APPLICATION STUDY OF GAS ENGINE DRIVEN HEAT PUMP TO HEATING EQUIPMENTS FOR COLD CLIMATE

Takeshi Yokoyama, Senior Manager, Solution Technology Dept. Tokyo Gas co., LTD., 1-5-20,Kaigan,Minato-ku,Tokyo,Japan
Takashi Murakami, Manager, Solution Technology Dept. Tokyo Gas co., LTD., 1-5-20,Kaigan,Minato-ku,Tokyo,Japan
Yuma Furuhashi, Engineer, Solution Technology Dept. Tokyo Gas co., LTD., 1-5-20,Kaigan,Minato-ku,Tokyo,Japan

Abstract: This study was conducted to research characteristics and merits of gas engine driven heat pump (GHP) as heating equipments for cold climate. While its cooling cycle is just the same as electric heat pump (EHP), its heating cycle is quiet unique. GHP utilizes not only aerothermal heat from ambient air but also waste heat from gas engine, resulting in high performance at low ambient temperature. From technical data, EHP for cold climate cannot keep its capacity at low ambient temperature even though it uses the special systems such as liquid injection and two stage compression. However, GHP maintains its capacity due to utilization of waste heat. About 20,000 units have been installed so far in Hokkaido which is as cold as major metropolitan cities in high latitude such as Stockholm, Helsinki, Moscow and Chicago, where outdoor temperature reaches less than -20 degree of Celsius. Even in Hokkaido, GHP is used with good performance without any back-up heaters. GHP has a possibility to be a suitable heating system in most of the cold region throughout the world.

Key Words: heat pump, gas engine, waste heat, aerothermal heat

1 INTRODUCTION

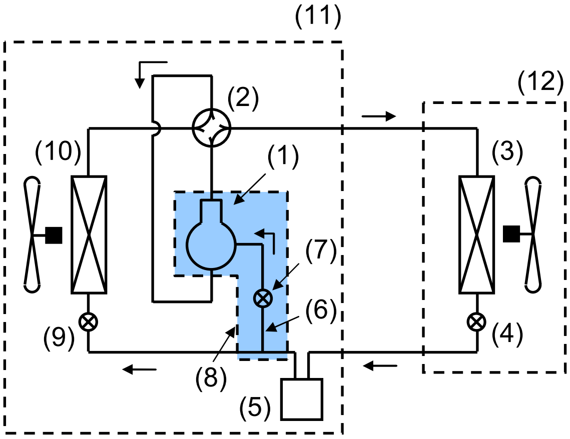
Formerly, furnaces and boilers are mainly used as heating equipments, and efficiency of these equipments cannot reach 100%. In contrast, COP of the EHP improves considerably that its efficiency on primary energy base exceeds 100%. However, the EHP has some defects that its efficiency and capacity decrease when the ambient temperature gets below zero degree of Celsius, due to frosting at the outdoor air heat exchanger and consequently decrease of evaporator temperature. To improve efficiency and capacity at low ambient temperature, recently the EHP for cold climate that uses special systems such as liquid injection and two stage compression is commercialized. But it still cannot keep its capacity when ambient temperature drops below about -10 degree of Celsius.

2 OPERATING CYCLE AND PERFORMANCE OF THE EHP FOR COLD CLIMATE

Recently, liquid injection and two stage compression systems are used to improve performance of the EHP at low ambient temperature. These systems work in the way as explained bellow.

2.1 Liquid Injection System

This system is consisted of a liquid injection line and a flow control valve as shown in Figure 1. In heating mode, a part of refrigerant liquid condensed at the indoor unit is injected to the intermediate room of the compressor through the flow control valve. It results in an increase of discharge flow rate and a decrease of discharge temperature. The former increases heating capacity, in addition, the latter enables it to raise rotation frequency of the compressor that also increases heating capacity.

