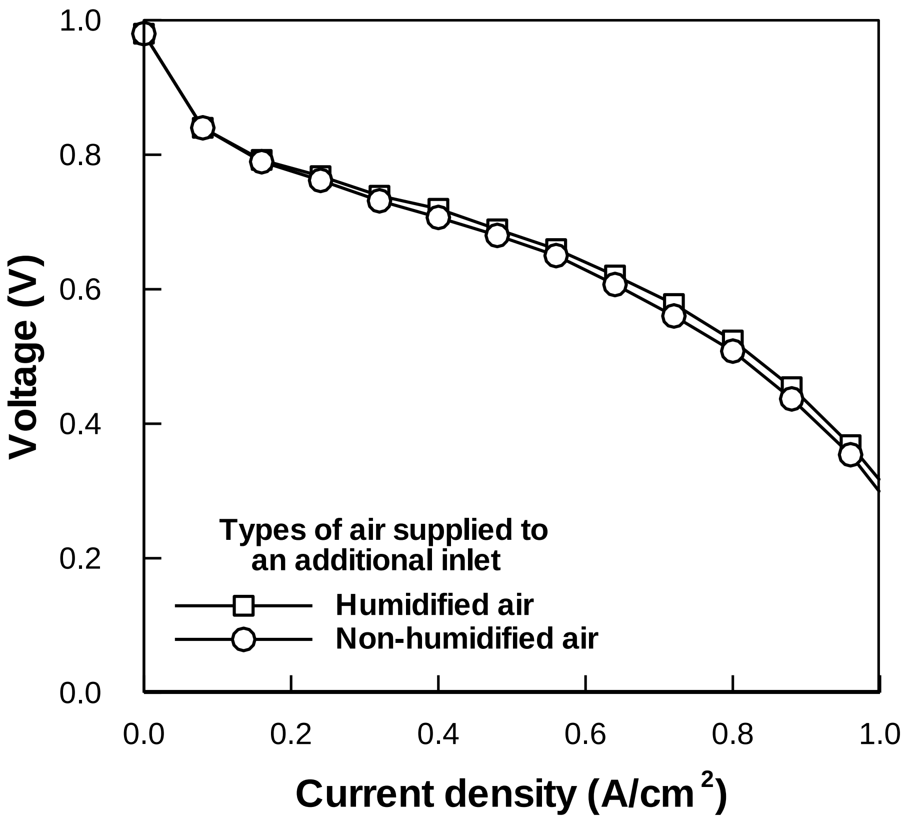


Fig. 3.10 I-V curve comparison supplying non-humidified or humidified air to an additional inlet of dual air supply fuel cell when air flow ratio was 40:60

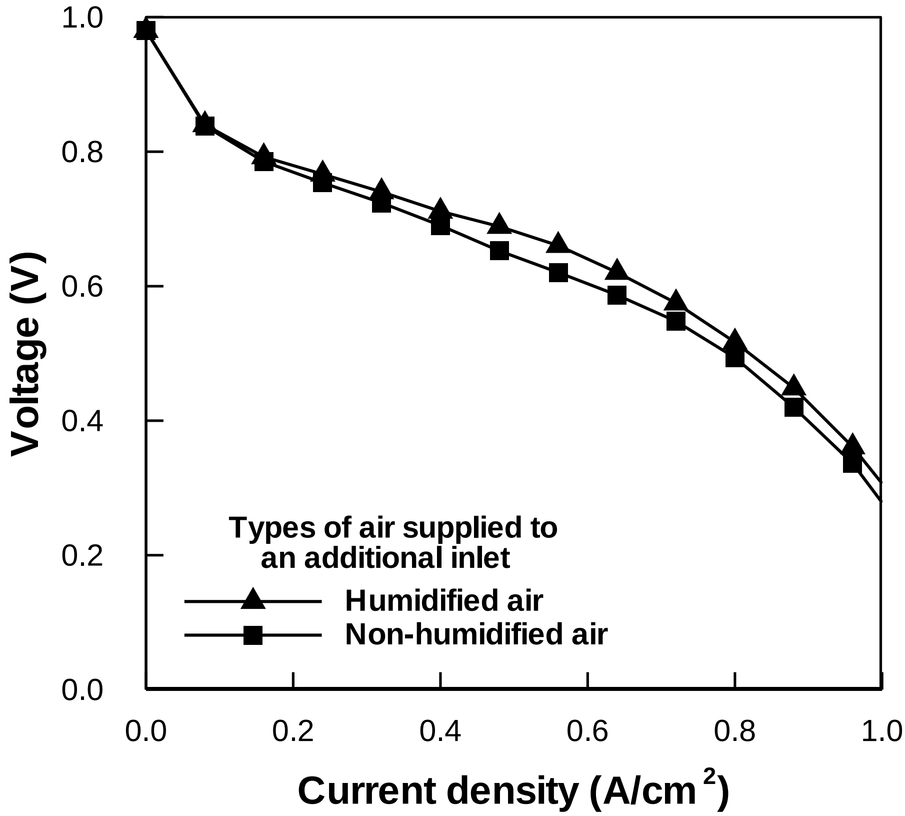


Fig. 3.11 I-V curve comparison supplying non-humidified or humidified air to an additional inlet of dual air supply fuel cell when air flow ratio was 30:70

3.5 Additional experiment: comparison of activation cycle

Unit fuel cell consists of some components, gasket, gas diffusion layer, membrane electrolyte assembly (MEA), bipolar plates and end plates. After these components are assembled, activation cycle should be loaded to fuel cell to hydrate membrane. First in activation cycle, voltage varied from 0.65 V to 0.5 V, voltage value was maintained for 10 minutes in each step. After that, voltage values are set to 0.9 V first. And then voltage decreases to 0.85 V, finally to 0.4 V while decreasing voltage gap is 0.05. it takes 1 minute for each step. Totally, one activation cycle is made up of 14 steps.

