CALORIMETRY OF HEAT PUMP SYSTEM USING ULTRA-FINE FLUORESCENT WIRES AND PIV

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ABSTRACT

To understand transport phenomena of heat and fluid flow in various fields of engineering, it is essential to develop experimental methods for measuring the temperature field in a fluid flow. The two-color laser-induced fluorescence (LIF) technique is suitable for performing temperature measurements of water flow. This technique eliminates the influence of laser intensity fluctuations observed in the single-color LIF technique, which is a significant source of error in temperature measurement. However, the two-color LIF technique has not been applied to air flow. Although this problem was solved by developing a technique for spraying fluorescent dye mists, steadily maintaining the non-uniform diameter of the tracer particles of a fluorescent mist, which is thought to influence the evaluated temperature, has been difficult because the mist consistently descends and mixes with the surrounding flows. In this study, we propose a temperature measurement method that uses ultra-fine fluorescent wires to reduce the wire diameter to much less than that of a thermocouple. This is possible because its structure is simple, and any material can be used for the wire. Hence, ultra-fine wires whose Reynolds number is less than 1.0 can be selected. This means that turbulent flow is not generated downstream of the wire and that its wake is negligibly small. Furthermore, the number of wires decreases because a line profile of temperature can be measured using only one wire.

INTRODUCTION

To understand transport phenomena of heat and fluid flow in various fields of engineering, it is essential to develop experimental methods for measuring the temperature field in a fluid flow. The two-color laser-induced fluorescence (LIF) technique is suitable for performing temperature measurements of water flow. This technique eliminates the influence of laser intensity fluctuations observed in the single-color LIF technique, which is a significant source of error in temperature measurement [1-2]. However, the two-color LIF technique has not been applied to air flow. The reason for this is that although fluorescent dyes can be dissolved in water mist, visualizing the air flow successfully has been difficult because the mist vaporizes easily and dissipates immediately. Although this problem was solved by developing a technique for spraying fluorescent dye mists [3], steadily maintaining the non-uniform diameter of the tracer particles of a fluorescent mist, which is thought to influence the evaluated temperature, has been difficult because the mist consistently descends and mixes with the surrounding flows.

A ground source heat pump (GSHP) system uses pipes which are buried in the ground to extract heat from the ground. For improving the energy-saving performance of the GSHP system, the GSHP system using a direct expansion method was proposed. This system is estimated to reduce the power consumption of air conditioning over 50%. However, it is difficult to measure the output power of the heat pump because the Freon gas used for the heat pump is the two-phase flow and it decreased the measurement accuracy the flow rate. Therefore, we measured the difference of enthalpy between inlet and outlet of the indoor equipment of the heat pump system. For evaluating the enthalpy of the inlet and outlet, it is necessary to measure the distributions of temperature and velocity of the inlet and outlet. PIV method is applied to measure the velocity distribution. For the measurement of the temperature distribution, it is not appropriate to use the fluorescent mist during the experiment [3] because it pollutes the atmosphere of the room.

In this study, we propose a temperature measurement method that uses ultra-fine fluorescent wires to reduce the wire diameter to much less than that of a thermocouple. This is possible because its structure is simple, and any material can be used for the wire. Hence, ultra-fine wires whose Reynolds number is less than 1.0 can be selected. This means that turbulent flow is not generated downstream of the wire and that its wake is negligibly small. Furthermore, the number of wires decreases because a line profile of temperature can be measured using only one wire.

EXPERIMENT

Experimental Apparatus and procedure

The temperature field of air flow was measured using the experimental apparatus shown in Figure 1. Ultra-fine wires of less than 50 micrometers in diameter were set in the test volume. Fluorescent paint (containing Rhodamine B) was coated on the surface of the wires. The test volume was illuminated by using two UV lights (Wavelength, 300–400nm; Power, 20 W). The paint emits a very tiny orange-colored fluorescent light whose intensity changes with the temperature of the atmosphere [1, 2]. A very high sensitivity color camera (Nikon D7100, ISO 25600, 14 bit, 6,000×4,000 pixels) was used to record the visualized image.