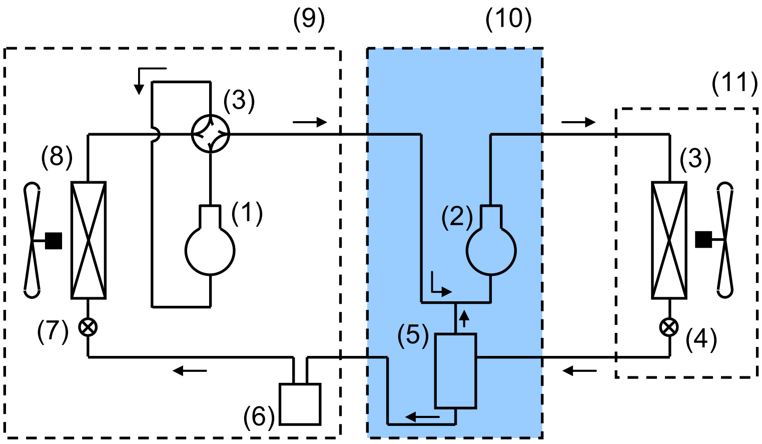


(1)Compressor, (2)Four-way valve, (3)Indoor heat exchanger, (4)Indoor expansion valve, (5)Receiver, (6)Injection line, (7)Flow control valve, (8)Injection system, (9)Outdoor expansion valve, (10)Outdoor heat exchanger, (11)Outdoor unit, (12)Indoor unit

Figure 1 Schematics of refrigerant of liquid injection system

2.2 Two Stage Compression Technology

This system is consisted of an outdoor unit of normal EHP and an additional unit that have a compressor and a gas liquid separator as shown in Figure 2. The second compressor located in the additional unit is designed to provide higher pressure resulting in a higher heating capacity under low ambient temperature. Refrigerant condensed at indoor unit is separated into gas and liquid at the gas liquid separator. As a result, refrigerant flow rate transmitted to the indoor unit is increased so that heating capacity increases.

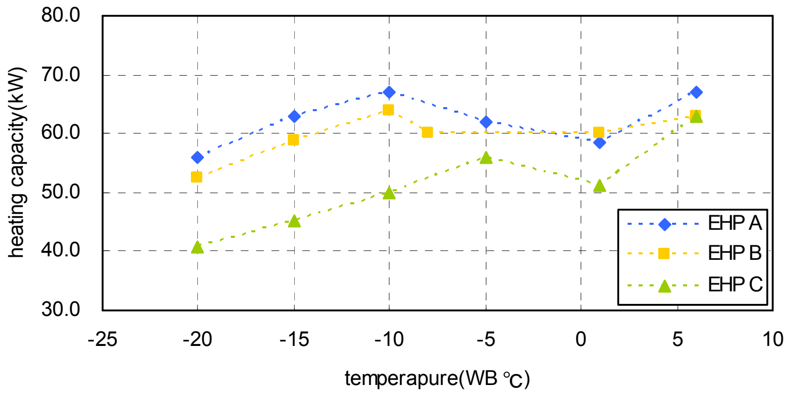


(1)Compressor, (2)Second compressor, (3)Indoor heat exchanger, (4)Indoor expansion valve, (5)Gas liquid separator, (6)Receiver, (7)Outdoor expansion valve, (8)Outdoor heat exchanger, (9)Outdoor unit, (10)Additional unit, (11)Indoor unit

Figure 2 Schematics of refrigerant of two stage compression system

2.3 Performance of the EHP For Cold Climate In Heating Mode

Figure 3 shows the heating capacity of EHPs for cold climate (A, B: liquid injection, C: two stage compression) described in technical data provided by the manufactures. These EHPs for cold climate cannot keep their capacity when ambient temperature drops bellow -10 degree of Celsius even though it uses the special systems such as liquid injection and two stage compression.



