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Hydrogen Energy and Fuel Cell Systems

Open Alliance and Open Innovation - Toward a Professional Society in the 21st Century -

Nobuhide Kasagi

President JSME
The University of Tokyo

Introduction

It is an honor and a great responsibility to serve as President for the JSME, which has a long history and a great impact in science and technology. I am looking forward to working together with JSME members on various occasions during the year ahead.

Over the last century, science and technology made tremendous advances, and fulfilled various demands of the human society, such as preventing disasters or accidents, overcoming illnesses, providing ample commodities, and promoting industries.Now, the mission of engineering is to secure sustainability under environmental constraints, guarantee good health and improved comfort in the lives of people with diverse values, and establish a safe and peaceful global society.I understand that the JSME has to move timely and proactively by perceiving its role in the new era. From this standpoint, Continued on page 2

Current Status of on-site Fuel Cell Power Plants for Business and Industrial Uses

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Introduction

Tokyo Gas has been evaluating the performance of sub-MW class on-site fuel cell power plants for more than three decades, since Tokyo Gas and Osaka Gas first participated in the TARGET program launched in the US in 1967. We have mainly operated 50kW, 100kW and 200kW on-site phosphoric acid fuel cell (PAFC) plants as a co-generation system for commercial facilities. We have accumulated considerable data and evaluated the performance of PAFC's electrical / thermal characteristics, reliability and durability from a composite total of 1,103,000 hours from more than 30 plants' operation.Under our evaluation of these items, on-site PAFCs have Continued on page 3

Development of a Super High Pressure Hydrogen Booster Compressor for Refueling Stations

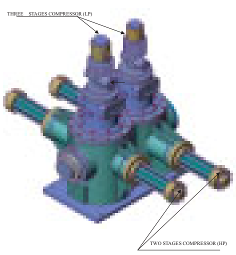
Yasuo Fukushima

Hitachi Plant Technologies, Ltd.

Introduction

1. Introduction

The development of hydrogen energy applications are rapidly increasing to prevent global warming, and to maintain the reduced emission profile. Various approaches have been investigated to increase the Fuel Cell Vehicle capabilities (hereinafter called FCV) to equal that of a gasoline engine in terms of distance traveled and refueling requirements. Based on the above circumstances, we are developing a hydrogen booster compressor for refueling stations to achieve a discharge pressure of up Continued on page 5



Prototype DMFC for a Laptop PC

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Introduction

A Direct Methanol Fuel Cell (DMFC) is one of candidates for the next generation power source for portable equipments, such as portable PCs, cellular phones, PDAs, because energy density of liquid methanol is higher than that of secondary batteries. Assuming (30%) power generation efficiency of 30%, energy density of methanol is 1.5Wh/cc, whereas that of Lithium Ion Battery (LIB) is 0.3Wh/cc. DMFC is a kind of chemical fuel and air are injected into a stack, the exhaust from the stack are processed, the process parameter of the feed rate,concentration of methanol and Continued on page 7

OPEN ALLIANCE AND OPEN INNOVATION
- Toward a Professional Society in the 21st Century -

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Continued from page 1I would like to take the initiative toward the following three goals.

Strengthened Competitiveness of JSME

First, I believe that the JSME should make a steady effort to review and rebuild its fundamentals, so that it can really contribute to the society as a professional community responsible for engineering and technology related to machines and mechanical systems.

Research explorations and exploitations of new technological fields are the most important pillars that determine the significance of JSME. At the 2006 Spring Meeting of JSME, Technical Division Chairs spoke about their visions for mechanical engineering and technology, all of which illustrated the future directions of JSME. With their messages, I feel very confident of a bright future of JSME, and would like to encourage all JSME members to make a challenge for innovating mechanical engineering. In other words, we need to renew our methodology of creation and manufacturing from being empirical and inductive to being farsighted and deductive.

I also believe that JSME can prove its true worth, if members of professional knowledge and talents share the responsibilities of technological innovation and human resource development in the society. I encourage all Regional Branches and Technical Divisions of JSME to promote the members' active participation in various JSME activities, while I want to emphasize the importance of collaboration between Branches and Divisions themselves, and also with industries, governmental organizations and academia including overseas sectors. Since JSME has started a new system, which enables inter- and trans-disciplinary activities in new frontiers, it is your turn to actively participate in any of these.

