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Development of water treatment technology for residential fuel cell system

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ABSTRACT

In order to realize maintenance-free “Ene-farm” of residential fuel cell systems, a new water-treatment technology using vapor-separation membranes has been developed. It is proposed that water vapor in exhaust gas of the fuel cell systems is recovered by the water-separation membranes and is indirectly cooled by coolant water in hot-water tank. It is expected that pure condensed water is recovered from water vapor in exhaust gas using hydrophobic membranes which are used for membrane distillation. It is simulated a requested specifications of the new water treatment device. In the case of a conventional fuel cell system, it is simulated that over-38% vapor in feed is needed to recover for operating the fuel cell system without supplying tap-water.

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2. BODY OF PAPER

2.1. INTRODUCTION

Tokyo Gas Co., Ltd. (hereafter “Tokyo Gas”) has continued development of “Ene-Farm” fuel cell co-generation system, which became the world's first commercialized fuel cell system when it went on sale in Japan in May 2009. Figure 1 shows the appearance of the latest model of “Ene-farm”.

Fig. 1 Appearance of the latest model of “Ene-farm”.

The “Ene-Farm” fuel cell co-generation systems generate electricity through a chemical reaction between oxygen in atmosphere and hydrogen extracted from city gas. The heat generated as a byproduct of this process is also used for supplying hot water. This system is extremely eco-friendly. Since the electricity is generated and used at the same place, there are no losses in electric transmission line. And, heat produced during generating electricity can be used effectively.

Figure 2 shows the unit sales of “Ene-farm” in Tokyo Gas. Tokyo Gas has shipped a total of 30,000 units at the end of April 2014. The “Challenge 2020 Vision” as Tokyo Gas group’s long-term vision for energy and the future was pressed in November 2011 and 300,000 units will be installed by 2020. A Japan-wide plan was approved in a cabinet meeting in June 2013 and 5.3 million units will be installed by 2030 in Japan.

To expand the “Ene-Farm” market, reduction of maintenance costs is one of the most important issues. The “Ene-Farm” needs periodic maintenance, which utility workers change consumable supplies such as water treatment devices, desulfurizers, air filters and gas sensors. We have been developed for reduction the numbers of periodic maintenance times with Panasonic Corporation as shown Fig. 2. The first “Ene-Farm” model released in 2009 needs about nine periodic maintenances averagely for ten years, but the second model released in 2011 needs about three times. Furthermore the third model released in 2013 needs about two times, and the latest 2014 model needs only a single maintenance averagely for ten years.

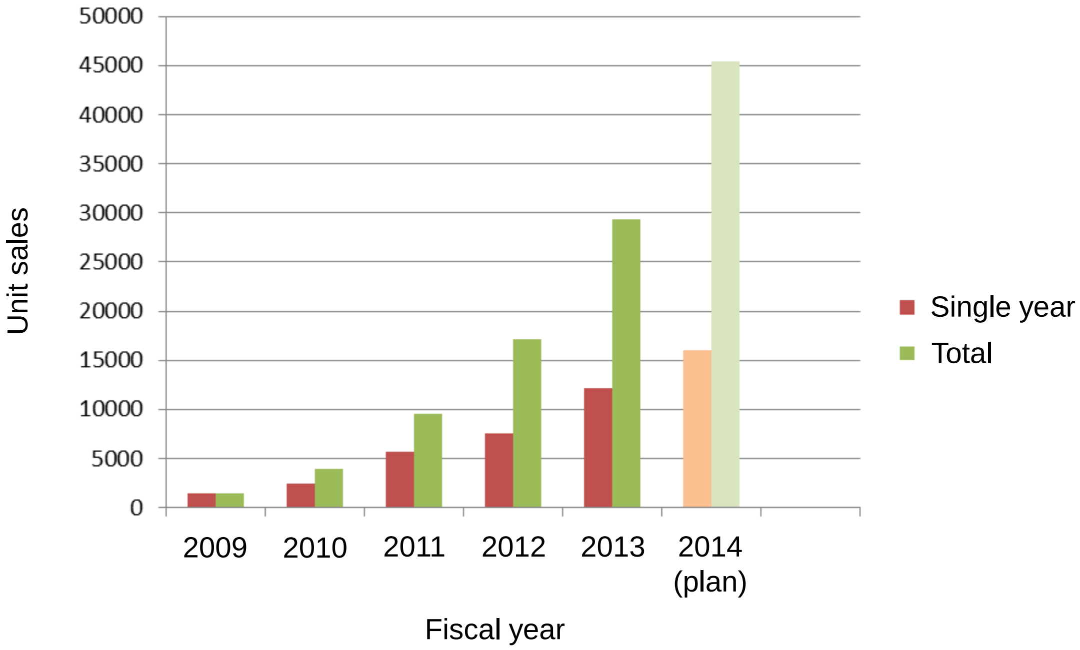

Fig. 2 “Ene-farm” sales of Tokyo Gas.

