DEVELOPMENT OF CENTRIFUGAL SEPARATOR IN NEW CLEANING SYSTEM USING SPONGE BALLS FOR HEAT EXCHANGER

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ABSTRACT
A device was proposed to separate sponge balls from water, used in the cleaning system of heat exchangers. This experimental study was conducted to investigate the operational behavior of the centrifugal separator, aiming at improving its efficiency. The circulation behavior of a single particle (simulating the sponge ball) in the rotating flow generated inside the transparent scale-down model of the centrifugal separator was examined. It was observed that the tendency of the particle moving away from the circulation center in radial direction became stronger with increasing flow rate. Furthermore, the separation efficiency was found to depend strongly on the ratio of the flow rate conveying particles to the inlet flow rate. This dependence became less significant with the increase of the inlet flow rate.

KEY WORDS
Multiphase flow, Solid-liquid two-phase flow, Separator, Image processing, Heating tube, Scale, Separating time

INTRODUCTION
This study has the final goal of developing a new cleaning system for a heat exchanger in air conditioning facilities. During the operation of a heat exchanger, scale (due to impurities of coolant) usually accumulates on the inner and outer wall of the pipe as time goes by. As a result, the scale buildup deteriorates the heat transfer on the pipes and indirectly causes substantial amount of energy loss, lowering the performance of the refrigerating system. Therefore, it is necessary to clean the heat pipes regularly for recovery and maintenance of the efficiency of the refrigerating system.

Existing cleaning methods include those using chemical solutions, brushes and sponge balls [1, 2]. The first two conventional methods are economically inefficient and time-consuming as they compel the suspension of the facility operation as well as the dismantling of equipment. Due to these shortcomings, the cleaning process is not carried out with an enough short interval sometimes, making it difficult to operate the refrigerating system at its optimum capacity at all time.

On the other hand, the cleaning method using sponge ball has the advantages of requiring no dismantling work of equipment and involving no manpower for the cleaning process. However, there arises the need to equip the refrigerating equipment with a two-phase flow pump capable of circulating both the coolant and the sponge balls in the system. This requires additional cost for the facility. Moreover, the conventional sponge ball cleaning system is not suitable for large scale equipment which needs highly pressurized circulation system. Furthermore, clogging up of sponge ball at a grid separator in the system sometimes occurs. All of these problems prevent the widespread usage of the conventional sponge ball cleaning system. Therefore, the purpose of the study is to overcome all these problems and create a better sponge ball cleaning system.

Figure 1 is a conceptual diagram of the new sponge ball cleaning system. Sponge balls in the ball collector are delivered into the heating pipe in the heat exchanger by the water flow from the pump. After cleaning, the sponge balls are collected at the separator and return to the ball collector. The process is done by the water flow and valve sequence. To prevent the clogging up of the sponge balls at the separator, a centrifugal separator device is introduced. The system is easily built at low cost without the two-phase flow pump for coolant and balls and also feasible in large scale equipment.

As the initial step in the development of the new cleaning system, the circulation behavior of the sponge ball at the centrifugal separator was studied by the simulation of transparent scale-down equipment, in which the solid particle was used instead of the sponge ball. The particle motion was measured by image processing. In the rotating flow inside the device, the radial position of the particle moved away from the center due to the centrifugal force. Affected by flow turbulence, the particle showed a rather complex trajectory. It also found that the circulation behavior of the particle depended on the ratio of the flow rate conveying the particle at the particle outlet to the flow rate of the inlet pipe.

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Fig.1 Ball-Cleaning System
EXPERIMENTAL APPARATUS AND MEASUREMENT METHOD

1. Outlet for particles and conveying water (extraction pipes)
2. Inlet for water and solid particles
3. Outlet for water only
The x-y Cartesian coordinate is taken in the cross section of the separator. The r is the distance from the center.
Fig.2 Test section

The test section built at the scale of 1/7 of the actual device is schematically shown in Fig. 2. The experimental apparatus mainly consists of a test section, a pump, a particle injector and a storage tank. Water is used as the working fluid. The sponge ball is simulated by a polystyrene particle which is also reduced to about 1/7 of the actual size of the sponge ball (diameter: 3.2 mm, specific gravity: 1.07).