Same activation cycle was applied to normal and dual air supply fuel cell. That means same voltage value was loaded to each fuel cell. The amount of the air and hydrogen supplied to each fuel cell is also the same. Activation cycle comparison can be seen in Fig. 3.13. Even if same voltage was loaded to each fuel cell, higher current was measured in dual air supply fuel cell than normal fuel cell. In previous experiments, same current was loaded to normal and dual air supply fuel cell. And then voltage was measured for each cell. At that time dual air supply performs better than normal fuel cell when the amount of the air and hydrogen supplied to fuel cell is the same. In case of this experiment, same voltage was loaded to each fuel cell, current was measured for each fuel cell.

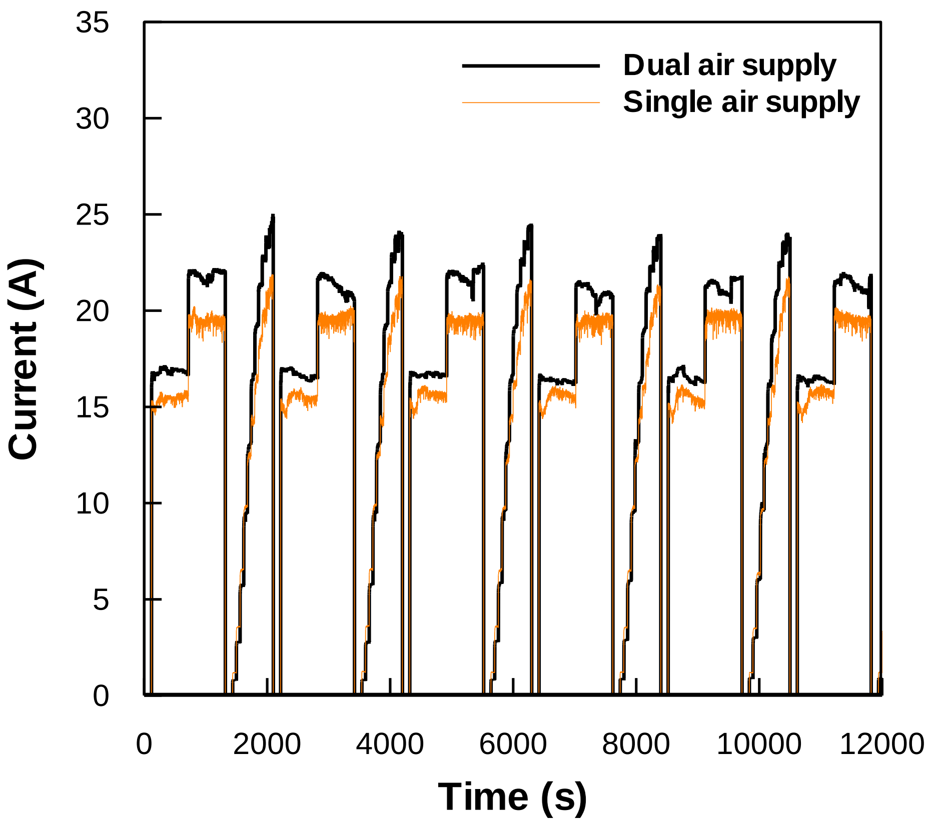


Fig. 3.12 Activation cycle comparison using normal and dual air supply fuel cell

3.6 Summary

In this chapter, dual air supply fuel cell was investigated on various operating conditions. Main variable was main to second air flow ratio, stoichiometric ratio of air, and relative humidity of air supplied to an additional air inlet. In the experiment conducted on various air flow ratio, optimal main to second air flow ratio can be found. In that air flow ratio, dual air supply fuel cell showed the best performance. Second, experimental study was conducted on various air stoichiometric conditions using normal and dual air supply fuel cell. On the same air SR condition, dual air supply fuel cell performs better than normal fuel cell. Dual air supply fuel cell also showed better performance even if smaller amount of the air was supplied to dual air supply fuel cell than normal fuel cell. Lastly, non-humidified air or humidified air was supplied to an additional air inlet of dual air supply fuel cell, then performance was compared. Supplying humidified air to an additional air inlet showed better performance than supplying non-humidified air to an additional air inlet case on all of the air flow ratio cases.

Chapter 4. Stability characteristics and EIS measurement of dual air supply PEMFC

4.1 Introduction

Experiment was conducted on various operating conditions on previous chapter. Main variable was main to secondary air flow ratio, air stoichiometric ratio, relative humidity of air supplied to an additional air inlet. Performances of dual air supply fuel cell were measured and compared. And then, we found optimal value of various operating parameters when dual air supply fuel cell is operated. In this chapter, stability characteristics were investigated on various air flow ratio conditions by experiments. Then voltage fluctuation was measured and compared in each case. Electrochemical Impedance Spectroscopy (EIS) method was applied to dual air supply fuel cell to check electrochemical characteristics of dual air supply fuel cell.

4.2 Stability characteristics

In addition to the performance of fuel cell, stability is also important characteristics to be considered in fuel cell. if fuel cell is not stable, it can cause durability and safety problem. So stability characteristics were investigated using dual air supply fuel cell to find optimal air flow ratio for stability.

4.2.1 Experimental conditions

Objective of this experiment is to measure stability characteristics of dual air supply fuel cell on various air flow ratio, and experimental results would be compared with that of normal fuel cell also. Operating parameters and values are shown in Table 4.1. Stoichiometric ratio of hydrogen and air was 1.5 and 2.0 respectively and temperature of fuel cell was set to 65^{o}C. Relative humidity of hydrogen and air was 100%. Voltage was measured on various air flow ratio, from 100:0 to 30:70. 20 A was loaded for 1000 seconds to check voltage fluctuation for each case.

