Development Status and Enlightenment of Japanese Household Fuel Cells

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Abstract

Japan's experience in related technologies and commercialization of household fuel cell cogeneration systems is at the world's leading level. The article systematically analyzes the solid-state polymer fuel cell cogeneration system mainly used in Japan, and provides a corresponding overview of the development of Japanese domestic fuel cells, then researches on relevant policies that formulated by the Japanese government to promote the promotion and application of household fuel cells. combined with the basic national conditions of China's energy environment, it is known that the development and promotion of household fuel cell cogeneration systems in China is feasible. Japan's experience in the promotion and application of fuel cells for homes is worth learning.

Keywords

Domestic fuel cell, Cogeneration of heat and electricity, Policy; popularize, Japan.

1. Introduction

Traditional thermal power generation systems mainly rely on fossil energy such as coal. 50% to 60% of the combustion energy loss in boilers, steam turbines and other equipment [1], and there will be about 5% of power transmission loss, and at the same time, causing serious pollution to the environment. The limitations of development have become more and more significant. Fuel cell is a high-efficiency clean power generation technology with comprehensive energy conversion rate of 70~90%. It has the characteristics of dispersion, users can get rid of the limitation of centralized power supply and greatly reduce the loss of power transmission process [2,3] . The fuel cell for household use not only has high power generation efficiency, but also can generate heat energy for household heating and hot water supply in the process of power generation. This is in line with the continuous improvement of urbanization in China, and the rapid increase in demand for electricity and heat by residents [4,5]. However, there is currently no very effective way to deliver hydrogen directly to home and store it. Therefore, combining natural gas hydrogen production system with domestic fuel cell cogeneration system [6] is a practical solution commonly used in the Japanese market. [7,8]. Figure 1 shows the Japanese domestic fuel cell energy supply model.

In the development and application of domestic fuel cell systems, the Japanese market is in the forefront of the world, mainly including Panasonic, Eneos Celltech, Tokyo Gas Company, NEDO, etc. [9]. The Japanese government is committed to reaching 1.4 million household fuel cells by 2020 and 5.3 million in 2030, accounting for about 10% of households [10,11]. Figure 2 shows the market forecast for the world's domestic fuel cell system [12]. It can be seen that the market size of the Japanese household fuel cell is increasing year by year, and it accounts for a considerable proportion in the world domestic fuel cell market. Through the exploration of Japanese household fuel cells, it has certain enlightenment for the development of domestic fuel cells in China.