The test section comprises a main cylindrical body (58mm in inner diameter and 86mm of length) and a total of 5 protruding pipes (an inlet pipe, an outlet pipe for draining liquid and three extraction pipes for collecting particles). The water and particles are transported to the test section through the inlet pipe of 30 mm in diameter. In order to create rotational flow in the test section, the inlet pipe is positioned in a way that its center axis is dislocated from the center axis of the test section. A cylinder structure (32mm in diameter) made from punching board material (hole diameter of 2mm and overall opening ratio of 29.6%, see Fig. 6) is installed at the center part of the test section to act as a filter or catcher for the particles, preventing the particles from flowing out through the outlet pipe (30mm in inner diameter).

On the other hand, three smaller pipes (each measuring 7mm in inner diameter) for collecting the particles are protruding from the top, the side and the bottom wall of the main cylindrical body, respectively. These pipes are called as extraction pipes in which the solid particles and conveying water are flow out. Each of the pipes is equipped with a valve to control the conveying water flow rate. A flow meter is mounted on each of the pipes mentioned above in order to measure the flow rate of each pipe. Inlet flow rate was set at 50, 100, 150L/min.

The circulation behavior of the particles is captured by a high speed video camera arranged as in Fig. 2 at the rate of 1000 frames/s. Telecentric lens is used to prevent the parallax effect. Two experiments, one for observing the behavior of a single particle and another for measuring the total collecting time of 100 particles, were conducted.

RESULTS AND DISCUSSION

Behavior of a single particle
Figure 3 shows the trajectory (black solid line with solid circles) of a single particle circulating in counter-clockwise in the test section under the closed condition of the valves on the extraction pipes. In the condition, the conveying water flow rate was zero and the particle did not flow out from the test section. The outer and inner circles illustrated by solid lines outline the boundaries (imposed by the cylindrical wall of the test section and the porous structure inside it) in which the particle exists. As the trajectory of the particle was produced by tracing the center of gravity of the particle [3], understandably the trajectory could approach the walls by the smallest distance of the particle radius. This existence limit is shown by the dotted lines. When the inlet flow rate was low (Fig. 3 (a)), the particle mainly existed near to the inner cylinder side, occasionally deviating in radial direction due to flow turbulence. The particle was observed to circulate more often in the vicinity of the outer cylinder with the increase of the flow rate (Fig. 3(b) and (c)).

Figure 4 shows the radial distributions of the frequency of particle existence to examine the circulation behavior of the particle in more detail. The abscissa denotes the distance from the center, which minimum corresponds to the surface of the inner punching board and the maximum, the wall of the cylinder. The radial distributions were obtained from the images of the particle captured in a time span of 2 seconds. At low inlet flow rate (Fig. 4 (a)), the radial distribution exhibited a peak near to the inner cylinder surface. The distribution spread out as inlet flow rate increased (Fig. 4 (b) and (c)). This can be attributed to the tendency of the particle to move towards the outer wall of the device as the flow rate increased. Figure 5 shows the radial distribution of the particle when the inlet flow rate and the conveying flow rate of the side extraction pipe were set at 100L/min and 7.8L/min, respectively. Compared to the case of no conveying flow (Fig. 4 (b)), the radial distribution of the particle was flatter. This is apparently due to the changes in the flow field and the variation of distribution also suggested that a slight change in the flow field near to the outlet pipe could greatly influence the behavior of the particle.
Fig. 3 Track of a particle on the section of a ball separator

Fig. 4 Radial distribution of the frequency of a particle existence for 2 s.