As a means of disseminating members' latest research results, we will open our new Publishing Center, which will strengthen the entire JSME's publication and marketing activities. We should supply internationally competitive English journals and reliable manuals and standards in addition to the steady publication of well-established Japanese Transaction Journals. The enhancement of member services and the function strengthening of the JSME Headquarters by aggressively introducing IT are urgent issues that must be addressed.

Contribution to Human Resource Development

Second, the JSME should play a major role in human resource development. Japan has a small land area with poor natural resources and a large population that speaks a language unique in the world. Therefore, what supports the country is only our potential human resources and culture. These facts offer a good chance for Japan to demonstrate a human rich sustainable country by educating people mentally, morally and physically.

Two distinct issues exist. One is the "issue of quantity," *i.e.*, the decrease in the number of engineers due to falling birthrate, aging population, and declining popularity of science among students. The other is the "issue of quality," *i.e.*, human resource education tailored to meet the needs of the new century. Engineers in a global society must possess, in addition to advanced professional knowledge and skills, the ability to identify and solve problems taking into consideration social, environmental and economical contexts. To help the member's progress in these directions, JSME has established a new Human Resource Development Promotion Center, and provides opportunities that enhance the competence of individual engineers by developing qualities such as panoramic viewpoints, global environmental literacy, and technology management ability.

Misconducts and failures related to science and technology have occurred recently. These are serious issues. We must once again be aware of our responsibilities as professional engineers with good moral values, and establish the autonomy to promote model engineers who are respected by the society. Fortunately, JSME already has its own ethics codes, so what we need to do is to implement a system of making them function.

Presence of JSME as Community of Mechanical Engineers

Third, JSME should contribute to the enhancement of the pride and status of engineers by earning the trust and confidence of the society. Therefore, JSME's important mission also exists in identifying socially demanding multidisciplinary problems such as the environment, energy, robotics and humanoids, safety technologies and biomedical research, and offering technological solutions to these problems.

We should aim at promptly publicizing and disseminating the achievements and proposals from JSME. For the Annual JSME Meeting to be held this coming September, we have selected our grand message, "Toward Materializing an Affluent and Sustainable Society." We have also set forth three themes that represent some of the major activities of JSME, *e.g.*, "Human Recourse Development," "Energy" and "Biomedical Engineering."

The establishment of "Memorial Day for Machines and Mechanical Systems" on August 7th, which had been a pending issue, was finally approved by the Meeting of

JSME Council Members last March. I expect that it will offer a meaningful opportunity for us to think about the relationship between technologies and the society, the roles of engineers, and other issues, together with people even outside scientific fields. Through this event, JSME should exert its presence and further cultivate the collaboration with relevant governmental, industrial and academic sectors inside and outside Japan.

Open Alliance and Open Innovation

To achieve the goals stated above, I would like to encourage open alliance and promote open innovation by providing opportunities that are inclusive without building barriers to any aspect of activities. It is essential for every section in JSME to have an open culture, to explore possibilities of alliance with other sections within and outside JSME, to develop new technologies that can materialize remarkable dreams, and to foster human resources with noble ambitions. I want to develop fascination in JSME in the sense that its member can make new experiences, create new knowledge, and achieve self-development through various encounters with many fellow engineers of diverse values.

Finally, I thank former President Dr. Yuya Taguchi, and all of the previous members of Governors Board, Regional Branches, Technical Divisions and other committees for their dedication in a number of actions that have strengthened the structure and activities of the Society. In my determination to do the best for the further development of JSME, I would sincerely ask for your understanding and support, and welcome your comments on any of the above matters.

Current Status of on-site Fuel Cell Power Plants for Business and Industrial Uses

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Energy Solution Business Dept.

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Continued from page 1 technically attained the commercial level.

From FY2005, our activity related to molten carbonate fuel cell (MCFC) had been started to obtain higher electrical efficiency for on-site generation. We are verifying the performance of 250kW MCFC power plant in cooperation with Kawasaki Heavy Industries Ltd. and evaluate its performance, reliability and durability under power plant's operation and maintenance experience.