Figure 2 shows a flowchart of the temperature measurement technique. First, the relationship between temperature and fluorescent illumination was determined and the calibration curve was generated. Next, visualized images of the illuminated wires were captured and the temperature distribution was evaluated by red images.

The incident light from the UV light and its scattered light becomes negligible because the color filters used to produce the red images do not transmit UV light.

RESULTS AND DISCUSSIONS

It was necessary to evaluate the tracing accuracy of the ultrafine fluorescent wire as it is related to the temperature of the atmosphere. The temperature variance of a nylon wire surrounded by air was evaluated by numerical simulation using an unsteady one-dimensional thermal diffusion equation of cylindrical coordinates. Figure 3 shows the change of temperature when the initial temperature of the wire was 300 K and that of atmosphere was 320K. The tracking time is defined as the time until the temperature difference becomes smaller than 0.1 K. In these conditions, the tracking time is less than 1 ms. This evaluation did not take into account the influence of convective heat transfer by the difference between the speed of the mist and the surrounding air. Therefore, the actual tracing accuracy will be higher than is indicated by this result, because the influence of the convective heat transfer leads to an improvement in the tracing accuracy. Figure 4 shows the time variation of the fluorescent intensity. A UV light whose power is 30 W was illuminated for 24 hours. The result shows that the intensity had not changed. It shows that the influence of the quenching by illumination [1,2] is negligible in this experimental condition.

Figure 5 shows a temperature distribution in the thermal buoyant plume generated by a heater (Power, 30 W). It shows that a hot plume was generated on the upper side of the heater. The fluorescent wires were not oscillated and any vortices were observed during the experiment. The flow field was not disturbed and it shows that temperature. In future studies, the line profile will be extended to three dimensions by using multiple wires. The number of wires required for measuring the three-dimensional temperature distribution will be lower than that required when using thermocouples.

Figure 6 shows the temperature distribution applied to measure the temperature distribution on the outlet of the GSHP system. It shows that the temperature was almost homogeneous and it was locally lower near the boundary of the outlet. It was well fit in the temperature distribution measured by scanning thermocouples.

Conclusion

We proposed a temperature measurement method that uses ultra-fine fluorescent wires to reduce the wire diameter to much less than that of a thermocouple. The measurement method was applied to measure the temperature distribution in the thermal buoyant plume generated by a heater. It shows that a hot plume was generated on the upper side of the heater and it shows that the LIF technique was well suited for measuring the temperature field of an airflow.

References

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[3] S Funatani, K Toriyama and T Takeda "Temperature measurement of air flow using fluorescent mists combined with two-color LIF" Journal of Flow Control, Measurement & Visualization 1 (2013) pp.20-23