Fig. 5 Radial distribution of a particle existence with conveying flow of 7.8 L/min (main flow rate; 100 L/min)
Simulation of the separation of 100 sponge balls
In the actual refrigerating system, approximately 100 sponge balls are injected into the heat pipes for a certain cleaning condition. In this study, simulation experiment by injecting 100 particles was conducted to observe the particles' behavior and to assess the effectiveness of the separator. Figure 6 shows the images of the particles inside the separator. These images were taken when the valve on the side extraction pipe was opened. Figure 6(a) shows the particle behavior from the side view of the cylindrical separator and Fig. 6(b) shows the cross-sectional image of the separator with the particles circulating in it. The particles were dispersed around the circumference of the inner cylinder with no cluster being formed in the separator (Fig. 6(b)). However, from the side view, more particles were observed to be distributed to the left section of the cylindrical which was nearer to the outlet pipe. This is because the particles were moved by the flow heading to the outlet pipe. From this result, the particles can be collected more efficiently by placing the extraction pipe near to the outlet pipe. However, a number of particles were observed to remain in the opposite section (right section) of the separator in several runs of experiments. Particles that were located far from the outlet pipe took time to be removed from the separator, hence affecting the efficiency of separation remarkably. Therefore, we can say that the opposite space of the outlet in the separator is not necessary and should be removed to make effective separation.

Figure 7 shows the variation of separation time of particles with the ratio of the conveying flow rate of the extraction pipe to the inlet flow rate. Here, the separation time is the necessary time for all particles in the separator to flow out through the extraction pipe after opening the valve on the corresponding extraction pipe. It is obvious that the separation time reduced when the inlet flow rate was increased. As mentioned above in the case of a single particle, when the inlet flow rate increased, the particle moved closer to the outer wall of the separator due to stronger centrifugal force. The reason for the behavior of a single particle also can apply in the case of multiple particles.

In order to estimate the separation time in the case of an actual device, the separation time of the simulation was multiplied by \( 7 \), which means that the non-dimensional time of flow in the simulation of the same Reynolds number makes equal to that in the actual separator. Figure 8 shows the separation time for the actual separator. The dotted line in Fig. 8 denotes the time of 5 minutes. Separation time of 5 minutes is set as a target time to separate all the particles in actual operation and also serves as a criterion in evaluating the performance of the separator. Figure 8 shows that it is possible to achieve this target time for the present separator. Figure 8 (b) shows a close-up view of the time range below 500 s. Judging from the figure, the separation time can be expected to decrease further with the increase of inlet flow rate. By increasing the maximum inlet flow rate in the current experiment from 150 L/min to 400 L/min which corresponds to the operational condition in the actual system, the separation time below 1 minute can be expected.

Figure 9 shows the relation between the separation time and the conveying flow rate of the extraction pipe. At the same conveying flow rate, the separation time became shorter with the lower inlet flow rate. The mechanism of the tendency may be as follows: The inlet flow creates circulation flow which also entrains the particles into the circulating flow path. On the other hand, the outflow around the extraction pipe also influences the particle motion. When the inlet flow rate is large, the influence of the outflow on the particles' movement is comparatively weak and particles flow along the circulating flow. When the inlet flow rate is small, the behavior of the particles is significantly affected by the outflow and the particles flow out through the extraction pipe.

![Image of separator](image-url)

(a) The side view of the separator

![Image of separator](image-url)

(b) The front view of the ball separator

Fig.6 Example of particles image
CONCLUSIONS

In this study, the centrifugal separator for the new sponge ball cleaning system was proposed and its performance was examined by the experiment using a transparent scale-down model. The circulation behavior of a single particle in a separator was observed. It was found that the single particle, under the influence of the centrifugal force, moved to the outer wall of the cylindrical separator when the inlet flow rate was increased.

The separation time of 100 particles was also obtained. When the inlet flow rate was increased, the separation time became shorter by the increasing centrifugal force. At a constant conveying flow rate of the extraction pipe, the separation time became shorter with lower inlet flow rate.

The separation time at the actual separator was estimated and less than 5 minutes for the operation condition. The 5 minutes is the target time in the actual ball cleaning system.

By the observation of particle motion, we found that the opposite space of the outlet in the separator was not necessary and should be removed to make effective separation.

REFERENCES