Transaction Paper

Airflow fields simulation on passive pulsing air classifiers

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Synopsis

Early research showed that the separation of particles based upon their density was not possible in steadily rising air streams. The terminal velocities of moving spheres are determined by their aerodynamic characteristics. This prevents particle separation by density in standard air classifiers. Passive pulsing air classifiers have accelerated airflow in certain regions, which achieves density-dominant separation. Numerical simulation of airflow within passive pulsing air classifiers was done to estimate airflow patterns near a damper. Analysis of those results shows the significant acceleration of the airflow above the damper. Laboratory trial separations have shown that passive pulsing classifiers are superior to standard air classifiers.

Keywords: pulsing airflow, passive, simulation of airflow models, acceleration effect, density

Introduction

Vertically rising, or cross-flow, air streams are used for separating particles according to their different physical characteristics in conventional methods of separation. Such methods have been used to separate wheat from chaff in agriculture industries and to extract ore from overburden in mineral processing for a long time. In recent years, airflow classification research has considered the important problems of applying air classifiers to the separation of municipal solid waste (MSW) for resource recovery and of separating valuable metals from waste electronic products.

Classification of particles within steadily rising air streams is based on the particles having different terminal velocities in free fall. The terminal velocities, in turn, are dependent upon the particles' sizes, shapes and densities. The terminal velocities of valuable minerals and their tailings often overlap each other since actual particles have a range of sizes and shapes independent of their constitution. This causes low separation efficiency when utilizing standard straight-pipe air classifiers, so the desired density-dominant separation is not achieved[1].

Consider spherical particles A and B in a certain rising airflow, where particle B is a relatively denser particle but its size is small enough to be aerodynamically lighter than particle A, which is relatively less dense but large enough to be aerodynamically heavier. Density-dominant separation could be achieved if the denser sphere B fell and the less dense sphere A rose. However, a conventional air classifier cannot achieve density-dominant separation since the less dense sphere, A, is aerodynamically heavier and thus falls faster than sphere B. For this reason, such particle pairs are referred to as 'confused' particles. These greatly concern air-classifier designers. The objective of this study of the separation mechanism of passive pulsing air classifiers is to achieve density-dominant separation, rather than aerodynamic-characteristics dominant separation.

Laboratory experimental settings

Because the performance of standard straight-pipe air classifiers is not satisfactory, since they are not able to achieve a density-dominant separation, zig-zag air classifiers and passive pulsing air classifiers became the designs of interest for study (Figure 1)[2].

Passive pulsing air classifiers have a cross-sectional area, which expands and contracts along the length of the device. Thus, the airflow is constricted in certain regions during its rising through the device. This imposes a distance-varying airflow, which alternately accelerates and decelerates as the airflow passes through the constricted regions. The particles are subjected to an acceleration due to the actions of aerodynamic drag upon them. Previous research showed that the acceleration effect on the particles would not only change the order of confused particles' rise and fall, but also favours the density-dominant separation of the particles[3].

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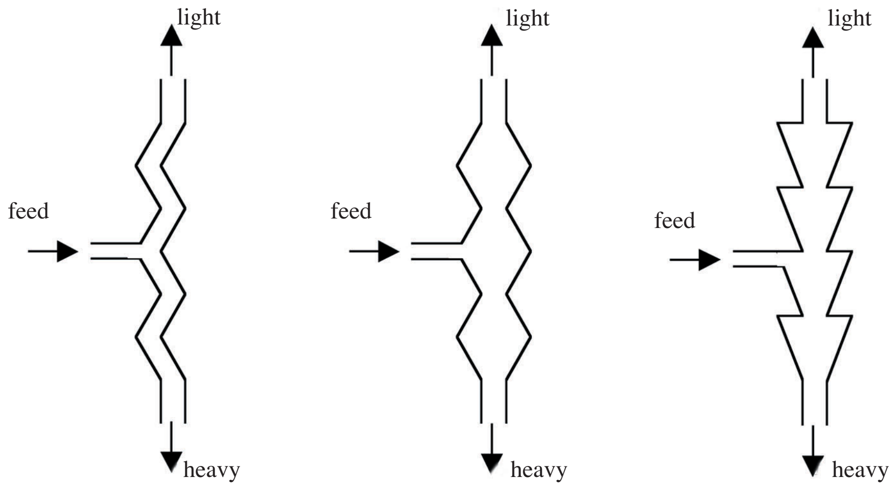