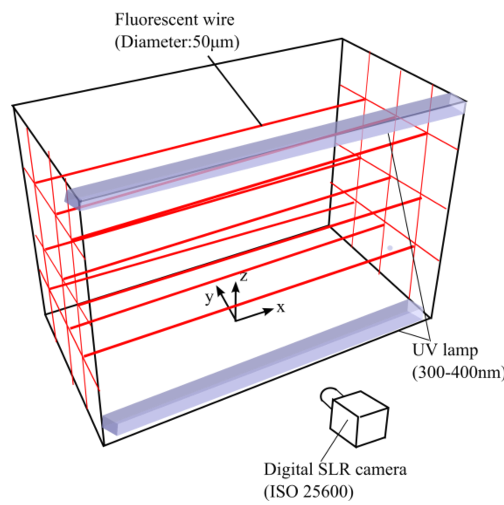

Fig.1 Experimental setup

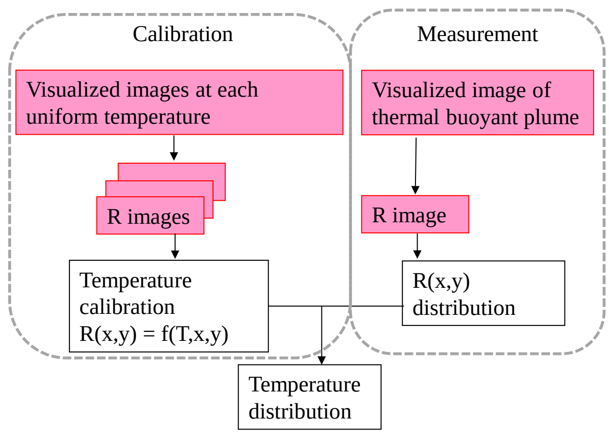

Fig.2 Flowchart for measuring temperature

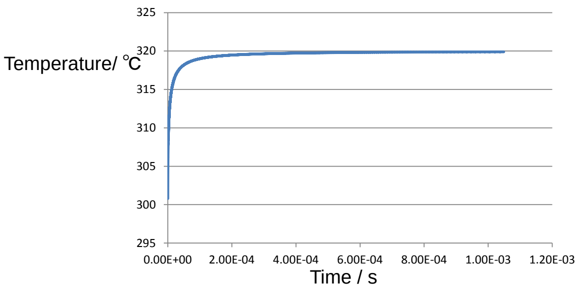

Fig.3 Tracking accuracy of ultrafine wire

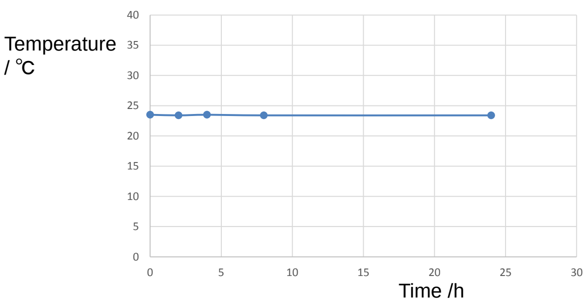

Fig.4 Time variation of fluorescent intensity

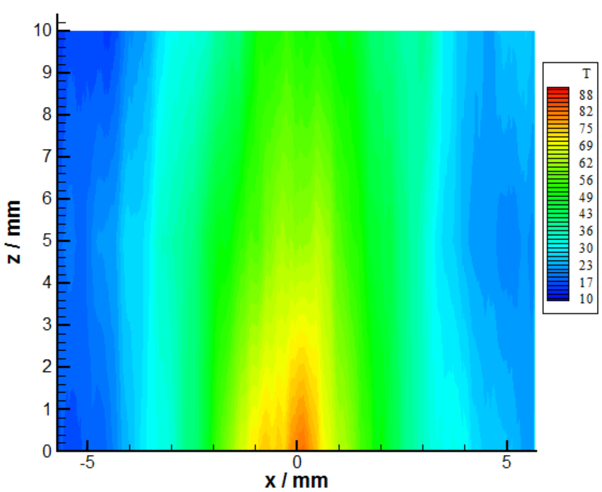

Fig.5 Temperature distribution of thermal buoyant plume

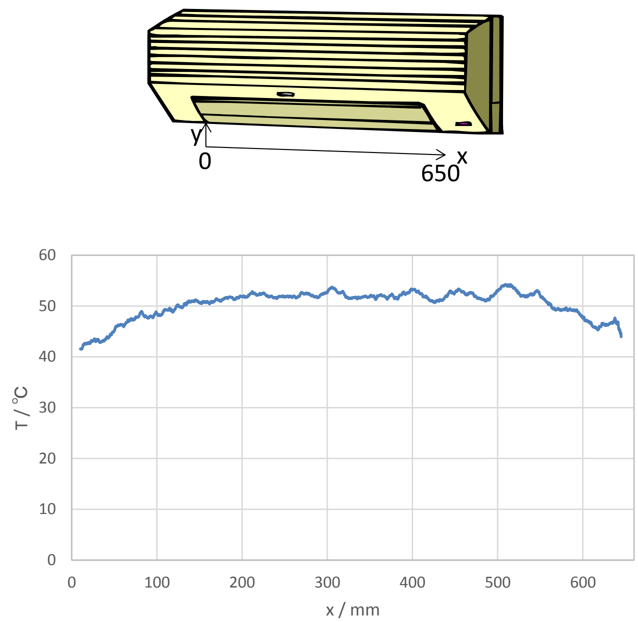

Fig.6 Temperature distribution of the outlet of GSHP systmem