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HYBRID GAS HEAT PUMP WATER HEATER

WITH THERMAL EFFICIENCY 120%

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ABSTRACT

In Japan, electric heat pump water heaters ('Eco Cute') that use CO_2 as the refrigerant is spreading rapidly, which has been a big threat to gas companies in Japan and similar threats could be imposed on European gas companies.

To improve the heat efficiency of gas water heaters, we studied a hybrid type water heater that combines a conventional gas water heater and a heat driven heat pump cycle. With a target heat efficiency of approximately 120%--a dramatic increase over the 90% efficiency of a conventional gas water heater--this hybrid gas water heater (here after known as HGWH) is expected to be an energy-saving replacement for household or commercial users and could be a countermeasure against the Eco Cute. The HGWH combines a single-stage adsorption heat pump cycle and a conventional gas water heater, which are operated either simultaneously or independently depending on the outside temperature, making year-round high heat efficiency operation. We evaluated the feasibility of HGWH using a prototype we constructed. We found that a compact system can be achieved, and heat efficiency of this HGWH achieves 110% to 120%, which is comparable with heat efficiency of Eco Cute.

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Verwijderd: LOGIC BEHIND

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1. INTRODUCTION

With the enactment of the Kyoto Protocol-COP3 in February 2005, rectified countries are expected to step-up their efforts to achieve energy saving. The sudden rise in crude oil and LNG prices has created a rapid increase in demand by users for energy saving equipment and management technology.

Given such a background, 'Fully electrified residences' is being promoted in Japan, mainly by electric power companies, where all household appliances are powered by electricity. As such, the percentage of 'Fully electrified residences' is rising every year among new housing developments. With regards to water heaters, use of electric heat pump water heaters ('Eco Cute') that use CO2 as the refrigerant is spreading rapidly. With help from government subsidies, 5.2 million Eco Cute units are due to be introduced by 2010. This is a big threat to gas companies in Japan. Moreover, Japanese Eco Cute manufacturers have made press releases regarding export of the equipment to the European market, and as such, similar threats could be imposed on European gas companies.

Verwijderd: Fully electrified residences

Verwijderd: Fully electrified residences

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Gas water heaters have achieved efficiencies up to 95% by recovering the latent heat of its exhaust gas. By combining a heat pump to pre-heat the inlet water to a gas water heater using heat in the air, there is a possibility of achieving even higher efficiencies. Toho Gas is involved in the development of a hybrid gas water heater (hereafter 'HGWH') that uses a combination of an adsorption heat pump and a gas water heater (boiler). We describe the content of the development in this paper.

Verwijderd: recovering the latent heat of its exhaust gas

Verwijderd: (hereafter "hybrid gas water heater")

2. AIM OF HGWH

Figure 1 shows the (expected) relationship between heat efficiency, output and outside temperature for gas water heaters, electric heat pumps, and the HGWH in question. Unaffected by outside temperature, the heat output and efficiency of the gas water heater (shown by thin line in Figure 1) is fairly consistent. Electric heat pump water heater (shown by dotted line) achieves heat efficiency of over 100% under high outside temperatures, even when considering the heat loss of a hot water tank. However, the heat efficiency drops as the outside temperature drops. When outside temperature reaches 5 degrees Celsius, moisture in the atmosphere forms frost on the air heat exchanger, which rapidly lowers heat transfer performance, and so a defrosting operation becomes necessary that consumes extra energy. Therefore, thermal efficiency is expected to be lower than that of the gas water heater.

Verwijderd: water heater

With the HGWH, when outside temperature is low and hot water demand is high, heating is provided mainly by combustion heat of the gas water heater. On the other hand, when outside temperature is high and hot water demand is low, heating is provided mainly by the heat pump. By taking this approach, we expect that a higher heat efficiency could be achieved averaged over the year when compared with sole operation of a gas water heater or electric heat pump water heater.

