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Separation Performance of Zigzag Air Classifier

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The separation performance of zigzag air classifier with angle of 90 degrees was studied using narrow size fractions of thin square samples and granular samples. The simulation results of air velocity inside the classifier indicated that the zigzag geometry induces a flow pattern consisting of an upward flow and a circulation flow. Experimental results showed that overflow product recovery was described as an integral calculus of normal distribution as a function of dimensionless air velocity (V_A/V_{A50}), where V_A is superficial air velocity and V_{A50} is the V_A at the fifty percent recovery. The V_A values were predicted using the equations derived from dynamics for a particle dropping in air. A monitoring system that utilizes changes in acoustic signals emitted during the process of air classification was developed to separate PET with desired recovery or grade. The technical feasibility of the on-line monitoring of the PET recovery and grade was demonstrated by measuring relative energy of the signals.

Introduction

Air classification has been used in industry and agriculture in such processes as limestone sizing, shredded automobile scrap recovery, and seed and grain cleaning [1]. In a zigzag classifier, a vertical air column is segmented into angled sections or stages. These stages ideally add areas of turbulence within the throat of the classifier. Thus, the air flow in a zigzag configuration is composed of a central column of air flow with disrupted, turbulent air flow at the stage intersections [1,2]. However, separation performance of zigzag air classifier is not clearly understood. In this study, the separation performance of zigzag air classifier with angle of 90 degrees is studied using narrow size fractions of thin square samples and granular samples. Distinct noises are emitted when particles impinge on the walls of the zigzag air classifier. Fundamental studies on the impact sound are performed by analyzing the sound emitted by the impact of a spherical particle on a circular plate. A monitoring system that utilizes changes in acoustic signals emitted during the process of air classification is developed to separate PET with desired recovery or grade. The technical feasibility of the on-line monitoring of the PET recovery and grade is demonstrated by measuring relative energy of the signals.

Experiments

Acoustic Emission from the Impact of a Particle on a Circular Plate

A schematic diagram of the experimental apparatus is shown in Fig. 1 [3]. Twelve spherical beads were used in the experiments. They were glass beads of 2.00, 3.95, 6.00, 8.80 and 11.10 mm diameter, high carbon chromium bearing steel (SUJ) of 1.65, 2.45, 4.00 and 11.15 mm diameter and nylon of 4.00, 6.35 and 9.55 mm diameter and were chosen to emphasize the extremities in approaching the Hertz impact conditions. A 34 cm diameter and 3.16 cm thick steel plate (S45C) was used for the circular plate. Beads were dropped from different heights above the center of the plate. The settling velocities were measured using laser system as shown in Fig. 1. Sound emissions were detected by a sensor (AE-900S-WB, NF Corp.) fixed at the plate. The initial peak frequency (f_p) and the peak height (P) of the impact signal were measured using the digital storage scope (DS-9121, IWATSU).

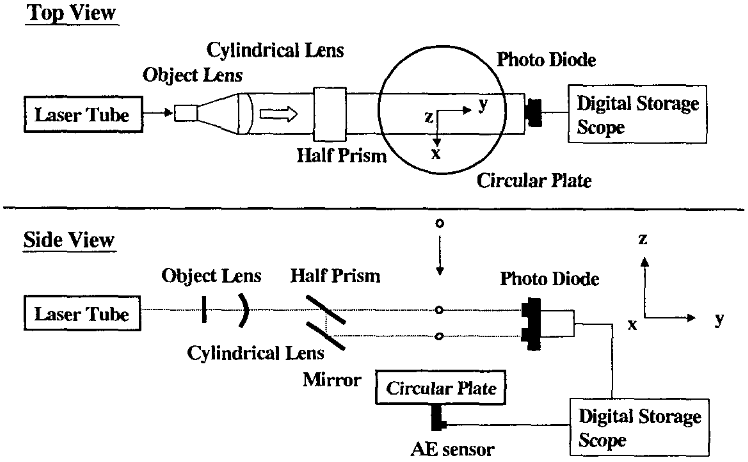

Fig.1 Experimental apparatus for impact velocity and impact sound measurements of particle.