4.2.2 Experimental results

Stability measurement can be seen from Fig. 4.1 to Fig. 4.8. Fig. 4.1 shows stability characteristics of normal fuel cell. In this case, voltage fluctuates largely and measured voltage decreased as time goes by. Fig. 4.2 shows voltage measurement data using dual air supply fuel cell when air flow ratio is 90:10. Voltage fluctuates less than that of normal fuel cell. Voltage decrease phenomenon didn't occur in dual air supply fuel cell. As the amount of the air supplied to an additional air inlet, voltage fluctuates less. Average value of voltage become higher also, that can be seen in previous chapter. When air flow ratio was 40:60, voltage fluctuation was the smallest for all of the cases. But when air flow ratio was 30:70, voltage fluctuation value increased. We could confirm in previous chapter that Dual air supply fuel cell showed the best performance when air flow ratio was 40:60. At that air flow ratio, dual air supply fuel cell shows the most stable performance.

Table 4.1 Experimental conditions for stability measurement

Operating parameter	Value
SR of hydrogen	1.5
SR of air	2.0
Temperature [^oC]	65
Relative humidity of hydrogen [%]	100
Relative humidity of air [%]	100
Main to secondary air flow ratio	100:0~30:70

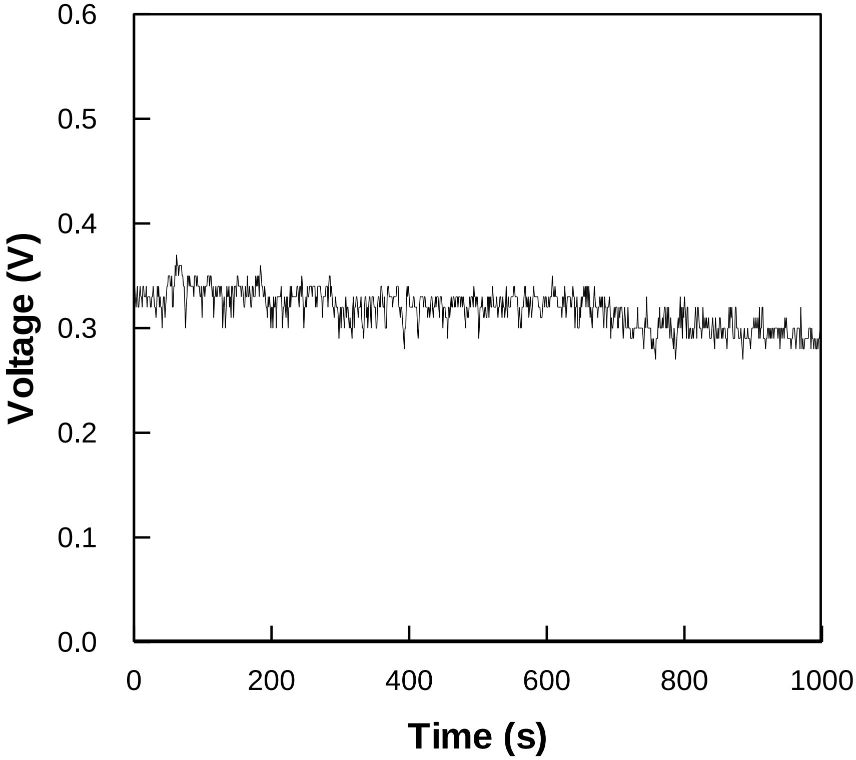


Fig. 4.1 Voltage measurement using normal fuel cell while 20A was loaded for 1000 seconds

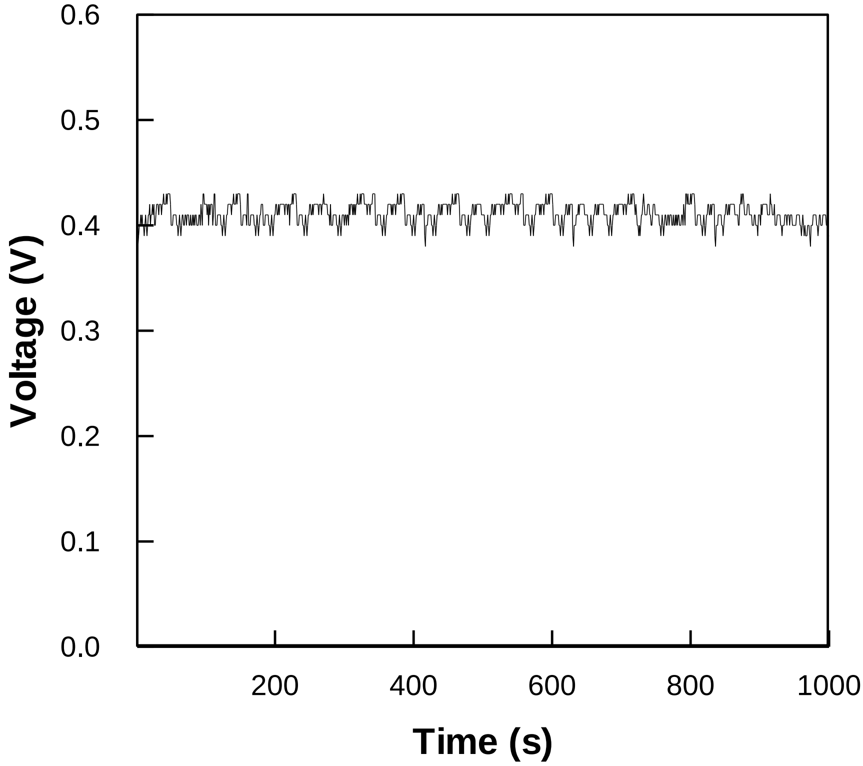


Fig. 4.2 Voltage measurement using dual air supply fuel cell when air flow ratio is 90:10, 20A was loaded for 1000 seconds