Figure 1—Passive pulsing air classifiers

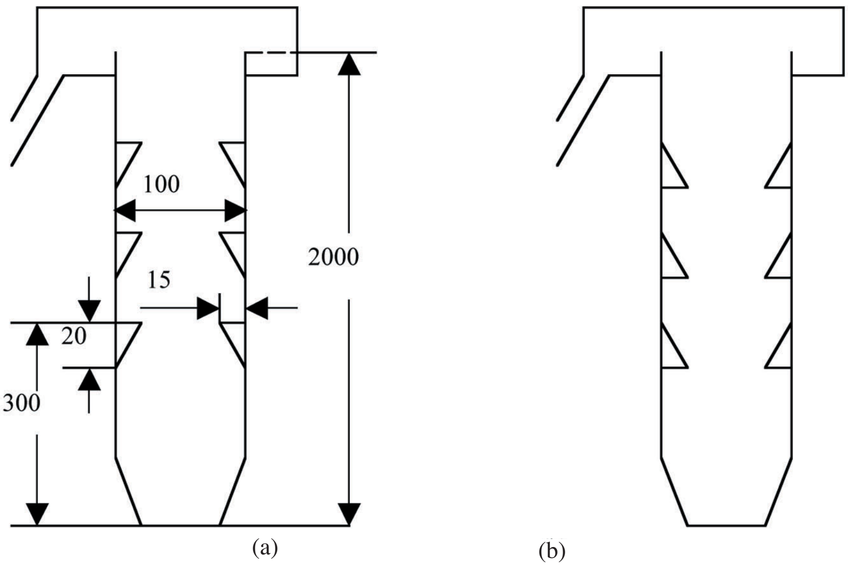


Figure 2—Laboratory passive pulsing air classifiers

Two passive pulsing air classifiers were adopted as experimental systems in actual, laboratory material separation tests (Figure 2)[4].

Figure 2(a) represents a design where the ampliations have a ramp cross-section, which gradually introduces a constriction when passing from the bottom to the top of the device. The total length of the separating column is 2000 mm and the lowest constricting damper is fitted 300 mm above the column bottom. The damper reduces the column radius by 15 mm over a vertical distance of 20 mm. Figure 2(b) represents an alternate design where the constriction is gradually reduced when passing from bottom to top. Otherwise, its geometrical parameters are the same as classifier (a). Laboratory classifiers are fitted with three or four dampers, generally. Only a representative section of the separating column is selected for computer simulations of the airflow fields in the separating area[4].

During the laboratory separation process, a Memrecam Ci3 Moving Particle Analyzer of NAC Corporation, made in Japan, is used for taking photographs and analysing the flow. The highest photographing speed of the Memrecam Ci3 camera is 2 000 frames/s. In the experiments, we set the camera speeds at 500 frames/s. Specialized image analyzing software, the New Movias, was used for image computations to obtain the kinematic characteristics of the moving particles in the airflow. The images and analysis results of the separation process, which were obtained by the Memrecam Ci3 and the New Movias, and the numerical simulation results of the airflow patterns are compared here .

Simulation of the airflow patterns

Boundary conditions and airflow patterns analysis

During actual separation experiments, the separation results of plastic and aluminium pieces showed both air classifiers (Figure 2) were relatively ideal for material separating when the air velocity was 10 m/s. So, in simulations, the air velocity was set at 10 m/s. The simulations assume that the air velocity is symmetrical at the inlet and that the cross air velocity, perpendicular to the direction of inlet airflow, is zero, and that the boundary condition is no slippage at all sides (all velocity embranchments are zero). Because the airflow is within a low speed range (<100 m/s) and it is compressed slightly, the flow of air can be regarded as uncompressed flow. As a result, in simulation, we regard it as an uncompressed airflow.