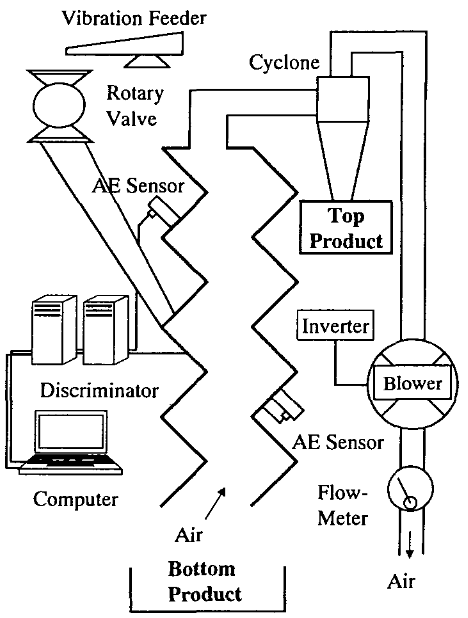

Fig.2 Schematic diagram of the experimental set up.

Set Up of a Zigzag Air Classifier

The experimental set-up (Fig. 2) consists of the feed system, the zigzag air classifier, the underflow (bottom) product collection vessel and a cyclone for the separation of the overflow (top) product particles from the air flow that sucked through the channel by a blower. The classifier used in this study is a 90 degrees zigzag air classifier made of acrylic plate. Samples shown in Table 1 were used for batch experiments. One model sample was supplied to the center of air stream at the height of 1/4 from the lower end of the zigzag air classifier using tweezers. This operation was repeated 30 times. The recovery of an overflow product was calculated.

Table 1 Sample materials used and their weights based on unit of surface area of sample

Model Particles	Weight per Unit of Surface Area (g/m^2)
Paper 1 (PA1)	64
Paper 2 (PA2)	145
Paper 3 (PA3)	225
Plastic Flake 1 (PL1)	165
Plastic Flake 2 (PL2)	350
Plastic Flake 3 (PL3)	543
Aluminum Foil 1 (AL1)	43
Aluminum Foil 2 (AL2)	88
Aluminum Foil 3 (AL3)	140

In the continuous experiments, the sample is fed into the classifier by means of a vibrating feeder and a rotary feeder. The experiments were carried out with PET bottle flakes obtained from PET recycling factory. Sound emissions were detected by a sensor (AE-900S-WB, NF Corp.) fixed at the side of the classifier as shown in Fig. 2. The relative energy (*Er*) from the discriminator was routed to an analog/digital converter (A/D) and stored in the data logger computer.

Results and Discussion

Zigzag Air Classifier

A zigzag air classifier consists of a number of segments with a rectangular cross section joined together at a fixed angle to create a zigzag shaped channel. The simulation results of air velocity inside the classifier are shown in Fig. 3. The results indicated that the zigzag geometry induces a flow pattern consisting of an upward flow and a circulation flow, and that the downward circulations flow enter the main upward flow at the protruding edge [2].

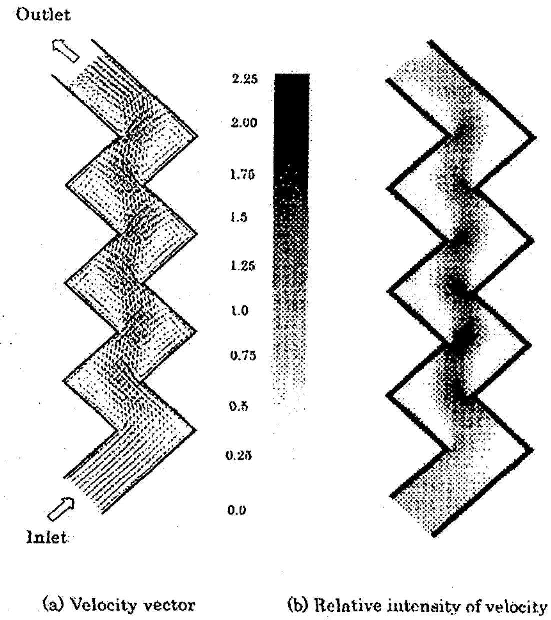

Fig. 3 Simulation results of fluid velocity in the zigzag air classifier. (Inlet air velocity : 4.1 m/s)

