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Study on Heat Transfer Characteristics according to Flowing Particles in a Cold Water Tube

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Abstract : This experiment was conducted to investigate the effect of particles on the heat transfer characteristics of fluids flowing in a cold water tube. Plastic beads with 3 different sizes were used as flowing particles with cold water. An experimental test section was composed of concentric double tubes having diameters of 25mm for the inner tube and 50mm for the outer tube. The materials for the inner and outer tubes are copper and PVC respectively. It was found that the particles enhanced the heat transfer coefficient by random and vortex motion in the fluid. Hence the heat transfer coefficients for the fluid with 2mm, 5mm and 2×6mm particles were 7%~37% higher than the fluid without the particles.

Key words : Flowing particles, Plastic beads, Cold water tube, Heat transfer characteristics

Nomenclature

A : area of heat transfer [m^2]
c : specific heat [kJ/kg·℃]
d : diameter[m]
G : mass flow rate [kJ/h]
h : local heat transfer coefficient [W/m^2·℃]
k : thermal conductivity [W/m·℃]
K : overall heat transfer coefficient[W/m^2·℃]
L : length of test section [m]
q : heat flux [W/m^2]
Q : heat transfer amount [W]
t : temperature [℃]
Δt : temperature difference [℃]
Δz : length of infinitesimal part [m]
ξ : volume concentration of plastic beads [%]

Superscript

c : cold water
i : inside
m : mean value
o : outside

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s : infinitesimal part

w : pipe wall

1. Introduction

Air-conditioning in the summer season is essential for people who work in an office or factory. For this reason, the air-conditioner has been used extensively for cooling and providing comfort for people.

The cooling coil of the air-conditioner is used to cool the indoor room by cooling the air. And the cooling water of the refrigerator is supplied to the cooling coil.

A decrease in the cooling efficiency of the cooling coil produces an increase in energy consumption and this will bring about the disruption to the surrounding ecology. Therefore, an enhancement of heat transfer efficiency of the cooling coil is fundamental to solve these problems.

Recent researches have been focused on the arrangement, materials and shapes of the cooling coil and are used to increase the efficiency of heat transfer[1]-[3]. However, such a conjugation has brought about an increase in pressure drop of air side. Also, the coil material of high heat exchange capacity will increase the initial costs of device. Using finned coils would also increase manufacturing costs.

Other researches have been attempted to use the effects of drag reduction[4],[5], eddy motion[6],[7], surfactant[8] and the ice slurry experiment as particles which have been carried out widely[9]. However, the ice slurry system should solve the ice blockage problem which is caused by the ice crystallization during it flows inside a pipe.

In order to solve these problems and to increase the heat transfer in a cooling coil, this experimental study used three sized plastic beads slurry. Also, research had been conducted on the plastic beads in a water mixture to clean the inside of pipe[11] rather than to increase heat transfer[10]. The experimental results were arranged as local and mean heat transfer coefficients in accordance with the radial and axial directions, respectively.

2. Experimental apparatus and test methods

Fig. 1 shows an experimental apparatus used in this study. The apparatus mainly consists of cold and load water circulation parts.

The cold water flows inside the pipe and load water flows outside the pipe with counter flow directions. Cold water was maintained at a constant temperature by way of a refrigerator and it flows to inside pipe with a circulating pump. The sight glass was attached to an inlet side so as to check the flow condition of the plastic beads.

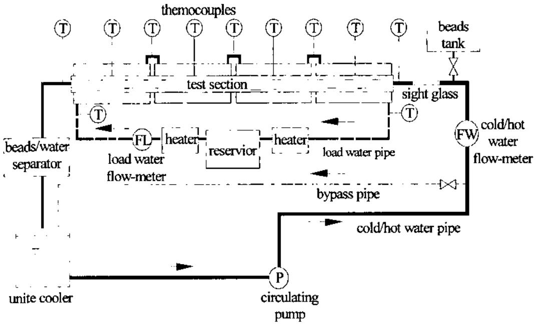


Fig. 1 Schematic diagram of experimental apparatus.

