ELSEVIER

Journal of Power Sources 106 (2002) 51–59

JOURNAL OF POWER SOURCES

www.elsevier.com/locate/jpowsour

Feasibility study of the co-generation system with direct internal reforming-molten carbonate fuel cell (DIR-MCFC) for residential use

Kimihiko Sugiura[a,*], Ichiro Naruse[b]

[a]Osaka Prefectural College of Technology, 26-12 Saiwai, Neyagawa, Osaka 572-8572, Japan
[b]Toyohashi University of Technology, 1-1 Tempaku, Toyohashi, Aichi 441-8580, Japan

Abstract

The possibility of introducing a co-generation system with a direct internal reforming-molten carbonate fuel cell (DIR-MCFC) for residential use is examined by a feasibility study. First, the structure of a system, which can maintain the cell temperature (650 °C) without the heat supply, is constructed by calculating heat and material balances among the system components. Secondly, a model family, which might use the co-generation system with a DIR-MCFC, is constructed from the results of a questionnaire on room layout, number of family members, and the number of electric appliances and consumption of electric power in Osaka. Thirdly, calculating the electric power and hot-water demand supply balance optimizes the scale of the co-generation system with a DIR-MCFC for residential use. Finally, the running costs of this optimum system using city gas or propane gas are considered. As a result, the optimum scale of a co-generation system a with DIR-MCFC and using city gas is 3 kW, while it is 6 kW for the case using propane gas. The co-generation system using city gas is suitable for a house. On the other hand, the system using propane gas is suitable for an apartment. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Molten carbonate fuel cell; Co-generation; Residential use; Feasibility study

1. Introduction

Molten carbonate fuel cells (MCFC) have a high efficiency for converting chemical energy to electric energy directly and this energy conversion efficiency is constant even if the scale of the MCFC changes. Because the MCFC exhausts any SO_x or NO_x and produces no noise, it is excellent for environmental preservation. Moreover, the MCFC can use various gases such as natural gas and coal gas as fuel. Because the system efficiency can be improved further by the connecting the MCFC with a gas turbine, the MCFC is expected to be an alternative thermoelectric power source of the future [1]. In the New Sunshine project, the pressurizing performance of the MCFC has been evaluated with a view to connecting the MCFC to a gas turbine [2–4]. The proof test of the 1 MW plant, which was the final goal of this project, was evaluated in Kawagoe from July 1999 to March 2000, and this plan succeeded [5,6].

From the viewpoint of miniaturization, the energy conversion efficiency of direct internal reforming-molten carbonate fuel cells (DIR-MCFC) is higher than that of a MCFC alone, because the reforming reaction is promoted beyond its chemical equilibrium value by consuming hydrogen in the cell reaction. As the heated MCFC reaction has to be cooled by cathode gas, the system has to have a big blower. However, the system with a DIR-MCFC does not need a big blower and can be miniaturized, because the DIR-MCFC is cooled by the endothermic reaction of a catalyst. Moreover, steam is used more effectively in the DIR-MCFC [7]. The DIR-MCFC can be reduced in size more than the MCFC. Therefore the system with DIR-MCFC can be applied for small scale power generation.

From the viewpoint of a small power generator, the polymer electrolyte fuel cell (PEFC) has recently been highlighted as a transportation vehicle and a home co-generation system. Though the PEFC is suitable as the power supply for a vehicle that uses hydrogen or methanol as the fuel, a home co-generation system with a PEFC has a problem of using city gas as fuel, because the reforming temperature of city gas is higher than the operation temperature of a PEFC, the membrane could be melted. Therefore, companies plan to decrease the gas temperature by exchanging the heat of the gas with cooling water. This heat-exchanged water is applied to the hot-water supply in home. However, amount of heat produced is too little to supply the hot-water for home use. The system efficiency is decreased and heat has to be supplied from the outside for satisfying

* Corresponding author. Tel.: +81-72-820-8537; fax: +81-72-821-0134.
E-mail address: sugiura@sys.osaka-pct.ac.jp (K. Sugiura).

0378-7753/02/$ – see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S0378-7753(01)01022-9

Nomenclature

A	electrode area (cm^2)
A_{ex}	area of heat exchange (m^2)
c_p	specific heat (J/(mol K))
ΔH	enthalpy (J mol)
I	current density (A/cm^2)
k	overall heat transfer coefficient ($W/(m^2 K)$)
n	cell number
Q	heat flux (kW)
Q_E	output power (kW)
Q_{loss}	thermal radiation from DIR-MCFC (kW)
Q_{ref}	heat flux from reforming reaction (kW)
T	cell temperature (K)
U_f	fuel gas utilization (=0.75)
U_{ox}	oxidant gas utilization (=0.5)
Y	mass flow rate (mol/s)

Subscripts

AI	anode inlet
AO	anode outlet
CI	cathode inlet
CO	cathode outlet
i	anode inlet gas species (H_2O, CH_4 or C_3H_8)
j	anode outlet gas species (H_2, CO_2, N_2, H_2O)
k	cathode gas species (O_2, CO_2, N_2, air)

the hot-water demand [8]. These problems will be solved by using a fuel cell with a high operation temperature.

