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Heat transfer characteristics of a cooling jacket with double spiral paths for ball screws

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Abstract. In order to contain the thermal expansion of a positioning device where a ball screw is used, a new type of water jacket with double spiral paths has been designed for cooling the nut directly by circulating the temperature-controlled cooling water. It was found that with the proper adjustment of the inlet temperature, it was possible to control the thermal expansion within 5μm. However, the heat transfer characteristics has not been investigated. In order to make understanding of the heat transfer performance of the water jacked, a new experimental system was established. With a certain heat flux and different flow quantities, the inlet temperature and the outlet temperature of the water jacket whose inner water was heated by a rubber heater were measured, by which the heat transfer characteristics was investigated. Also a flow visualization experiment was carried out. It was found that the spiral path could improve the heat transfer performance.

1. Introduction

Thermal expansion of the positioning device is an ordinary phenomenon indirectly caused by temperature increasing of the mechanical part such as bearing or ball screw. Since the friction force generates at the contacting metal surfaces of the ball and inner bearing or tubes, it will directly cause the temperature changes for the positioning device. When thermal expansion problem occurs, the accuracy of the positioning device will be deeply influenced. Therefore, it is necessary to find ways to handle thermal expansion problem.

So far, several methods of cooling the heated part of the device positioning directly or indirectly to the level of the room temperature have been suggested. For example, a method of employing a hollow ball screw axis where the liquid coolant is flowed in and out to bring the extra heat out from the heated ball screw was proposed[1]. It was reported that the temperature of the cooling system could be controlled, however, the cost of introducing this kind of cooling system is very expensive. Besides, though there is a cooling method for cooling the ball screw nut[2], this method has not been widely utilized because the cost of introducing this system is so high too. In working machine, a method of applying the proper preload to the positioning system in advance by considering the expanded length caused by the thermal expansion had been proposed. Peltier module and water jacket to cool a positioning system where ball screw was directly connected with a motor was proposed by the authors[4,5]. However, the heat transfer characteristics has not been investigated. In order to make understanding of the heat transfer performance of the water jacked, a new experimental system was established. With a certain heat flux and different flow quantities, the inlet temperature and the outlet temperature of the water jacket whose inner water was heated by a rubber heater were measured, by which the heat transfer characteristics was investigated. Also a flow visualization experiment was carried out.

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2. Experiment

In Figure 1, the experimental system-up demonstrated. This system consists of a screw water jacket in side which a rubber heater in set, power device, pressure gauges and thermocouples for measuring inlet and outlet's pressure and temperature respectively. The temperature values will be recorded by a data logger.

The structure of the cooling jacket with double spiral paths is shown in Figure 2. The dimension of the jacket is listed in Table 1.

Table. 1 Dimension of the jacket

Out diameter (mm)	Inner diameter (mm)	Length(m)
86	50	78

Cross-section of the cooling jacket is shown in Figure.3. The surface of the cooling jacket is covered with the heat insulator while the rubber heater is set inside the cooling jacket. Inner heat insulator is set to prevent the heat flowing towards the axial.