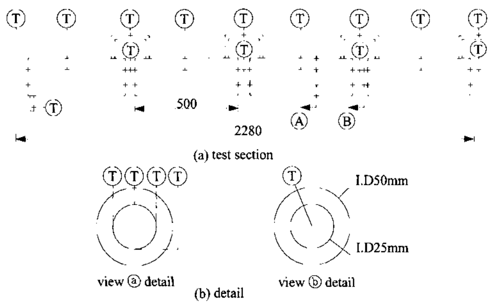


Fig. 2 Schematic diagram of test section.

The load water side consists of a storage tank, an auxiliary and main pre-heater, a circulating pump, and a flow meter.

The inner pipe is a copper tube with a 25mm inside diameter and a 28mm outside diameter.

The outer pipe is a poly vinyl chloride(PVC) pipe with a 50mm in inside diameter. The test section consists of co-axial double pipes and are divided by four sections as shown in Fig. 2.

The T-type thermocouples were bonded at 4 positions to measure the inner pipe outside wall temperatures. Thermocouples were used to measure the temperatures of cold and load water at the inlet and outlet.

Cold and load water were maintained at 7℃ and 20℃ by refrigerator and an auxiliary heater. And both exchange heat at the test section.

The beads tank was installed at the inlet of the test section and regularly input the beads into the test section.

Table 1 shows the specification of plastic beads used in this experimental study.

Flow velocity was kept at 0.5~1.0 m/s in order to prevent clogging in the test section. In this study, the experiment was started when the flow condition reached steady state for a one hour period.

Table 1 Specification of plastic beads

classify	size	shape	specific weight
(A)	No	Pure water	1,000kg/㎥
(B)	2mm		1,111kg/㎥
(C)	5mm		1,164kg/㎥
(D)	2×6mm		1,315kg/㎥

The heat transfer amount Q[W] of the heat exchanger is the amount of heat flow into the fluid inside the pipe so this is calculated by equation (1).

$$Q = K \cdot A \cdot \Delta t_m \quad (1)$$

where, K is the overall heat transfer coefficient of test section[W/m^2·℃] and A is the heat transfer area[m^2] also, Δt_m means the average temperature of the test section[℃]. However, the overall heat transfer coefficient K is unknown in the real system.

In this study, equation (2) is used to calculate the amount of heat transfer measuring the cold water temperature and the flow rate for an infinitesimal part.

$$Q = G_c \cdot c_c \cdot \Delta t_c \quad (2)$$

where, G_c, c_c, Δt_c are the mass flow rate[kg/h], specific heat[kJ/kg·℃], and temperature difference between the inlet and outlet of cold water in the test section, respectively. The specific heat of cold water is regarded as 4.2 kJ/kg·℃ which is the average value in this experimental range. The sensible heat of the plastic beads is very small compared to the value of cold water, so it is possible to neglect the sensible heat of the plastic beads.

Heat flux q[W/m^2] at an infinitesimal part was calculated by equation (3).

$$q = \frac{Q}{\pi \cdot d_i \cdot \Delta z} \quad (3)$$

where, Q is derived from equation (2) of heat transfer amount[W], d_i means the inside diameter of the inner pipe [m](=0.025), Δz is the length of each infinitesimal part[m](=0.5).