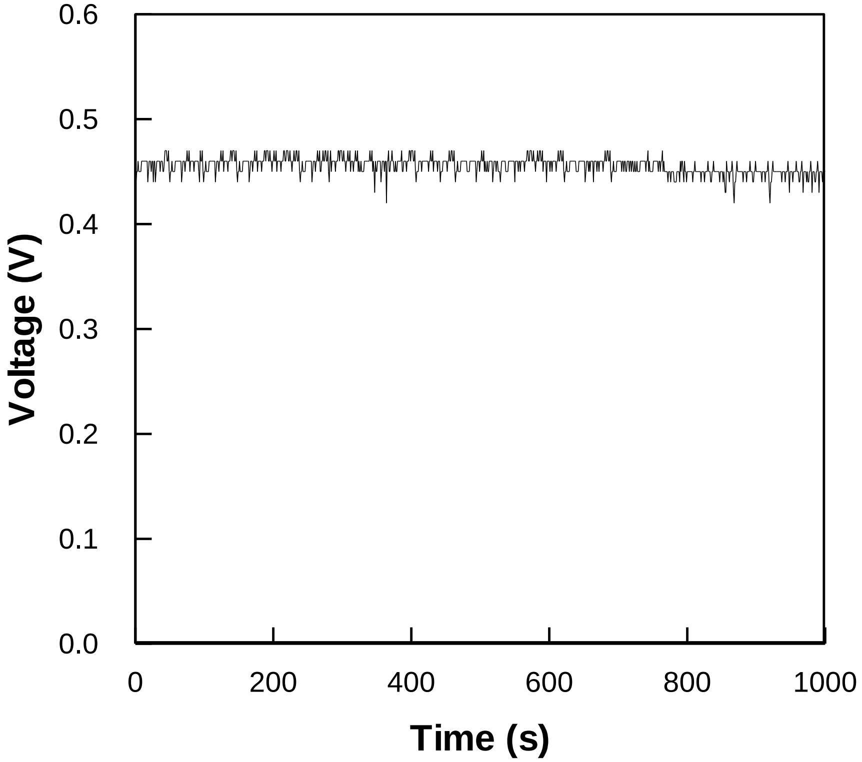


Fig. 4.3 Voltage measurement using dual air supply fuel cell when air flow ratio is 80:20, 20A was loaded for 1000 seconds

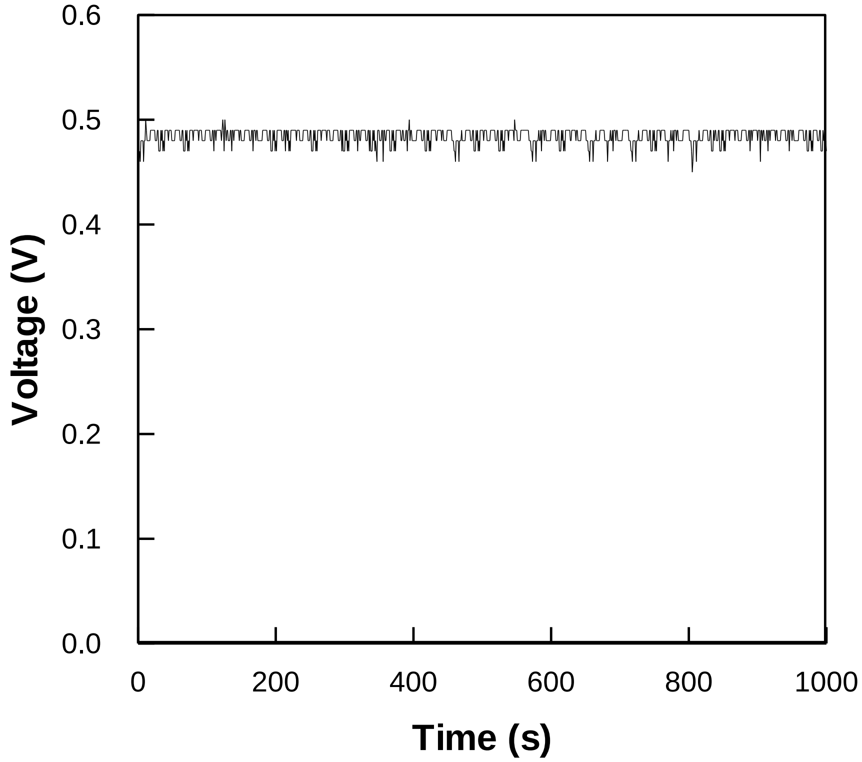


Fig. 4.4 Voltage measurement using dual air supply fuel cell when air flow ratio is 70:30, 20A was loaded for 1000 seconds

