CALORIMETRY OF GROUND SOURCE HEAT PUMP USING DIRECT EXPANSION METHOD －MEASUREMENT OF FLOW RATE USING PIV METHOD－

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ABSTRACT

The GSHP that use a direct expansion method is expected to have higher performance of energy-saving than the conventional type of the GSHP. We evaluated the quantity of heat by measuring temperature, humidity and flow rate at the indoor unit of the GSHP system. The purpose of this study was to improve the accuracy of the flow rate measured by hot wire anemometers using PIV method. The average of difference between the flow rate obtained by the hot wire anemometers and the PIV method was 23.6% in the heating operation and was 24.0% in the cooling operation. We obtained the compensation formula which corrects the result of the hot wire anemometers using the results of PIV method. The average of difference between the compensated flow rate by the hot wire anemometers and the flow rate by the PIV method was reduced to 5.2% in the heating operation and 1.9% in the cooling operation. The compensation formula is used performance evaluation of the GSHP system. The COP obtained by conventional method was 3.4 in the heating operation. The compensated COP was 2.8.

INTRODUCTION

Recently, ground source attracts attention as renewable natural energy. The underground temperature is stable throughout a year and is lower than the air temperature in summer and higher than that in winter. [1] Thus, a ground source heat pump (GSHP) has superior performance of energy-saving.

A GSHP that uses an indirect heat exchange method has already been commercialized so far. In the conventional type of the GSHP, water or antifreeze are used as a heat exchange medium flowing into the underground. The depth of a borehole is about 100 m. This system does not spread widely in Japan, because initial investment cost (particularly, excavation cost of borehole) is high. [2]

On the other hand, the other type of the GSHP that use a direct expansion method is expected to have higher performance of energy-saving than the conventional type of the GSHP. The GSHP using direct expansion method uses a copper tube in which the refrigerant flows through between the indoor unit and the underground heat exchanger. This system performs direct heat exchange with underground. Therefore, the depth of a borehole can be less than 100m. It is difficult to obtain the amount of heat exchanged of the GSHP using the direct expansion method because the state of refrigerant in the copper tube is not stable. [3]

We evaluated the quantity of heat by measuring the enthalpy difference of air at the indoor unit of the GSHP system using direct expansion method. The enthalpy was obtained by measuring temperature, flow rate and humidity at the inlet and outlet of the indoor unit. Four units of hot wire anemometers were used for flow rate measurement. [4] However, as the distribution of the flow velocity in the outlet of the indoor unit was not uniform, it was difficult to obtain the average flow rate from only 4 points of velocity.

This paper describes the improvement to the accuracy of the flow rate using the PIV method. The PIV method has higher accuracy than hot wire anemometers in measuring flow rate. The result of measuring the flow rate by PIV method compensates for the flow rate measured by the hot wire anemometers.

EXPERIMENT

Experimental Apparatus

Figure 1 shows a schematic diagram (heating operation) of the experimental apparatus, which is GSHP system using a direct expansion method set up at University of Yamanashi. The GSHP system consists of the heat pump that the air/refrigerant heat exchanger replaced by the borehole-type underground heat exchanger made by copper tubes. The four way valve changes the circulating direction of a refrigerant when operation mode is changed. The underground heat exchanger is two long pipes connected by a U-shaped fitting at the bottom of a hole bored. The size of a borehole is 165.2 mm in diameter and 30m in depth. 10.0kg of R410A was used as a refrigerant and was mixed with compressor oil. Power of the indoor unit is 2.8kW in the cooling operation / 4.0kW in the heating operation. Heat transfer area of air conditioner is 17.4 m^2.

As Figure 2 shows, a rectangular duct is set at the outlet of the indoor unit. Cross sectional area of air in outlet of the duct is 0.0495m^2. Two thermometers (Pt100: class A), two hygrometers, and four hot wire anemometers are set to the indoor unit. Temperature and humidity are measured at inlet and outlet of the indoor unit. Flow velocity is measured at outlet the duct.

We used the smoke generator and the diode laser (532nm, 1000mW) for visualization of air flow. The smoke generator supplies smoke with inlet of indoor unite. The diode laser visualizes particle of smoke at outlet of indoor unite. The high speed camera (1000fps, 640x480 pixels) takes pictures of visualized particles. The diode laser and the high speed camera set on the traversing device. The position of the diode laser and the high speed camera are traversed automatically. The flow velocity was measured by PIV and its analytical algorism is direct cross-correlation method.