As the system with a DIR-MCFC is operated at high temperature and can be constructed as a compact system, it is expected to be the power generator of the co-generation system for residential use. Therefore, this study evaluates the adaptability of residential to a co-generation system with a DIR-MCFC. First, the structure of an optimum system, which can maintain the cell temperature (650 °C) without a heat supply form outside, is constructed by calculating heat and material balances among the system components. These components are a DIR-MCFC, a heat exchanger, a catalytic combustor, a condenser and a gas mixer. The optimum system is defined by solving simultaneous equations involving the number and position of each piece of equipment, and is judged by the cell temperature that can be 650 °C. This system adopts a CO_2 recycle system so that the carbon dioxide for the cathode is taken from the exhaust gas of the anode. The co-generation system used city gas or propane as fuel. A model family, which might use the co-generation system with a DIR-MCFC, is constructed from the results of a questionnaire on room layout, number of family members and the number of electric appliances and consumption of electric power in Osaka. In this model the family does not use gas for cooking, for bath, etc., and gas is only used for the DIR-MCFC. By calculating the electric power and hot-water demand the scale of the co-generation system is optimized for residential use [9]. The optimum scale is decided by the total electric power and heat demand for 1 day or 1 week. The DIR-MCFC is always operated under constant output even if the power demand changes. Therefore, the system has storage batteries for load leveling. Hot-water from the DIR-MCFC is supplied to bathroom, kitchen, and floor heating. And warm water, after use, is saved to the storage tank and used for lavatory and washing machine, etc. Finally, the possibility of introduction of a co-generation system with the DIR-MCFC is examined by calculating the operation cost of this system, and comparing the running costs with traditional lighting and heating expenses.

2. Governing equations and analytical methods

The co-generation system, fueled by city gas or propane, comprising of a DIR-MCFC, heat exchanger, steam separator, blower, gas mixer and catalytic combustor is shown in Fig. 1. There are a number of governing equations that hold for the processes taking place in the equipment as described in this section.

2.1. Chemical reactions involved

The electro-chemical reactions occurring at the fuel cell electrodes are represented in Eqs. (1)–(3).

In the anode:

$$H_2 + {CO_3}^{2-} \rightleftharpoons H_2O + CO_2 + 2e^- \quad (1)$$

In the cathode:

$$\frac{1}{2}O_2 + CO_2 + 2e^- \rightleftharpoons {CO_3}^{2-} \quad (2)$$

The overall cell reactions sum to

$$H_2 + \frac{1}{2}O_2 \rightleftharpoons H_2O \quad (3)$$

Reforming reactions under which the steam-carbon ratio is 3, arise in the anode too. The reforming reactions for the cases when the system is fueled by city or propane gas, respectively, are considered as follows.

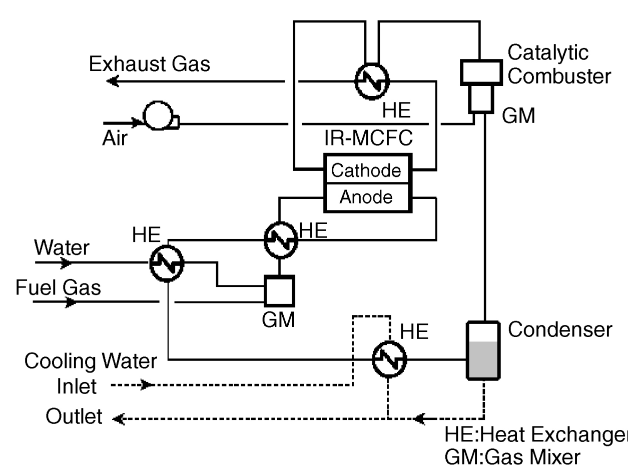

Fig. 1. Basic composition diagram of the co-generation system with the DIR-MCFC.

2.1.1. Case of city gas

The Osaka City gas contains CH_4 (88%), C_2H_6 (6%), C_3H_8 (4%) and C_4H_{10} (2%). The concentration of city gas varies but in the present work, a proportion of CH_4 (95.65%) and C_3H_8 (4.35%) was assumed since the thermal data for C_2H_6 and C_4H_{10} were not readily available. Therefore, the reforming reaction for the case of city gas is written as

$$9565CH_4 + 435C_3H_8 + 32610H_2O \rightleftharpoons 10870CO_2 + 42610H_2 + 10870H_2O \quad (4)$$

Case of propane:

$$C_3H_8 + 6H_2O \rightleftharpoons 3CO_2 + 10H_2 \quad (5)$$

2.2. Material balance

The hydrogen flow rate required for cell reaction by Nernst equation modified for MCFC was determined as follows:

$$Y_{H_2} = 5.5 \times 10^{-6} IAn \quad (6)$$

The mass flow rate for the case of each fuel at anode side is as presented below.

City gas:

$$Y_{CH_4,AI} = \frac{9565}{42610}\frac{Y_{H_2}}{U_f} \quad (7)$$

$$Y_{C_3H_8,AI} = \frac{435}{42610}\frac{Y_{H_2}}{U_f} \quad (8)$$

$$Y_{H_2O,AI} = \frac{32610}{9565} Y_{CH_4} \quad (9)$$

$$Y_{H_2,AO} = \frac{42610}{9565} Y_{CH_4} - Y_{H_2} \quad (10)$$

$$Y_{CO_2,AO} = \frac{10870}{9565} Y_{CH_4} + Y_{H_2} \quad (11)$$

$$Y_{H_2O,AO} = \frac{10870}{9565} Y_{CH_4} + Y_{H_2} \quad (12)$$

Propane:

$$Y_{C_3H_8,AI} = \frac{1}{10}\frac{-Y_{H_2}}{U_f} \quad (13)$$

$$Y_{H_2O,AI} = 9Y_{C_3H_8} \quad (14)$$

$$Y_{H_2,AO} = 10Y_{C_3H_8} - Y_{H_2} \quad (15)$$

$$Y_{CO_2,AO} = 3Y_{C_3H_8} + Y_{H_2} \quad (16)$$

$$Y_{H_2O,AO} = 3Y_{C_3H_8} + Y_{H_2} \quad (17)$$

The mass flow rate at the cathode side is determined by the amount of hydrogen consumed in the reaction of cell and catalytic combustor. In addition, carbon dioxide at the cathode side is supplied by CO_2 recycled from the anode outlet gases. Therefore, each of the gas flow rates may be expressed as follows:

$$Y_{Air,CI} = \left(\frac{\frac{1}{2}\frac{Y_{H_2}}{U_{ox}} + \frac{1}{2}Y_{H_2,AO}}{0.21}\right) \quad (18)$$

$$Y_{CO_2,CI} = Y_{CO_2,AO} \quad (19)$$

$$Y_{H_2O,CI} = Y_{H_2,AO} \quad (20)$$

$$Y_{O_2,CO} = \frac{1}{2}\frac{Y_{H_2}}{U_{ox}} - \frac{1}{2}Y_{H_2} \quad (21)$$

$$Y_{CO_2,CO} = Y_{CO_2,AO} - Y_{H_2} \quad (22)$$

$$Y_{H_2O,CO} = Y_{H_2O,CI} \quad (23)$$

$$Y_{N_2,CO} = 0.79Y_{Air,CI} \quad (24)$$

2.3. Heat balance

2.3.1. DIR-MCFC

Considering heat balance at the DIR-MCFC, the following components are notable; cell reaction, reforming reaction, inflow heat flux, outflow heat flux, output electric power and heat loss from the cell. The heat balance equation can be written as follows:

$$(Q_{cell} - Q_E) - Q_{ref} + (Q_{AI} - Q_{AO}) + (Q_{CI} - Q_{CO}) - Q_{loss} = 0 \quad (25)$$

Each heat flux expressed using the enthalpy is shown as follows.

Heat flux of cell reaction:

$$Q_{cell} - Q_E = \Delta H_{H_2O} Y_{H_2} - Q_E \quad (26)$$

Heat flux of reforming reaction:

City gas:

$$Q_{ref} = \frac{(10870\Delta H_{CO_2} - 9565\Delta H_{CH_4} - 435\Delta H_{C_3H_8} - 21740\Delta H_{H_2O})Y_{CH_4}}{9565} \quad (27)$$

Propane gas:

$$Q_{ref} = (3\,\Delta H_{CO_2} - \Delta H_{C_3H_8} - 6\,\Delta H_{H_2O})Y_{C_3H_8} \quad (28)$$

Inflow heat flux and outflow heat flux:

$$Q_{AI} = \sum(c_{pi}Y_i)T_{AI} \quad (29)$$

$$Q_{AO} = \sum(c_{pj}Y_j)T_{AO} \quad (30)$$

$$Q_{CI} = \sum(c_{pk}Y_k)T_{CI} \quad (31)$$

$$Q_{CO} = \sum(c_{pk}Y_k)T_{CO} \quad (32)$$

The heat loss (Q_{loss}) from DIR-MCFC is estimated to be 10% of the total heat flux of DIR-MCFC [10].

2.3.2. Other facilities

The heat balance of heat exchanger (compact type) is defined as follows [11,12]:

$$Q = Y_1 c_{p1}(T_{1,\mathrm{I}} - T_{1,\mathrm{O}}) = Y_2 c_{p2}(T_{2,\mathrm{O}} - T_{2,\mathrm{I}}) \quad (33)$$

$$Q = kA_{\mathrm{ex}} \frac{(T_{1,\mathrm{I}} - T_{2,\mathrm{O}}) - (T_{1,\mathrm{O}} - T_{2,\mathrm{I}})}{\ln\{(T_{1,\mathrm{I}} - T_{2,\mathrm{O}})/(T_{1,\mathrm{O}} - T_{2,\mathrm{I}})\}} \quad (34)$$

Here subscripts "1" and "2" are, respectively, fluid of high temperature and low temperature. In addition, subscripts "I" and "O" represent inlet and outlet, respectively. The cathode gases are heated up by burning the remaining hydrogen at the anode; the heat flux in the catalyst combustor is decided by the remaining hydrogen amounts at anode outlet.

In the gas mixer, gas temperature after mixing is determined by heat fluxes of each gas before mixing. Cooling water, after cooling the gases in the heat exchanger, is reused as hot-water supply. The drained hot-water, separated from the steam gas at the anode outlet in the condenser, is also used as a hot-water supply. All equations of heat balance are rearranged on gas temperature in each equipment outlet thus needing simultaneous solution. The temperature of each pieces of the equipment is obtained by the solving the system of simultaneous equations by the Gauss–Jordan method [11]:

$$\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{pmatrix} \begin{pmatrix} T_1 \\ \vdots \\ T_n \end{pmatrix} = \begin{pmatrix} b_1 \\ \vdots \\ b_m \end{pmatrix} \quad (35)$$

2.4. Calculation conditions

The performance of the pieces of equipment is assumed to be:

1. fuel gas utilization rate is 75% and oxidant gas utilization rate is 50%;
2. the temperature efficiency of heat exchanger is about 50%;
3. the electric power of blower, model AH-400 made by SHOWA Electric Corporation, is supplied from the DIR-MCFC.

The optimum system, which can keep the cell temperature (650 °C) without the heat supply, is obtained by solving the heat and mass balances under steady-state condition. Here, the parameters to be solved are heat exchanger location; number and the heat transfer area.

Convergence is attained when the fractional change in each temperature is less than 0.01%.

3. Model family and house

In order to be able to undertake this study, it is necessary to select the scale of co-generation system with DIR-MCFC.