1. Line-up of on-site fuel cell plant

Table 1 shows the current line-up of sub-MW class on-site fuel cell power plants for business and industrial use, that manufacturers can deliver in Japan. We have three types of on-site plants which includes; FP100 (100kW PAFC) manufactured by Fuji Electric Advanced Technology Co., Ltd. and delivered by Fuji Electric Systems Co., Ltd., PC25™C (200kW PAFC) manufactured and delivered by Toshiba Fuel Cell Power System Corp. and DFC300 (250kW MCFC) manufactured by Fuel Cell Energy Inc. and delivered by Fuel Cell Japan Co., Ltd. (Marubeni Cor-

Table 1 Line-up and Specifications of sub-MW class on-site Fuel Cell Power Plants

Category	Item	PAFC		MCFC
		Fuji Electric Group FP100 series	Toshiba FC Power System PC25™C	Fuel Cell Japan (FCE, Marubeni) DFC300 series
Standard Spec.	Rated Power	100kW	200kW	250kW
	Output Voltage	200V 210/220V	400/440V	380/480V
	Frequency	50/60Hz	50/60Hz	50/60Hz
	Elec. Efficiency	40% (LHV)	40% (LHV)	47% (LHV)
	Dimensions	3.8m * 2.0m * 2.5m	5.5m * 3.0m *3.0m	8.0m * 6.0m *3.0m
	Weight	10t	18.2t	37t
	Emissions	NOx<5ppm	NOx<5ppm	NOx<5ppm
	Noise	65dB(A) (at 1m)	60dB(A) (at 10m)	65dB(A) (at 3m)
Fuel	Standard	Natural Gas	Natural Gas	Natural Gas
	Options	LPG, ADG Bio-gas, Hydrogen	LPG, ADG Bio-gas, Methanol	ADG, Bio-gas
Electrical Interface	Standard	Grid Connected	Grid Connected	Grid Connected
	Options	Grid Independent	Grid Independent	Grid Independent
Heat Recovery	Standard	90C(HW) 50C(LW)	60C(LW)	
	Options	160C(ST) 50C(LW)	120C(HW) 60C(LW) 160C(ST) 60C(LW)	170C(ST) w/ Additional Boiler

HW:high grade heat water LW:low grade heat water ST:Steam

FP100 series

PC25™C

DFC300 series

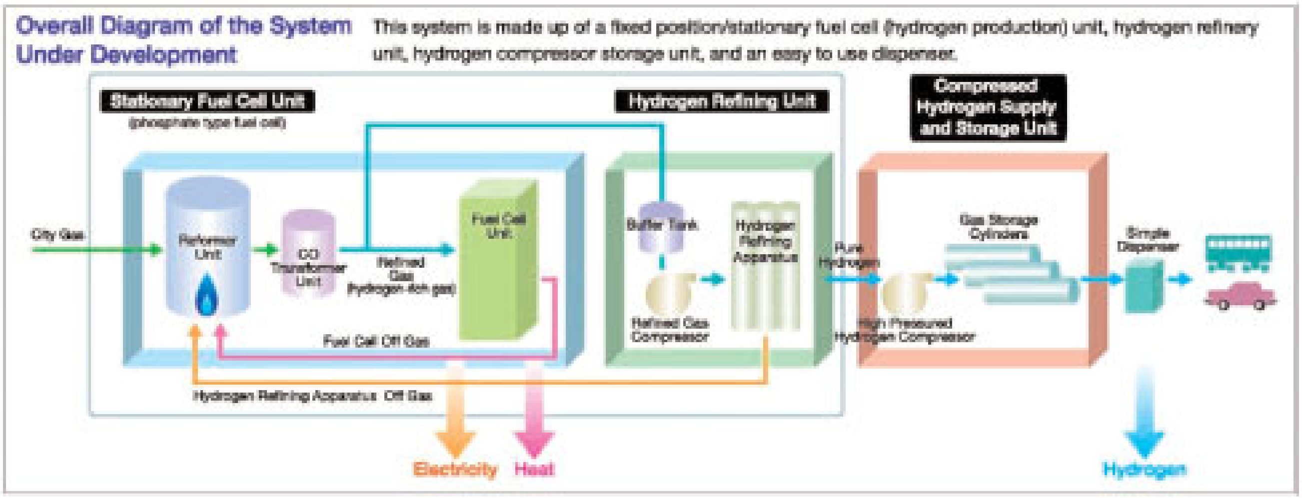

Figure 1: Overall diagram of small-scale hydrogen supply system

poration).