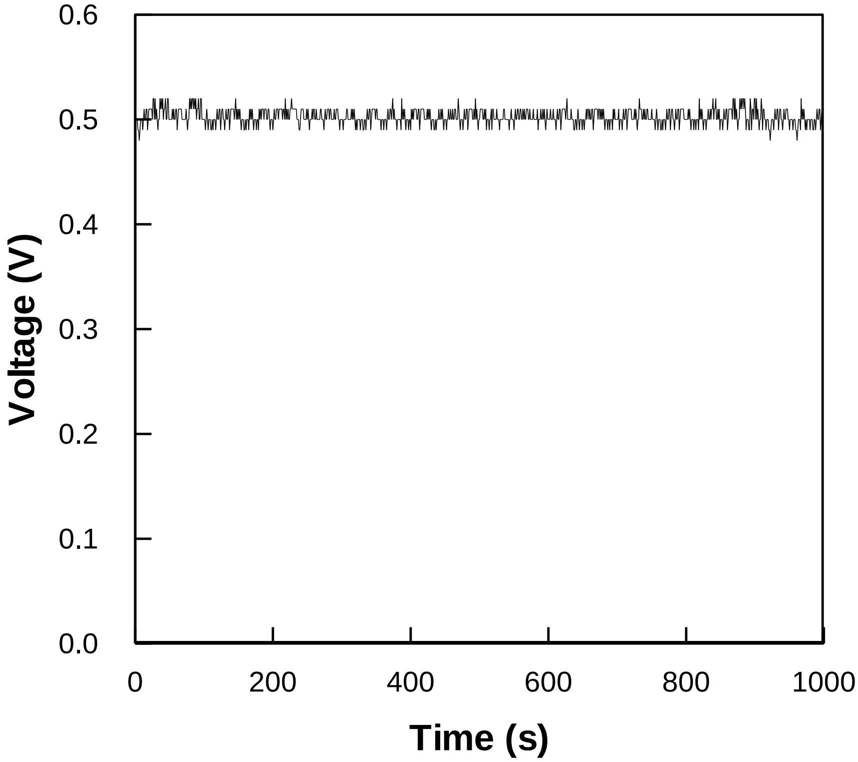


Fig. 4.5 Voltage measurement using dual air supply fuel cell when air flow ratio is 60:40, 20A was loaded for 1000 seconds

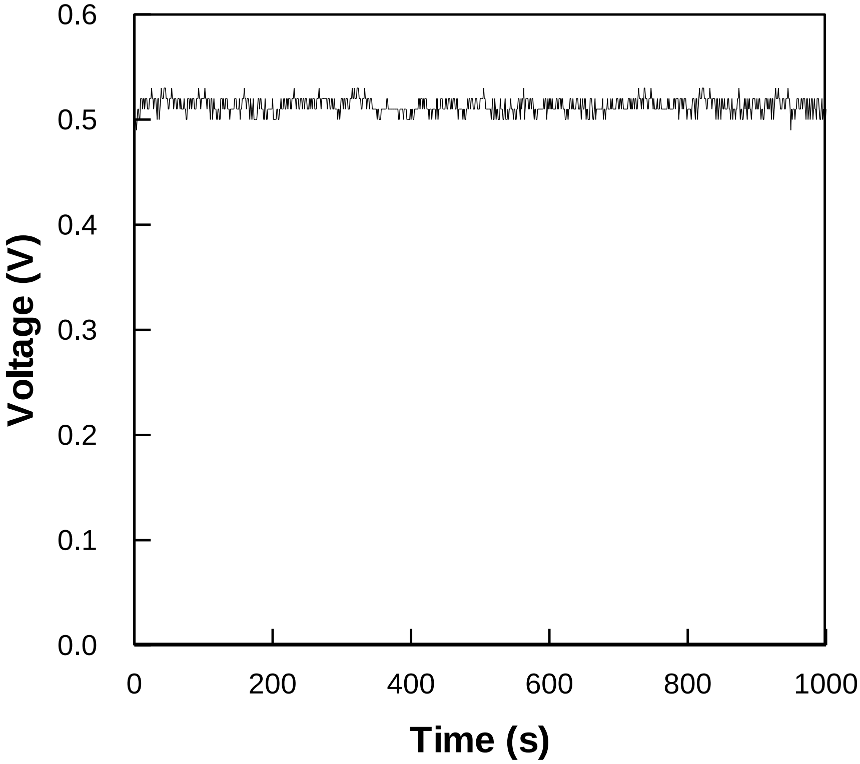


Fig. 4.6 Voltage measurement using dual air supply fuel cell when air flow ratio is 50:50, 20A was loaded for 1000 seconds

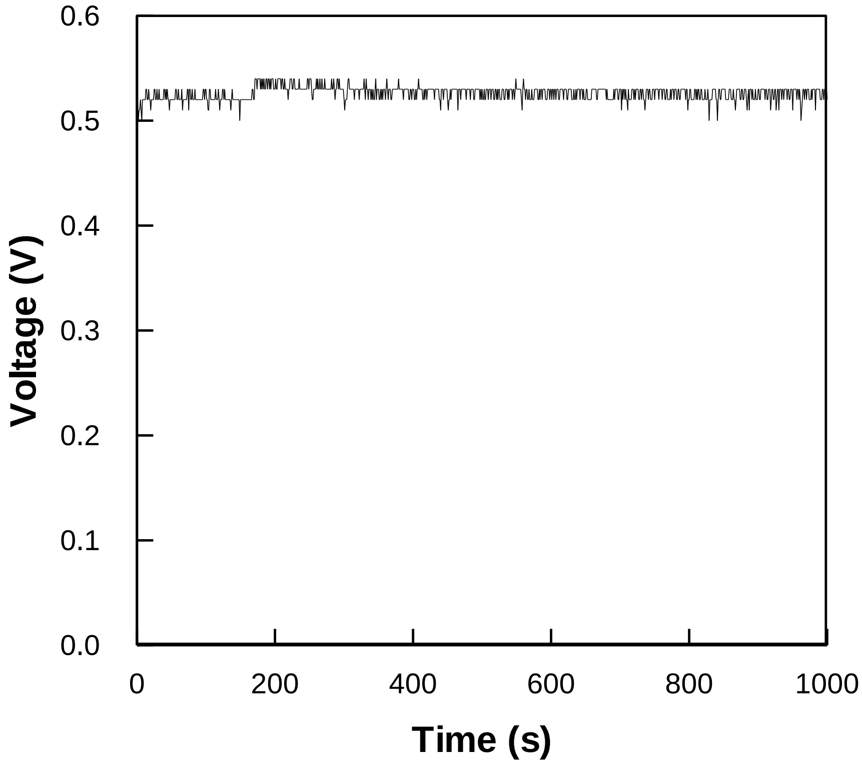


Fig. 4.7 Voltage measurement using dual air supply fuel cell when air flow ratio is 40:60, 20A was loaded for 1000 seconds