A: Liquid injection, B: Liquid injection, C: two stage compression

Figure 3 Performance of the EHPs for cold climate (20HP)

3 OPERATING CYCLE AND PERFORMANCE OF THE GHP

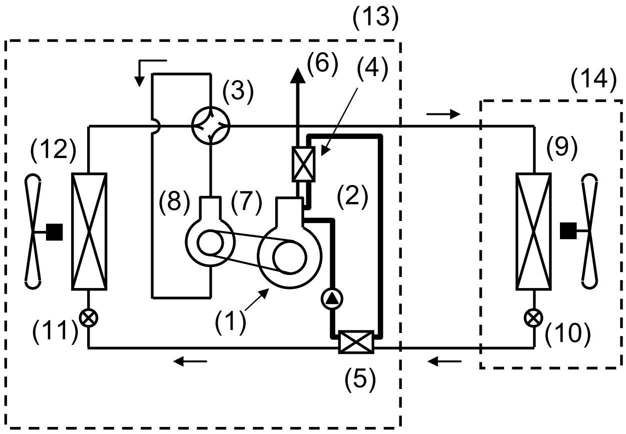
3.1 Outline of the GHP Operating Cycle

In cooling mode, air-conditioning cycle of the GHP is almost the same as that of the EHP. The only difference is that the EHP operates an electric motor to drive a compressor, while the GHP operates a gas engine instead of the motor.

However, in heating mode, the cycle of the GHP and its performance (COP and capacity) is quiet different from those of the EHP, so that the defects of the EHP, lower COP and decrease in capacity at low ambient temperature as described above, can be solved.

The GHP utilizes not only aerothermal heat from ambient air but also waste heat from gas engine as shown in Figure 4 and 5. As the amount of heat absorbed at the outdoor heat exchanger is smaller than that of the EHP, evaporator temperature can be higher, and thus, refrigerating cycle COP increases.

As for the GHP, evaporator temperature is almost independent of the ambient temperature. If the ambient temperature decreases, the amount of heat absorbed from the ambient air at the outdoor heat exchanger also decreases, while engine speed will increase and waste heat from the engine will increase and the heating capacity is maintained. If the ambient temperature decreases below evaporator temperature, the outdoor fan of the GHP will stop and refrigerant liquid will evaporate only by the waste heat from the engine. In this case, refrigerating cycle can be independent of the ambient temperature, thus the evaporator temperature and the heating capacity almost maintain.



(1)Engine, (2)Cooling water line, (3)Four-way valve, (4)Exhaust gas heat exchanger, (5)Water-refrigerant heat exchanger, (6)Exhaust gas line, (7)Transmission, (8)Compressor, (9)Indoor unit heat exchanger, (10)indoor unit expansion valve, (11)Outdoor unit expansion valve, (12)Outdoor unit heat exchanger, (13)Outdoor unit, (14)Indoor unit

Figure 4 Schematics of refrigerant and cooling water flow diagram of a typical GHP in heating mode

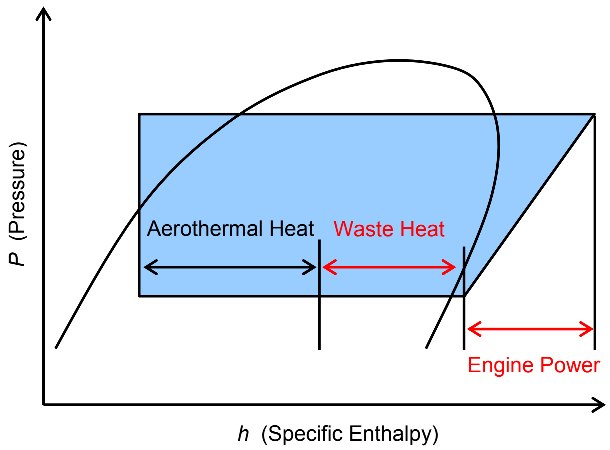


Figure 5 P-h Chart of the GHP at heating mod

3.2 Performance of the GHP in Heating Mode

Figure 6 shows the capacity of GHPs at low ambient temperature described in technical data. Unlike the capacity of EHPs as shown in Figure 3, their capacity doesn't decrease when ambient temperature drops bellow less than -10 degree of Celsius. It is because of utilization of waste heat.

Figure 7 shows the result of the performance test of the GHP (20HP) at the Tokyo Gas laboratories. The GHP keeps more than rated capacity (110%) and high COP(more than 0.9) without defrosting even at -5℃.