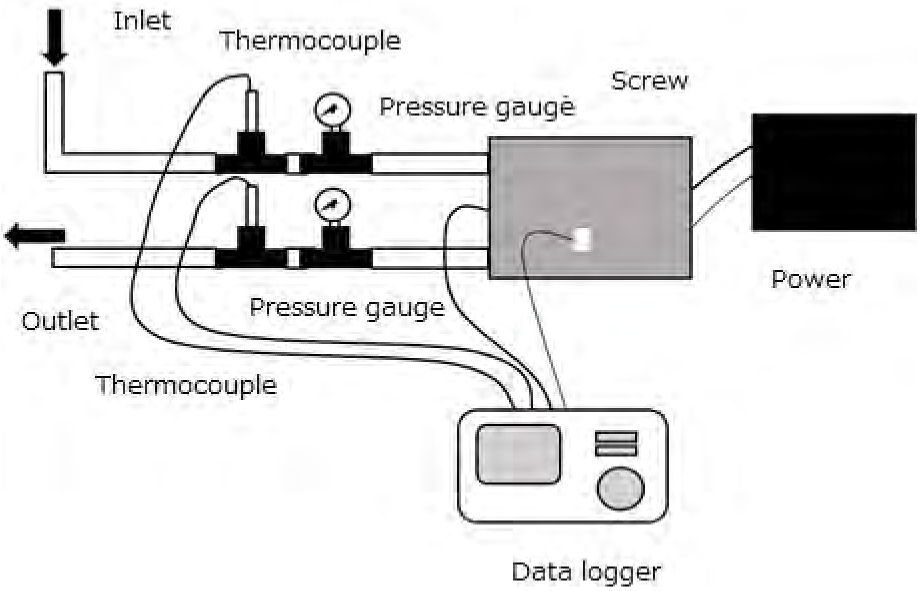

Figure 1. Experimental system-up

During the experiment, at beginning, water jacket is heated by a power device at different heat flux(439,951,1479 W/m^2) for 1 hour. Then cooling water of different flow rate will move into the test section through inlet and move out through outlet to cool the heated jacket.

Temperature values and pressure values before and after the test section as well as the inner jacket temperature and outer jacket are recorded.

