

# Molten Carbonate Fuel Cell Power Generation Technology and its Challenges

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## Research

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# Abstract

As a clean and efficient power generation device, molten carbonate fuel cell(MCFC)can directly convert chemical energy into electrical energy at the operating temperature of 650 degrees, avoiding the heat loss caused by the Carnot cycle, and effectively reducing the emission of CO<sub>2</sub> and other pollutants. This paper introduces the background, basic principle, system design and current situation of fused carbonate fuel cell at home and abroad, and explains the technical problems that molten carbonate power generation technology is facing. At the same time, the cost of the molten carbonate power generation system is analyzed, and the present cost and the cost after industrialization are compared and evaluated to provide a reference for the economy of the molten carbonate fuel cell power generation system.

## 1 Introduction

Climate change has become a hot topic in the world today<sup>[1]</sup>. The massive use of fossil fuels has caused a large amount of emissions of greenhouse gases such as carbon dioxide, which in turn leads to the greenhouse effect and global warming<sup>[2-3]</sup>. At the end of 2017, a study by the international hydrogen energy commission showed that by 2050, 20% of the reduction of carbon dioxide in the global environment will be accomplished by hydrogen, which will account for 18% of the world's terminal energy. Therefore, green and low carbon will become the inevitable trend of world energy development.

Hydrogen as a clean energy, has the characteristics of abundant resources, high calorific value and no pollution. The hydrogen energy field mainly includes hydrogen production, hydrogen storage, hydrogen transport and hydrogen fuel cell technologies. At present, the mainstream hydrogen fuel cells mainly include low-temperature fuel cells (proton exchange membrane fuel cell PEMFC, etc.) and high-temperature fuel cells (solid oxide fuel cell SOFC and molten carbonate fuel cell MCFC, etc.)<sup>[4]</sup>. Among them, the low-temperature fuel cells are mainly used in the field of mobile transportation, while the high-temperature fuel cells are mainly used in the field of distributed power generation<sup>[5]</sup>.

Molten carbonate fuel cell (MCFC) is a kind of high temperature fuel cell operating at 650°C, which has the advantages of wide fuel source, small land area, less pollutant emission and high generation efficiency<sup>[6]</sup>. Moreover, it can take air and CO<sub>2</sub> as raw materials to participate in electrochemical reaction, the CO<sub>2</sub> generated by the system can be recycled, and the greenhouse gas emissions can be greatly reduced. It is especially suitable for distributed power stations to realize heat and power co-generation, which has great practical significance for energy conservation, emission reduction and energy utilization efficiency.

Molten carbonate fuel cell (MCFC) can use natural gas, methanol, methane, coal gas, hydrogen-containing chemical droppings as raw materials, by means of electrochemical reactions to generate electricity. According to the MCFC principle, all fuels must be converted into 75% hydrogen-rich gas before entering the MCFC stack to generate electricity.

## 2 Mcfc Technology

### 2.1 MCFC Principle

The cathode of the molten carbonate fuel cell (MCFC) is fed with air and carbon dioxide. Oxygen and carbon dioxide in the air undergo reduction reaction at the cathode to obtain electrons and generate carbonate ions, which are transmitted to the anode through the molten carbonate. The anode feed of a molten carbonate fuel cell (MCFC) is hydrogen or hydrogen-rich gas. Hydrogen and carbonate ions oxidize at the anode, losing electrons and producing water and carbon dioxide. <sup>[4,7]</sup> The matrix between the electrodes provides structural support for the molten carbonate and acts as a gas trap. Electrons supply electrical appliances with electricity through external circuits. See Fig.1.

Fig.1 Principle of MCFC

### 2.2 MCFC System

A set of molten carbonate fuel cell power generation system mainly includes four parts: fuel treatment system, MCFC stack system, exhaust heat recovery and CO<sub>2</sub> circulation system, and control system <sup>[8]</sup>. The fuel treatment system can convert hydrocarbon fuels to hydrogen-rich gas by external reforming device or internal reforming technology. High temperature fuel cell stack system transforms chemical energy of the hydrogen-rich gas into electricity. Exhaust heat recovery and CO<sub>2</sub> cycle system uses the waste heat of exhaust gas by heat exchanger and separates CO<sub>2</sub> from the exhaust gas for recycling <sup>[9]</sup>. Control system controls the operation of the fuel cell system parameters such as gas flow, cell stack temperature, etc. through the control cabinet. See Fig.2.