Verwijderd: when outside temperature is low and hot water demand is high, heating is provided mainly by combustion of gas water heater. On the other hand,

Verwijderd: electrical

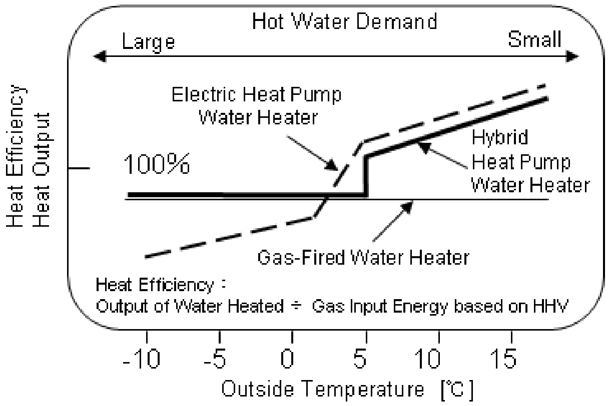

Figure 1. Expected Output and Heat Efficiency of HGWH

3. FOCUS ON THE ADSORPTION HEAT PUMP

To achieve advantages of the gas water heater such as high output, low cost and compact sizes, which have been preferred by users over the years, the supplementary heat pump must be compact and inexpensive. There are a variety of choices for heat pumps powered by gas, such as absorption type, adsorption type, and GHP. Toho Gas has focused attention on the adsorption type by considering various aspects for hot water use. (not for space heating use)

Adsorption heat pumps are driven by heat, and its output can be reduced to fairly low ranges through adjusting the amount of adsorption material being filled. Figure 2 shows a common structure of adsorption type heat pumps. The structure on the right hand side is suited for large size equipment with high outputs, where condensation and evaporation part is independently placed in a single vacuum container. Desorption and adsorption parts are switched alternatively during operation. For this type of structure, a vacuum valve and refrigerant pump are required inside the vacuum container, meaning that achieving compact size will be difficult.

The structure shown on the left hand side of Figure 2 uses two identical vacuum containers (units), where one unit is used for desorption and condensation, and the other unit used for adsorption and evaporation. In this type of structure, external fluids with differing temperatures are switched regularly to operate the adsorption cycle continuously. With this structure, there are no moving parts inside the vacuum container, and as such considerable reduction in size of vacuum container can be achieved. Also the structure is well suited to mass manufacturing, raising hope for low costs. Therefore, Toho Gas has focused attention on this type of structure.

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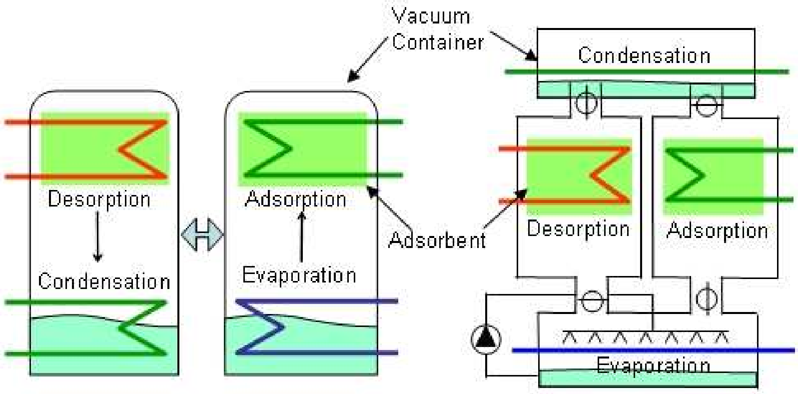

Structure Being Considered   Structure Suited to Large Size Equipment

Figure 2. Structure of Adsorption Type Heat Pumps

4. CONSTRUCTION OF HGWH

There are two basic structures for the HGWH that we suggest. The first type (all-in-one type), shown on the left hand side of Figure 3, combines a gas water heater and an adsorption type heat pump in a single package. The other type (add-on type), shown on the right hand side of Figure 3, saves energy by attaching a separate pre-heating unit to the water inlet line of the existing gas water heater. The all-in-one type contains a single combustion burner and two hot water heating circuits. One circuit is used to supply the hot water at about 70 degrees Celsius for driving heat pump; the other circuit is used for supplemental heating of the hot water that has been pre-heated by the adsorption heat pump. Above 5 degrees Celsius of outside air temperature, which is the practical operating temperature for the adsorption heat pump, water supply is pre-heated by the adsorption heat and condensation heat generated by the adsorption cycle. The supplementary heating circuit operates to attain the desired hot water temperature such as 50 degrees Celsius.