Radial direction heat transfer has a pronounced effect on the performance of heat exchanger, therefore the local heat transfer coefficient h[W/m^2·℃] was calculated by equation (4).

$$h = \frac{Q}{A_s \cdot (t_{cm} - t_{wm})} \quad (4)$$

where, A_s is the infinitesimal heat transfer area[m^2](=0.044) and t_{cm}[℃] is the mean temperature of cold water obtained from measuring the temperatures of the inlet and outlet at infinitesimal parts, t_{wm} means the temperature of the inside surface of inner pipe calculated from the average value as expressed in equation (5).

$$t_{wm} = \frac{t_{wiu} + t_{wils} + t_{wirs} + t_{wib}}{4} \quad (5)$$

where, t_{wiu}, t_{wils}, t_{wirs}, t_{wib} are the values of the four positions in the outside surface of the pipe. The inside surface temperatures value was calculated from equation (6) using a steady state one dimensional heat conduction.

$$t_{wi} = t_w + \frac{Q \cdot ln\left(\frac{d_0}{d_i}\right)}{2\pi \cdot k_w \cdot \Delta z} \quad (6)$$

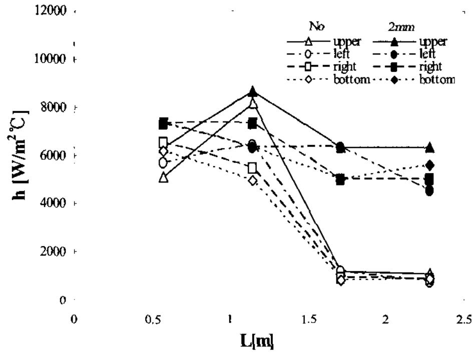
where, t_w is the outside surface temperatures of the inner pipe measured from thermocouples. d_0 and d_i are outside[m](=0.028) and inside[m](=0.025) diameters of the inner pipe respectively. k_w is the thermal conductivity of copper pipe used as an inner pipe[KW/m·℃](=0.4).

3. Results and Discussion

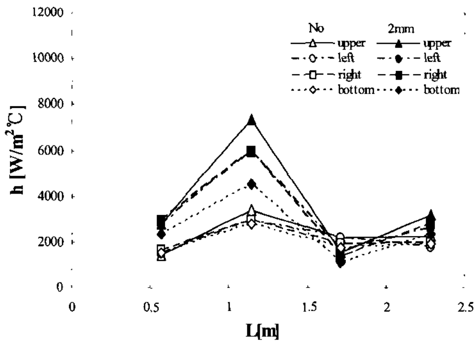
3.1 Local heat transfer coefficient according to wall position

Fig. 3 indicates the local heat transfer coefficient according to wall position about 2mm particle at flow velocities between 1.0m/s and 0.5m/s. At a flow velocity of 1.0m/s, the local heat transfer coefficient of the upper position shows a lower value than any other position in the inlet.

This result means that the buoyancy of the plastic beads affects the increase of local heat transfer at the upper position. At a flow velocity of 0.5m/s, the heat transfer coefficient of the upper position also shows a higher value than the other position in second side. Because in the second infinitesimal part the velocity which has an influence on the plastic beads flowing make the moving bed and the temperature difference of cold water is occurred by the moving bed in the second side, which makes it higher than the other side. When it is compared to no beads with a velocity of 1.0m/s and 0.5m/s, the case of 0.5m/s and 1.0m/s are higher than local heat transfer coefficient of no beads. Expecially when it is compared with no beads with a flow velocity of 1.0m/s, the heat transfer coefficient of the outlet is higher than with no beads because the plastic beads have an effect on the temperature boundary layer.



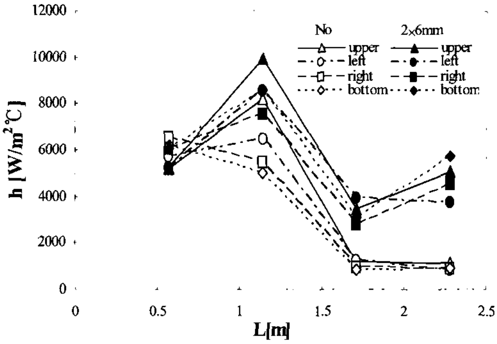
(a) v=1.0m/s



(b) v=0.5m/s

Fig. 3 Local heat transfer coefficient according to velocity.(2mm particle, ξ=2%)

Fig. 4 also indicates the local heat transfer coefficient according to the wall position at each infinitesimal part. The diameter of plastic beads is 2×6mm and the value of local heat transfer was compared with the flow velocities of both 1.0m/s and 0.5m/s.