Fig.2 The Process diagram of MCFC power generation system

The power generation system of multiple MCFC stacks can be combined by means of series and parallel connection. The parallel connection can amplify the power of the fuel cell stack, and the multi-stage series connection can improve the fuel efficiency and power generation efficiency. The combination of parallel and series can increase the power of the stack and achieve higher generation efficiency at the same time. For example, for the 100kW MCFC power generation system, four 20kW MCFC stacks can be connected in parallel and then connected in series with one 20kW MCFC stack. The four parallel battery stacks receive air separately. The anode tail gas still contains a large amount of unreacted hydrogen, reconnected it to the anode of the tandem MCFC stack, further utilizing the chemical energy of the unreacted hydrogen, and the cathode of the tandem MCFC stack is separately injected. This combination can effectively improve the fuel efficiency without changing the total amount of anode air intake, thus improving the power generation efficiency of MCFC power generation system <sup>[10-12]</sup>. See Fig.3.

Fig.3 100 kW MCFC system based on Aspen

### 2.3 State of Art

The main research institutions of molten carbonate fuel cell in China are Dalian Institute of Chemical Physics (Chinese Academy of Sciences), Shanghai Jiao Tong University and Huaneng Clean Energy Research Institute.

Dalian Institute of Chemical Physics—Chinese Academy of Sciences—mainly carried out basic laboratory research on materials science, and successfully assembled a MCFC stack with a working area of 110cm<sup>2</sup>. The power was less than 1kW. Shanghai Jiao Tong University carried out laboratory material preparation research and successfully assembled a 1.5kW MCFC battery stack. With the special support of GreenGen in 2008, Huaneng Clean Energy Research Institute has carried out researches on the preparation of key materials and components, the assembly of MCFC stacks, the sintering of MCFC stacks, the operation of MCFC stacks, etc. Huaneng Clean Energy Research Institute masters the core and key technologies of MCFC, successfully developed 2kW, 5kW and 10kW MCFC stacks and is working on developing 20-100kw MCFC power generation system. See Fig.4.

Fig.4 10kW MCFC stack of Huaneng Clean Energy Research Institute

For more than 20 years, the molten carbonate fuel cell (MCFC) has been proved to be the most suitable distributed power generation technology in the United States, Germany, Italy, Japan, South Korea and other developed countries after a lot of research and demonstration [13].

In USA, Fuel Cell Energy (FCE) has successfully developed 300kW, 1.4MW, 2.8MW MCFC product modules, and built about fifty 250kW-50MW MCFC power plants. The effective surface of a single cell is 1m<sup>2</sup>, the power generation efficiency is 47%-60%, and the cogeneration efficiency can reach 80-90% [14-15]. In the 1880s, Japanese IHI company began to study the MCFC power generation technology, mainly on the MCFC and gas turbine co-generation system. Currently the power can reach 250-300kw scale. And in 2005, IHI successfully operated two 300kW molten carbonate fuel cell and gas turbine (MCFC-GT) co-generation system with Toyota [16-17]. By adopting the MCFC technology of FCE, POSCO has built a number of MCFC power stations in South Korea, among which the largest MCFC power station can reach 59MW with a power generation efficiency of 47% [18-19].

## 3 Challenges

### 3.1 Technical Challenges

The difficulties in the technology of molten carbonate fuel cell power generation mainly lie in the development and system integration of the MCFC stack.

- Sealing problem of MCFC stack. MCFC belongs to high temperature fuel cell, and the sealing method of low temperature fuel cell cannot be adopted. It is necessary to develop a high temperature sealant that can seal at MCFC operating temperature.
- Corrosion problem of bipolar plate corrosion problem. The bipolar plate is corroded by the electrolyte molten carbonate of MCFC at high temperature and it is easy to be seriously corroded after long time

operation, which affects the durability and performance of the fuel cell [20].