When outside temperature is below 5 degrees Celsius, the adsorption cycle is stopped, and the supplementary heating circuit starts heating the water directly to attain the desired hot water temperature. Thus, the heat efficiency of the equipment as a whole becomes highest when it can take much heat from air (high outside temperature) and when there is minimum need for supplemental heating (low hot water demand).

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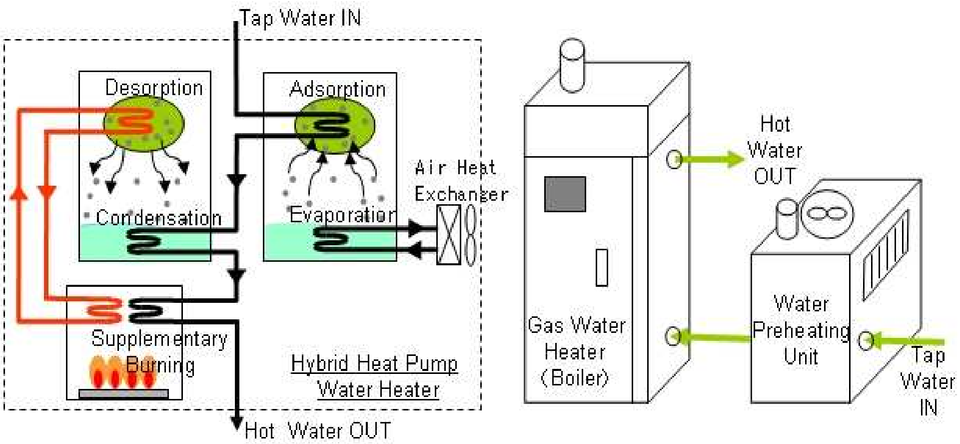

Combined Type (example) Add-on Type (example)

Figure 3. Example of HGWH Constructions

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5. CONSIDERATION OF HEAT PUMP CAPACITY RATIO

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With the HGWH, optimizing the ratio of heat pump capacity over the overall heating capacity is important when considering heat efficiency. The heat efficiency of the HGWH increases as the ratio of heat pump capacity is increased; however there are disadvantages in terms of equipment size and costs. Also, in recent years, energy efficiency over a fixed time frame is seen as more important, and thus grasping the actual hot water usage is essential from the aspect of deciding a product design. Actual hot water usage differs between household and commercial use. We have estimated the actual hot water demand for commercial use here. Results are shown in Figure 4.

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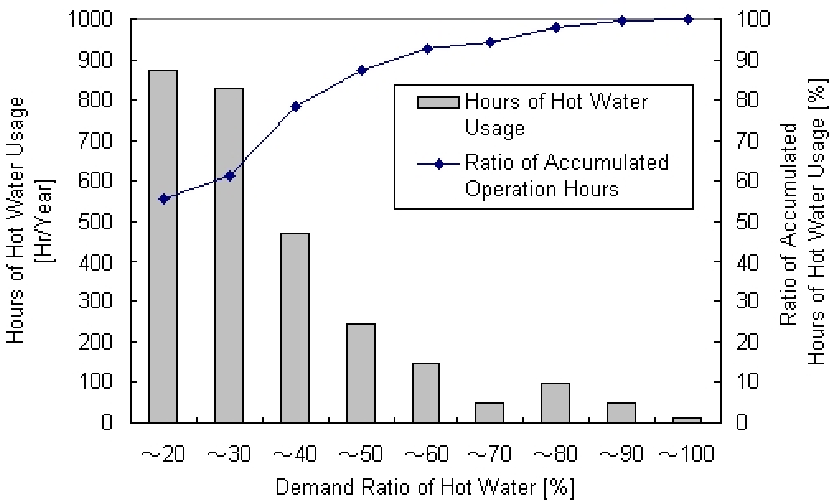