The most important factor related to the development of fuel cell technology is the durability of cell stack itself. At least cell stack life of 40,000hrs should be needed for commercialization. Mentioning about the stage of development, PAFC is at the commercial level and we have already verified its cell stack durability of 40,000hrs. And the cell stack life of the current FP100 series is designed for 60,000hrs. Otherwise MCFC is pre-commercial level and we have just started evaluation of its performance.
As of FY 2005, the number of cumulative installations all over Japan about PAFC and MCFC power plants are about 200 and 10 units, respectively.

A remaining hurdle to actually marketing PAFC plants is to reduce the cost. At the same time as we work toward the reduction of several costs related to the plant itself, in areas such as construction, maintenance and overhaul, we are also developing new applications by making the best use of the distinctive features of fuel cells. We have succeeded in developing a high efficiency DC system, a high quality and highly reliable power supply system etc., and now try to develop hydrogen supply system to meet on-site hydrogen demand such as FCV's fuel. We anticipate that these applications might expand the fuel cell market, in addition to the conventional co-generation market thereby promoting mass installation and mass production, which would ultimately bring down the price.

2. Applications

One application under development named "Small-scale Hydrogen Supply System with electric power & heat supply capabilities" is introduced. Actually, there are more movements to intend to introduce FCVs in Japan, but in addition to great expenses and mature performance, lack of hydrogen infrastructure has become obvious as a barrier to progress. Initial users of FCVs need convenient hydrogen infrastructure even in the transition stage. We intend to provide hydrogen infrastructure that can achieve both reduction of CO_2 emission and economic independence and to accelerate a widespread use of FCVs.
To provide hydrogen to the initial FCV users and realize reasonable price and high efficiency as well as reduction of CO_2 emission, we have started to develop hydrogen supply systems aiming at the initial FCV market. One of them is a hydrogen supply system that simultaneously generates electricity and heat. This system uses stationary fuel cell to produce hydrogen for FCVs while reliably providing electric power and heat for use in facilities and buildings.
This system consists of a stationary fuel cell unit, a hydrogen purification unit, a hydrogen compression and storage unit, and a simplified dispenser. Figure 1 shows overa ll diagram of the system. The capacity of stationary fuel cell unit (PAFC) is 100kW.
This system continues to operate as a cogeneration system, even if hydrogen is not being utilized. Hydrogen can be produced quickly when it is needed, and hydrogen generated is estimated to be more valuable than electricity that is reduced instead of hydrogen.
Therefore, users can maintain consistently high efficiency levels while minimizing environmental loads and achieving the optimal mix of electric power, heat and hydrogen from both environmental and economical perspectives. Furthermore, this system can be installed for cogeneration use only and reconfigured with additional components to supply hydrogen when FCVs are introduced later. This system is expected to be installed at sites where there is a demand for electric power and heat, and where FCVs are likely to be introduced. Locations would include public facilities of local governments, the corporate facilities of companies with commercial vehicles, bus depots, garbage collection facilities and expressway service areas.
Before the close of FY2004, we had constructed a hydrogen purification unit for test in pilot schemes. We will also continue to develop the overall system in this FY2006. The development of this new system is expected

to contribute to the accelerated introduction of FCVs by increasing the availability of hydrogen infrastructure.

3. Conclusion

Tokyo Gas has great expectations and interests in realization of higher efficient equipments with the aim of solving environmental issues and establishing a sustainable society. Natural gas will be one of the most potential and viable options as a primary energy source to produce electricity, heat and/or hydrogen at sites and it will be the important bridging energy until the renewable energy sources will come to be a real option at reasonable costs and reliability.