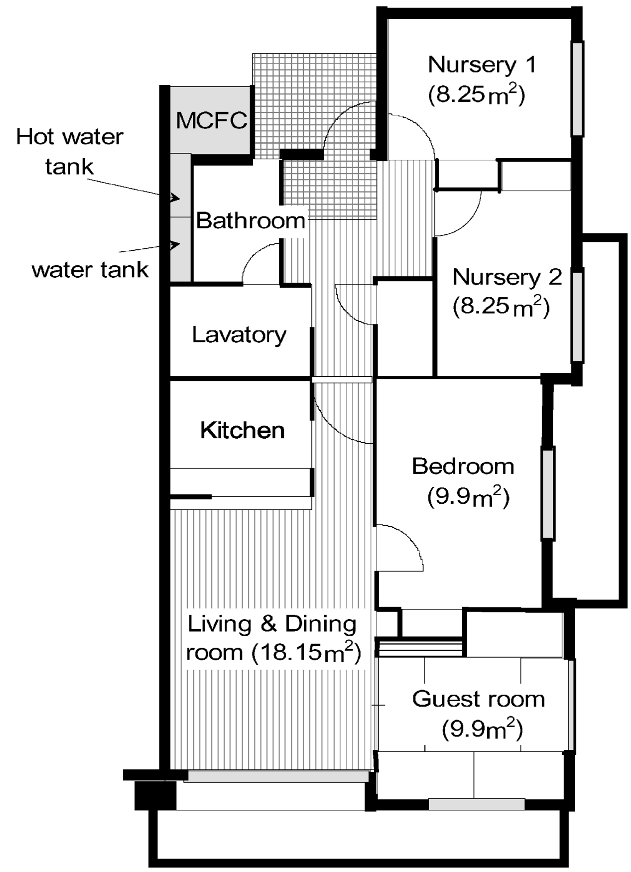

Fig. 2. Schematic drawing of the model house.

In this case, a model family is decided from the results of the survey on the room layout, the number of members in the family, and the number of electric appliances and the consumption of electric power based on the social aspects of Osaka City. The model family is constructed from the results of questionnaire as follows: (i) four persons, of which two are adults, one is a high school and one a junior high school student. (ii) The room layout is depicted in Fig. 2. Here, the model house is powered using only electricity. Gas is only used in the DIR-MCFC, and not supplied for kitchen and bathroom use. (iii) The electricity consumption during weekdays and holiday for three seasons is presented in Fig. 3. Here, electricity means the immediate consumption of electric power that is used directly for such used as lights audiovisual manufactures, etc. On the other hand heat refers to indirect consumption of electric power used to generate heat for such processes as cooking, electric heater etc. In Fig. 3, the electric power consumption for heat increases during mid-night. The consumption of electric power on holidays and specifically in winter is largest because heating facilities are frequently used during this period. Therefore, the DIR-MCFC system must cover the consumption of electrical power and heat demands of holiday and during winter as shown in Fig. 3(d).