- Volatilization loss of electrolyte. Electrolyte volatilization causes insufficient electrolyte in MCFC stack and affects the performance of fuel cell [21].
- The consistency of the MCFC stack. At present, the power of single MCFC stack is small. If amplification of the power is demanded, multiple MCFC stacks need to be integrated. Therefore, the consistency of MCFC stacks is crucial.

### 3.2 Economic Analysis

The cost of molten carbonate fuel cell power generation system mainly includes the cost of fuel treatment system, the cost of MCFC stack system, the cost of exhaust heat recovery and CO<sub>2</sub> circulation system and the cost of control system. Normally, the cost of the MCFC stack system accounts for about one third of the cost of the fuel cell power generation system. In the cost of MCFC stack system, the cost of bipolar plate is about two thirds of that of MCFC stack system. In the cost of bipolar plate, the processing cost is three times of the material cost. Therefore, the cost price reduction space of MCFC power generation system is very large. At present, the cost of MCFC stack is 12,000 to 15,000 CNY per kilowatt. With the scale enlargement, mass production and technological progress, the cost of MCFC stack can be reduced to 6,000 CNY per kilowatt, which is more competitive compared with traditional thermal power generation [22].

According to the market survey and cost analysis, the current costs of MCFC power generation system based on different fuels and different power scales are shown in Fig.5. The costs of MCFC power generation system based on natural gas, methanol, syngas as fuel are significantly reduced after industrialization. See Fig.6.

Fig.5 Cost of MCFC system based on different fuels at present

Fig.6 Cost of MCFC system based on different fuels after industrialization

## 4 Conclusion

This paper introduces the background, basic principle, advantages of MCFC, MCFC power generation system and system design methods. Besides, the status quo of MCFC power generation technology at home and abroad are also introduced, including the research status of the United States FCE, Japan IHI, South Korea POSCO, Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Shanghai Jiao Tong University, China Huaneng Clean Energy Research Institute.

This paper analyzes the cost of MCFC power generation system to provide a reference direction for compressing the cost of MCFC power generation system. With scale enlargement, mass production and technical progress, the cost of MCFC power generation system can be greatly reduced.

The current technical problems and challenges of MCFC power generation system are proposed, including the development of core and key technologies of MCFC stacks and the MCFC power generation system integration design.