Fuel cell is one of the most important and remarkable technology to cope with not a few energy, environmental and economical issues ahead. As the on-site co-generation system, fuel cells can deliver both electricity and heat with higher efficiency to meet from small to large demands. Some types of power plant are already commercialized and hundreds of units have been already installed worldwide and produce on-site "clean energy".

Besides, fuel cell has unique features and additive value would be derived to actualize a wide variety of applications. Especially fuel cell is congenial with hydrogen, therefore activities for research and development in many areas will be more active to realize hydrogen society in the future. Tokyo Gas will continue to make effort to diffuse fuel cell technologies to the wide range of real markets.

Development of a Super High Pressure Hydrogen Booster Compressor for Refueling Stations

Yasuo Fukushima

Hitachi Plant Technologies, Ltd.

Continued from page 1to 100MPa, which will enable the supply of fuel gas at 70MPa to the FCV. In order to achieve this specification, the compressor is also required to maintain longevity, safety and reliability levels, improve efficiency and to supply clean hydrogen. At super high pressure, we have accumulated compressor technology for many years for the LDPE polyethylene compressor at 350MPa. Based on this rich experience, we developed a prototype hydrogen booster compressor.

2.Main characteristics and concept

The basic concept of the reciprocating compressor is a plunger type and it supplies less lubricant to the rod packing area to reduce friction force between the seal surfaces and to minimize gas leakage through the shaft seal, which improves the life of wearing parts.

The lubricant can be completely trapped by the coalescing filters positioned downstream of the compressor.

3.Development of a prototype compressor

The compressor specifications are tabulated in Table 1. The cross-section of this compressor is outlined in Figure 1. The compressed section is divided into two sections due to the higher pressure ratio of 8.4.

The main benefits of the compressor are:

1)Alignment of the low-pressure (LP) and high-pressure (HP) plunger shafts on the same centerline to compensate the gas loading and inertia force. This arrange ment can reduce the load of the bearing and prevent coupling force acting on the crankshaft.

2)The taper roller bearings are adopted for the main bear ing, which can maintain a smaller bearing clearance for less noise and vibration.

3)The shaft seal, which consists of several numbers of rod packings, are separated into two parts, that is, low-pres sure and high-pressure. The combination of materials of copper alloy and engineering plastics, installed at the end of the plunger can prevent gas leakage from the shaft. The radial movement of the rod packing can be controlled against the reciprocating shaft movement to reduce the leakage of the gas.

4)The popet type valves were designed to obtain better performance and higher reliability after a detailed para

Table 1: Major specifications of the prototype compressor

Inlet pressure	10 MPa
Discharge pressure	Rated 84MPa (Max 100MPa)
Capacity	100 Nm3/h
Adiabatic efficiency	≧70%
Lubricant contents (at terminal point)	≤ 0.5 ppm

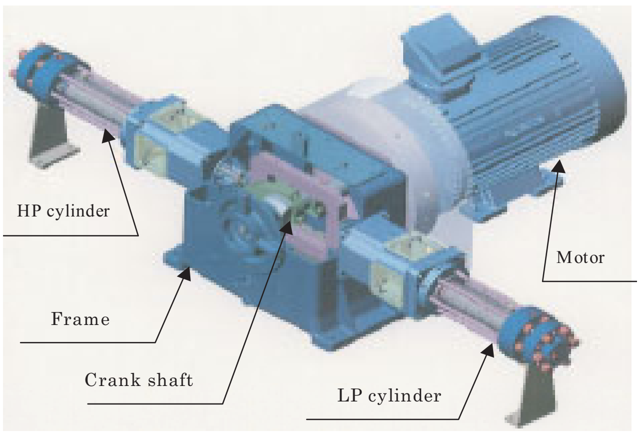

Figure 1: Proto type compressor (84 MPa)