Figure 4. Distribution of Hot Water Usage Hours by Demand Ratio

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Figure 4 is based on a trial calculation for the hot water usage hour by hot water demand for commercial use. The horizontal axis shows demand ratio of hot water, and the vertical axis shows the hours of hot water usage during a year. The maximum hot water demand is set to 100%. These figures have been set based on our knowledge and experience. In general, the hot water demand for commercial use is lower in 'average annual demand ratio' and hours of hot water usage is longer when compared with household hot water use. Average annual demand ratio is defined as the expression 'annual hot water supply output [kWh] divided by both hot water usage hours [h] and maximum hot water demand [kW]'. The annual average hot water demand calculated using data from Figure 5 is approximately 30%. Thus, if the capacity [kW] of the water heater is selected at maximum hot water demand of 100%, the average operational load ratio of the water heater comes to 30%. That is the reason why the capacity of the combining heat pump is set to about 30% of the overall capacity of water heater equipment; the majority (about 60%) of the water heater demand is covered by the heat pump operation; and the combustion heating can cover the peak hot water demand. By doing so, the annual energy efficiency will be expected to exceed 100%.

6. FEASIBILITY STUDY USING A PROTOTYPE

To investigate the feasibility of a HGWH, we constructed an all-in-one type prototype in March 2005 and carried out its performance test. The prototype has a heat output of 56kW together with a single-stage adsorption heat pump cycle and a conventional gas water heater. The planed performance of the prototype is shown in Table 1, a photograph of the unit external and the flow for the prototype are shown in Figure 5.

Item	Heat Output	Heat Efficiency
Unit	kW	%
Combustion Part	56	90-95
Heat Pump Part	16	138

Table 1. Specification of Prototype

Hot water output 56kW is the sum of heat source for heat pump and supplementary heating.

The condition of heat efficiency of 138% is outside temperature of 16 degrees Celsius and water inlet temperature of 17 degrees Celsius. And heat efficiency of 138% is calculated as the multiplication of heat pump cycle efficiency and combustion heat efficiency.

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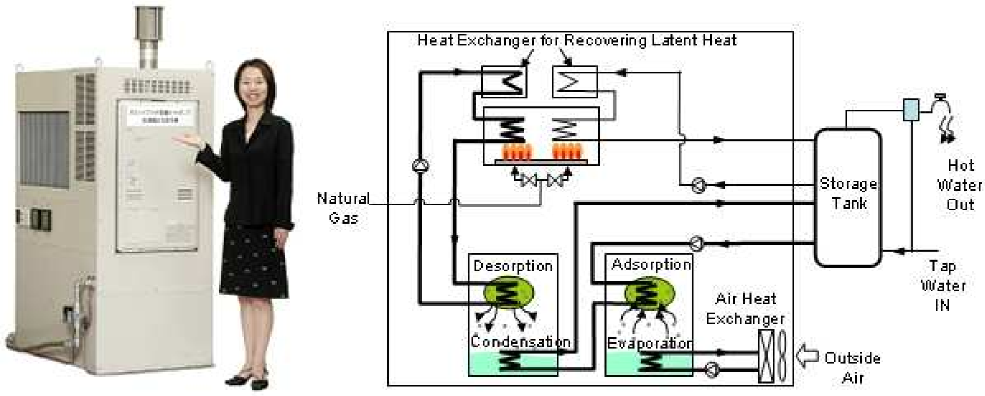

Figure 5. External Appearance And Flow of HGWH Prototype

- **Evaluation Result of The Prototype**

Table 2 shows measured performance results of adsorption heat pump part. The output of adsorption heat pump is lower than the planned output value of 16kW, but the results for heat efficiency was obtained as expected. We expect that by adjusting the amount of adsorption material, planed heat output can be achieved.