Fundamental experiments using narrow size fractions of thin square samples of papers, aluminum foils and plastic flakes and granular samples of coal, quartz and pyrite were conducted with a batch type zigzag air classifier. Figure 4 shows the relationship between superficial air velocity (V_A) and recovery obtained from the experiments using different samples. The recovery of various samples increased with the increase in V_A. Moreover, the air-recovery curves shifted to right-hand side as the sample weight per unit area shown in Table 1 became large. Figure 5 shows the relationship between V_A and recovery obtained from the experiments using different size of papers. The curve shifted to right-hand side with the increase of the size, wherein the sample weight per unit area was fixed. Figure 6 showed that the recovery was described as an integral calculus of normal distribution as a function of dimensionless air velocity (V_A/V_{A50}), where V_A is superficial air velocity and V_{A50} is the V_A at the fifty percent recovery. The V_{A50} values were predicted using equation (2) for thin square samples and equation (3) for granular samples such as coal, quartz and pyrite [2].

$$Recovery = \frac{100}{\sqrt{2\pi}\,\sigma} \int_{-\infty}^{x} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) dx \qquad \cdots(1)$$

$$x = \frac{V_A}{V_{A50}}, \quad \sigma = 0.16, \quad \mu = 1$$

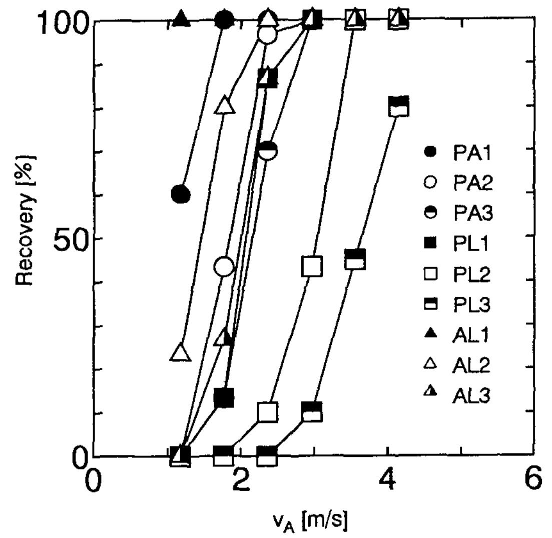

Fig.4 Relationship between superficial air velocity (V_A) and recovery. (Sample size: 20 mm x 20 mm, Materials: see Table 1)

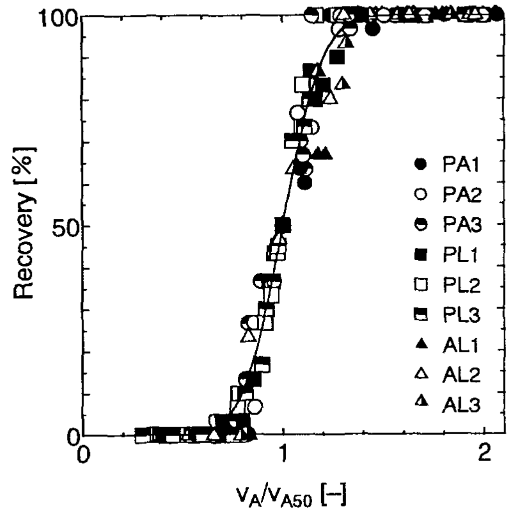

Fig.6 Relationship between dimensionless air velocity (V_A/V_{A50}) and recovery. Line is calculated based on an integral calculus of normal distribution as a function of dimensionless air velocity.(μ=1, σ=0.16)

For thin samples, V_{A50} is expressed as Equation (2).

$$V_{A50} = 12.52A^{-0.3859}\sqrt{m} \qquad (2)$$

Where, A is the surface area and m is the mass of thin sample.

For granular samples, V_{A50} is expressed as Equation (3).

$$V_{A50} = 3.547\sqrt{\rho_p D_p} \qquad (3)$$

Where, ρ_p is the particle density and D_p is the diameter of granular sample.