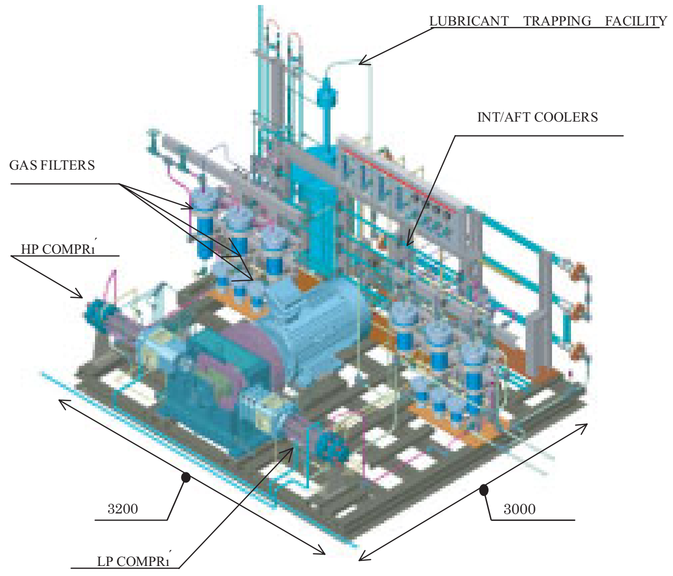

Figure 2: Closed Test Loop Facility

Table 2: Test Summary at 84 MPa discharge pressure

	Planned	Actual results
Capacity	100Nm3/h	100 Nm3/h
Adiabatic efficiency	≧70%	70.5%
Lubricant contents	≤ 0.5 ppm	10 ppb

meter survey of valve travel distance, valve spring force and mass of the valve.

5)A sulpher free lubricant (less than 4ppm) is adopted for the shaft seal system. Then, the trace of the lubricant is evident in the compressed hydrogen gas. However, the trace can be completely trapped by the coalescing filters.Target of the filtration is 0.5ppm.

6)Hydrogen embrittlement of steel under high pressure is the major concern of material selection, which is in direct contact with the hydrogen. Under super high pres sure condition, the behavior of hydrogen embrittlement is now under investigation throughout the world, howev er, careful consideration must also be given for limiting the discharge gas temperature, lowering the stress value by using FEM analysis, and using threading joints in stead of welded joints.

4.Test facility

A full pressure and load test facility was prepared for the operational test objective. The closed loop test facilities are outlined in Figure 2. Three kinds of test gases were used, nitrogen, helium, and hydrogen. The lubricant trapping facility was installed in the closed test loop to achieve a measuring accuracy of 0.005 ppb of lubricant.

5.Test results of 84 MPa operation

The test results at 84MPa discharge pressure is summarized in Table 2.

The gas leakage through the shaft seal could be minimized with the newly developed rod packing, which achieved the planned value for overall efficiency.

10 ppb (parts per billion) of the lubricant traces in the process gas is obtained from the cold trap measurement, which satisfies the requirement of hydrogen fuel quality as discussed in ISO/TC197/WG12.

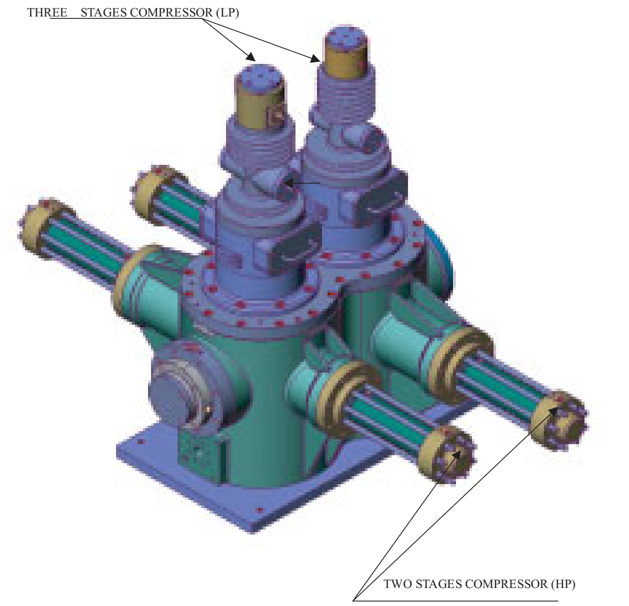

Figure 3 : New Compressor Model (100MPa)

Table 3: Major specifications of low pressure applications

	Planned value
Inlet pressure	0.6 MPa
Discharge pressure	100 MPa
Capacity	300Nm3/h
Adiabatic efficiency	73%
Lubricant contents	Less than 500 ppb

6.New developments of low inlet pressure applications

Our next target is to develop a low inlet pressure to cope with both the onsite and offsite servicing of refueling stations. The main compressor specifications are summarized in Table 3 and its outline is shown in Figure 3.