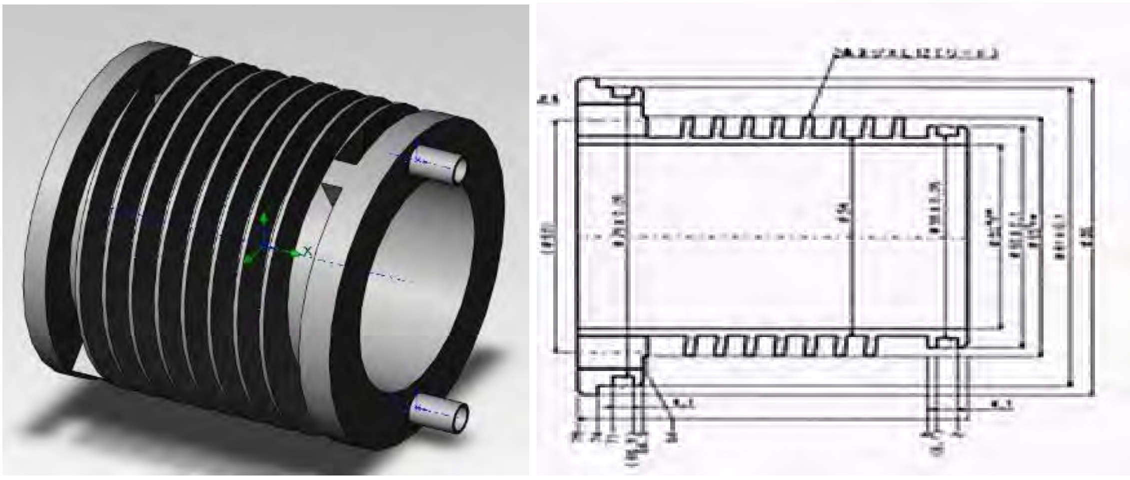

Figure 2. Structure of the water jacket

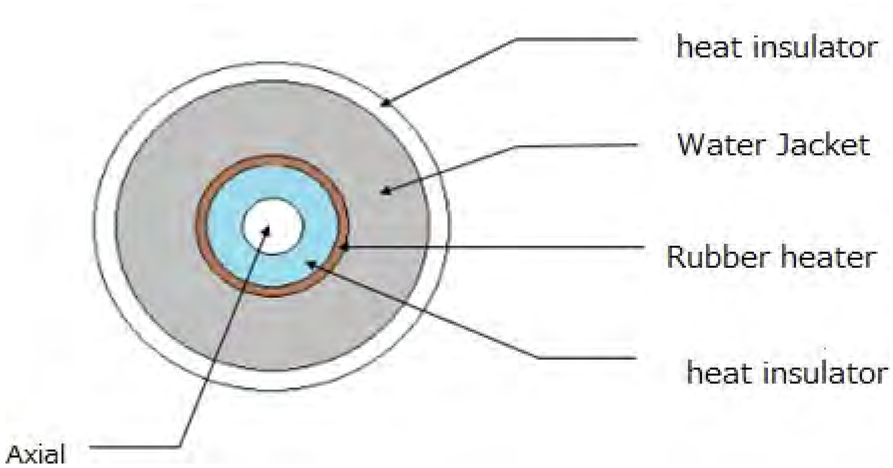

Figure 3. Cross-section of the Cooling jacket

Figure 4. Acrylic cover which is mounted on water jacket

In order to investigate the inner flow state inside the water jacket, a special acrylic cover is designed and manufactured. In Fig.4, The acrylic cover which is mounted on water jacket is shown. During flow visualization experiment, polystyrene beads are mixed with water are flowed into the water jacket for observation.

3. Results and discussions

3.1 Temperature change of the jacket at different heat flux.

Figure 5 and Figure 6 show the temperature change of the inner jacket temperature and external jacket temperature at heat flux of 439,951,1479 W/m^2, respectively.