In heating mode, the GHP shows higher performance than the EHP for the cold climate at low ambient temperature without any special systems such as liquid injection and two stage compression.

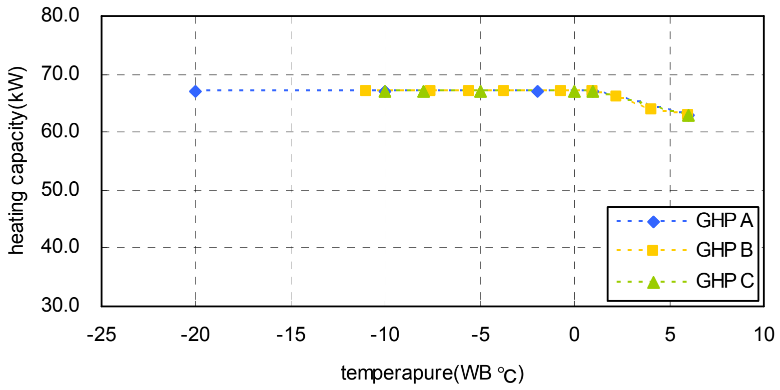


Figure 6 Performance of the GHP (20HP)

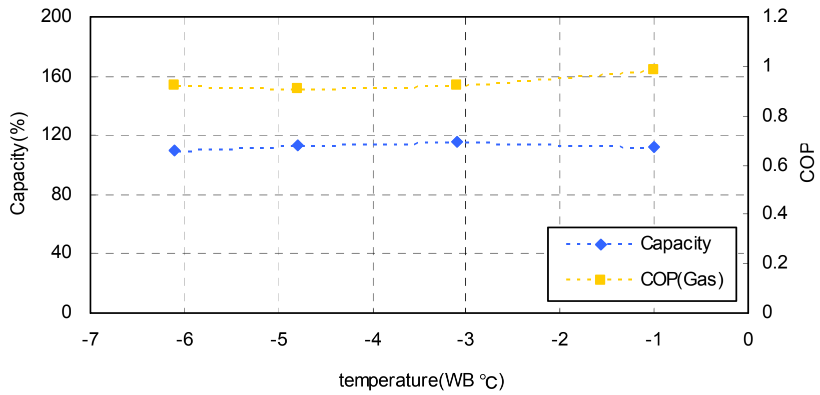


Figure 7 Results of the performance test of the GHP (20HP) at the Tokyo Gas psychrometric chamber

4 THE GHP AS THE OPTIMUM HEATING EQUIPMENT FOR COLD CLIMATE

In the island of Hokkaido, northern end of Japan, it is as cold as major metropolitan cities in high latitude such as Stockholm, Helsinki, Moscow and Chicago, where outdoor temperature reaches less than -20 degree of Celsius (See Figure 8).

Figure 9 shows GHPs installed at Hokkaido. GHPs are covered with snow, but the outdoor heat exchangers do not frost ! Even in Asahikawa in Hokkaido, the GHP is used with good performance without any back-up heaters. Figure 9 shows number of units having sold in Hokkaido. About 20,000 units have been sold in Hokkaido so far.

These things prove the GHP has a possibility to be a most efficient and cost effective system in cold climate because of its heat pump operation and no back-up requirement.