(a) v=1.0m/s

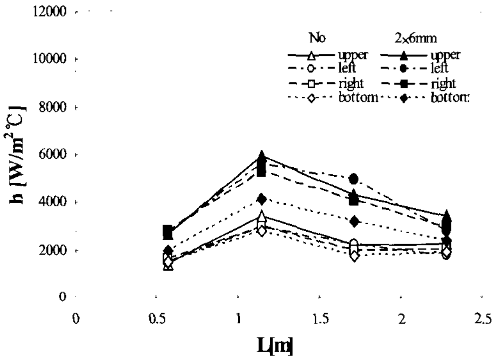


Fig. 4 Local heat transfer coefficient according to velocity.(2×6mm particle, ξ=1.8%)

The heat transfer coefficient of 1.0m/s at the inlet is similar with the velocity of 1.0m/s in Fig. 3. And the heat transfer coefficient of the bottom position at the outlet shows a higher value than the other position.

This result means that the 2×6mm plastic beads flowed out at the upper position of the first infinitesimal part and flowed out at bottom position of the second infinitesimal part because of density and gravity.

The heat transfer coefficient at 0.5m/s is also similar with at 0.5m/s of Fig. 3. The local heat transfer coefficient was higher in the second infinitesimal part.

This phenomenon can be explained by

the fact that while the plastic beads flowed out by the moving bed at a low velocity, a cold water temperature difference largely appears in the second infinitesimal part. And the heat transfer coefficients of wall position were similar at each infinitesimal part because the moving bed promoted a turbulent flow. Also the heat transfer coefficient including beads shows a higher than the heat transfer coefficient including no beads.

This can explain that the plastic beads have an effect on a flow regardless of a velocity. Altogether the heat transfer coefficient of a velocity of 1.0m/s shows a higher value between 1.0m/s and 0.5m/s.

3.2 Mean heat transfer coefficient of plastic to radial direction

Fig. 5 indicates the mean heat transfer coefficient of each size of plastic beads in cold water to radial direction. And the flow velocity was compared with 1.0m/s and 0.5m/s. At a velocity of 1.0m/s$(\xi=1.2\%)$, the heat transfer coefficient of plastic beads particles(5mm, 2×6mm) are entirely higher than with no beads and the heat transfer coefficient around the outlet region appears lower than around the inlet region. This is a typical phenomenon of heat transfer in a tube. When a length of test section is longer, the flow of cold water is also raised in a pipe and a temperature layer of the pipe wall also improved in the pipe so the heat transfer coefficient is reduced.

At a velocity of 0.5m/s$(\xi=2.8\%)$, the heat transfer coefficient shows a higher value than with no beads and when it is compared to 2mm beads and 2×6mm beads, the heat transfer coefficient of 2mm beads was higher than 2×6mm beads at the inlet but at the outlet the heat transfer coefficient of 2×6mm beads was higher than 2mm beads, because the specific weight of the 2×6mm particles is the biggest in relation to the other particles.