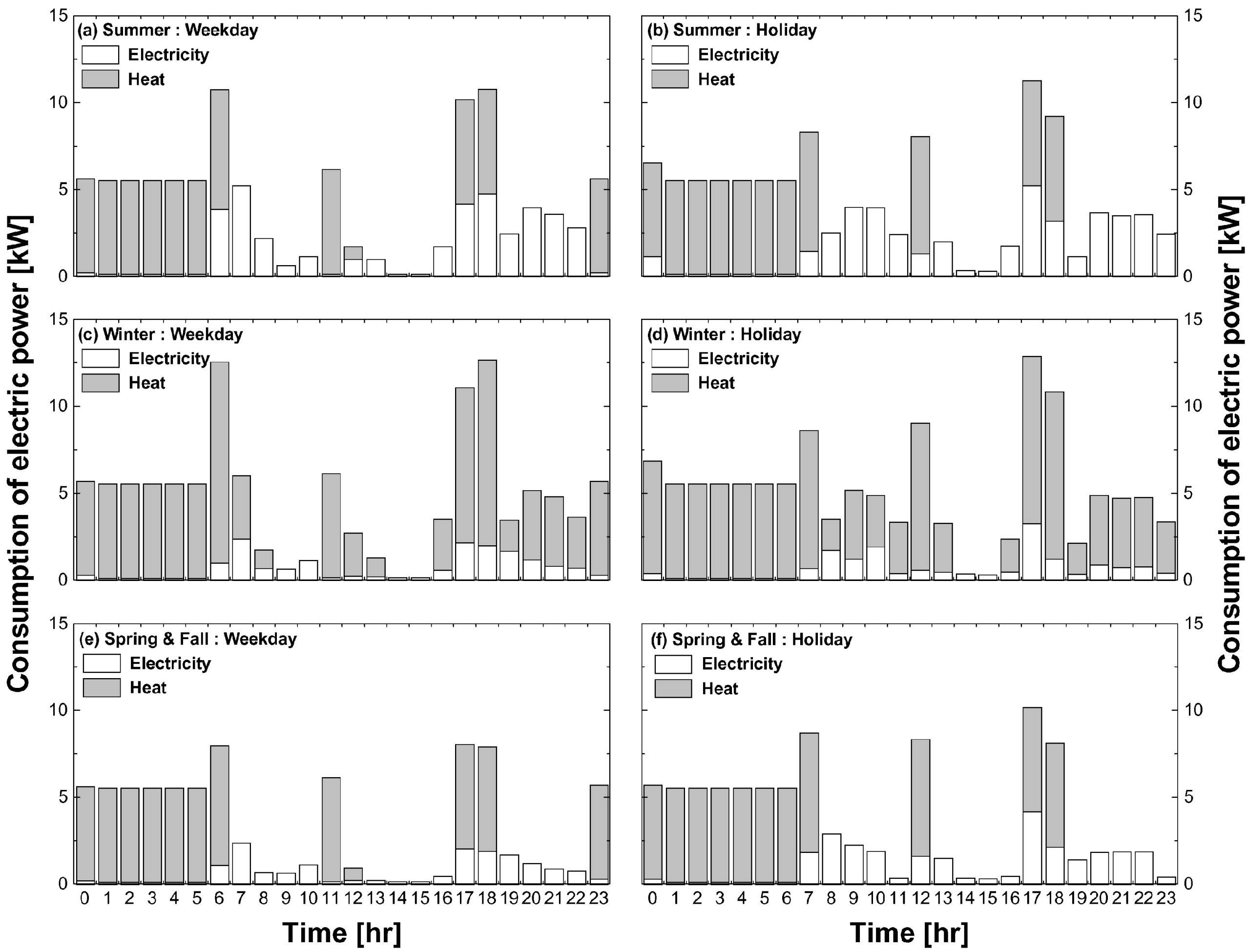

Fig. 3. The consumption of electric power in the model family.

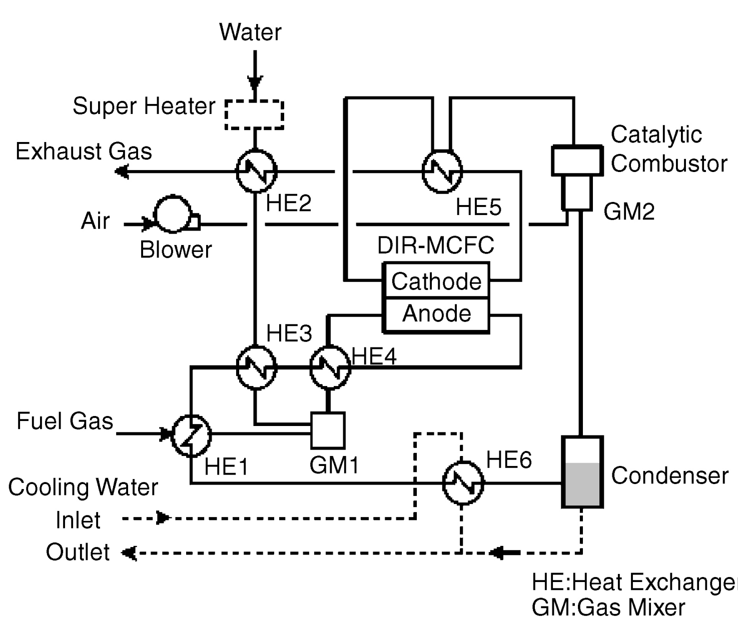

Fig. 4. Schematic flow of the optimum co-generation system with the DIR-MCFC.

4. Results and discussions

4.1. Optimum system

The optimum system, which can maintain the cell temperature at 650 °C without any heat supply, is optimized according to location, number and transfer area of the heat exchanges. At this stage the optimum system is constructed using a 6 kW DIR-MCFC, enough to cover the electrical power consumption during holiday and winter. The optimum system is constructed using six heat exchangers, two gas mixers, a condenser and a catalytic combustor as depicted in Fig. 4. Here, the super heater is only used with a propane system. Because the water supplied for steam reforming is 2.5 times compared to a city gas system, it cannot be vaporized by only two heat exchangers, thus DIR-MCFC cannot maintain the cell temperature. This necessitated the installation of more heat exchangers. The super heater power is supplied by power generated from the DIR-MCFC with an efficiency of 70% (inverter efficiency). Fig. 5 shows the comparison of the system performance, in terms of electric power, quantity of waste heat, hot-water supply and running cost for the city gas and propane using the optimum develop system. With the scaling up of the system, heat exchanger area is increased in order to maintain the heat balance of the system. As can be seen from the figures the electric power generated when using propane is lower than when city gas is used. This is because a propane the gas system uses a super heater which therefore when the reforming reaction occurs more water is needed. As mentioned earlier, DIR-MCFC propane systems of 5 kW or less cannot keep the cell temperature within the indicated level without a heat supply.

4.2. Application of the optimum system to residential use

Construction of the co-generation system with DIR-MCFC is optimized such that the scale of this system meets residential use. On applying the system to residential use, the electricity supply method and heat supply method from the system to the house included the following:

(i) The co-generation system can supplement the peak electric power consumption by using an accumulator, which has a charge/discharge efficiency of 70%.
(ii) The hot-water from the system with a bath, lavatory, kitchen and floor. As shown in Fig. 6, the area of floor heated is 3.3 m^2 in the bedroom and 2.5 m^2 in each nursery.
(iii) The air conditioner is used in all rooms in summer, spring, and fall, in the living and dining rooms.
(iv) By supplying exhaust gas from the system when using city gas, a stainless steel vessel is used as a cooking heater. However, once the exhaust gas from the system when using propane is at a low temperature, the cooking heater cannot be used. Therefore, the system with propane uses an electric heater for cooking.

Fig. 7 shows the electric power consumption, excess power and quantity of hot-water in the tank, for the case of a co-generation system of capacity 2 kW DIR-MCFC. This system is applied to a model family, whereas the indicated negative electric power consumption signifies surplus power that is charged to the accumulator. On the other hand, minus water means the deficit seen from this figure, electric power is insufficient to meet morning and evening demands although using the storage excess electric power during power shortage can solve this problem. As the hot-water supply is exhausted in the mornings, hot-water cannot be supplied to the house after 8 a.m. Moreover, the electric power supply is not enough to meet the demand of the air conditioner in summer, spring, and fall. Therefore, the co-generation system with 2 kW DIR-MCFC cannot be applied to the model family.