Where,

Airflow velocity at the inlet	10.0 m/s
Pressure at the exit	0 Mpa
Air temperature	20°C
Air density	1.205 kg/m^3
Air viscosity	1.8135 x 10^{-5} pa.s

According to the Reynolds formula, we calculated that the Reynolds number, Re, is more than 2 000. Hence, the flow in the separating column is turbulent.

To study the effective regions of the separating column of the two passive air classifiers shown in Figure 2, the fluid kinetic computation software ANSYS FLOTRAN for airflow pattern analysis was used. The simulated flow fields are used to discuss the mechanisms of material separation, and to interpret the differences in separating performance between standard and passive pulsing air classifiers.

Analysis of air stream pattern of passive pulsing air classifier A

The characteristics of passive pulsing air classifiers are that they have a high efficiency of separation and speedy separation. Effective separation of heavy and light particles can be achieved in a short time. The simulation results show separation efficiency is affected greatly by the dampers, and the regions above and below the dampers are the main separating regions. In these regions there are acceleration and deceleration effects, which lead to effective separation of materials. Pulsing airflow along the height of the column will be produced when multiple dampers are fixed.

Passive pulsing air classifier A has a lower sectional area, which gradually constricts, as shown in Figure 2(a). Its velocity vector distribution is shown in Figure 3. From the velocity vector distribution image, a sharp break of airflow velocity can be observed near the damper. The highest airflow velocity in the centre of the upper part is 18.5 m/s, and the velocity transition region from 10 m/s to 18.5 m/s is very small. The phenomenon shows airflow generates a remarkable acceleration effect here. The acceleration effect is highly favourable for achieving density-dominant separation of particles. The airflow velocity above the damper at the centre of the column in the Y direction reaches the highest value, and decreases gradually towards the sides, then increases slightly. This phenomenon is caused by eddies generated near the walls above the damper. The airflow velocity distribution gradually smooths out with an increase in height above the damper.

The airflow velocity distribution in the X direction is shown in Figure 4(a). In Figure 4(a) we can see that the absolute values of velocity at two small regions of the damper's sharp angle is relatively high, and the highest value of the velocity is 6.6 m/s. There are two symmetrical elliptic regions above the damper, and the velocity in the X direction in this region is higher. This is the most distinct difference between standard air classifiers and passive pulsing air classifier A. There is no obvious difference of velocities in the X direction in other regions, and the distribution is steady. Its alternating range is from –0.75 to 0.75 m/s.

The total pressure distribution of passive air classifier A is shown in Figure 4(b). It can be seen that the total pressure distribution is similar to the velocity distribution from the figure. The pressure below the damper and at the central region above the damper is the highest, and the value is 140 pa (relative value). The pressure near the walls above the damper is the lowest, and the value is –93.7 pa (relative value). According to this observation, we can deduce that the eddy-current phenomenon is produced in this region and the pressure distribution is symmetrical.