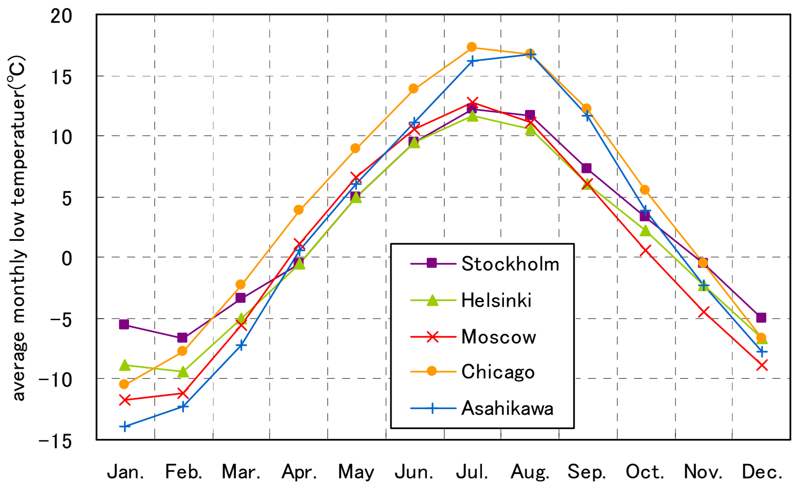


Figure 8 Average monthly low temperature at major cities in cold regions

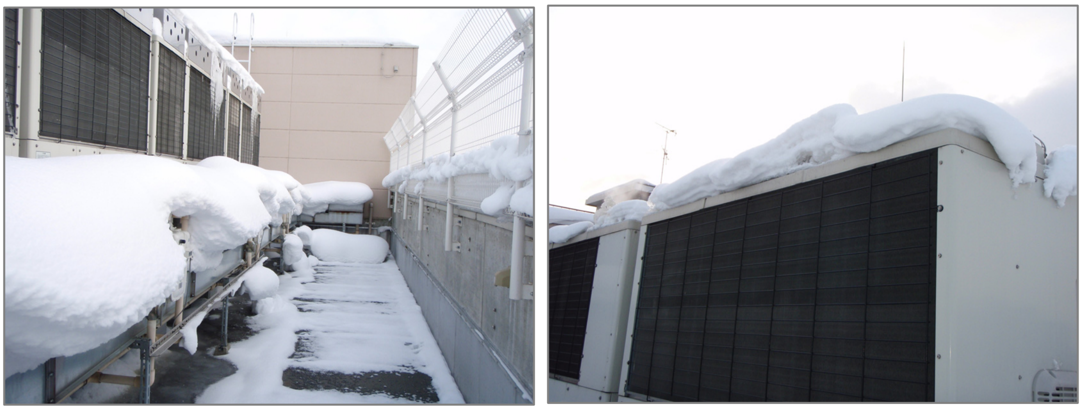


Figure 9 Photo of the GHPs at Hokkaido

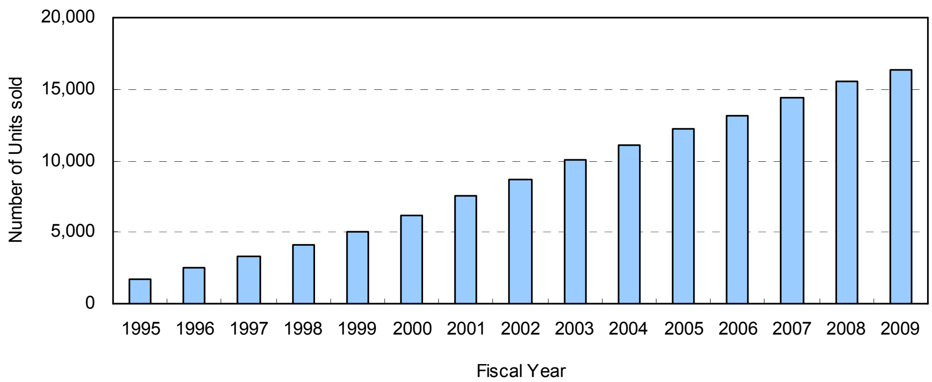


Figure 10 Number of units sold in Hokkaido

5 CONCLUSIONS

Characteristics and performance of the EHP for cold climate and the GHP in heating operation is described. The EHP for cold climate cannot keep its heating capacity at low ambient temperature even though it uses the special systems such as liquid injection and two stage compression, while the GHP maintains its heating capacity without any special systems when ambient temperature drops due to utilization of waste heat. In addition, because of its high performance at low temperature, a back-up heater is not required. The GHP has been used with good operation for many years in cold region in Japan, where outdoor temperature reaches less than -20 degree of Celsius. The GHP must be a suitable heating equipment in most of the cold region throughout the world.

6 REFERENCES

Kenichi Nakamura 2007. “High Heating Capacity Packaged Air Conditioners Liquid Injection Cycle,” *Refrigeration*, 82(952), p. 124-128.