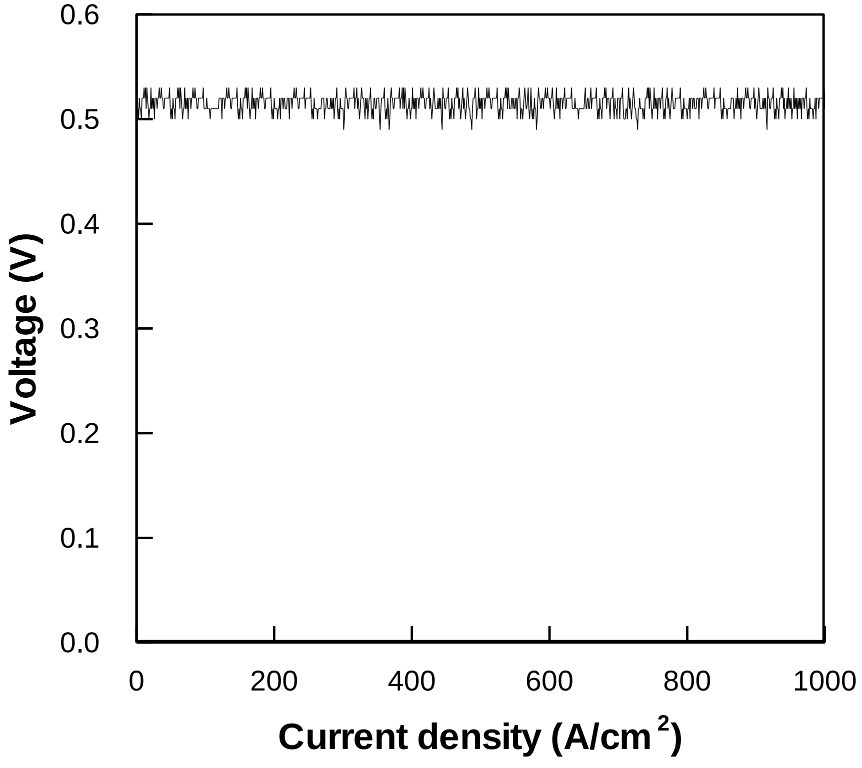


Fig. 4.8 Voltage measurement using dual air supply fuel cell when air flow ratio is 30:70, 20A was loaded for 1000 seconds

4.3 EIS measurement

To check electrochemical characteristics of dual air supply fuel cell, EIS measurement was conducted. Through EIS measurement, Resistance, Reactance, notion of that is electrical resistance, can be checked.

4.3.1 Experimental conditions

EIS measurement was conducted on low, middle, high current density region respectively. In each experimental case, Reactance and resistance were measured on various air flow ratio. The impedance spectra were recorded by sweeping frequencies from high to low frequency, from 4000 Hz to 0.3 Hz.

4.3.2 Experimental results

Experimental results of EIS measurement can be seen From Fig. 4.9 to Fig. 4.11. Fig. 4.9 shows EIS measurement when 6A was loaded on dual air supply fuel cell on various air flow ratio conditions. In case of normal fuel cell, reactance value showed the highest value among all of the cases. As the amount of the air supplied to an additional air inlet increased while total amount of the air supplied to fuel cell was the same, measured reactance value decreased. When air flow ratio was 50:50, 40:60, reactance value showed the smallest value. And then measured reactance started to increase when air flow ratio was 30:70.

Fig. 4.10 and Fig. 4.11 shows EIS measurement data when 12A and 18A was loaded on various air flow ratio conditions, respectively. Reactance indicated the highest value when normal fuel cell was used for EIS measurement in two cases. All of the air flow ratio conditions using dual air supply fuel cell showed lower reactance value than that of normal fuel cell. Reactance also dropped as the amount of the air supplied to an additional air inlet while total amount of the air supplied to fuel cell was the same.

Table 4.2 Experimental conditions for EIS measurement

Operating parameter	Value
SR of hydrogen	1.5
SR of air	2.0
Temperature [ºC]	65
Relative humidity of hydrogen [%]	100
Relative humidity of air [%]	100
Main to secondary air flow ratio	100:0~30:70
Loaded current [A]	6/12/18