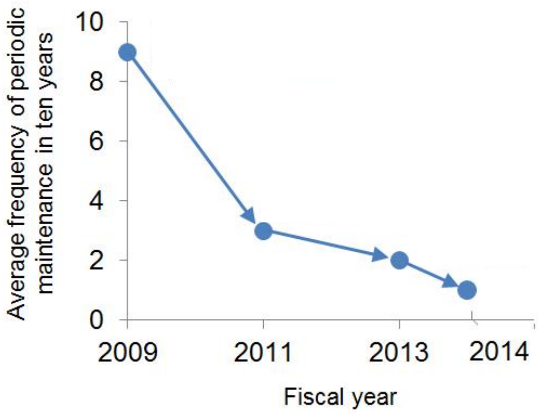

Fig. 3 Reduction of periodic maintenances.

However, maintenance-free systems are recently required with increasing the number of the “Ene-Farm”. In order to realize maintenance-free systems, further development of water treatment technologies is necessary. Residential fuel cell systems need deionized water for steam reforming reaction and the water could be produced by treating drainage water in the system. The water treatment device is required high durability and compact size. As the water treatment devices, ion-exchange resins, which are blend of cation and anion resins, are used most generally for residential fuel cell systems. The conventional fuel cell systems using ion-exchange resins as the water treatment device is able to realize the maintenance-free system, but the volume of water treatment device become large.

In this paper, we proposed a water-treatment technology using vapor-separation membranes which is a new technology under development in Tokyo Gas.

2.2. NEW WATER TREATMENT TECHNOLOGY

2.2.1. Concept

Tokyo Gas has been developed a new water treatment technology using vapor-separation membrane for maintenance-free systems.

Figure 3 shows a concept of a new water treatment technology for fuel cell systems. The vapor of exhaust gases in the fuel cell systems is separated by a membrane, and is indirectly cooled by coolant water in the hot-water tank. The cooled vapor is condensed as the pure water because impurities in the exhaust gas are not able to pass through the membranes.

The vapor-separation process from gases using vapor-permeation membrane is used for the dehydration of natural gas and various organic solvents and its recovery from the waste steam. The transport of water vapor and inert gases through membranes was reviewed in the previous articles[1-2]. More than one hundred vapor-gas separation systems using membranes have been installed worldwide for recovering liquefied petroleum gas, refrigerant gases, monomers such as ethylene, propylene and vinyl chloride, and for removing the acid gases H_2S and CO_2 from natural gas and hydrocarbon vapors from air streams in the petrochemical industry[3]. However, soluble impurities in the exhaust gases are able to permeate to vapor-permeation membranes and purity of the condensed water is not sufficient for the steam reforming water of the fuel cell systems.

Then we propose a water-treatment system using hydrophobic membranes, which are used for membrane distillation. Membrane distillation is one of the water treatment technologies[4], which have been mainly studied for desalination of seawater[5-7]. In the case of membrane-distillation system, the feed is not vapor but hot water. However, in the case of fuel cell systems the feed is vapor of exhaust gas. There is few previous research of water-treatment system, which the feed is vapor and the membrane is hydrophobic.

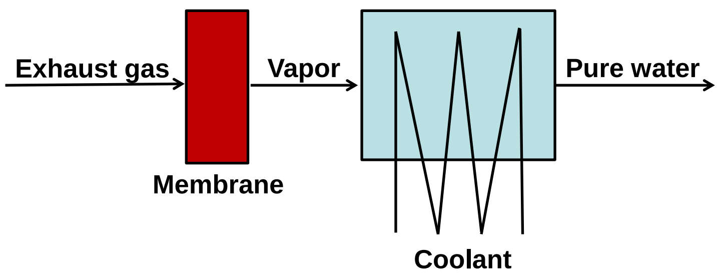

Fig. 4 Concept of new water treatment technology.