7.Conclusion

The current status in our development of a hydrogen booster compressor is outlined. We have achieved successful operation of a prototype compressor at 100MPa discharge pressure. Based on the success of prototype one, we plan to develop a larger compressor for future industrial standardization.

8.Acknowledgement

This development was funded by New Energy Development Organization (NEDO) of Japan.
We appreciate their generous support.

Prototype DMFC for a Laptop PC

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Continued from page 1temperature are controlled. We designed and made a DMFC system for portable usage based on cell performance and operating conditions. Cell performance such as I-V characteristic, methanol crossover affects on not only power generation efficiency but also amount of heat dissipation. Heat dissipation from DMFC systems is one of the important issues to be paid attention to make the DMFC system small and stable.

Energy and mass balance of DMFC

As shown in Fig.1, methanol/water as fuel and air are supplied to a DMFC to generate electricity. Heat, CO_2 and water are generated as byproducts. The generated electricity also changes in the form of heat finally. In order to make DMFCs possible to be used as power supply in portable equipment, enthalpy of fuel, water produced by fuel cell and water supplied as fuel should be released to ambient air.
Figure 2 shows the schematic of power generation mechanism of DMFCs. Anode catalytic layer and cathode catalytic layer are placed both side on proton conductive membrane. Methanol and water are fed to anode side and air is fed to cathode side. The following reactions are occurred:

Anode reaction : $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$ (1)
Cathode reaction: $3/2O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$ (2)

Proton passes through the membrane, but electron does not pass through it. Electron passes through external circuit. Then electronic power is generated. Methanol and water also pass through the membrane. This methanol is so-called as methanol crossover.
Figure 3 shows the schematic of cell voltage and methanol crossover flux dependence on current. The cell voltage and methanol crossover flux decrease with the increase of current. Generated power is the multiple of cell voltage and current, which has the maximum at a certain current, but the power generation efficiency is not the maximum at the maximum output power. In the case that the operating current is fixed, operating cell voltage and methanol crossover flux are fixed. Figure 4 shows the schematic of power generation efficiency. The horizontal axis shows the sum of methanol used for the power generation and crossover. Total energy of methanol used in a cell is the whole rectangular area in Fig.4. Electronic power extracted from a cell is a part of the whole rectangular area, and the power generation efficiency, η_{pwr} is defined as follow:

$$\eta_{pwr} = \frac{i_{op}}{(i_{op} + i_{c.o.})} \frac{V_{op}}{V_{cmb}} \quad (3)$$

where i_{op} is operating current, $i_{c.o.}$ is methanol crossover flux, V_{op} is operating voltage, and V_{cmb} is voltage equivalent to methanol enthalpy, which is 1.26V. Overall efficiency, η_{system} to supply power to an equipment, P_{supply}[W], is defied as follow:

$$\eta_{system} = \frac{P_{supply}}{F_{Methanol} \cdot \Delta H} \quad (4)$$

Where $F_{methanol}$[cc/h] is methanol feed rate, and ΔH is enthalpy change in methanol oxidation, which is 5 Wh/cc.

A prototype of DMFC for a laptop PC

A prototype of DMFC for a laptop PC was made, which specification is shown in Table 1. Concentrated Methanol is used as fuel and part of produced water through cathode reaction (2) is recovered from cathode exhaust gas. The system diagram is shown in Fig.5. Consumption rate of