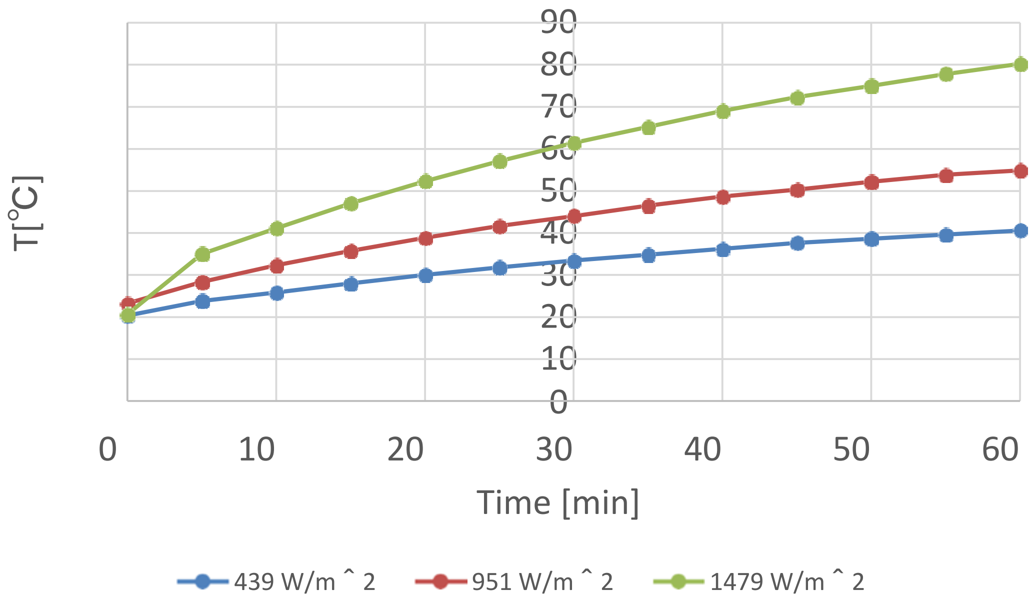

Figure 5. Temperature change of the inner jacket temperature

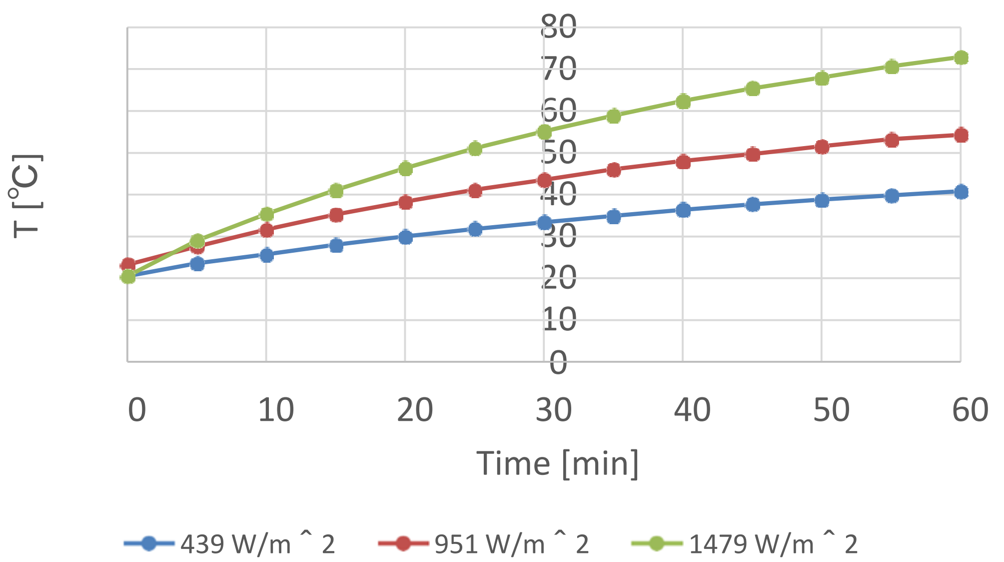

Figure 6. Temperature change of the external jacket temperature

As time passed, temperature inside the jacket and at the external jacket rose. In case of 1479 W/m^2, both temperature will rise to 80 and 72 degree, respectively. Since nature convection between the external jacket and the atmosphere occurred, the external temperature is almost 8 degree lower than the inner temperature. It is imagined that the heat source releasing heat inside the jacket will lead to the thermal expansion if cooling measure are not taken.

3.2 Cooling effect at different flow rate.

After the jacket was heated for 1 hour, water is flown into the test section to cool the water jacket. Outlet water temperature is shown in Figure 7 in case of heat flux =951 W/m^2. At beginning, the outlet water temperature was 40 degree. After the water flowed through the water jacket, the outlet temperature sharply dropped. Within 1 or 2 minutes, the outlet temperature tended to reach a stable state. If the flow rate is larger, the outlet temperature will be lower, which means that the cooling effect wouldbe better.