2.2.2. Configuration of a water treatment device

Figure 4 shows the configuration of a water treatment device for the fuel cell systems. The exhaust gases such as the cathode off-gas, the anode off-gas and the combustion gas are fed to inside of hollow fiber membrane, and the vapor translates to outside of hollow fiber membrane. The translated vapor is indirectly cooled by coolant water in hot-water tank. In the case of the actual device, many hollow fiber membranes are used.

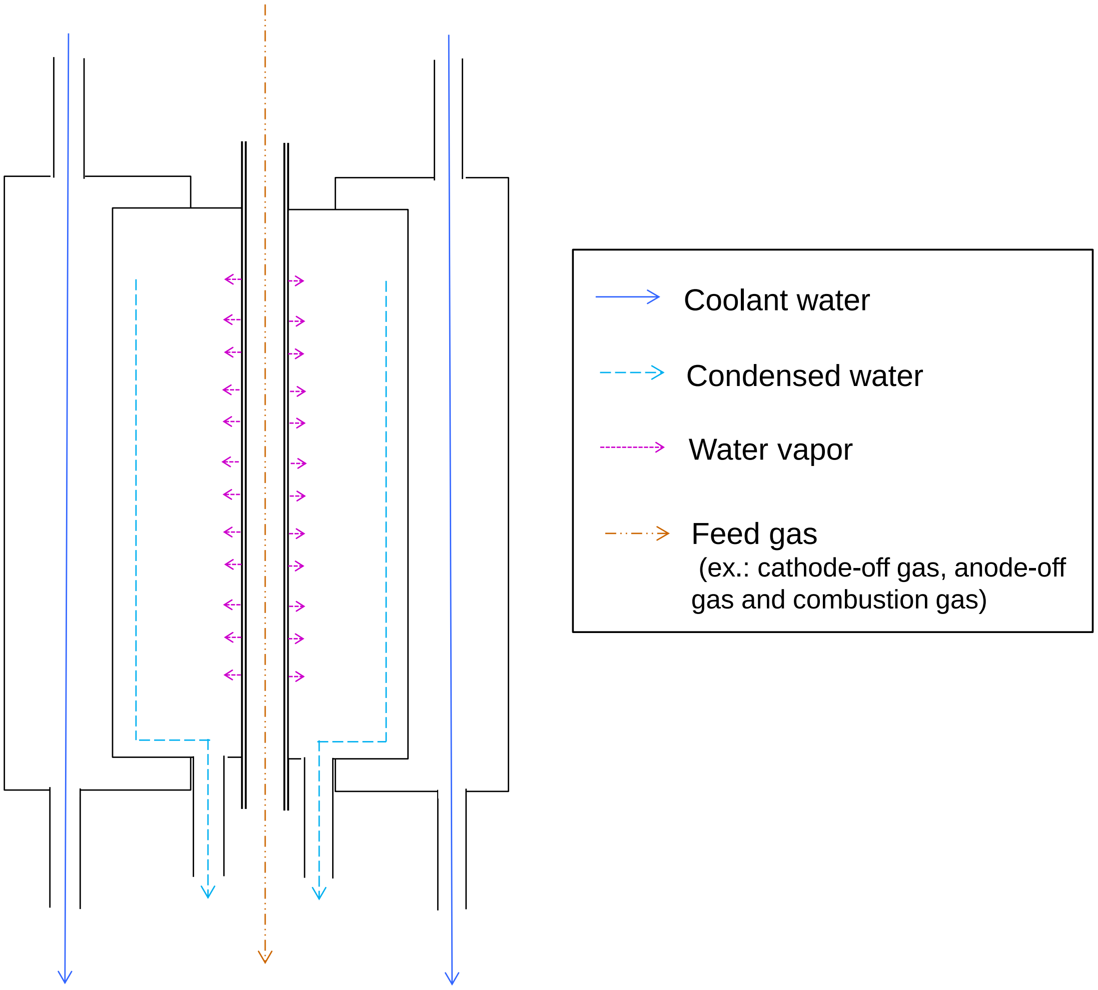

Fig. 5 Configuration of a water treatment device for fuel cell systems.