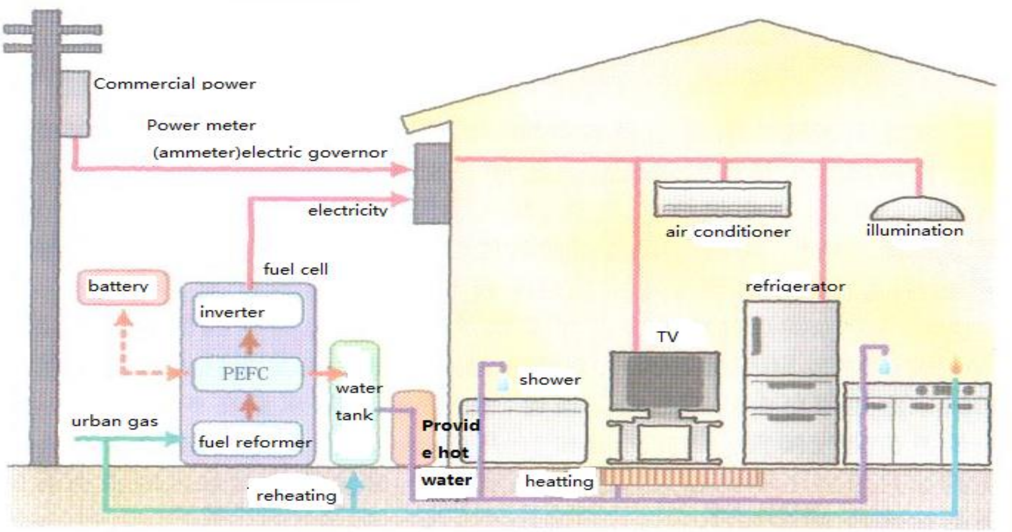

Fig. 1 fuel supply pattern

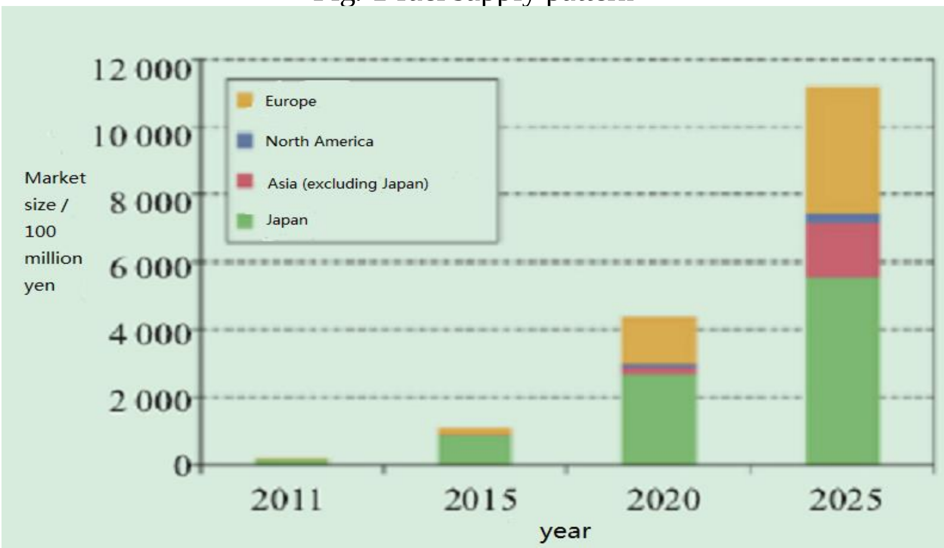

Fig. 2 world home fuel cell systems market forecast

2. Japanese household solid polymer fuel cell

Since 2009, Japanese household fuel cells have been commercialized, and this fuel cell system is called an energy farm [13]. At present, the domestic fuel cell for household use is mainly a low-temperature solid polymer fuel cell with a working temperature of about 80 degrees Celsius. This type of fuel cell mainly has the following advantages [14,15]:

1). The working temperature is low, it is easier to start and stop, and the operation time is short;

2). The electrolyte is a solid polymer membrane, which has the advantages of stable chemical properties, good hydrogen ion conductivity, low gas permeability, and relatively inexpensive manufacturing and processing.

3). The output power density is large, the volume is small and the structure is compact.

4). The heat ratio, that is, the ratio of the heat output power to the electric output power is between 1 and 1.3, which is much smaller than the thermoelectric ratio of 2.8 to 3.3 when the gas turbine is cogeneration.

Figure 3 shows the operation of a domestic fuel cell. The fuel cell can provide a fixed output power and store warm water in the water storage tank. The load fluctuation when the power consumption increases is dependent on the existing power system, which is the general working mode of the household fuel cell.