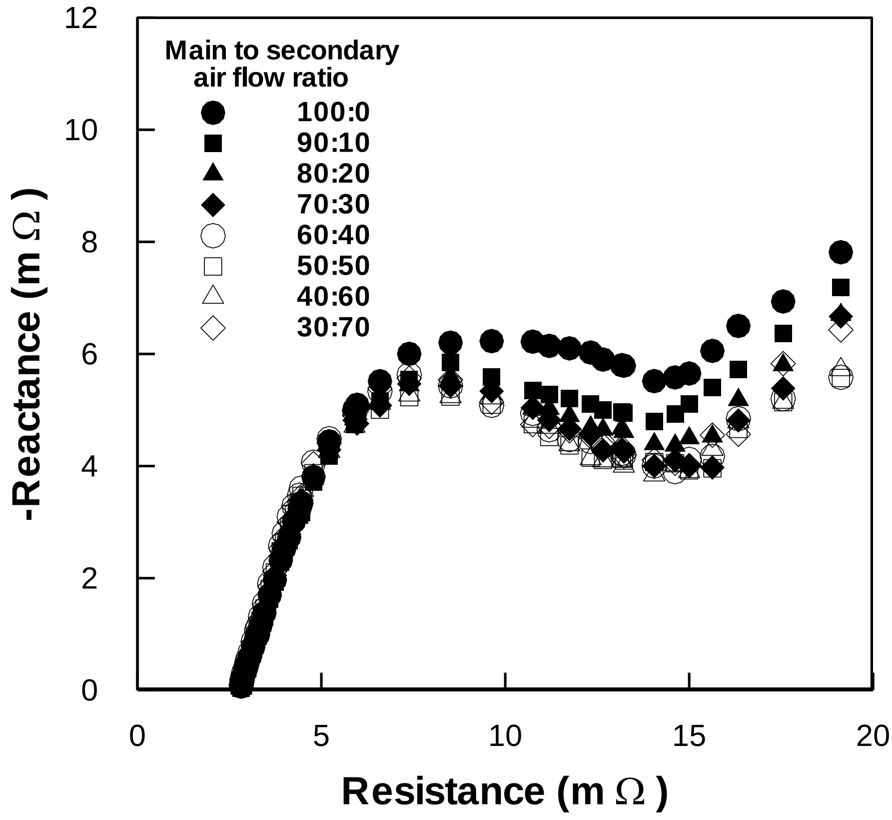


Fig. 4.9 EIS measurement on various air flow ratio, when 6A was loaded

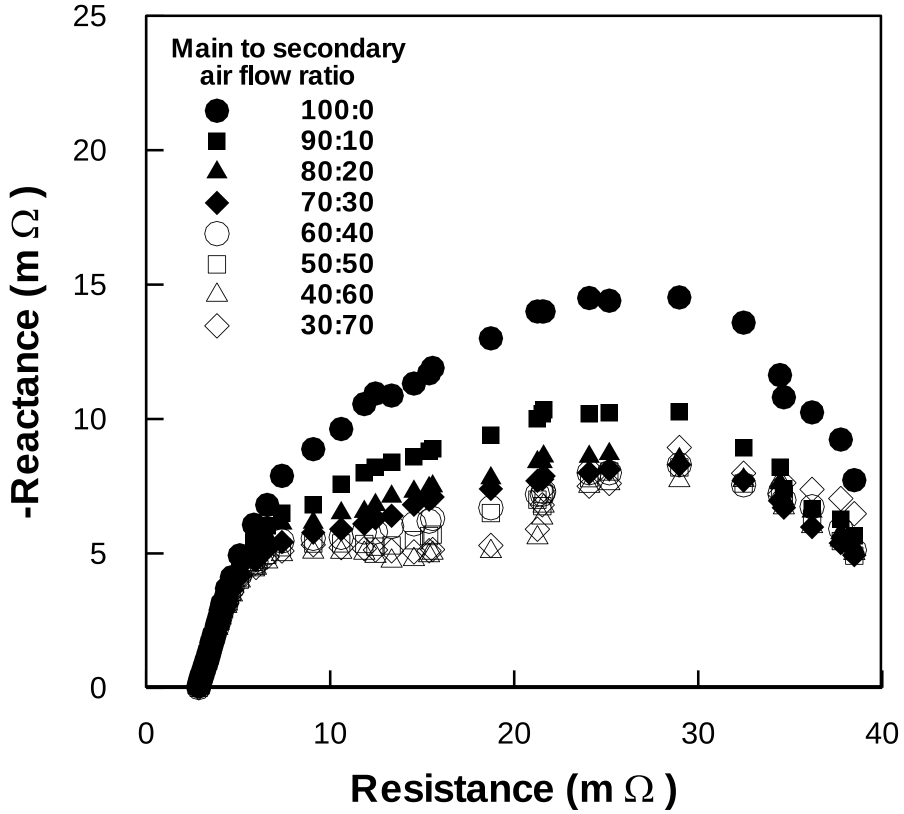


Fig. 4.10 EIS measurement on various air flow ratio, when 12A was loaded

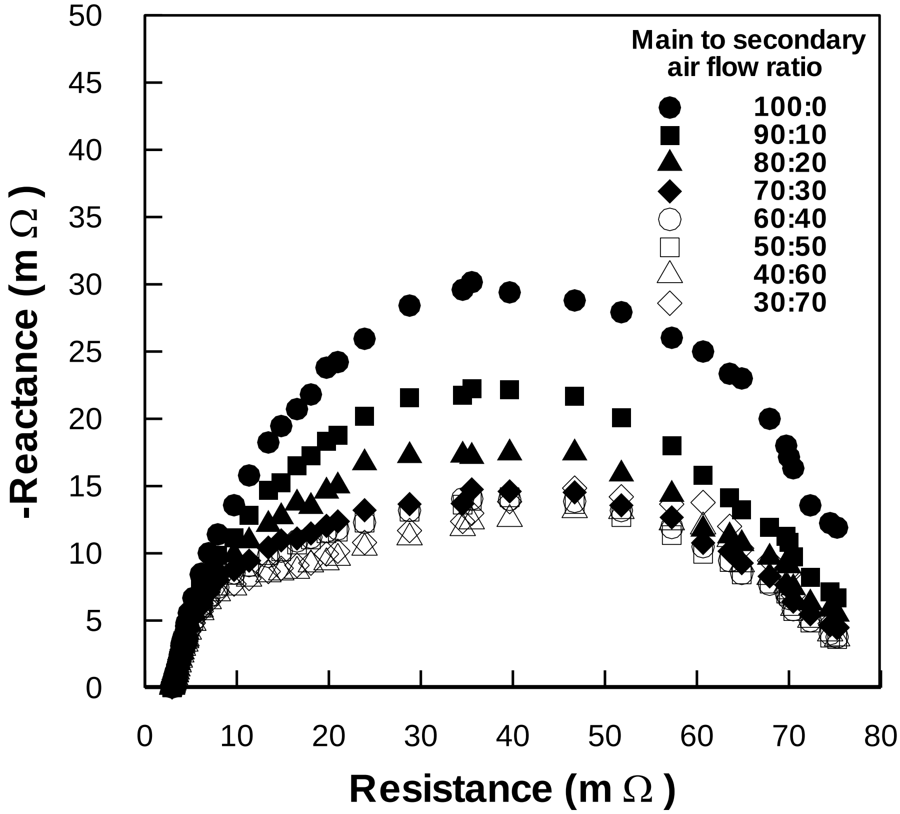


Fig. 4.11 EIS measurement on various air flow ratio, when 18A was loaded

4.4 Summary

Stability characteristics and EIS measurement were investigated in this chapter. To check stability characteristics, same current was loaded to each air flow ratio case, then voltage fluctuation was measured.