2.2.3. Configuration of a fuel cell system

Figure 5 shows a conventional polymer electrolyte fuel cell (PEFC) system. The exhaust gas is condensed at heat exchanger (HEX) and the impurities of the condensed water are removed using the ion-exchange resin.

Figure 6 shows a configuration of a PEFC system using the new water treatment technology. The exhaust gas is fed to the water treatment membrane unit which has function of HEX. The condensed water from the unit is high purity and is used for the steam reforming water and the coolant of the PEFC stack.

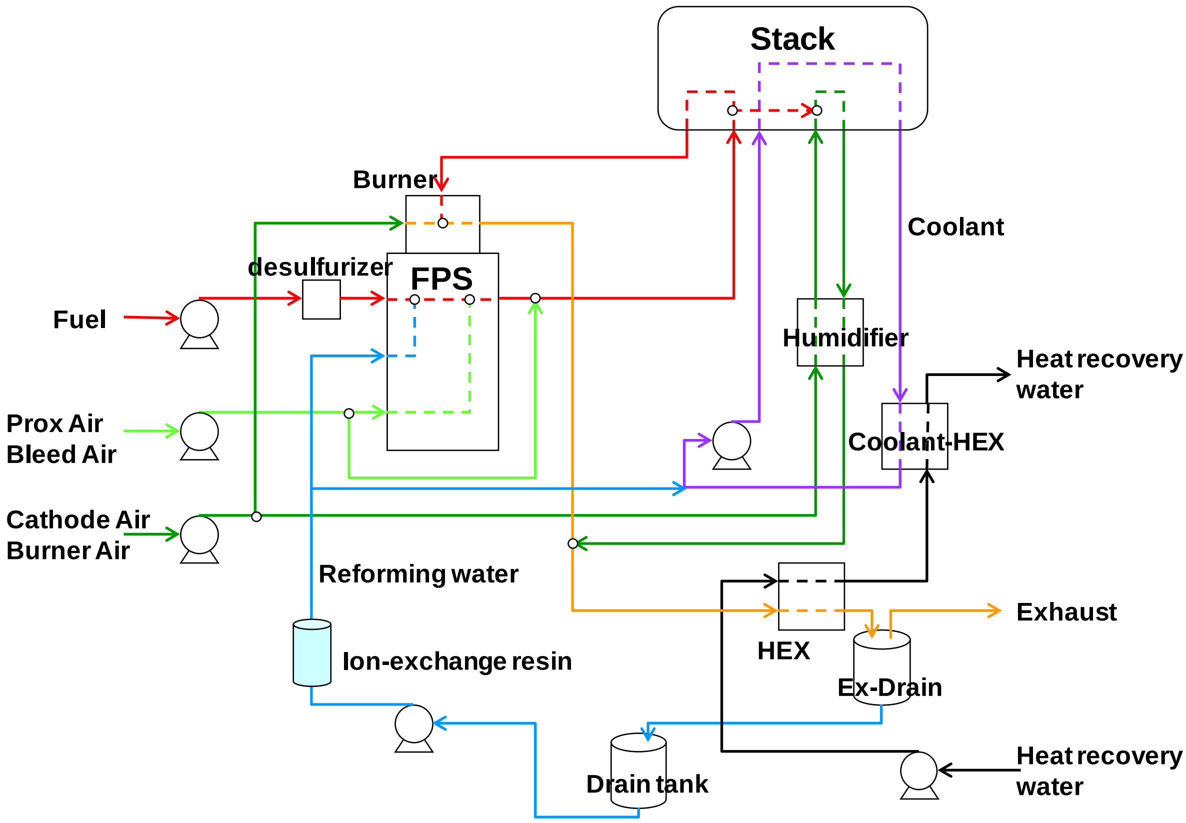

Fig. 6 Configuration of a conventional PEFC system.