By using the measured heat efficiency of the heat pump, the heat efficiency inclusive of the supplemental heating up to 56kW can be calculated. This is shown by the dotted line in Figure 6. On the other hand, the thin line shown in Figure 6 is the demand curve for the commercial hot water use that is same as shown in Figure 4. Assuming that the annual average hot water demand ratio is approximately 30%, the annual average output of HGWH can be calculated as 16.8kW, and the average heat efficiency as 116%. Therefore, we believe that achieving annual energy efficiency above 100% is possible by using the HGWH.

Item	Heat Output	Heat Efficiency	Condition
Unit	kW	%	
Planned Value	16.0	138	Outside Temp. 16℃
Measured Value 1	11.8	137	Outside Temp. 17℃ Water Supply Temp. 18℃
Measured Value 2	13.1	141	Outside Temp. 27℃ Water Supply Temp. 25℃

Table 2. Measured Performance of Adsorption Heat Pump Part

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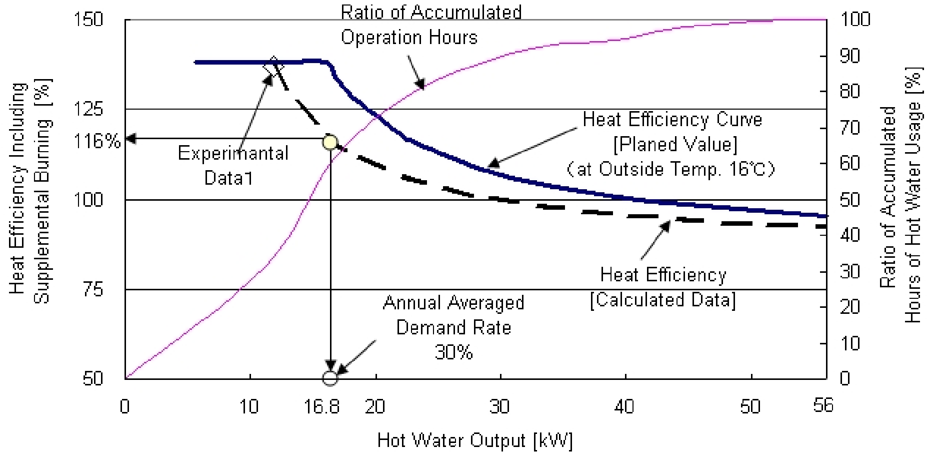

Figure 6. Expected Heat Efficiency of HGWH

Furthermore, the size of the prototype constructed turned out to be fairly compact, its dimensions are depth 1100mm, width 750mm, and height 1500mm, a figure inclusive of gas water heater, adsorption heat pump cycle, air heat exchanger, fan, pumps, electromagnetic valve, control panel etc. We compared the size of this prototype with other water heaters like a commercially available commercial-use gas water heater and commercial-use Eco Cute (electric heat pump water heater). Comparing in terms of the volume [m^3] per 1kW heat output, the prototype turned out to be approximately twice that of conventional gas water heater, but is half of that of commercial Eco Cute. This fact demonstrates the advantages of a conventional gas water heater such as its compactiveness and larger heat capacity that have contributed towards minimizing size of the prototype.

7. CONCLUSION

To improve heat efficiency of gas water heater, we made the feasibly study of a HGWH that uses a combination of an adsorption heat pump and a conventional gas water heater. By the prototype that combines a heat pump, which has 1/3 heat output of the gas water heater combined, we have shown that even with the prototype, a compact size can be achieved when compared with an commercial electric water heater 'Eco Cute'. Also, we demonstrated a big improvement in heat efficiency when compared with conventional gas water heaters as well as the possibility of competing with 'Eco Cute'.

The next step is product development in corporation with Japanese gas water heater manufacturers in the aim of marketing the HGWH in the next couple of years.

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