Analysis of air stream pattern of passive pulsing air classifier B

The velocity vector distribution of passive pulsing air

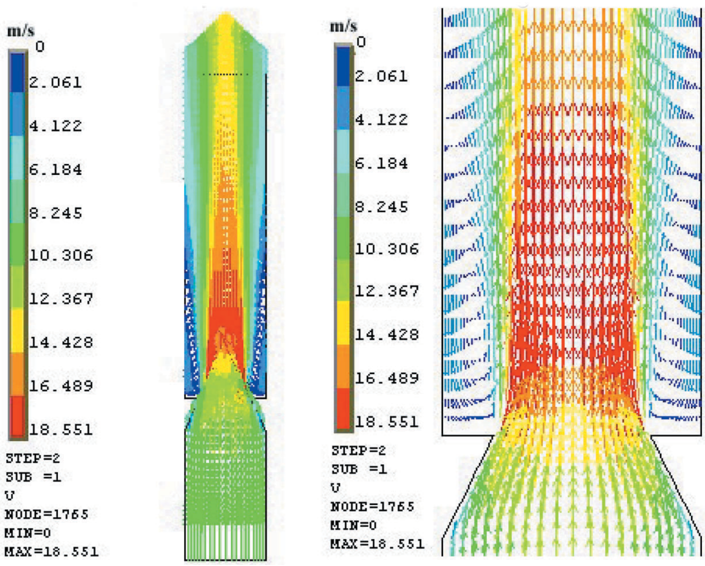
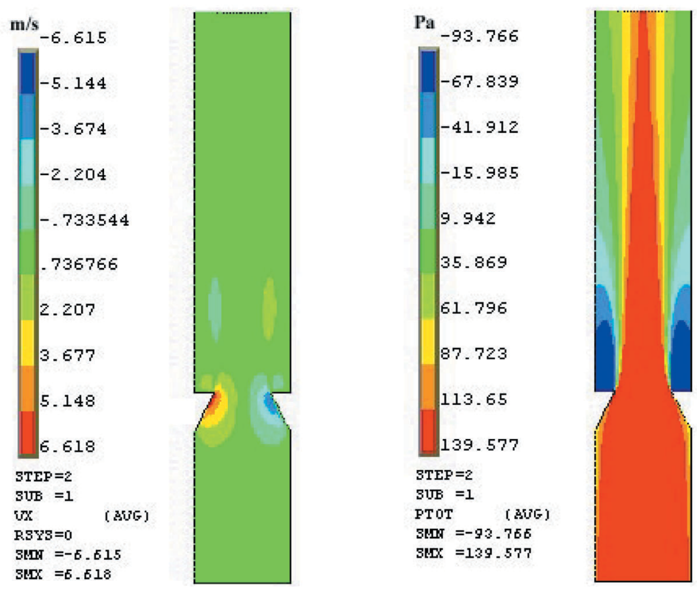


Figure 3—Velocity vector distribution in passive pulsing air classifier A

classifier B is shown in Figure 5. In the figure we can see that the effect of the damper on the airflow velocity distribution is very significant. The airflow velocity around the damper and at the central part above it reaches about 20 m/s. This is twice the velocity as at the inlet and also much greater than the corresponding velocity of passive pulsing air classifier A. Also, the velocity gradient is steeper than seen in classifier A. This phenomenon indicates acceleration happens in this region. Two symmetrical eddies form above the damper near the walls. The photos taken with the Memrecam Ci3 moving particle analyser confirm that there is an eddy-current field here. The eddy disperses the materials, which makes an efficient separation between the heavy and the light particles. The high velocity air stream in the centre of the column takes the light particles out quickly, so the separating time is shortened. The air current gradually stabilizes with increasing height above the damper.

The velocity vector distribution in the X direction of passive pulsing air classifier B is shown in Figure 6(a). It can be found from the figure that the velocities at the two very small regions near the damper's sharp angle are very high. The highest absolute value is 11 m/s, which is much higher than 6.6 m/s of that in air classifier A. It indicates that more intense eddies occur here. The velocity in the X direction above and below the damper shows little variation, the alternating range is from –1.3 to 1.3 m/s.

The total pressure distribution of passive air classifier B is shown in Figure 6(b). The figure indicates that the pressure in regions near the damper is very high, reaching 248 pa (relative value), which is much higher than the



(a) (b)

Figure 4—Velocity vector distribution in X direction and pressure distribution of classifier A