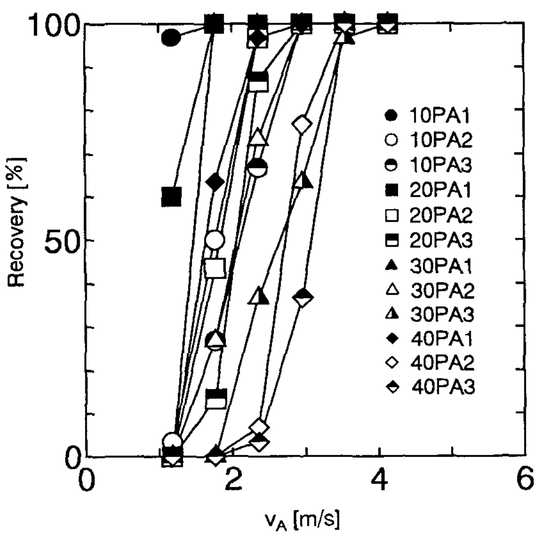

Fig.5 Relationship between superficial air velocity (V_A) and recovery. (Sample: Paper, Numbers before PA mean size of square sample.)

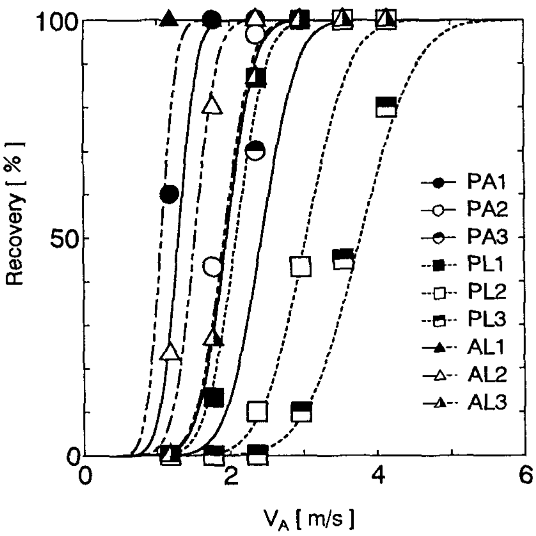

Fig.7 Comparison between experimental results and recovery curves calculated using equations (1) and (2)

Figures 7 and 8 show comparison between experimental results and recovery curves calculated using equations (1) to (3). The good agreement between the calculated and measured values is noteworthy.

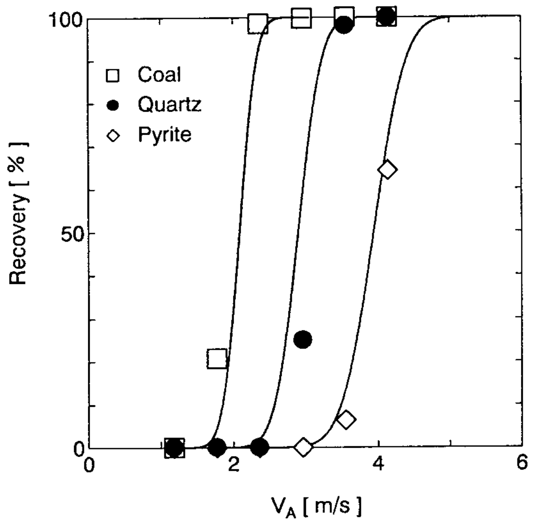

Fig.8 Comparison between experimental results and recovery curves calculated using equations (1) and (3)

Acoustic Emission from the Impact of a Particle on a Circular Plate

Distinct noises are emitted when particles impinge on the walls of the zigzag air classifier. Fundamental studies on the impact sound were performed by analyzing the sound emitted by the impact of a spherical particle on a circular plate [3]. An apparatus for the measurement of particle velocity and the diameter of a spherical particle using acoustic emission due to the impact is developed. Based on the dropping experiments of nylon, high carbon chromium bearing steel (SUJ) and glass particles, the initial peak height (P_1) and the peak frequency (f_p) of the impact sound are related to the impact velocity (v), particle diameter (D), Young's modulus (E_p), Poisson's ratio (μ_p) and particle density (ρ_p). The P_1 and f_p are empirically expressed by Eqs. (4) and (5) respectively. Figures 9 and 10 show the relationship between measured results and calculated results obtained by Eqs. (4) and (5). If the properties of spherical particle are known, it is possible to estimate D and v from these equations by measuring P_1 and f_p of the acoustic signal due to the impact of a particle. If a mass of spherical particle is known, it is also possible to estimate E_p and μ_p from these equations by measuring D and v using the apparatus.

