HEAT RECOVERY IN MULTI-GHP (GAS-DRIVEN HEAT PUMP) SYSTEM

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ABSTRACT

The heat recovery in multi heat pump system using engine as a prime mover for heating and cooling the building was investigated. The quantities of heat which can be recovered from engine was measured and analyzed depending on heat recovery devices such as the cooling jacket, manifold, and heat exchanger. In order to utilize the exhaust gas from engine properly and effectively, heat recovery system performance was also compared according to the cooling water flow direction and the types of exhaust gas heat exchanger. In this study, the 67~69 % heat recovery rate from engine wastes was obtained.

Key Words: ***waste heat recovery, exhaust gas, GHP (gas driven heat pump), heat exchanger.***

1 INTRODUCTION

In Multi-GHP system, a compressor is operated with a gas engine to conduct heating and cooling through several indoor units, whereas the conventional electric driven heat pump (EHP) uses an electric motor for compressor operation. Since the Multi-GHP system uses gas fuel, it can reduce peak electricity load during the summer. It is a highly efficient heating/cooling system with the advantage of compromising the performance decrease during the winter and in cold regions, constituting the biggest problem in EHP, by recovering heat released from the engine and the cooling heat of the engine coolant. The outdoor temperature in winter time in our nation is relatively low, so the use of heat pump with an air heat source method is limited to certain areas. GHP system with gas cooling advantages has been in the spotlight as a system with excellent cooling and heating performance even in very cold weather, so its development and import/distribution in the nation are currently active. (Kim 2003, Kim, and Seo 2003)

GHP system consists of gas engine to operate a compressor; a compressor to compress refrigerant; a condenser and an evaporator as an element of heat pump; an expansion device; a heat exchanger to recover heat released from engine gas; a circulating pump; a safety device, and control system, and so on. Among those, heat exchanger collects friction heat and gas heat generated by gas engine and converts it to useful ends. So, it should be able to perform as exhaust manifold and muffler at the same time and its corrosion resistance should be excellent as well. Particularly, pressure drop in exhaust gas is an important variable in design because it affects the engine performance directly. In this study, a heat exchanger to efficiently recover the heat of combustion gas generated from the engine gas of Multi-GHP has been developed and statistical analyses have been conducted. Several prototypes of heat recovery heat exchanger also have been developed and their performance tests have been conducted.

2 SIMULATION OF WASTE HEAT RECOVERY SYSTEM IN MULTI-GHP

As depicted in Fig. 1, normally 25~35% of total heat released from engine has been known to be used as shaft horse power, 15~20% is emitted as radiant heat and non-recoverable heat, 30% as engine coolant, and 20% as exhaust gas.(Park 2002) This means 50% of total input energy is recoverable. The temperature of exhaust gas after engine operation is about 450~600°C. In this study, to recover such exhaust gas and exhaust heat of engine coolant, the heat recovery system consisting of HX1 (exhaust manifold heat exchanger) and HX2 (exhaust gas heat exchanger) was developed as shown in Fig. 2.

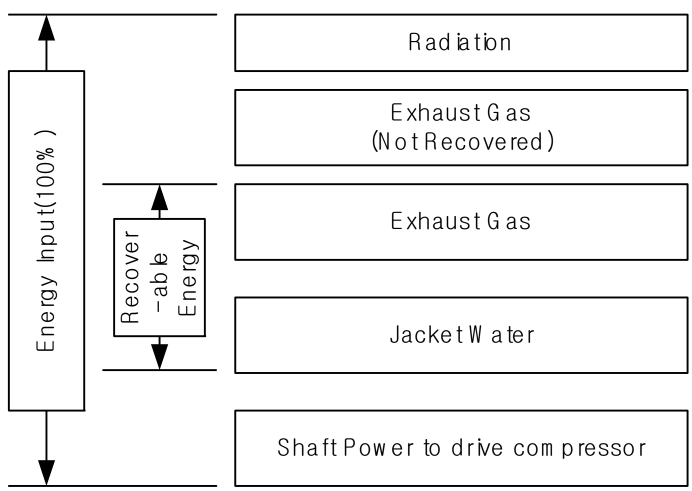

Fig. 1. Heat balance of gas engine

The performance goal of heat recovery system was the 65% recovery of 20 HP heat from gas engine and less than 700 mmAq of pressure drop in exhaust gas at the same time. For the design and construction of the heat recovery system, HX1 and HX2 could have been assembled as one body to reduce heat loss through exhaust pipes etc, but we separated them out due to space consideration, engine maintainability relating to the structural characteristics of the engine. Since exhaust manifold HX1 directly contacts about 450~600°C exhaust gas generated after the engine starts, it was particularly made to be able to tolerate high temperatures, and was constructed in shell & tube type consisting of an inner exhaust gas path connected with the exhaust pipe of the engine with four cylinders and an outer shell where coolant flows.