## Declarations

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## Figures

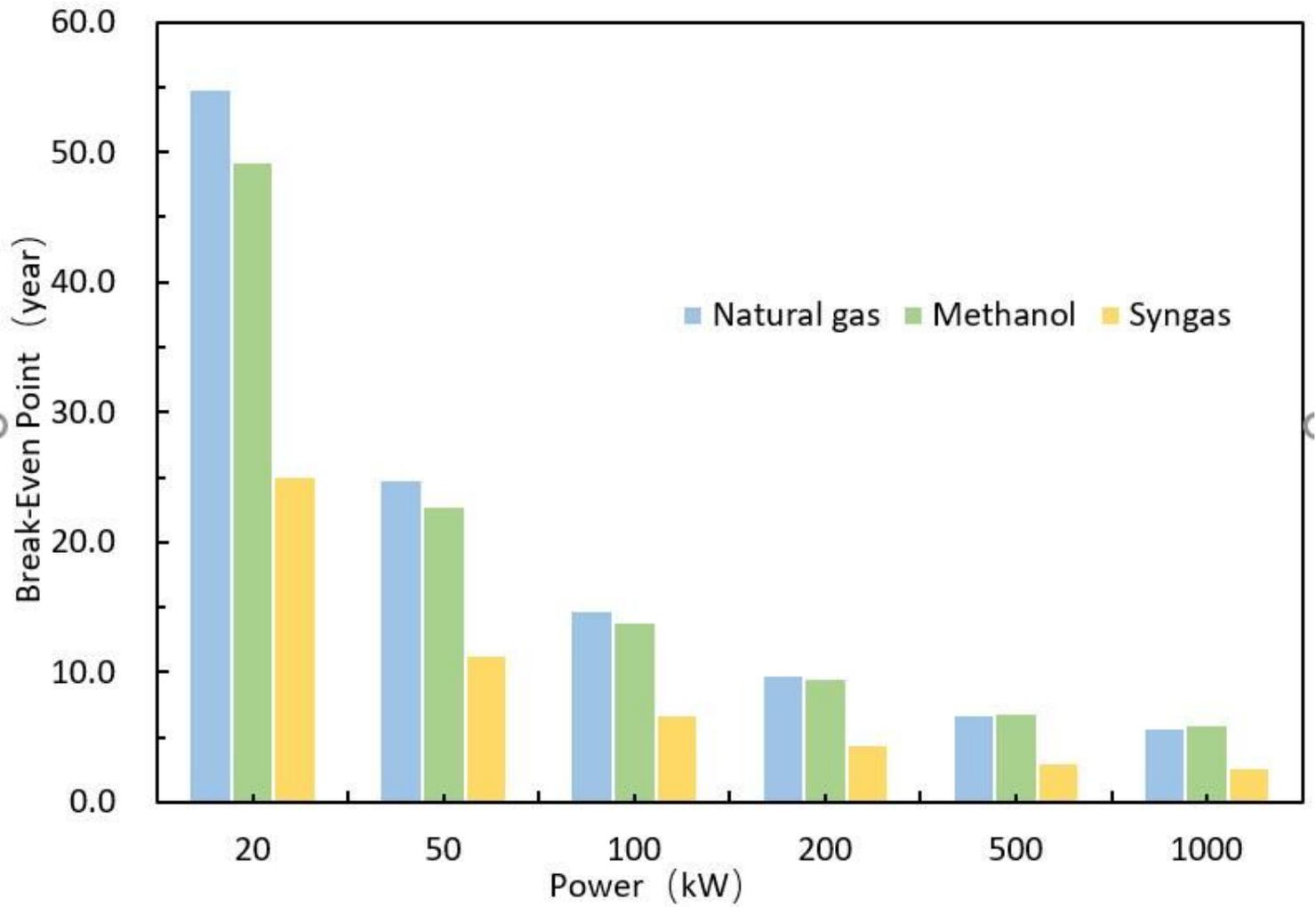


Figure 1

Cost of MCFC system based on