Fig. 8 shows the consumption of electric power, the storage of excess power and the quantity of hot-water when

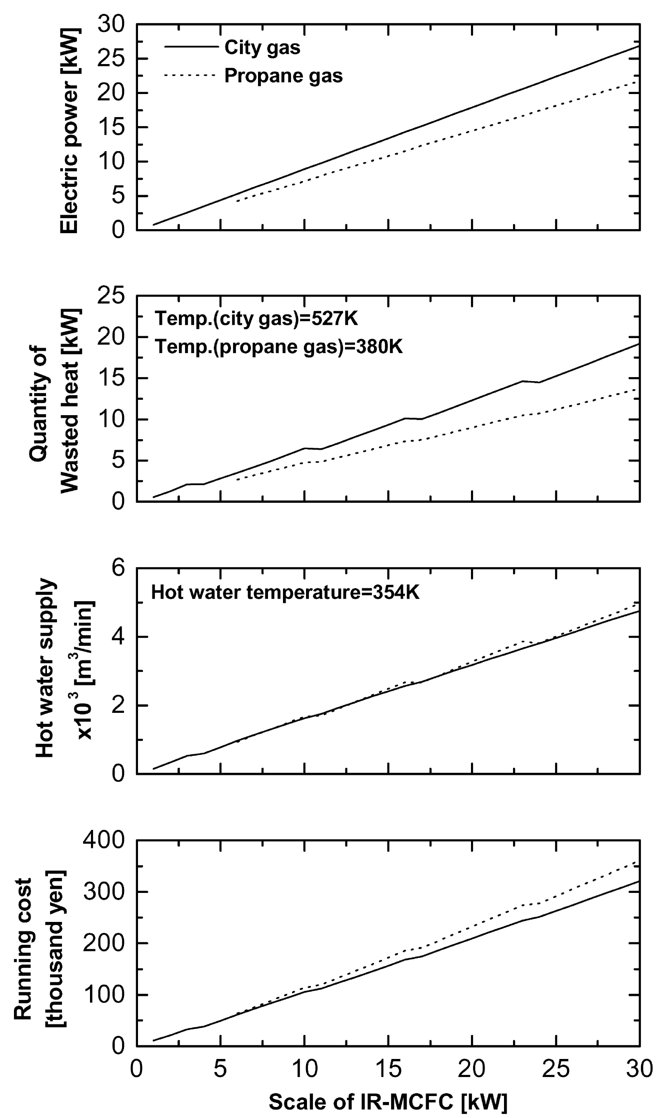

Fig. 5. Performance of the DIR-MCFC system.

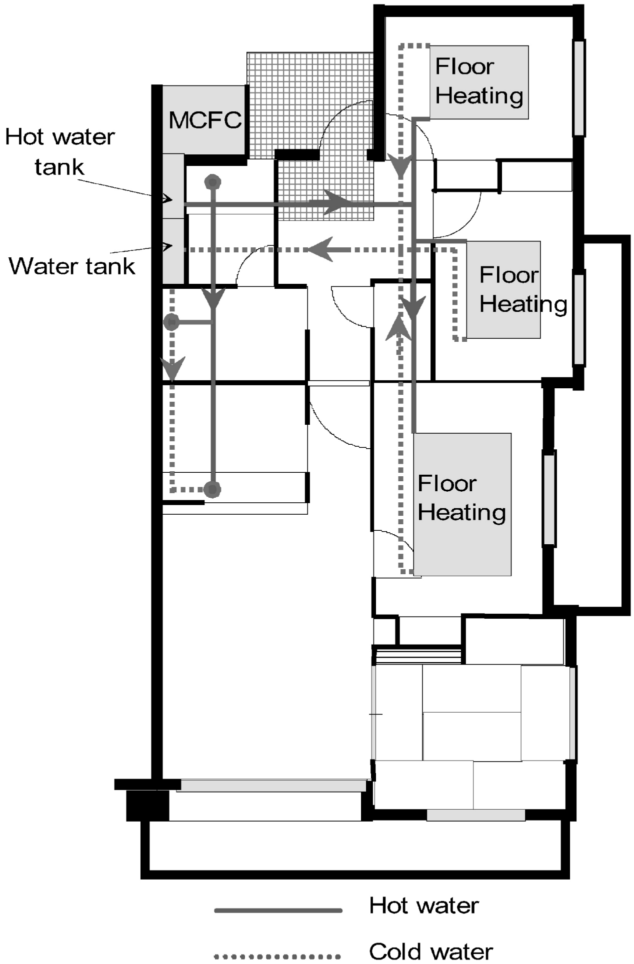

Fig. 6. Schematic drawing of hot-water supply.

a co-generation system of 3 kW DIR-MCFC is applied to the model family. The electric power demand is fully satisfied and a hot-water supply is almost enough to meet the demand except after 8 p.m. However, this problem could be solved using the storage of excess hot-water from weekdays during hot-water shortage on holidays. It can be seen that the electric power supply is sufficient for the demand even if the model family used the air conditioner in summer, spring, and fall. Therefore, the optimum scale of the co-generation system with DIR-MCFC using city gas, is a promising choice when propane is used as fuel. In a co-generation system with a DIR-MCFC of less than 5 kW the cell temperature cannot be maintained at (650 °C) without heat supply. However, a co-generation system of a 6 kW DIR-MCFC is applied to the model family to check its suitability. The results for this case are shown in Fig. 9 where the electric power consumption is in shortage during meal preparation because the system does not use the cooking heater using exhaust gas. However, using the electric cooking heater it is possible to solve this problem, as the electric power is enough. As the scale of DIR-MCFC using propane gas is large than when using city gas, excess storage power and hot-water are in excess. Therefore, the co-generation system using propane gas is suitable for application to apartments rather than a single unit house.