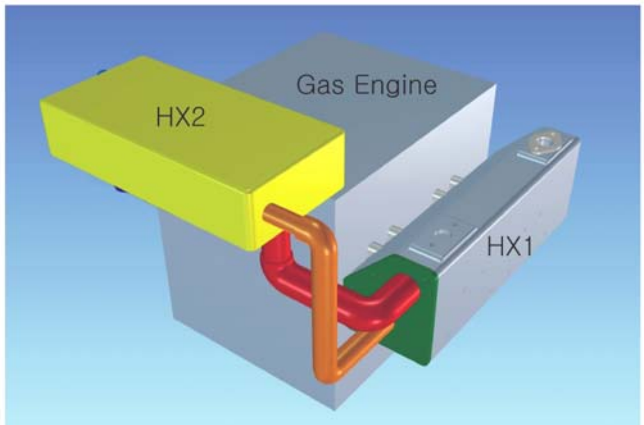

Fig. 2. Exhaust gas waste heat recovery system

Temperature gradient, velocity field, pressure field, and thermal stress on the wall of heat exchanger due to exhausted heat were analyzed using Fluent and ANSYS as shown in Fig. 3, and the analysis results were incorporated in the design. Based on statistical analysis, the pressure drop in exhaust manifold HX1 was predicted to be about 40 mmAq at 2000rpm of engine revolution and 6 Nm^3/h of fuel flow rate. Also, materials plastic behaviors were observed to reflect the characteristics of bilinear isotropic hardening, so the analysis of strain due to thermal stress was followed. The analysis result was that strain was less than about 0.002% which is safe compared to the yield pint of strain rate of about 0.2%.

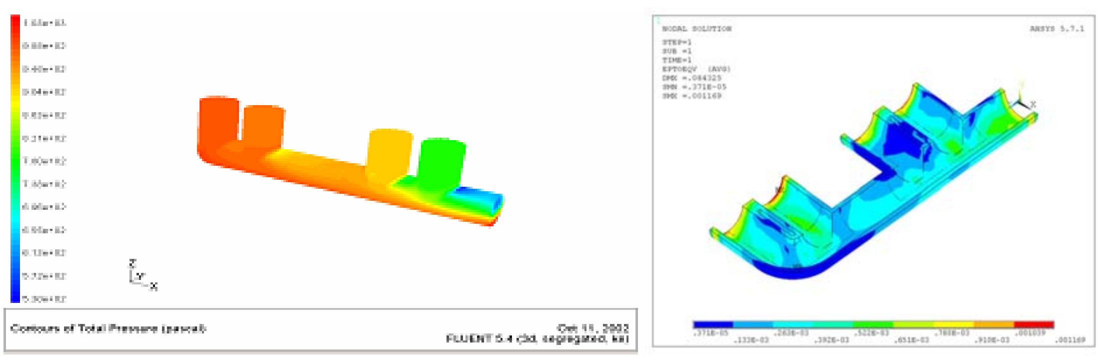

Fig. 3. Numerical simulation results for HX1

In case of the exhaust gas heat exchanger HX2, the quantity of heat transfer is much higher than HX1, so highly efficient heat exchanger is required. A brazed type plate heat exchanger, which is broadly used for refrigeration and air-conditioning, does not fit in the temperature range to be used. Specially the path is narrow and has corrugated surface to enhance heat transfer. The configuration provides a high possibility to act adversary for pressure drop in exhaust gas. With a shell & tube type heat exchanger, it is hard to obtain a large heat transfer area within a small space, therefore it is not suitable. Considering these factors, a plate & shell type heat exchanger where a plate with relatively simple corrugation and broad path, was used as exhaust gas heat exchanger HX2 in this study. At this time, since exhaust gas has acidity of about Ph 4~5, SUS316 was used in the construction because of its high acid resistance, and its sufficient durability and corrosion resistance even against incomplete combustion fuel and combustion products.

3 EXPERIMENTAL PERFORMANCE TESTS

Experimental equipments were prepared to test the heat recovery system developed as described above. Testing equipments consist of a 2.4 liter (2351cc) gas engine equipped with a LNG fuel supply system to make the same exhaust gas conditions used in the design conditions, a generator with the capacity of maximum power of 30 kW and a load bank to consume the engine power, coolant circulating loops, and a heat exchanger to rid of recovered heat, and so forth. Besides, a torque meter to measure engine power, a flow meter to measure fuel consumption, water, and four wire leads RTD (4W RTD) to measure brine temperature, a K type thermocouple to measure the temperature of exhaust gas, a magnetic flow meter to measure circulating fluid flow, a micromanometer to measure the pressure drop of exhaust gas heat exchanger HX2, etc. were installed. All the signals including power, temperature, flow, etc. were detected by HP VXI data acquisition system and appeared on a PC screen and were saved through HP VEE program. The schematic diagram of the performance testing equipments for the heat recovery system is shown in Fig. 4.