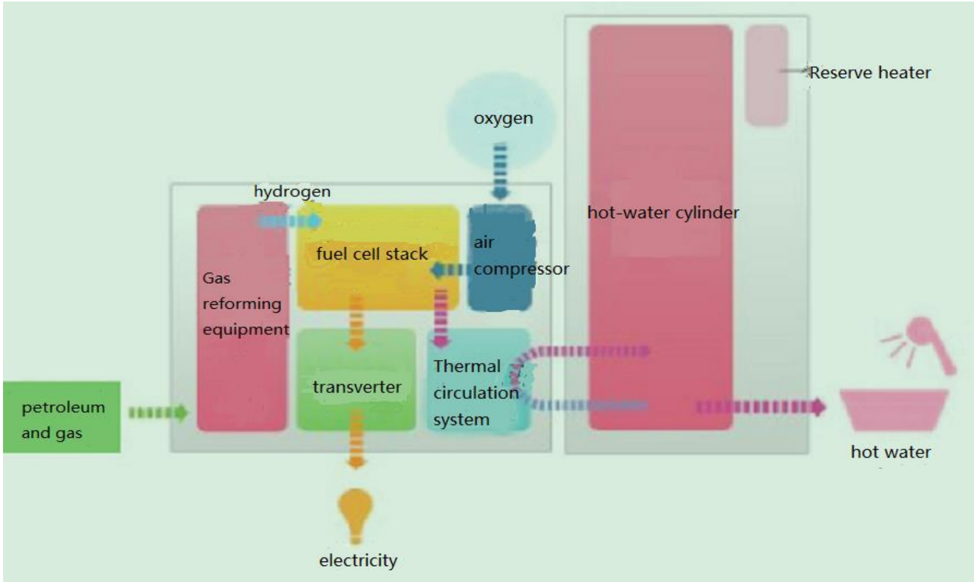

Fig. 3 Fuel cell operation in Japanese homes

2.1 Flow of fuel in the system

Take city gas as fuel cell fuel as an example (as shown in Figure 4). After the gas is boosted by the compressor, the city gas enters the desulfurizer to desulfurize and then enters the reformer. The purpose of the city gas is twofold. First, as a fuel, provide the necessary heat energy for the progress of the reforming reaction, and the water vapor required to the reaction; second, used as a raw material for the production of hydrogen.

Unused hydrogen discharged from the fuel stage is sent to the combustion unit of the fuel processing unit as a fuel for combustion utilization. The steam reforming reaction requires a high temperature of 650 ° C or higher, and the reaction is endothermic, so high temperature and heat energy are necessary conditions. High-temperature fuel cells can use their lamination devices to dissipate heat because of their high operating temperature, while solid polymer fuel cells operate at temperatures of only about 80 ℃, making it impossible to use the heat emitted by their stacking devices to react, requiring additional combustion. A portion of the fuel provides the necessary heat.

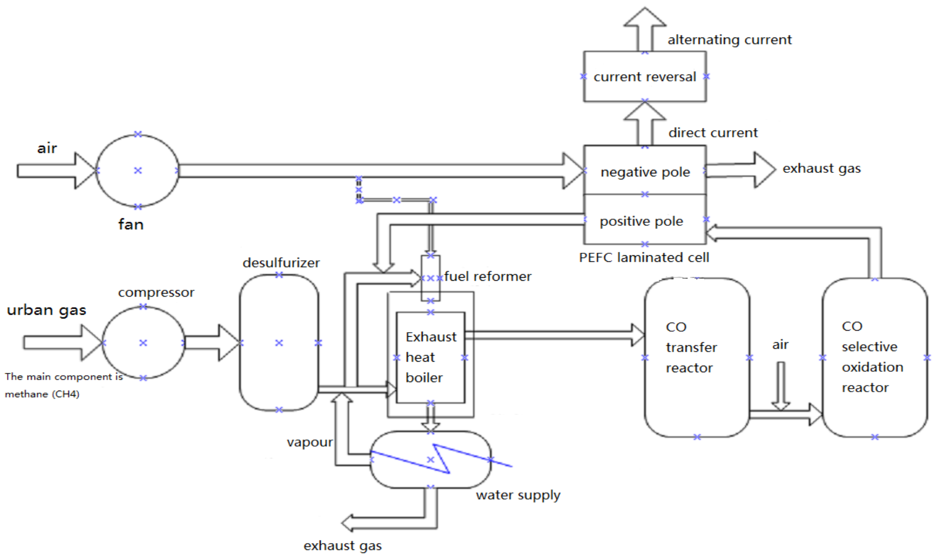

Fig. 4 energy flow of home fuel cells

Compressor: necessary equipment for insufficient pressure supply of city gas;