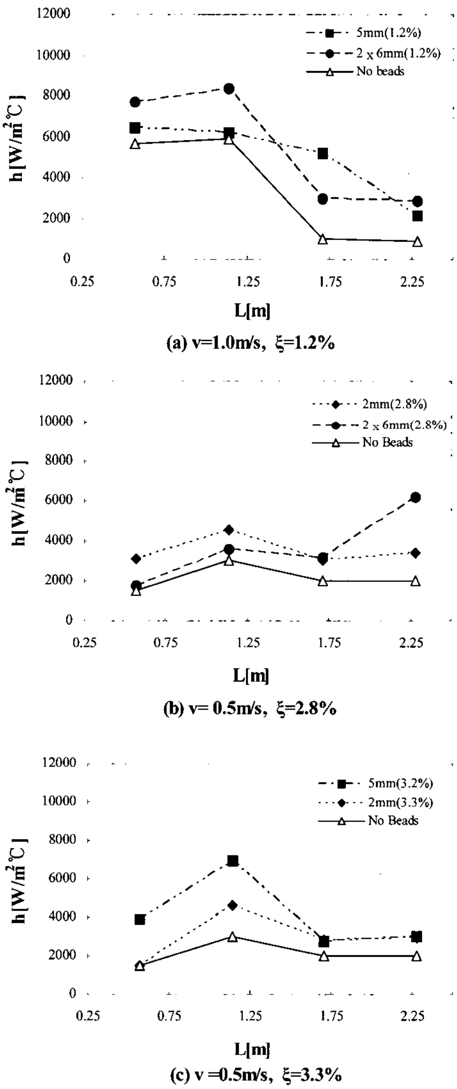


Fig. 5 Mean heat transfer coefficient of particles to radial direction.

At a velocity of 0.5m/s(ξ=3.3%), the heat transfer coefficient of the 5mm beads shows a higher value than the heat transfer coefficient of the 2mm beads in the second infinitesimal part.

It can be explained that particles have an effect at low velocity when the particles are bigger and their specific weight are higher.

3.3 Mean heat transfer coefficient of particles to axial direction

Fig. 6 indicates the mean heat transfer coefficient of plastic beads particles in cold water where the flow velocity is 1.0m/s. From Fig. 6, the heat transfer coefficients of 2mm, 5mm and 2×6mm beads were 32%, 7% and 37% better than with no beads. So it is clear that there is an effect of heat transfer enhancement on each size of particles at 1.0m/s. Especially the heat transfer coefficient is clearly appeared in 2×6mm in diameter of particles.

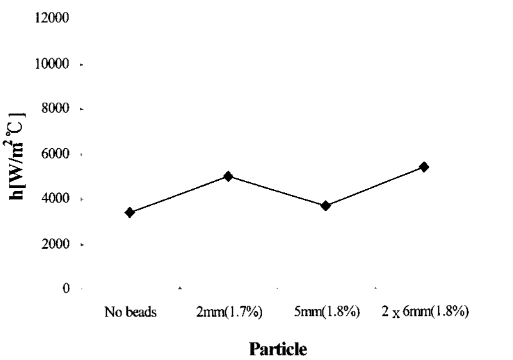


Fig. 6 Mean heat transfer coefficient of particles to axial direction.(v=1.0m/s)

Consequently, This results can improve heat transfer by putting proper particles in the cold water coil and also make vortex motion. It is expected that the heat exchanger can be small.

4. Conclusions

The heat transfer enhancement of the plastic beads particles in cold water has been investigated experimentally in a circular tube of co-axial double pipes.

The following conclusions can be obtained.

(1) Heat transfer coefficients of plastic beads particles with 2mm,5mm, 2×6mm in cold water increase about 7%~37% higher than the cold water with no beads.

(2) Local heat transfer according to wall position has no constant trend by the effect of a velocity. Thus heat transfer coefficient at the upper position of the pipe is always not higher than the other positions at the total heat exchanger.

(3) The heat transfer coefficient of a high velocity particles shows higher value than the case of a low velocity particles.

(4) Heat transfer coefficient of 2×6mm beads was higher than 5mm, 2mm beads at the same concentration because 2×6mm beads has irregular shape which gives more effect on the temperature layer.

(5) These can be expected to design and produce a cold water tube such as heat exchanger if it is used by proper particles according to velocity and diameter.

Acknowledgement

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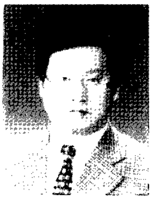

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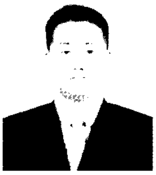

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