The coolant in the expansion tank goes through the flow meter and then HX2 and HX1. Then it absorbs engine heat, boils when going through the engine jacket, and then cools down exchanging heat with outer coolant. It finally flows back into the expansion tank. On the other hand, the exhaust gas of the engine goes through HX1 and then HX2, and then is released to the outside. The shaft horse power generated by engine is converted into electric energy at the generator, and then converted into heat energy at load bank released to the atmosphere.

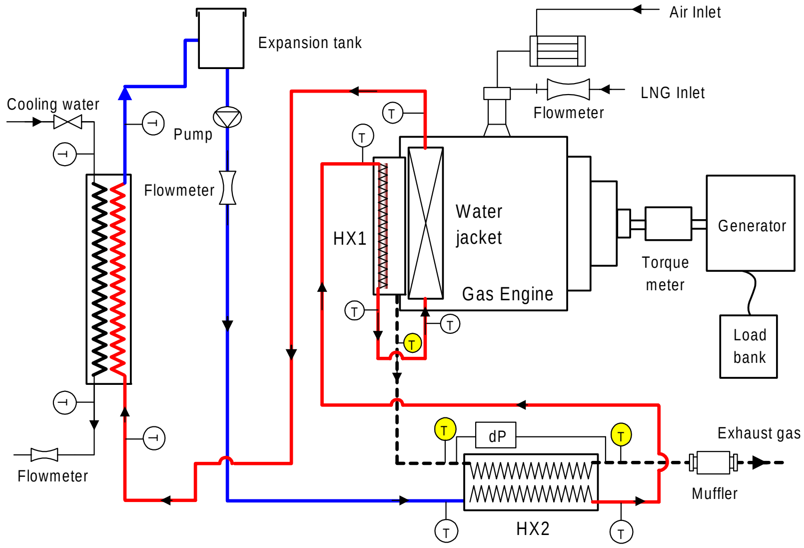

Fig. 4. Schematic diagram of an experimental apparatus

Performance tests were conducted by developing one starting product of exhaust manifold heat exchanger HX1 and several prototypes of an exhaust gas heat exchanger HX2. Tests with using Japanese A company's HX2 also accompanied for performance comparison. The factors that effect heat recovery performance includes engine revolution, load factor, coolant opening temperature, coolant flow, the size and shape of HX2, and so on. In this study, an analysis was conducted on performance change according to load factor change and HX2 change. The common testing condition for all cases was 1830 RPM of engine revolution, 65°C of coolant inlet temperature, 0.65 kg/s of coolant flow, , which were the design operation conditions.

4 RESULTS

Fig. 5 depicts the test results of heat recovery performance according to engine load factor change using Japanese A HX2. The ratio of total heat recovery (Q_{jacket}+Q_{HX1}+Q_{HX2}) to total input energy is 54.7% when the engine efficiency is low, and 49% with high engine efficiency. The efficiency of heat recovery, defined as equation (1), was 63.7% when the engine efficiency was high, and 59.9% with low engine efficiency. This is because engine efficiency decreases as engine load factor decreases and consequently a relatively high rate of heat occurs. Particularly, heat loss changes according to engine load factor, but the range of change is relatively small; the rate of heat loss rapidly increases as engine load factor decreases.

$$\eta_{recovery} = \frac{Q_{jacket} + Q_{HX1} + Q_{HX2}}{Q_{input} - Power} \qquad (1)$$

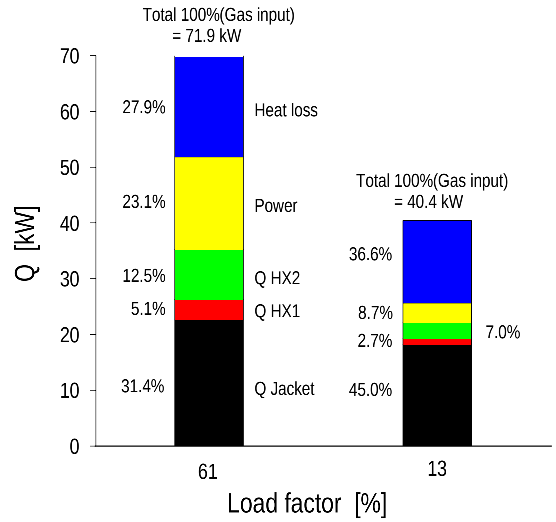

Fig. 5. Waste heat recovery variations

Table 1. System comparison between developed HX2 and Japanese one

	Japan A Co.	KIER 10 plates	KIER 15 plates
$T_{gas,jacket,out}$ [°C]	624	616	622
$T_{gas,HX1,out}$ [°C]	574	550	563
$T_{gas,HX2,out}$ [°C]	151	66	66
$T_{coolant,HX2,in}$ [°C]	65.0	65.0	65.0
$T_{coolant,jacket,out}$ [°C]	80.5	80.8	80.9
Load factor [%]	61.1	61.2	61.6
Dimension [mm]	φ170×L500	390×195×40	390×195×55
Weight [kg]	11.6	8.5	11.8