Desulfurizer: use desulfurizer to remove H_2S ;

Fuel reformer: Hydrocarbon reacts with water vapor to form hydrogen:

$$CH_4 + H_2O \to CO + 3H_2 \tag{1}$$

CO transfer reactor: carbon monoxide and water transfer reaction:

$$CO + H_2O \to CO_2 + H_2 \tag{2}$$

CO selective oxidation reactor: converts the remaining carbon monoxitde in the transfer reaction into carbon dioxide:

$$CO + H_2O \to CO_2 + H_2 \tag{3}$$

S/C, which is the ratio of the number of moles of water vapor supplied to the number of moles of carbon contained in the feedstock, is an important indicator of the fuel cell system. When a large amount of hydrogen is required to be generated, the larger the S/C ratio, the better, but when it is large to a certain extent, the heat required to generate the corresponding water vapor is also larger, and the overall efficiency of the system is lowered. The S/C standard value is 3.

2.2 Air and water flow in the system

The air filtered through the air filter has three destinations in the fuel cell system. First, the combustion portion of the fuel processing unit, provides thermal energy for the reforming reaction. Second, the selective oxidation reactor, to reduce the CO concentration up to 10 ppm or less; Third, the air electrode of the stacking device of the fuel cell itself, which is used as an oxidant for system reaction. The stacking device is made up of a plurality of single cells stacked, and it is necessary to send excess air to ensure that all the single cells are filled with air.

Water is the most important element in the material flow of the system, and the supply of water must be appropriate. When hydrogen ions move from the fuel electrode to the air electrode, the water also moves, and the water generated by the reaction on the air electrode combines with the water carried by the hydrogen ions to discharge a large amount of water. When the humidification of the fuel electrode is interrupted for a long time, the electrolyte membrane may be aged; when the air is extremely filled with a large amount of water, the grooves on the separator may be clogged and the air flow may be hindered. Therefore, the humidification of the fuel electrode and the water treatment of the air electrode are major issues affecting the performance of the fuel cell, and improper handling can cause troublesome problems. For example, in winter in cold regions, when water is formed into ice, problems such as the inability of the fuel cell to operate may occur.

2.3 The flow of heat in the system - the heat recovery system

The function of the heat recovery device is to recover thermal energy from the lamination device, on the one hand, to provide the user with stable thermal energy, and on the other hand, to maintain a constant operating temperature of the lamination device. The cooling water absorbs heat from the laminating device, and the heat exchanger transfers the heat energy to the pipe water and stores it in the water tank. In order to avoid a short circuit in the high-voltage state of the single cell when the cooling water passes, the cooling water used here is pure water. Storage heat can coordinate the relationship between output and demand. If the water temperature of the water storage tank is low and cannot meet the needs of users, it can be heated by buying electricity.

2.4 Separator

In the laminating device, the passage space of fuel, hydrogen, air, water, and the like is provided by the separator, and in addition, the separator also undertakes the task of electrical and gas connection between the cells. The separator is sealed to prevent leakage when high pressure air and gas are supplied. Since the separator is in contact with a strongly acidic electrolyte membrane, a material having excellent electrical conductivity and corrosion resistance is generally used. For example, a carbon resin mixed with carbon and resin is required to be as thin as possible and less than 3 mm.