different fuels after industrialization

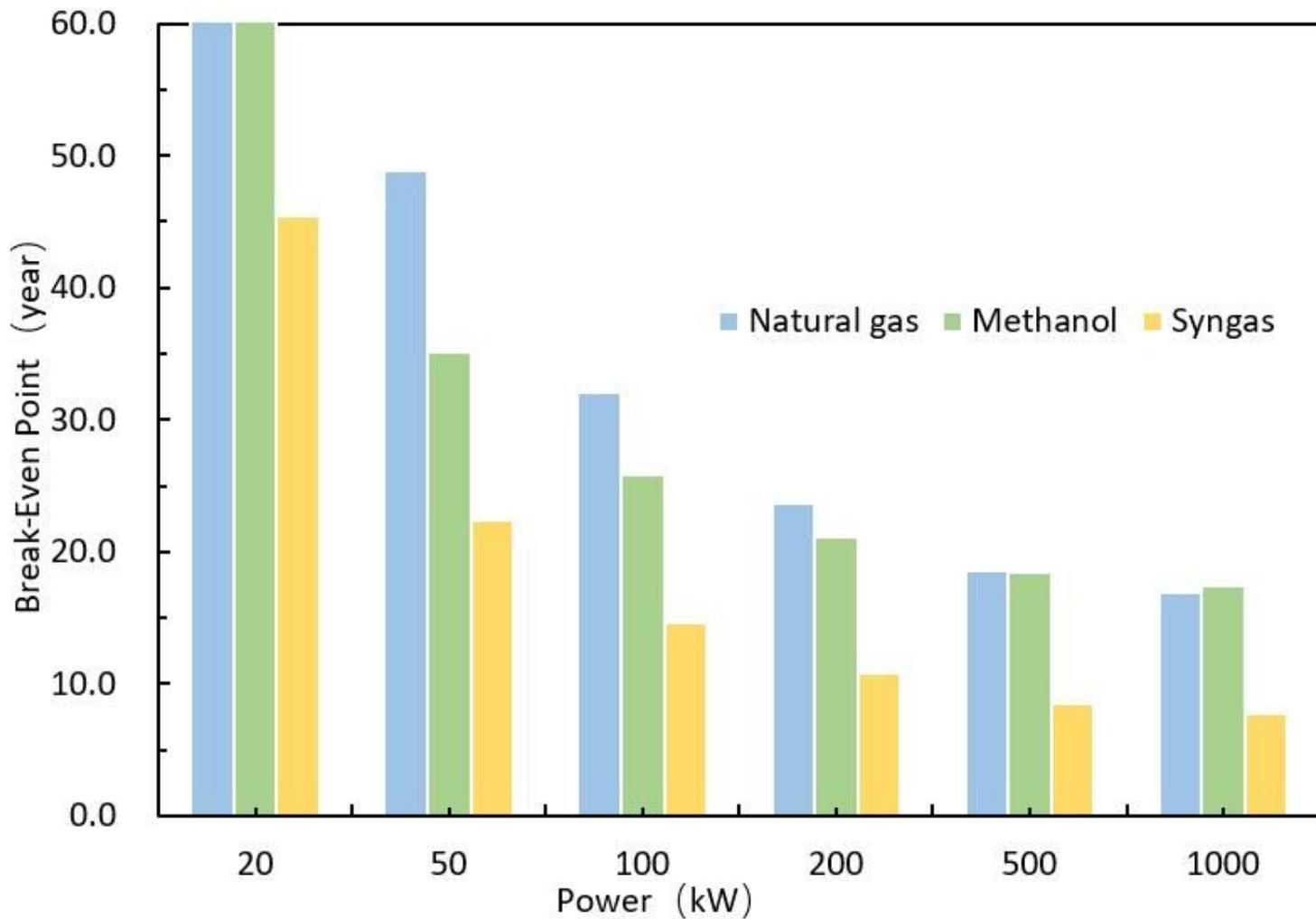


Figure 2

Cost of MCFC system based on different fuels at present