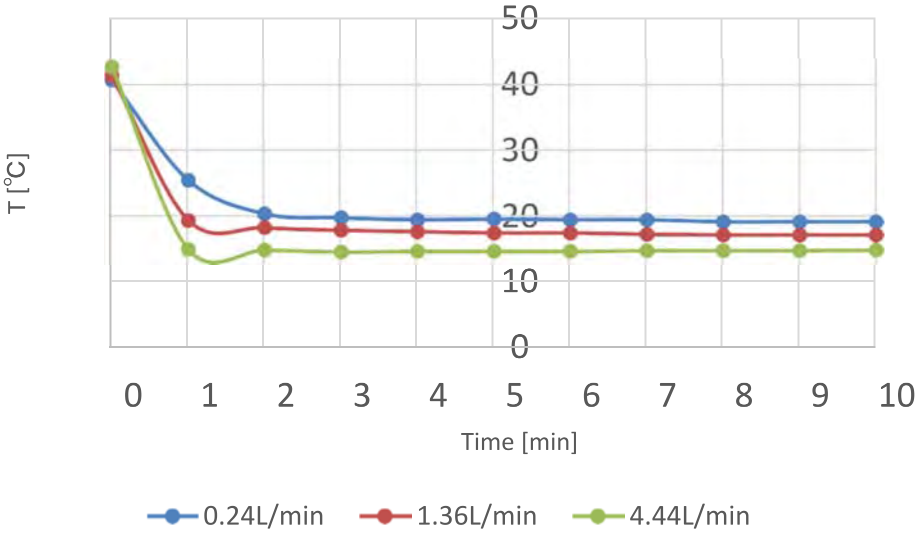

Figure 7. Outlet water temperature

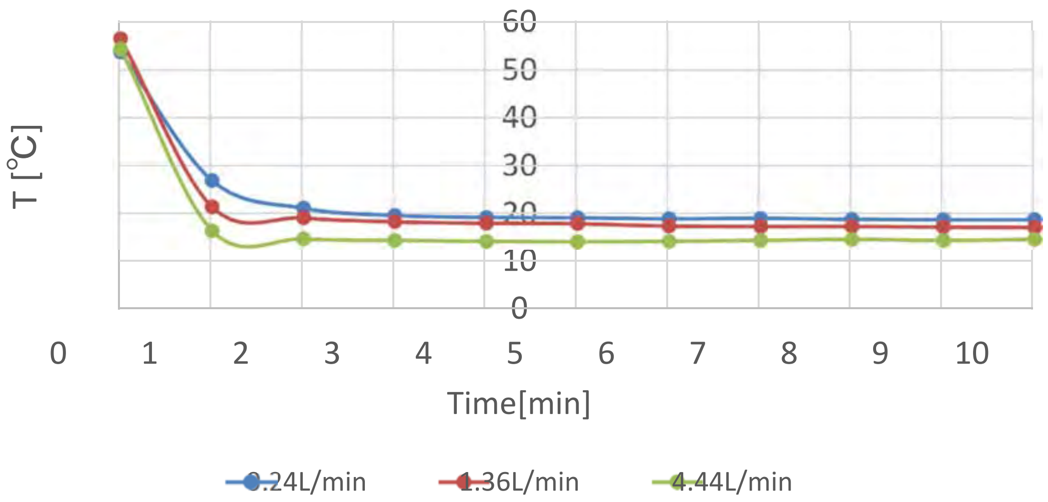

Figure 8. Inner jacket temperature(heat flux=951 W/m^2)

Inner temperature and external temperature changes are demonstrated in Figure 8 and Figure 9, respectively. Just like the outlet water temperature, the external jacket temperature as well as the inner jacket temperature would become stable after 1 or 2 minutes. In case of heat flux =951 W/m^2, the external jacket temperature and inner jacket almost became the same, which demonstrated that water jacket well function and the cooling effect was realized.

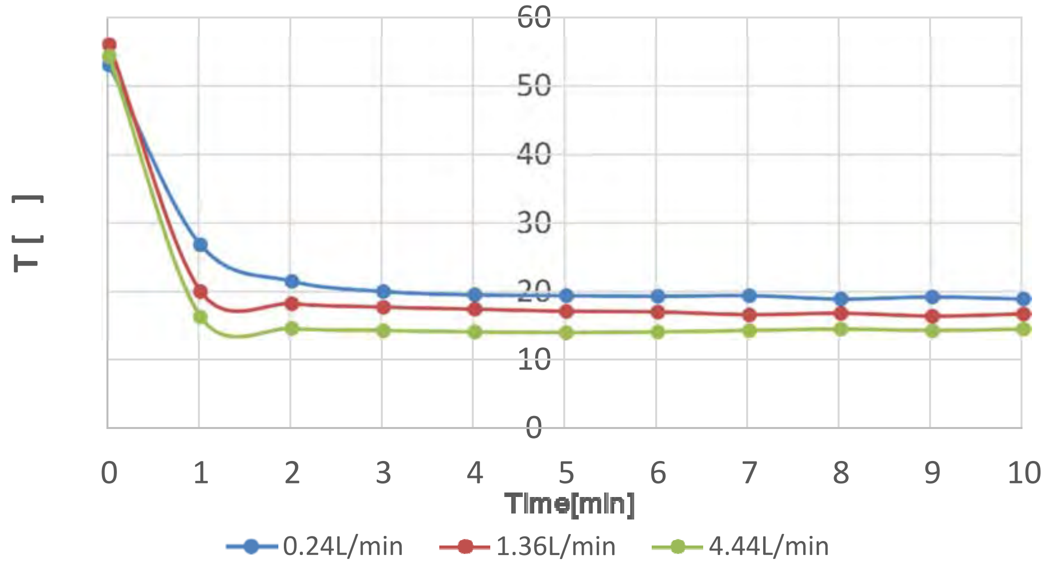

Figure 9. Inner jacket temperature(heat flux=951 W/m^2)