2.5 Electrolyte membrane and its aging mechanism

The premise of the promotion of household fuel cells is that their safety and durability are guaranteed. Membrane aging problems are an important cause of fuel cell durability. Improving the durability of the fuel cell requires analysis of the cause of the film aging, and the film works under conditions of low current, high voltage, low humidification, high oxygen concentration, etc., to accelerate aging. The aging mechanism of the membrane is: At the fuel electrode, the fuel undergoes a redox reaction with oxygen leaking from the air electrode to generate H_2O_2, in the presence of iron ions, OH^- quickly generates and attacks the electrolyte membrane, causing pinholes in the electrolyte membrane, which is the process of aging of the electrolyte membrane. Therefore, the pipe water must pass through the deionizer to enter the fuel cell system.

3. Development of Japanese household fuel cells

Solid polymer fuel cells have low operating temperatures and are easy to start and stop, which is one of their advantages, but low temperature work also brings some problems. On the one hand, the use of thermal energy is limited, and it is necessary to equip a larger storage tank; on the other hand, under low temperature working conditions, the fuel cell has stricter restrictions on the content of carbon monoxide in the reformed gas, and it is difficult to reduce the use of precious metal catalyst, the cost is difficult to reduce. The medium-temperature operation type fuel cell having an operating temperature in the range of 120 ° C to 180 ° C uses the same ion exchange membrane as the polymer electrolyte fuel cell, and has the advantage that no humidification is required. The limit for carbon monoxide contained in the reformed gas is also looser than that of the solid polymer fuel cell, and the carbon monoxide concentration is only required to be less than 3%.

In addition, the development of solid oxide fuel cells for home use is also one of the current research directions for household fuel cells [16]. It can be seen from Table 1 [17] that the power generation efficiency of the solid oxide fuel cell is 45% under the same 1kw rated output power, while the power generation efficiency of the internal combustion engine and the solid polymer fuel cell is only 20%. , 35%. The electric energy demand in the home is greater than the thermal energy, and it is more suitable to use the solid oxide type thermal power generation with relatively small thermoelectric rate.

For solid oxide fuel cells, the supply temperature of hot water is increased, the value of heat energy is reflected, and the heat storage tank can be designed to be more compact. Compared with the solid polymer fuel cell, there is no strict control of the CO content, no complicated water management is required, and the reformer and the laminating device are integrated, the fuel cell system itself becomes more compact.

Table 1 Comparison of household thermal power generation

	Constant output power (KW)	Power generation efficiency (%)（%）	Constant heat output power (KW)	Thermo-electric ratio
Engine type thermal power generation	1	20	3.25	3.25
Solid polymer type thermal power generation	0.7~1	35	0.9~1.29	1.29
Solid oxide type thermal power generation	1	45	0.66	0.66

Household fuel cell systems also have some disadvantages in using solid oxide fuel cells. The first is that the working temperature is high, and the start and stop are not agile. Therefore, the solid oxide fuel cell adopts the working mode of continuous operation in the day and night, which increases the waste of energy to some extent. Second, the solid oxide fuel cell is susceptible to thermal shock. With the influence of oxidation, it is likely to cause damage to the material, and it is not easy to ensure reliability and durability. Third, ceramics and heat-resistant alloys are mostly used in the laminating device and peripheral parts, so cost reduction is also a problem.

4. Japanese government policy on household fuel cell systems

Government departments such as Osaka Gas and Tokyo Gas led the construction of "energy station" supply system, take advantage of family fuel cell system combines hydrogen in city gas with oxygen in the air to achieve self-sufficiency in household electricity use.

Table 2 Related authentication methods

Project	Result
The form of certification	The form of certification is divided into government certification and civil certification. Civil certification must also ensure the safety of equipment
Scope of certification	The scope of certification is based on the whole structure of the whole machine (fuel cell part, reverse conversion device of hot water reserve system, etc.) If you only certify a single machine, you must ensure the safety of the entire structure.
Certification method	Formal inspection and factory inspection (or sampling inspection)

In order to promote the safe use of fuel cells, the Japanese government established a review committee for household fuel cell certification systems and issued relevant certification method strategies, as shown in Table 2 [18]. Subsidies are provided for the purchase and construction and installation costs of household fuel cell systems, as shown in Table 3. Specifically implemented by the FCA (Fuel Cell Promotion Association). Lower cost due to technological advances, government subsidies for household fuel cell systems are decreasing year by year. and subsidies were terminated at the end of 2016. As of December 2015, Japan's household fuel cells sold a total of 150,000 units; by the end of 2014, the Japanese government had invested 76.69 billion yen in fuel cell and household fuel cell systems [19].