$$P_1 = 7.99\times10^{-1}\times D^{2.49}\times v^{1.27}\times E_p^{0.372}\times \mu_p^{0.738}\times \rho_p^{0.353} \quad (4)$$

$$f_p = 1.11\times10^{-2}\times D^{-0.945}\times v^{0.120}\times E_p^{0.0522}\times \mu_p^{-1.11}\times \rho_p^{-0.018} \quad (5)$$

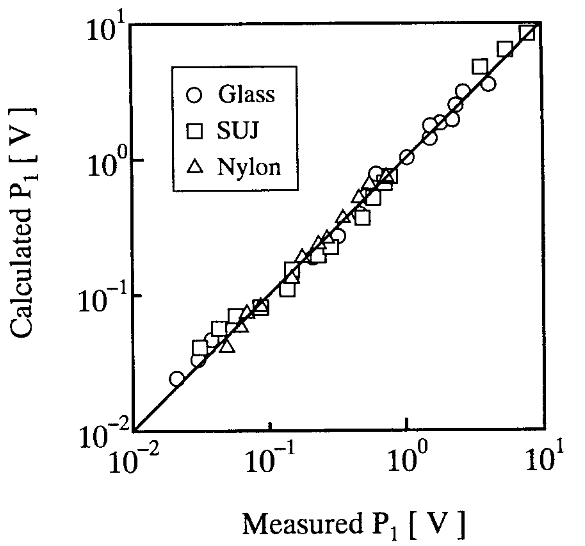

Fig.9 Relationship between calculated P_1 from equation (4) and measured P_1.

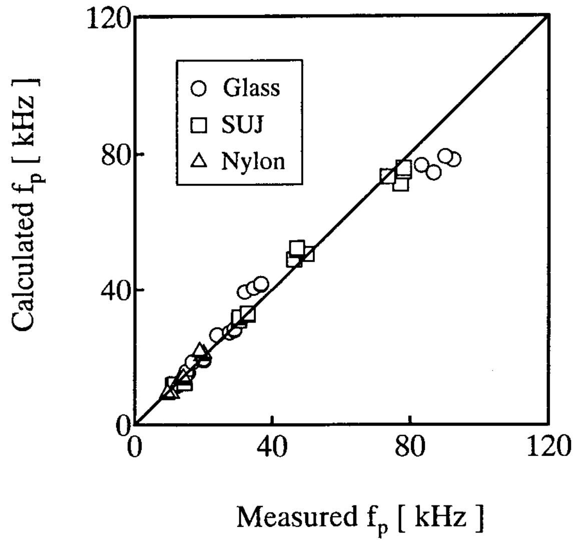

Fig.10 Relationship between calculated f_p from equation(5) and measured f_p.

On-line monitoring for zigzag air classification

In the zigzag air classification process, the particles impinge on the wall of the zigzag vessel causing it to vibrate and emit acoustic sounds. As the number of particles increases, the initial burst-type emission becomes a pseudo-continuous-type emission due to overlapping of events. The event rate and oscillation rates are dependent on the threshold setting and are ideal for burst type signals. Noises emitted by large number of particles are continuous-type signals, which make adjustments of the amplifier gain and the threshold level very critical [4,5]. Envelope processing of the signal is independent of the threshold, making it suitable for monitoring noise emission of impact particles. The envelope of a signal is a fluctuating d.c. output whose amplitude is proportional to the energy inherent in the signal. Since noises emitted by particles are attributed to the release of energy due to the impact of particles, the measurement of the parameters related to the energy content of the signal, such as envelope, is considered to be an indication of the impact energy of the particles. Fluctuation in the envelope is eliminated by passing it through an averaging circuit. In this study, henceforth, the output of the averaging circuit is called the relative energy or *Er*.

Figure 11 shows relationship between top product throughput rate of zigzag air classifier and *Er*. In this experiment, PET or polystyrene samples were used. This result indicates that *Er* increases with an increase in number of the impact particles at the wall in the upper part of zigzag air classifier. With a constant particle diameter, *Er* increases with an increase in the number of impact particles (N) and with a constant N, *Er* also increases with an increase in the particle diameter. *Er* is a function of amplitude and considered to be proportional to P_1 expressed in Equation (4). Thus, *Er* is considered to be a function of v, D, E_p, N, ρ_p and μ_p.