When dual air supply was applied to fuel cell, voltage fluctuated less than that of normal fuel cell. the amount of the air supplied to an additional air inlet increased, voltage fluctuation decreased to when air flow ratio was 40:60. While air flow ratio was 30:70, voltage fluctuation increased again. So, optimal air flow ratio for stable fuel cell system using dual air supply fuel cell can be 40:60.

EIS measurement was conducted on various air flow ratio conditions to figure out the performance difference when air flow ratio changed. Measured reactance has the highest value in case of normal cell. When dual air supply fuel cell was used, that of reactance value became smaller than that of normal fuel cell. In all current density cases, Reactance value decreased as the amount of the air supplied to an additional air inlet while total amount of the air supplied to fuel cell was constant. As current loaded to fuel cell increased, value gap of reactance became bigger when air flow ratio varied in each current condition. It can demonstrate performance difference in each current condition when air flow ratio varied.

Chapter 5. Conclusion

In this study, dual air supply concept was applied to fuel cell in parallel channel. We called it dual air supply fuel cell. Air can be divided and supplied to main and an additional air inlet. We checked various characteristics of dual air supply fuel cell.

Experiment was conducted on various air flow ratio conditions. Through this experiment, we verified that optimal air flow ratio in which dual air supply fuel cell performs the best exists.

When we changed stoichiometric ratio of air as a main variable in the experiment, we found that dual air supply fuel cell performed better than normal fuel cell even if smaller amount of the air was supplied to dual air supply fuel cell than normal fuel cell. So, dual air supply fuel cell can reduce energy consumption of air blower in fuel cell system.

Stability characteristic of dual air supply fuel cell was also investigated. When dual air supply was applied in the experiment, Voltage fluctuated less than that of normal fuel cell.

Lastly, EIS measurement was carried out to find the reason of performance difference when air flow ratio varies. We found tendency that reactance decreased as the amount of the air supplied to an additional air inlet increased while total amount of the air supplied to fuel cell was constant.

In conclusion, dual air supply fuel cell is effective to enhance the performance of parallel channel fuel cell. Also, that fuel cell can increase efficiency of fuel cell system by reducing parasitic power of fuel cell system component.

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국 문 초 록

산업화가 진행됨에 따라, 환경오염과 지구온난화 문제가 해결해야 할 중요한 문제로 대두되고 있다. 이에 따라 전 세계적으로 친환경, 신재생 에너지에 대한 관심이 높아지고 있다.

그 중 수소연료전지는 수소와 산소가 반응하여 연료에 저장된 화학적 에너지를 전기적 에너지로 변환시키는 장치이다. 반응 후 물과 열이 생성되고, 오염물질을 만들어내지 않으며, 높은 효율, 높은 전력 밀도, 낮은 온도에서 작동이 가능한 장점 등으로 인해 차세대 에너지 원으로 각광받고 있다.

하지만 수소연료전지의 대중화를 위해 해결해야 할 과제들이 존재하는 것이 사실이다. 성능 향상, 연료전지 내 유동 분배, 물 관리, 높은 비용 등의 문제가 있으며, 이를 해결하기 위해 다양한 각도에서의 연구가 진행되고 있다.

본 연구에서는 평행 유로 연료전지 내 유동이 균일하지 않은 문제를 해결하기 위해, 기존 연료전지에 추가 공기 공급부를 설계하였다. 기존 공기 공급부와 추가 공기 공급부를 통해 공기를 분배하여 연료전지 내에 공급해 줄 수 있게 된다. 이 연료전지를 공기 이중 공급 연료전지로 명명하였다. 해당 연료전지를 통해 평행유로 연료전지의 성능 향상 및 안정성 향상을 목표로 하였다.

공기 이중 공급 연료전지 특성 파악을 위해, 첫 번째로 다양한 공기 분배 비 조건에 따른 성능 측정을 진행하였다. 일반적인 연료전지와 비교했을 때, 공기 이중 공급 연료전지가 더 높은 성능을 보

이는 것을 확인 할 수 있었고, 최대 성능을 나타내는 최적의 분배비 또한 찾을 수 있었다.

두 번째로, 일반적인 연료전지와 공기 이중 공급 연료전지를 이용하여 다양한 공기 당량비 조건에 따른 성능 분석 실험을 진행하였다. 실험 결과, 일반적인 연료전지와 비교했을 때 더 적은 양의 공기를 공기 이중 공급 연료전지에 공급해주었는데도 불구하고, 공기 이중 공급 연료전지가 일반적인 연료전지보다 더 높은 성능을 나타내는 것을 확인할 수 있었다. 이 결과를 연료전지 시스템 측면에서 봤을 때, 이중 공기 공급 연료전지 적용 시 공기 블로어의 소모동력 감소를 이끌어낼 수 있으며, 이는 연료전지 시스템 효율 향상에 기여할 수 있다.

마지막으로 실험을 통해 이중 공기 공급 연료전지 이용 시 성능뿐만 아니라 안정성 또한 향상되는 것을 확인할 수 있었다. 결과적으로 평행 유로 형상에 이중 공기 공급 연료전지 적용 시 성능 향상, 연료전지 시스템 효율 향상, 안정성 향상을 확인할 수 있었다.

주요어: 고분자 전해질막 연료전지, 이중 공기 공급, 유동 분배, 평행 유로

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