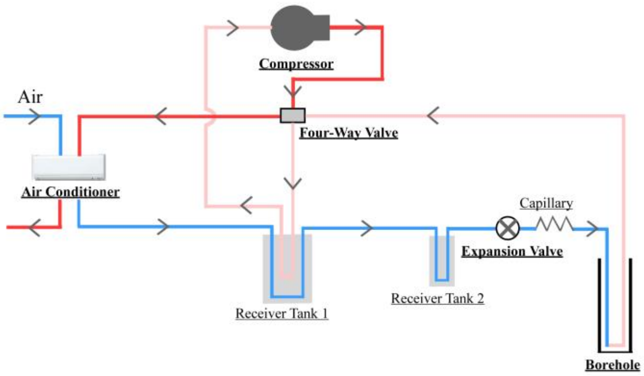

Figure 1 GSHP system using direct expansion method (heating operation)

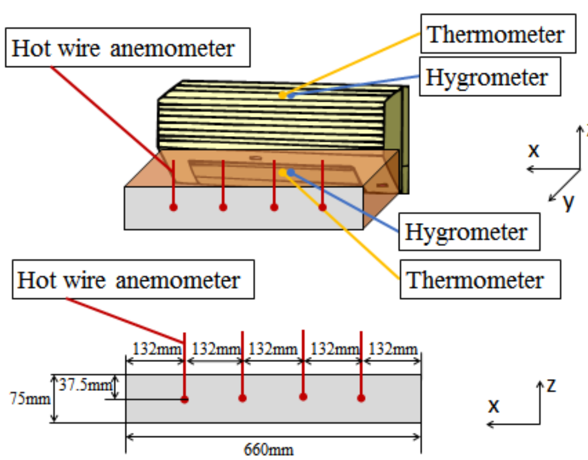

Figure 2 Measurement system using anemometers

Experimental Procedure

We used Coefficient of Performance (COP) for performance evaluation of GSHP using direct expansion method. COP can be calculated as follows,

$$COP=Q/W=\Delta h\times\rho\times A\times v/W=\Delta h\times\rho\times V/W \quad (1)$$

In here, Q: quantity of heat [kW], W: power consumption of the compressor, Δh: specific enthalpy at inlet and outlet of indoor unite [kJ/kg], ρ: air density [kg/m^3], A: cross sectional area of air in outlet of the duct [m^2], v: flow velocity [m/s], V: flow rate [m^3/s], respectively.

The flow velocity in the outlet of the duct at the indoor unit is always measured by four hot wire anemometers. The average of four hot wire anemometers was used as measurement value.

As Figure 3 shows, the PIV method measures the flow velocity of entire outlet of the duct at the same time as measuring by hot wire anemometers. Experimental Procedures of the PIV method was carried out as follows.

1, The smoke generator supplies smoke with inlet of indoor unit. The smoke comes out of the outlet duct.

2, The diode laser visualizes particle of smoke at outlet of the duct.

3, The high speed camera takes pictures of visualized particle.

4, The diode laser and the camera are traversed to the end of the duct.

5, The analytical software analyzes particle pictures. The flow velocity distribution is analyzed.

The experimental condition is shown Table 1. The temperature in the cooling operation is set to 23°C. The temperature in the heating operation is set to 24°C. The stable flow velocity is obtained in high load operation.

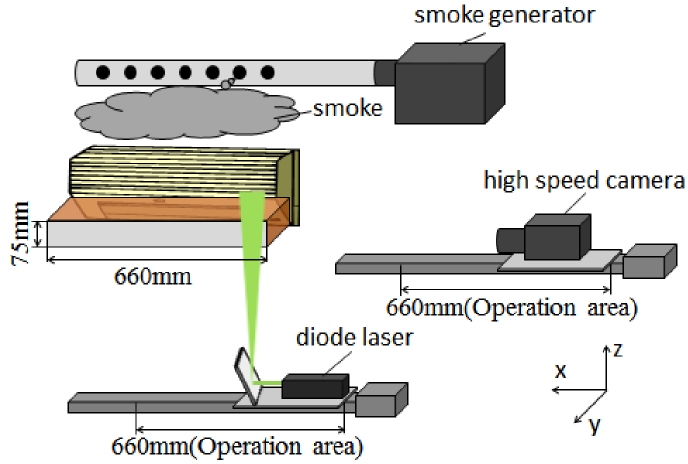

Figure 3 Measuring system using PIV method

Table 1 Experimental conditions

Condition of the PIV Method	
Frame rate of camera [fps]	1000
Traversing speed [mm/s]	100
Traversing distance [mm]	660
Condition of the Indoor Unit	
The number of wind velocity	1(min) , 2 , 3 , 4(max)
Setting temperature in the heating operation [°C]	24
Setting temperature in the cooling operation [°C]	23