4.3. Economical approach

As the optimum co-generation system for both construction and scale has been decided, this system was evaluated on the basis of running cost. Here, the basis is in terms of the amount of power, gas, water and buying electric power during shortage. The selling of the surplus power

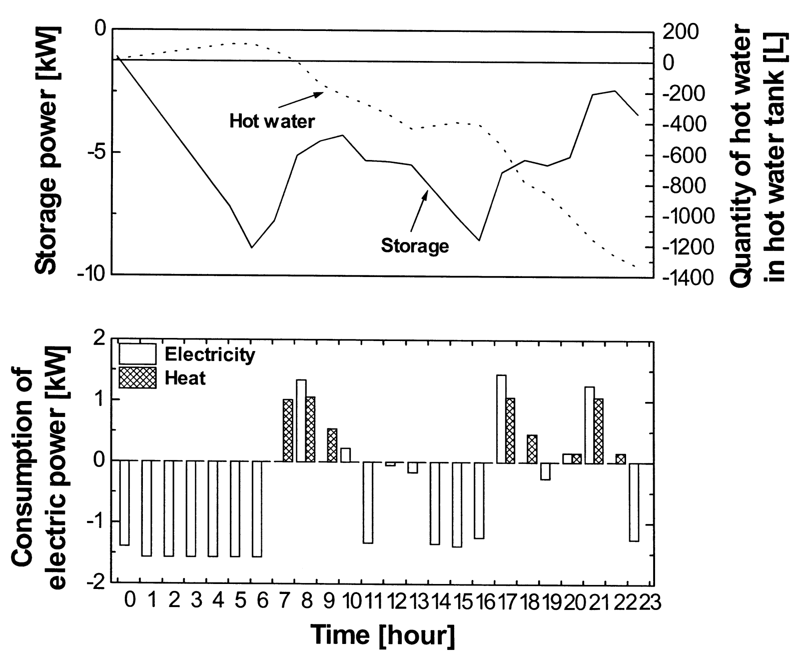

Fig. 7. Applying the 2 kW DIR-MCFC system using city gas to the model family.

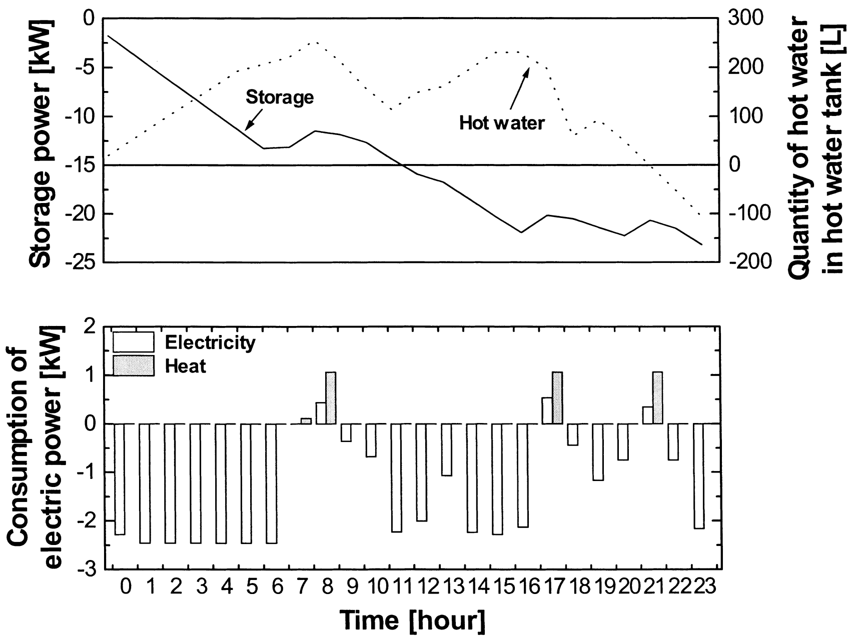

Fig. 8. Applying the 3 kW DIR-MCFC system using city gas to the model family.

is calculated using a list of rates from each of the respective companies, that is, Kansai Electric Power Co., Osaka Gas Co. and the Waterworks Bureau of Osaka City. This cost did not include the construction fee. Comparison of running costs per month of the co-generation system and the traditional lighting and heating expenses per family is shown in Table 1. Although the co-generation system needs gas and water, it does not need electric power. As seen from this table, the gas consumption rate of the co-generation system is more than the former gas rate, but the lighting and heating expenses are almost same as the traditional one. The reason for this is that the co-generation system profits by selling the excess electric power to Electric Power Corporation. Usually the lighting and heating expenses in spring and fall are cheap, thus the profit gained by selling the excess electric power to Electric Power Corporation is substantial. In the case of the system using propane, as the scale of DIR-MCFC increases, the lighting and heating expenses increase. It therefore follows that the co-generation system when using propane is suited to an apartments rather than to a single unit

