Cold Experiments of Rotary Vaned-disk and Wheels for Slag Atomization

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(Received on February 3, 2003; accepted in final form on April 9, 2003)

1. Introduction

Rotary atomizers have been historically well-known as an effective device for granulating a high viscous liquid such as gel, oil, and slurry. Many papers on the rotary atomizer have been reported, which can be classified into experimental work and theoretical one. In the latter case, the experimental data were reformed, in order to derive the dimensionless relationship. The obtained several results are useful for the wide applicability of the relationship.

Friedman et al. first investigated several centrifugal atomizers under different conditions, then successfully deriving an empirical equation. At the almost same time, Oyama et al. studied the relationship between drop size distribution and operating factors such as a disc diameter and rotating speed. The obtained relationship was useful for equipment design. Most noteworthy, Fraser et al. studied the flow characteristics of liquid films formed by several kinds of rotary devices, then deriving the most practical, semi-empirical relation of drop size. In contrast, Tanazawa et al. accomplished a filamentation theory of viscous liquid, to predict the transition conditions from drop to ligament formation. Their work was greatly contributed to the elucidation of granulation mechanism, the design of equipment and the optimization of operating data.

On the other hand, hot molten slag has recently been drawing attention from the environmental and energy aspects. Iron and steelmaking furnaces and a melting furnace of municipal waste emit a huge amount of liquid slag over 1 800 K. At the present time, all of them were cooled by the atmosphere or water without any recovery of heat in spite of its large heat content. Heat exchange of liquid slag seems to be not easy. It is, thus, a quite crucial subject to expand contacting area between slag and gas medium for heat recovery. From this viewpoint, we applied a flat disk to the slag granulation in a previous study, in which the effect of several operating conditions on drop diameter was mainly examined. As a result, we obtained successfully uniform spherical drops of less than 1 mm by air blowing.

However, we observed so-called ‘slippage’ of the molten slag on the disk in the experiments, which causes inefficiency of energy transfer. For preventing the slippage and for transferring centrifugal force to the drop motion efficiently the use of radial vane was be promising. We have still several questions on rotary vaned disk. How many vanes are necessary? What is mechanism of atomization by vaned-disk? Therefore, the purpose of this note is to study fundamental characters and to comparatively analyze them fundamentally from an engineering aspect.

For this purpose, three kinds of the device; the flat disk, the vaned-disk and the wheels were prepared for the experiments and the effect of cup shape with/without different vanes on the drop size was mainly examined. The obtained findings will provide valuable information for recovering of molten slag by gas efficiently.

2. Method

Figure 1 shows an experimental apparatus of the rotary atomizer used in this study. It consists of the three parts; the liquid supplier, the rotary device with the plastic-made cup and the drop receiver. Diluted water, instead of slag, was supplied by a roller pump at the desired rate into the center of rotating devices. The tachometer measured the rotating speed of the cup. The receiver was placed to collect drops as much as possible at the specified position; 160 mm in height and 400 mm from the center of the device. The shape of the receiver was rectangular (65×33×6 mm), being filled with a liquid thermoplastic to keep drops. In this method, drops were independently collected without rejoining among drops, since they sink into the thermoplastic bath gradually. The photos, taken by the digital microscope, revealed the size and number of drops obtained. In fact, this method was more practical and less least expensive than that by a high-speed video camera.

Except the shape of rotary device, experiments were carried out under the constant conditions: 28.3 rps in the rotating speed, 1.67×10⁻³Nm1/s (1 Nl/min) in a liquid supplying. Five kinds of the rotary cups were prepared, as shown in Fig. 2. Note that devices of B, C, D, and E were originally made from the device of A. The central bottom of every device was connected to the motor. The vaned-disks of B and C have four or eight vanes. The wheels of D and E have four or eight vanes with cover. The materials of vane and cover were transparent acrylic resin, being constructed with...
The experimental procedure was the following:
1) The device, the motor, and the stand were first placed in the specified position, and then they were assembled.
2) The receiver was firmly placed on the above-mentioned position after being filled up with thermoplastic.
3) The rotating speed of cup was controlled to be 28.3 rps by using the tachometer.
4) The experiments started when the rate of liquid supplement became fixed.
5) By removing the cover of the receiver for five seconds, some drops were collected after the disk surface was photographed at steady-state liquid flow rate and rotating speed of cup.

3. Results and Discussion

Figure 3 is photographs of the cup surface during the experiments. They show an atomization of the liquid definitely, which depended on each device strongly. A sheet-shaped liquid was uniformly discharged from the surroundings of the A device, in contrast a thread-shaped one, so-called ligament, from that of the B, C, D and E ones. Even dry zone was also observed there, because the vanes dammed circumferential flow of the liquid. Reversely, radial flow of the liquid was concentrated in the rotating wheels, the D and E devices, because all of the liquid was discharged along the vane from lip of the device at an accelerating speed thanks to the cover. It is obvious that the vaned-disks, B and C devices, splashed some liquid out over the vanes.