RESULTS AND DISCUSSIONS

Measurement Difference of PIV Method and Anemometers

Figure 4 and 5 show the results of the experiments in heating operation and in cooling operation. The flow rate by the anemometers was measured higher than the flow rate by the PIV method in all settings. These flow rates are shown Table 2. The maximum difference flow rate between hot wire anemometers and PIV was 36.2% in heating operation and that was 27.4% in cooling operation. The average of the differences between the flow rate by the anemometers and the flow rate by the PIV method was 23.6% in heating operation and was 24.0% in cooling operation.

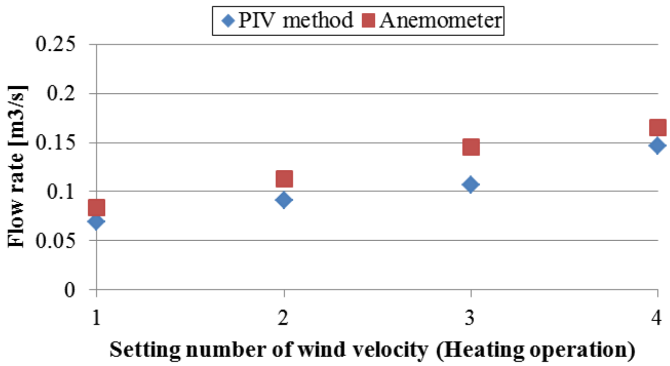

Figure 4 Flow rates measured by hot wire anemometers and PIV
(Heating operation)

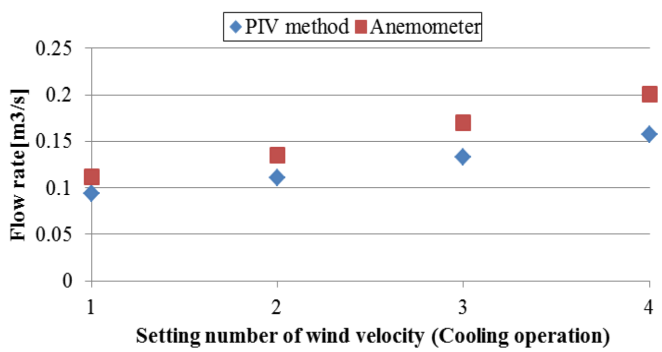

Figure 5 Flow rates measured by hot wire anemometers and PIV (Cooling operation)

Table 2 Flow rates measured by PIV and hot wire anemometers

Operation mode	Setting of wind velocity	Flow rate by PIV [m^3/s]	Flow rate by hot wire anemometers [m^3/s]	Difference between PIV and hot wire anemometers [%]
Heating	1	0.0690	0.0842	21.9
	2	0.0911	0.1129	23.9
	3	0.1065	0.1450	36.2
	4	0.1469	0.1653	12.5
Cooling	1	0.0937	0.1119	19.4
	2	0.1107	0.1351	22.0
	3	0.1334	0.1698	27.3
	4	0.1574	0.2005	27.4

Compensation Formula

The PIV method has high accuracy than the anemometers in measuring flow rate, because the PIV method can measure the flow velocity at the entire outlet of the duct. Thus, we compensated the flow rate by anemometers using the results of the PIV method. Figure 6 indicates the relationship of flow rate between hot wire anemometers and PIV. The compensation formula was obtained by least square method.

$$V' = -0.2143V^2 + 0.8401V \quad (2)$$

In here, V': the compensated flow rate by the anemometers, V: flow rate by the anemometers, respectively.

This compensation formula was used in all conditions. The anemometers can measure the more accurate flow rate by using the compensation formula. Therefore, we can measure the flow rate of indoor unit for a long time and high accuracy.