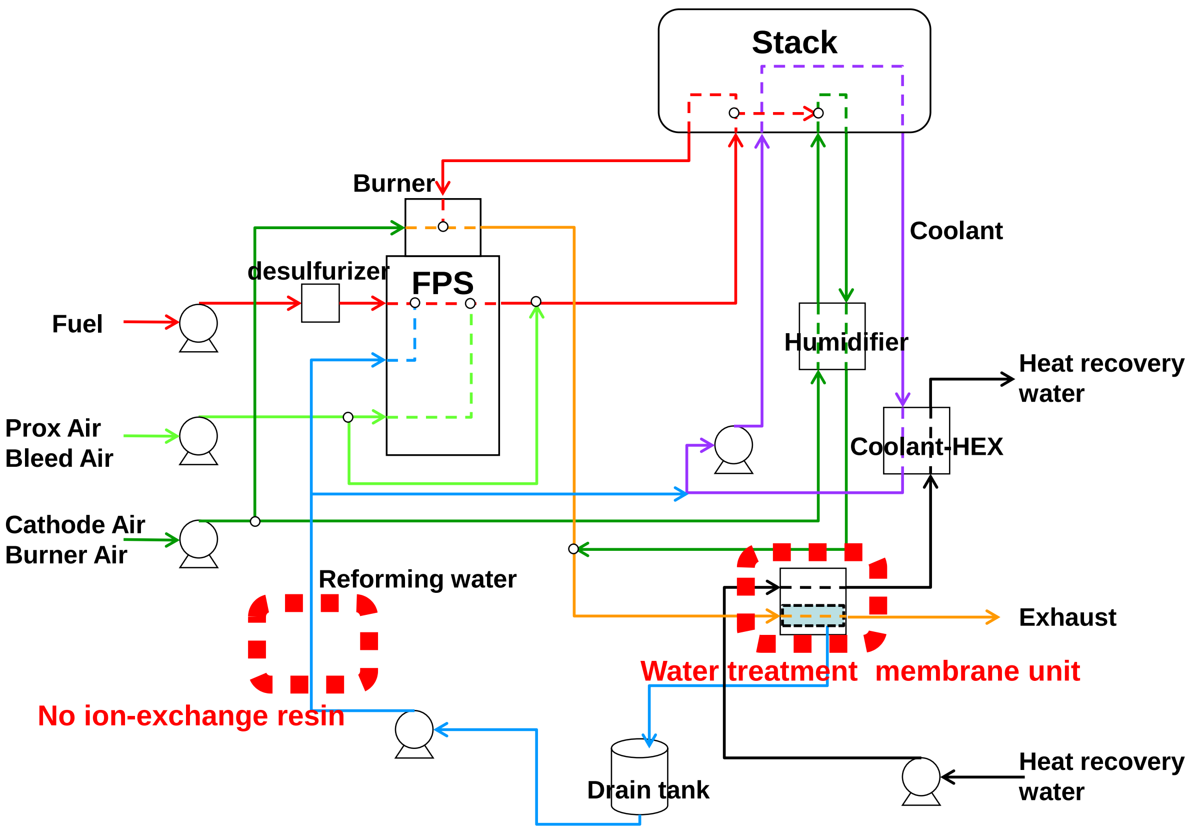

Fig. 7 Configuration of a PEFC system with a new water treatment technology.

2.2.4. Required specifications of a water treatment device

Table 1 shows a simulated condition of the feed gas to the water treatment membrane unit at general operating condition with conventional 1 kW PEFC system shown as Fig. 7. In order to operate this system without the supplying tap-water, the vapor of the combustion gas is recovered as the condensed water. It is simulated that the dew point of outlet gas needs less than 47 °C in order to recover sufficient condensed water. Then the recovery rate of the condensed water from vapor in feed is over 38%.

Table 1 Condition of the feed gas.

Total flow (NL/min)		92
Component (NL/min)	N_2	60
	O_2	6.7
	CO_2	4.0
	H_2O	21
Temperature (°C)		65
Dew point (°C)		59
Pressure (kPaG)		2.0

2.3. FUTURE PERSPECTIVE AND CONCLUDING REMARKS

In order to expand the “Ene-Farm” market, water treatment technologies for maintenance-free system are required. We proposed a new water treatment technology using the vapor-separation membranes. The vapor in exhaust gases is separated by the membrane and is indirectly cooled by the coolant water in the hot-water tank. It is expected that the pure condensed water is recovered from the exhaust gas using the hydrophobic membranes, which is used for the membrane distillation. In order to operate the fuel cell systems without supplying tap-water, the sufficient condensed water is needed for the steam reforming water. It is simulated that over-38% vapor in feed is needed to recover. For the future, we plan to measure the rate of recovery and the quality of condensed water with prototype unit, and confirm the durability and the size for “Ene-farm”.

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