The drops collected during the experiments were graphically evaluated. Based on the observations by the digital microscope, number and size of all the drops collected was evaluated by using a computer.

Figures 4(a) and 4(b) show the drop size distribution collected in all of the experiments. The scattering data is within a standard error span, resulting in waved profile over 0.5 mm of drop diameter. That is, the distribution function, $f(d_m)$, against drop size, in which $\Delta d_m$ is the width of drop size, $n$ is the drop number within $\Delta d_m$, and $N$ is the total drop number. Figure 4(a) is for the vaned-disks, and Fig. 4(b), the wheels, together with the conventional flat disk. The conventional flat disk, A device, as a reference distributed the drop size from 0.05 to 0.90 mm, which had non-symmetric peak with sharp inclination on the smaller side. From 0.05 to 0.20 mm, the three curves were almost superimposed in both figures. On the larger side, the flat disk seems to produce more than the others did. To emphasize this effect of vanes on the drop size, larger part of the flat disk with the vaned-disk or wheel was colored by grey. We can realize clearly that generation of the larger drops, from 0.31 to 0.90 mm, were decreased by adding vanes and the cover to a flat disk. Difference between the vaned-disk and the wheel was caused by the cover, which exterminated liquid splashed.

Table 1 gives average diameters of drops collected in each experiment. The largest drop is 0.260 mm in the flat disk A device.
disk, second, 0.243 to 0.248 mm in the vaned-disk and smallest, 0.229 to 0.236 mm in the wheel. This means, even under the same operating conditions of rotating speed, cup diameter, etc., the vaned-disk was definitely more effective for decreasing the drop size by 6.5 to 4.6 % and the wheel, 11.9 to 9.2 % than the flat disk. The results showed the importance of suppressing slip on the surface of the flat disk and enhancing centrifugal forces ($F = \frac{mr^2\omega^2}{2}$).

Table 2 gives comparison between measured average drop and calculated one by reported equations yet, which well explained by the equations by Frazer et al. and Friedman et al. within error of only 5 %. The equation of Friedman et al.\(^3\) seems to enable us predict even the measured data of vaned-disk successfully. In using the equation, wetted peripheral length was defined as all of circumference and length of vane although the dry zone was observed in the experiment. Regarding to the wheel disk evaluation, strangely the wetted peripheral is defined only from vanes. This is probably the reason why their prediction is much different from measured one. Like that, the definition of the wetted peripheral in theory is completely different from the experimental data.

In conclusions, the wheel rotating disk enhanced atomization most efficiently than the normal vaned-disk and flat disk. The results will be very helpful for designing device of molten slag atomization with heat recovery.

**Table 1.** Comparison of average diameters at different types (mm).

| Type     | A    | B    | C    | D    | E    |
|----------|------|------|------|------|------|
| Average diameter | 0.260 | 0.245 | 0.248 | 0.229 | 0.256 |

**Table 2.** Comparison of the measured average drop and the calculation one.

|            | Measured | Frazer \(^5\) | Friedman \(^6\) | Kitamura \(^8\) | Oyama \(^9\) |
|------------|----------|---------------|----------------|----------------|-------------|
| Flat disk  | 0.260 (100%) | 0.272 (100%) | 0.274 (100%) | 0.294 (113%) | 0.749 (258%) |
| Vaned disk | 0.240 (100%) | -              | 0.22-0.24 (92-100%) | -             | -           |
| Vaned wheel | 0.23 (100%) | 0.35-0.37 (132-165%) | 0.56-0.60 (243-300%) | -             | -           |

\(^*\)Wetted periphery (only for vaned disk) = 2πr × number of vanes × length of vane, Unit mm

**Table 3.** Reported equations for predicting drop size in a rotary atomizer.

| Equation of average drop | Researchers |
|--------------------------|-------------|
| $d = 2 \times 10^{-3} \cdot \sqrt{\frac{D^2}{Q}} \cdot \left( 1 - \frac{r}{D} \right)^{1/4} \cdot \frac{r}{D}^{1/4}$ | Frazer et al.\(^5\) |
| $d = 0.6 \cdot r \cdot \left( \frac{1}{r} + \frac{1}{P} \right)^{1/2} \cdot \mu \cdot \frac{r}{D}$ | Friedman et al.\(^6\) |
| $d = 6.6 \cdot \frac{r \cdot D}{\nu^{1/2} \cdot (\eta \cdot \nu)^{1/2}}$ | Kitamura et al.\(^8\) |
| $d = 400 \cdot N^2 \cdot Q^{1/4} \cdot \eta^{1/3}$ | Oyama et al.\(^9\) |

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