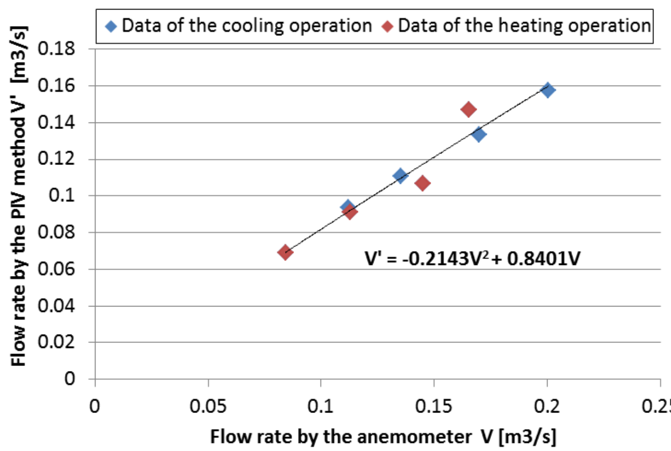

Figure 6 Compensation formula of flow rate

Comparing the Compensated Flow Rate and the Flow Rate by the PIV Method

Results of the compensation of flow rate by the anemometers are shown in Table 3. The maximum difference between the compensated flow rate and the flow rate by the PIV method was 10.2% in heating operation and that was 2.6% in cooling operation. The average of the differences between the compensated flow rate and the flow rate by the PIV method was 5.2% in heating operation and that was 1.9% in cooling operation. The compensated flow rate is nearly the flow rate by the PIV method. This indicates to obtain measuring accuracy of the same level as the PIV method, even if only the hot wire anemometers measure the flow rate.

Table 3 Flow rates applied compensation

Operation mode	Setting of wind velocity	Flow rate by PIV [m^3/s]	Compensated flow rate [m^3/s]	Difference between PIV and compensated flow rate [%]
Heating	1	0.0690	0.0692	0.2
	2	0.0911	0.0921	1.1
	3	0.1065	0.1173	10.2
	4	0.1469	0.1330	9.4
Cooling	1	0.0937	0.0913	2.6
	2	0.1107	0.1096	1.0
	3	0.1334	0.1365	2.3
	4	0.1574	0.1598	1.6

Performance Evaluation for GSHP system with direct expansion method using the Flow Rate Compensation

The COP is calculated by eq. (1). When calculating the COP by the compensation formula, the compensated flow rate was used.

$$\text{The compensated COP} = \Delta h \times \rho \times V'/W \tag{3}$$

Figure 7 shows the heat exchange rate which air accepts from working fluid at the indoor unit, power consumption of compressor and COP, in heating operation. Preset temperature of the indoor unit is 20°C. The stable data was obtained for 2 hour later from the start of operation. The output power was about 3kW. The power consumption was about 1kW. Figure 8 shows the difference between the COP and the compensated COP. The average of the COP was 3.4. The average of the compensated COP was 2.8.

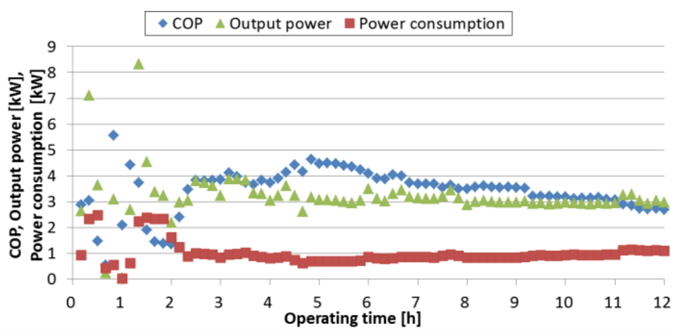

Fig 7 COP on heating operation (February 2, 2016)

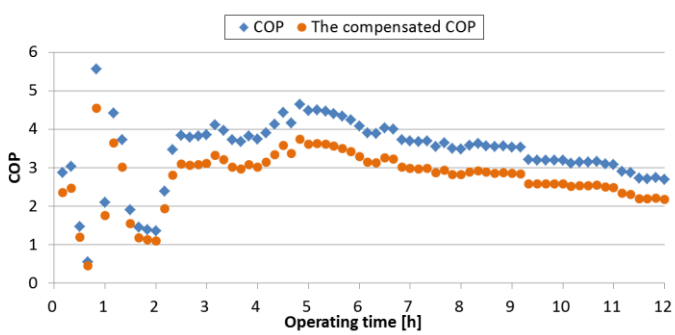

Fig 8 Difference between COP and compensated COP

CONCLUSION

The experiment for the flow rate measurement of the indoor unit was carried out. Results are concluded as follows.

1. The average of the differences of flow rate between hot wire anemometers and PIV method was 23.6% in the heating operation and that was 24.0% in the cooling operation.

2. The compensation formula was $V' = -0.2143V^2 + 0.8401V$.

3. The average of the differences between the compensated flow rate and the flow rate by the PIV method was 5.2% in heating operation and was 1.9% in cooling operation.

4. The COP by the anemometers was 3.4 in the heating operation. The compensated COP was 2.8.

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