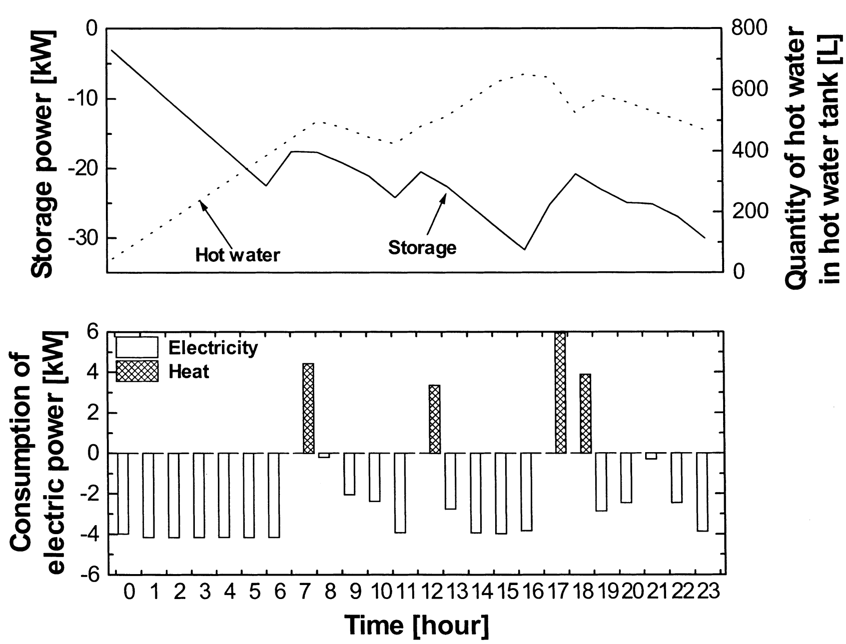

Fig. 9. Applying the 6 kW DIR-MCFC system using propane gas to the model family.

Table 1
Comparison of the running cost of co-generation system with the former system

Fuel	Season	Gas		Water		Sale of power		Running cost (yen per month)
		Quantity (m^3 per month)	Rate (yen per month)	Quantity (m^3 per month)	Rate (yen per month)	Quantity (kWh per month)	Rate (yen per month)	
City gas	Summer	223	29487	23	3576	405	10241	22822
	Winter	223	29487	23	3576	576	14646	18417
	Spring & fall	223	29487	23	3576	801	20262	12801
Propane gas	Summer	344	55445	41	8054	658	16649	46850
	Winter	344	55445	41	8054	731	18505	44994
	Spring & fall	344	55445	41	8054	1036	26209	37289
	Fuel	Gas		Water		Electric power		Lighting & heating expenses
		Quantity (m^3 per month)	Rate (yen per month)	Quantity (m^3 per month)	Rate (yen per month)	Quantity (kWh per month)	Rate (yen per month)	
Traditional	City gas	50	7582	50	7959	379	9589	25130
	Propane	15	7220	50	7959	379	9589	24768

house in terms of running cost. As mentioned above, it is obvious that the co-generation system with DIR-MCFC is more practical for residential use.

5. Conclusion

The possibility of introducing a co-generation system with DIR-MCFC for domestic use has been examined in this feasibility study. From the results obtained, it can be concluded that:

1. The co-generation system with DIR-MCFC could keep the cell temperature within 650 °C without any heat supply. Such a system consists of six heat exchangers, two gas-mixers, and a condenser. Such a system consists of a catalytic-combustor, and a blower.
2. The optimum scale when using city gas is determined to be 3 kW, while it is 6 kW in the case of propane.
3. The efficiency of lighting and heating is almost the same as the traditional source, although the co-generation system offers economical gains by selling electric power to the Electric Power Corporation.
4. The co-generation system using city gas is a viable choice for domestic use, especially on single units. The propane gas model is best suits use in apartment houses.

Acknowledgements

With deep grief, the authors mourn the untimely death of Professor Kazutomo Ohtake, who was one of the pillars of this research. He has pioneered a lot of ideas and his close supervision and guidance resulted in the present outcome. The authors are also indebted to Associate Professor Ryohei Yokoyama of Osaka Prefecture University for his considerable assistance on system analysis.

References

[1] T. Abe, E. Koda, J. Thermal Nuclear Power Generation 45 (7) (1994) 797–807.
[2] P.F. van den Oosterkamp, A.A. Goorse, L.J.M.J. Blomen, J. Power Sources 41 (1993) 239–252.
[3] M. Krumpelt, R. Kumar, K.M. Myles, J. Power Sources 49 (1994) 37–51.
[4] P. Kraus, J. Power Sources 49 (1994) 53–59.
[5] K. Takahashi, T. Mizukami, T. Kahara, S. Takahashi, in: Proceedings of the 2000 Fuel Cell Seminar in Portland, pp. 671–674.
[6] T. Ogawa, A. Matsunaga, T. Matsuyama, H. Kasai, K. Miyazawa, in: Proceedings of the 2000 Fuel Cell Seminar in Portland, pp. 712–715.
[7] Y. Fujita, T. Nishimura, T. Okada, M. Matsumura, J. Hosokawa, in: Proceedings of the 2000 Fuel Cell Seminar in Portland, pp. 675–678.
[8] K. Shindo, T. Ouki, A. Fuju, O. Tajima, N. Nishizawa, T. Susai, in: Proceedings of the 2000 Fuel Cell Seminar in Portland, pp. 492–495.
[9] K. Sugiura, K. Ohtake, in: Proceedings of the 28th JSCE Fall Symposium, September 1995, p. 307.
[10] Y. Miyake, N. Nakanishi, T. Nakajima, Y. Itoh, T. Saitoh, A. Saiai, H. Yanaru, J. Power Sources 56 (1995) 11–17.
[11] JSCE, Programming of Chemical Engineering with BASIC, Baifukan, 1985, pp. 82–88.
[12] Handbook of Heat Exchanger, Nikkan Kougyo Sinbunsya, 1965, pp. 196–199.