Table 1 presents the results of heat recovery performance test using the two manufactured HX2 prototypes in comparison to the test results with Japanese A HX2. The temperature of exhaust gas from the engine jacket reached proximately 610~620°C, and cooled down to 550~570°C going through HX1. The temperature of exhaust gas after going through HX2 was approximately 150°C using Japanese A HX2, whereas it was 70°C using both HX2 prototypes. It is assumed that the Japanese A HX2, a heat exchanger of shell & tube type, does not have a large heat transfer area compared to its size. Figures 6~8 show the comparisons of pressure loss, fuel consumption, and heat recovery efficiency at each HX2. When using prototype HX2 developed in this study, the pressure loss and fuel consumption were lower and the heat recovery efficiency was higher than when using Japanese A HX2. In case of starting product HX2, even with 10 plates, the final temperature of exhaust gas reached 70°C and the heat recovery efficiency was higher than 65%. Thus, it turned out to display a thermally satisfactory performance.

Concerning pressure drop, however, it did not show any improvement compared to Japanese A HX2, so HX2 with 15 plates is considered to be a better fit to Multi-GHP system.

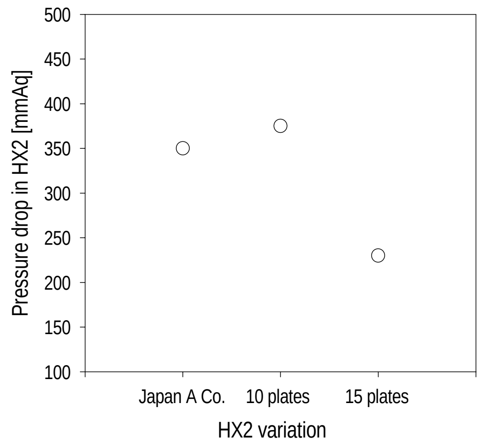

Fig. 6. Pressure drop in HX2 variations according to number of plate variations of HX2

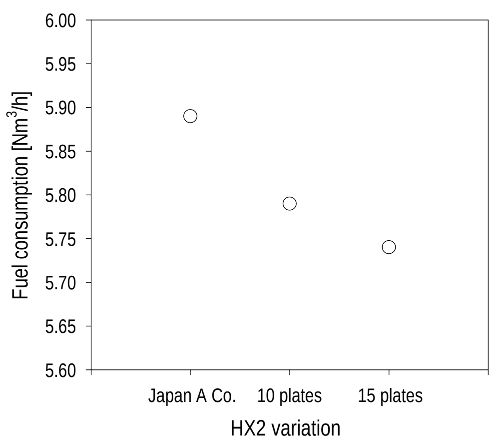

Fig. 7. Fuel consumption variations according to number of plate variations of HX2

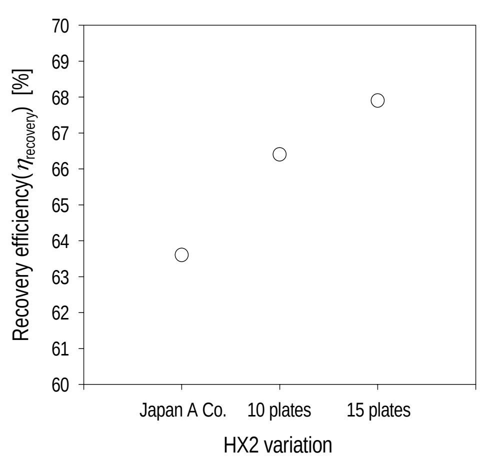

Fig. 8. Recovery efficiency variations according to number of plate variations of HX2

5 CONCLUSIONS

In this study, several prototypes were developed and performance tests were conducted to develop the heat recovery system for Multi-GHP. The following conclusions have been obtained.

1. The unrecoverable heat occurred similarly regardless of change of engine load factor. Due to the decrease of power consumption, a relatively high rate of exhaust heat occurs and consequently heat loss rate increases. For the same heat recovery system, the higher the engine efficiency, the better the heat recovery efficiency. Therefore, engine efficiency needs to be improved for the performance improvement of GHP system.

2. According to the test results under the design operation conditions, approximately 66~68% of the heat from the gas engine can be recovered from the heat recovery system of engine exhaust gas that has been developed in this study. The pressure drop of the exhaust gas heat exchanger was about 230 mmAq. Therefore, it appears to have an excellent performance compared to the conventional imported engine exhaust gas heat recovery system.

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