**Figure 3**

10kW MCFC stack of Huaneng Clean Energy Research Institute

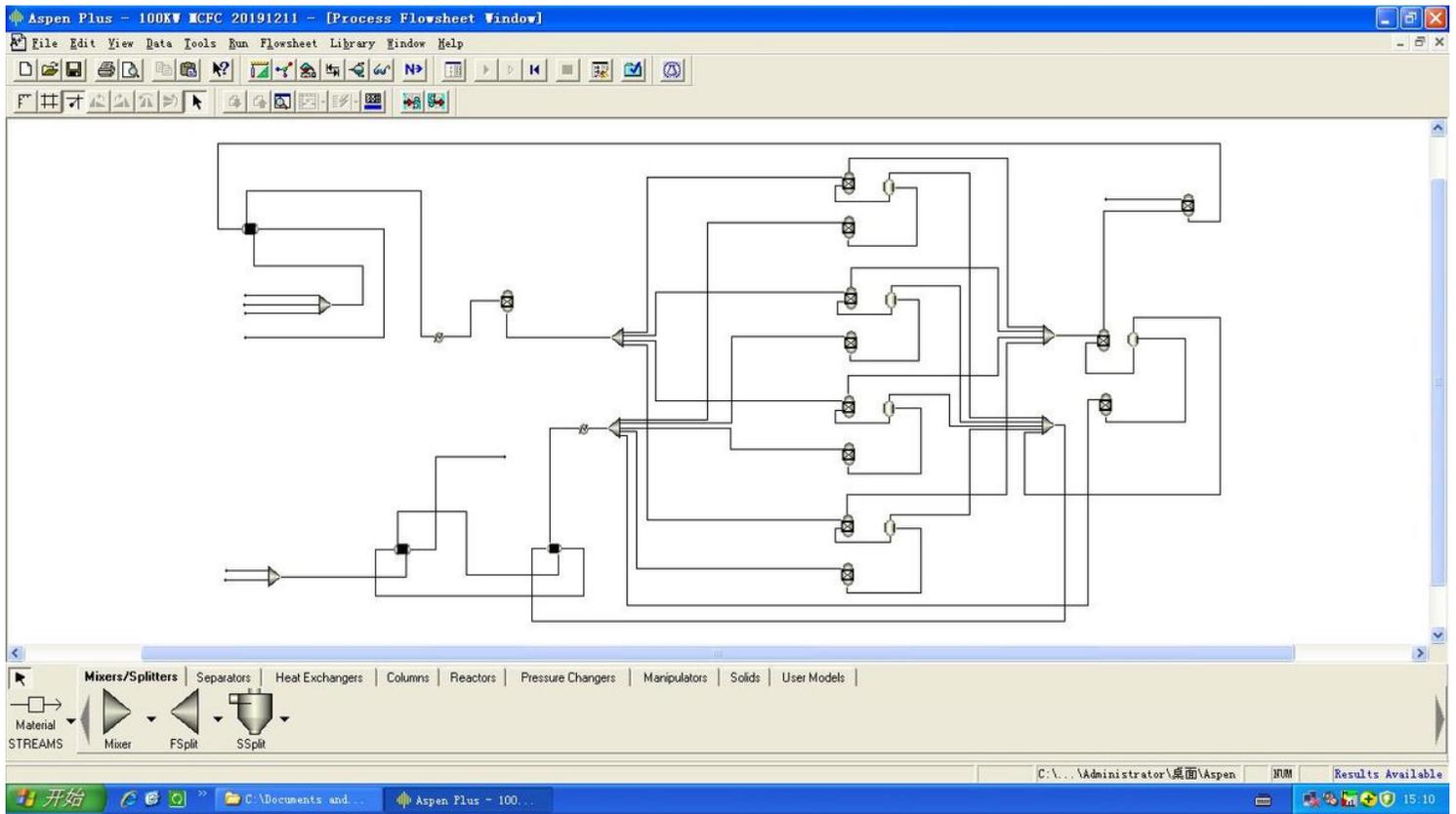


Figure 4

100 kW MCFC system based on Aspen