3.3 Cooling effect at large heat flux.

Figure 10 shows Inner jacket and external temperature changes in case of heat flux=1479 W/m^2 and flow rate Q=3.6l/min. In Figure 10, the temperature difference between the inner jacket and the external jacket was almost 10 degree. It is confirmed that if the heat flux is larger to some extent, the inner temperature and external temperature could not be the same. In order to cool the water jacket to a target temperature, the flow rate should be adjusted properly.

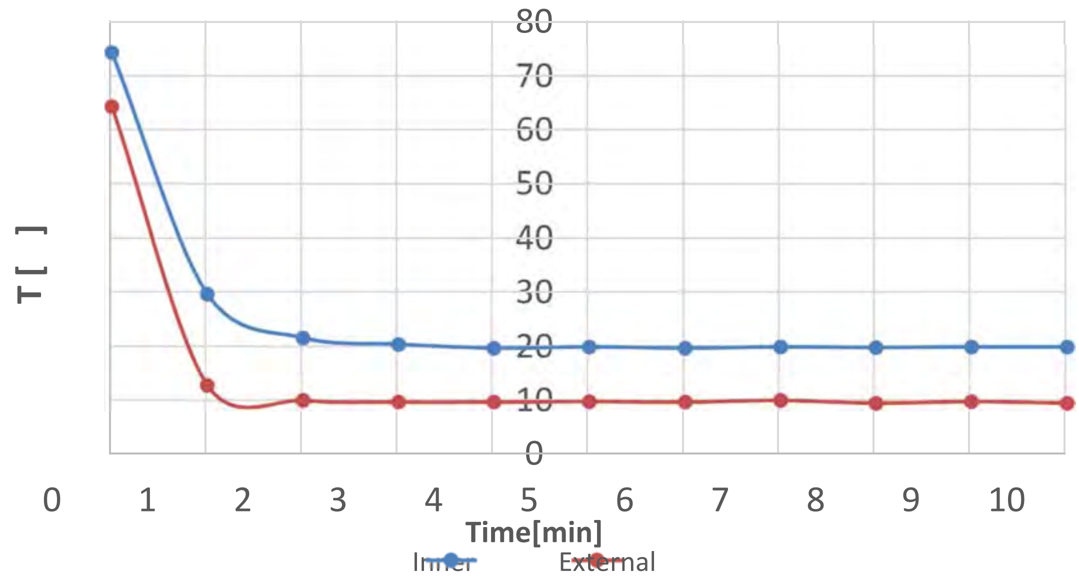

Figure 10. Inner jacket and external temperature (heat flux=1479 W/m^2, Q=3.6l/min)

3.4 Pressure drop.

Pressure drop at different flow rate is shown in Figure 11. As flow rate increased, the pressure drop increased in the form of second order. It is imagined that though the heat transfer characteristics of this water jacket was improved, however, the pressure drop was large than an ordinary flow path.