Fig. 1 Overall balance of material and energy in a DMFC for a portable equipment

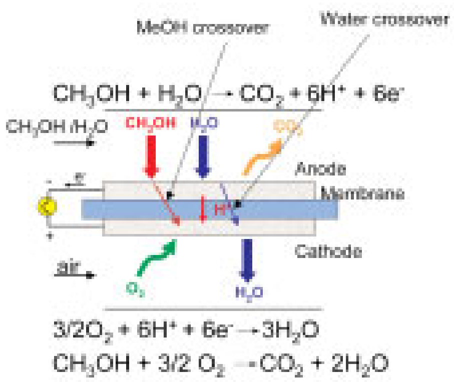

Fig.2 Schematic reaction diagram of DMFC phenomena

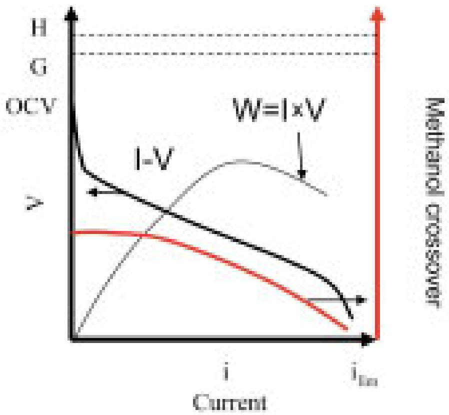

Fig. 3 Schematic diagram of polarization curve and methanol crossover dependence of current

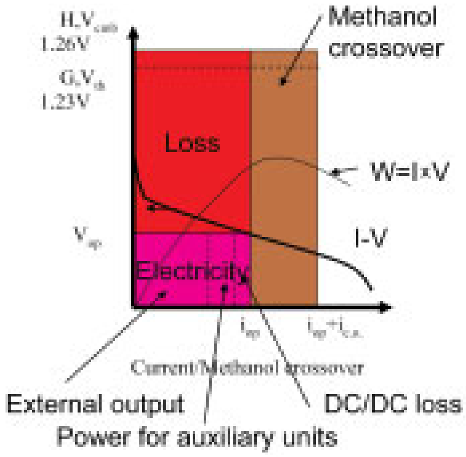

Fig. 4 Schematic diagram of power generation efficiency of DMFC

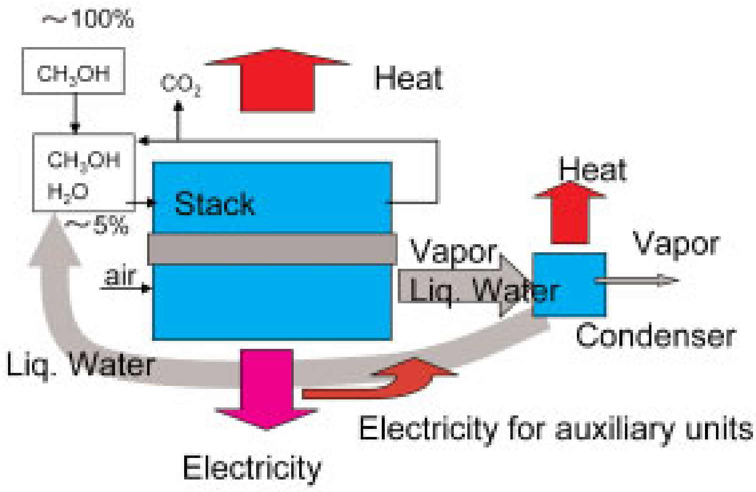

Fig. 5 One example of DMFC system

neat methanol as fuel was about 10cc per hour, which correspond to 1.3Wh/cc of specific methanol power density and 26% of overall efficiency from methanol to electricity. Total heat generation is 50W. Not only a stack, fuel, and pumps, but also heat radiation system and heat dissipation control is necessary to the DMFC system. The heat dissipation control keeps the stack temperature and the water recovery rate constant.

References

1) Y. Sato et al, 2005 AIChE Annual Meeting, Conference Proceedings, 215f

2)http://www.toshiba.co.jp/about/press/2006_01/pr0501.htm

Table 1 Prototype DMFC specification

DMFC Size：W320xD75xＨ60ｍｍ including cartridge space
Output for PC : 10-13W
Running time : 10ｈ per cartridge
Cartridge : W57xD65xＨ47 Methanol（>95%）: 100cc
Environmental temperature：10-30℃ humidity：30-70%

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