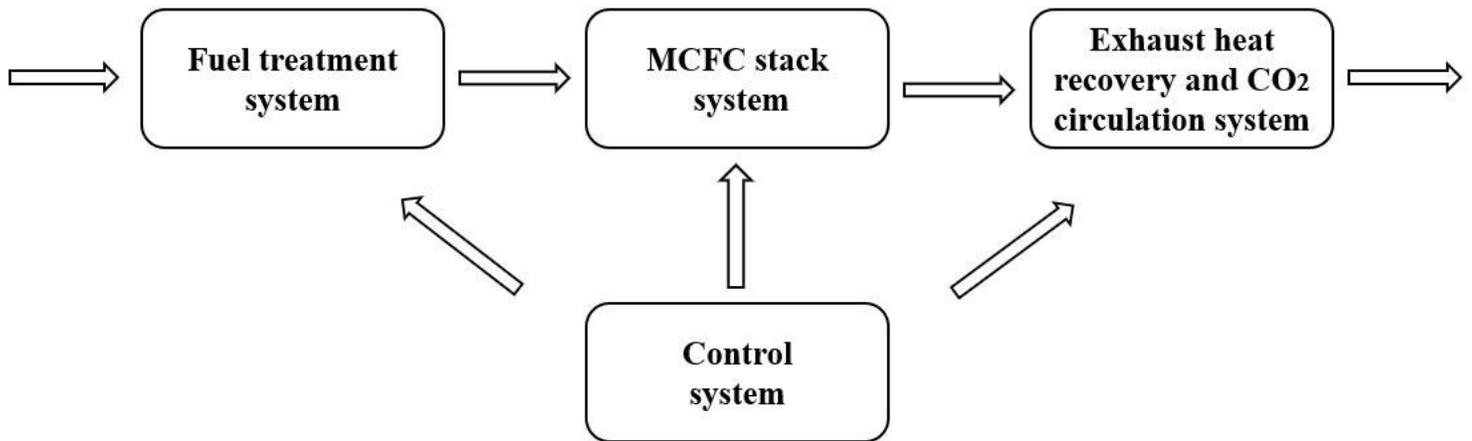
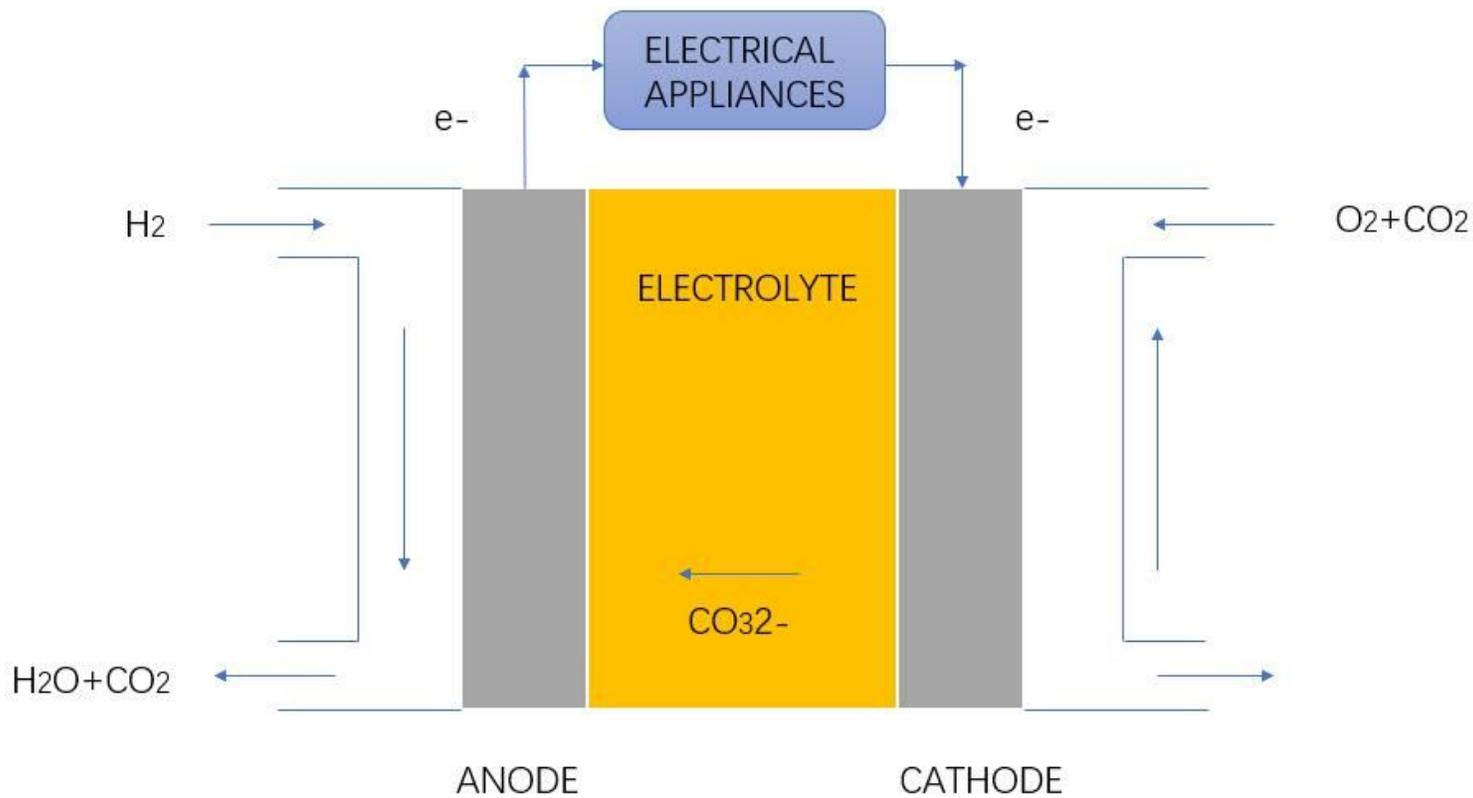


Figure 5

The Process diagram of MCFC power generation system



**Figure 6**

Principle of MCFC