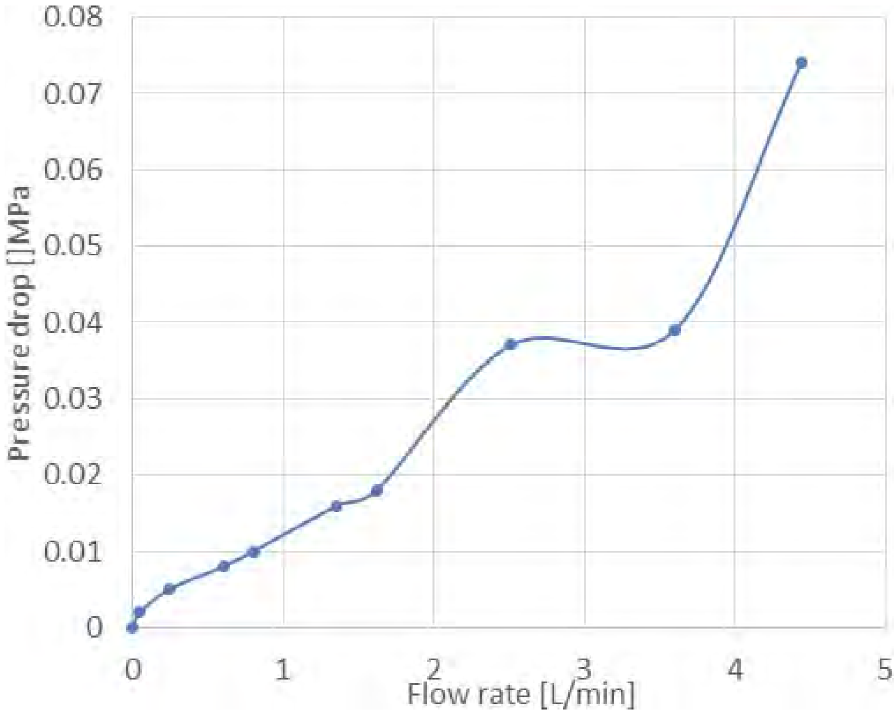

Figure 11. Pressure drop at different flow rate

3.5 Flow visualization.

An example of the flow visualization is shown in Figure 12. When water mixed with polystyrene beads are flowed into the water jacket, the phenomenon where water flowed along one spiral path to the end of the jacket and flow back to the outlet along another spiral path was well observed.

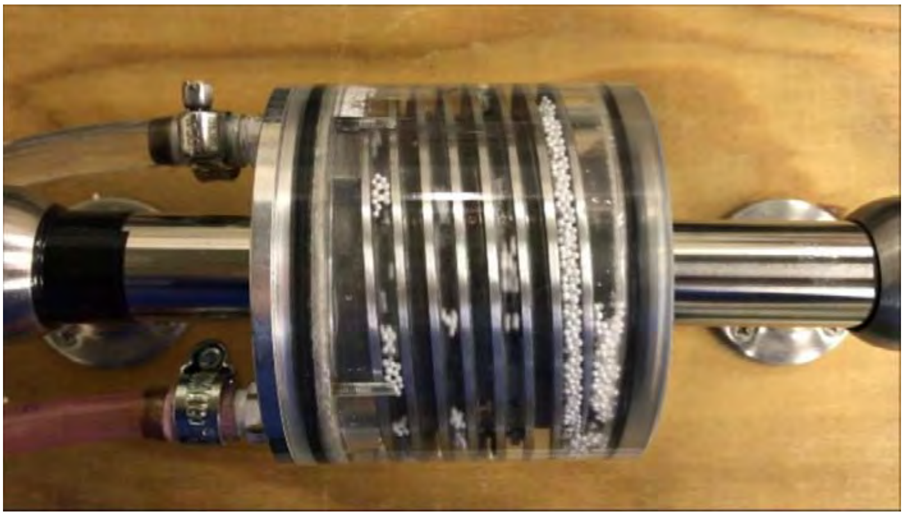

Figure 12. Flow visualization result

3. Conclusions

(1) An experimental system setup was established to investigate the heat transfer characteristics of the water jacket with dual spiral screw path;

(2) When heat flux up to 951 W/m^2 is applied to the water jacket, the inner temperature and external temperature were almost the same. However, in case of larger heat flux, the cooling effect dropped.

(3)Pressure drop increased in the form of two second order as flow rated increased

Acknowledge

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