Table 3 Japanese household fuel cell system and fuel cell subsidy standards

Fuel cell	Actual price <base price	Base price < actual price < highest price	Highest price < actual price	Additional subsidy amount
PAFC	150,000 yen	70,000 yen	0	It can be used for any non-new-family homes, fuels using liquefied petroleum gas, and cold zones, If it is sold below the maximum price, it can add 30,000 yen.
SOFC	190,000 yen	90,000 yen	0	

Note: The benchmark prices of PEFC and SOFC are 1.27 million yen and 1.57 million yen respectively; the highest price of PEFC is 1.42 million yen, and the highest price of SOFC is 1.69 million yen.

The Japanese government is working hard to reduce the cost of fuel cells, making home fuel cells the largest fuel cell market. The fuel cell is a highly efficient and clean power generation mode. When the household fuel cell system is widely used, the traditional household power supply mode will undergo a huge transformation. The distance between power production and consumers will be closer, and the construction of large power plants will be reduced. Pollution is effectively controlled. In addition, fuel cell systems can significantly reduce CO_2 emissions and contribute to global climate change trends [20].

5. Domestic household fuel cell

China has released the "Energy Innovation Revolution Key Action Roadmap" and "Energy Technology Revolution Innovation Action Plan (2016-2030)", which lists fuel cell and hydrogen energy innovation technologies as key development tasks. However, the current research on domestic fuel cell cogeneration system is still in its infancy, mainly by some universities. Xiaotong Li built a kilowatt-scale cogeneration fuel cell system model on Matlab/Simulink platform, and analyzed the dynamic characteristics of the family fuel cell system, and studied the dynamic behavior of the system under variable load [21]; Yujie Huang based on PV-PEMFC-Battery's domestic cogeneration system to study. Under certain optimized ratios, it is concluded that the system generates 484,640 kwh in the 20-year life cycle and the heat production is 107,960 kwh, which can meet the basic electricity demand of household users and the most of heat demand [4]; Yingwei Kang et al. established a dynamic model of a solid oxide fuel cell micro-cogeneration system, and simulated the dynamic behavior of the system under average current density disturbance [22,23,24,25] .

In recent years, some domestic enterprises have begun to focus on the research and development of cogeneration fuel cell equipment. At the 2010 Shanghai World Expo, Shanghai Shenli Technology Co., Ltd. demonstrated its own 3KW high-temperature proton exchange membrane fuel cell cogeneration system, which has a hot water outlet temperature of 50 ° C and can be used in the environment of -4 °C - 40 °C. Under the support of the 863 Program, the Dalian Institute of Chemical Physics of the Chinese Academy of Sciences has successfully developed a distributed fuel cell cogeneration system.

6. Conclusion

There is a big gap between domestic fuel cell cogeneration systems and Japan, which has entered the stage of commercial application. As far as fuel cell technology is concerned, there is no big gap between China and Japan. The reason why the commercialization and promotion process of Japanese household fuel cells is in the world's leading position is inseparable from the policy strategy, strategic goals and financial support formulated by the Japanese government to promote the development of fuel cell and hydrogen energy technologies. China's development and application of fuel cells for household use can be combined with China's specific national conditions, draw on Japan, moderately increase government and social capital investment in household fuel cell technology, improves the specific measures and rules for domestic fuel cells in the fuel cell technology development planning and development technology roadmap, and strives to put the commercial application of the household fuel cell cogeneration system on the agenda as soon as possible in China.

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