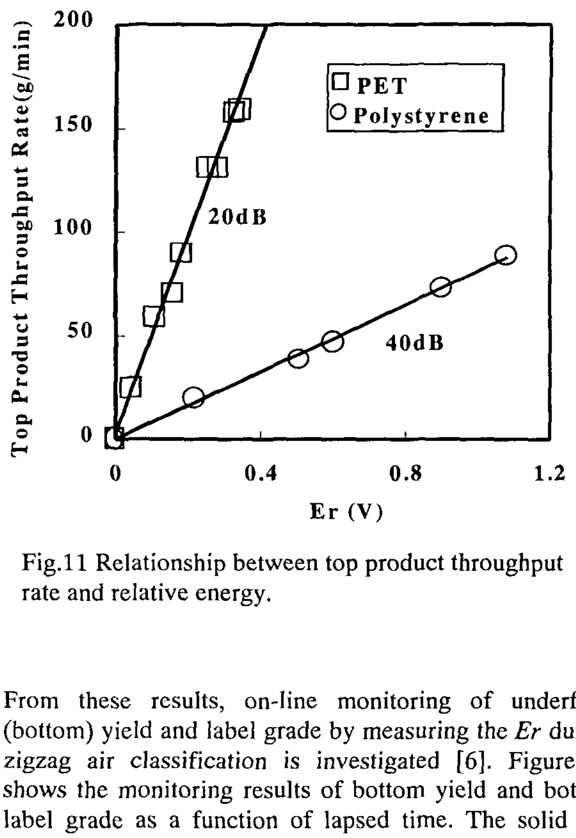

Fig.11 Relationship between top product throughput rate and relative energy.

From these results, on-line monitoring of underflow (bottom) yield and label grade by measuring the *Er* during zigzag air classification is investigated [6]. Figure 12 shows the monitoring results of bottom yield and bottom label grade as a function of lapsed time. The solid and broken lines show the average estimated values obtained from *Er* and the average measured values, respectively. The closeness of the estimated and measured average values clearly demonstrates the feasibility of the method of noise measurement for on-line monitoring of yield and grade.

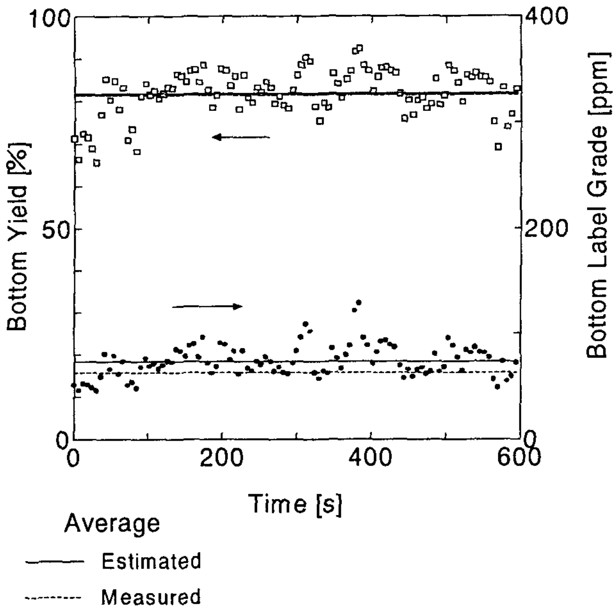

Fig.12 Calculated bottom yield and bottom label grade as a function of lapsed time. Lines indicate average values.

Conclusions

The separation performance of zigzag air classifier with angle of 90 degrees was studied using narrow size fractions of thin square samples and granular samples. Experimental results showed that overflow product recovery was described as an integral calculus of normal distribution as a function of dimensionless air velocity (V_A/V_{A50}). The V_A values were predicted using the equations derived from dynamics for a particle dropping in air.

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A monitoring system that utilizes changes in acoustic signals emitted during the process of air classification was developed to separate PET with desired recovery or grade. The technical feasibility of the on-line monitoring of the PET recovery and grade was demonstrated by measuring relative energy of the signals.

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