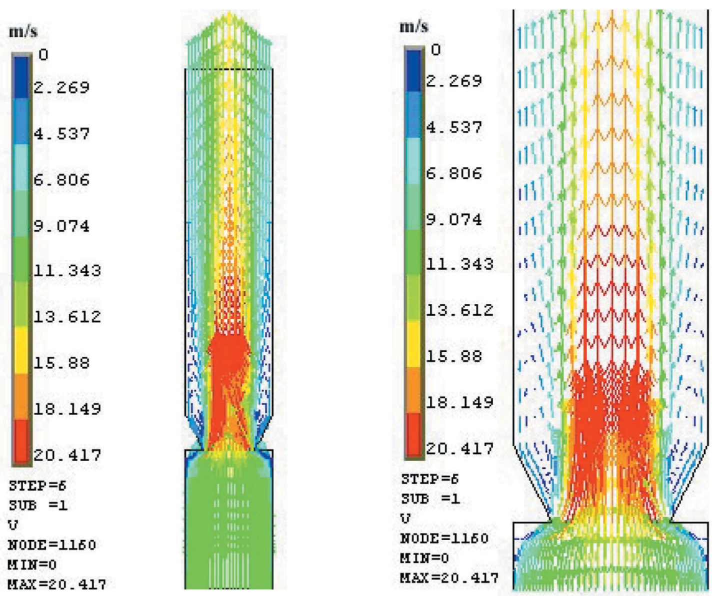


Figure 5—Velocity vector distribution in passive pulsing air classifier B

pressure in air classifier A in the same region. The pressure distribution of classifier B is very different from that of classifier A, and its high pressure region is localized at a relatively small area below the damper. The phenomenon shows the acceleration of the airflow is generated here. The pressure at both sides above the damper is lowest, even having a negative value. It is caused by the eddy-current effect, and the pressure pattern is symmetrical.

From the above flow pattern analysis, it is indicated that classifier configuration B is more effective than classifier A in flow acceleration. So the classifier B was selected for following laboratory separation experiments.

Separation experiments

A laboratory-scale air classifier was constructed from several segments of plexiglases column, whose internal diameter was 50 mm and whose length was 300 mm, joined together by flanges. Dampers, whose dimensions are the same as that in classifier B in Figure 2, were fitted at the flange joints. Four configurations of pulsing air classifiers were tested by installing one, two, three and four dampers. These were labeled respectively classifiers C, D, E and F. The air classifier labeled G is a standard straight-pipe air classifier without dampers.

Pieces of aluminum and polyester plastic were used as feed materials. The pieces had specific gravities of 2.70 g/cm^3 and 1.60 m/cm^3, respectively. The geometrical sizes of the aluminum pieces and the polyester plastic pieces were 10 x 7 x 2.8 mm and about 10 x 10 x 3 mm, respectively. 200 aluminium pieces and 200 polyester plastic pieces were weighed and then mixed together and fed into the air classifier. The samples were collected at the top collecting plate and bottom discharge gate. The separating airflow velocity was 10 m/s, and the separating time was 100 seconds. Most materials were separated before 20 seconds; a few materials were separated after 20 seconds in the classifiers. When the separating time reached 60 seconds there were almost no additional light particles being separated, suggesting the separating operation is over by this time.

For evaluating the separation effect, the total separation efficiency[5] of light and heavy production is a key index. Also, the range of air velocities useful for separation is another important index[6].

The total separation efficiency, E_f, can be calculated by the formula[5]:

$$E_f = [(X_1/X_o)\times(Y_2/Y_O)]^{1/2}$$

where X_1 is the mass of light material in the product; X_o is the total mass of light material in the feed; Y_2 is the mass of heavy material in the product and Y_0 is the total mass of the heavy material in the feed.

Separation experiments of actual material indicate that air classifier D has the highest separation efficiency, followed by classifiers C and E. The results of separation experiments also indicate that pulsing air classifiers C, D, E and F, which are fixed with dampers, are more efficient than the standard, non-pulsing, air classifier before 60 seconds separating time. After the separating time exceeds 60 seconds, nearly no additional light products in air classifiers labeled C, D and E are separated. Only in air classifier F are a few heavy products separated as light products, so the separation efficiency of air classifier F falls. This phenomenon shows the number of dampers should be in an appropriate range .

Table I indicates the experiment data of separation efficiency with different air classifiers. Figure 7 is the diagrammatic interpretation of Table I.

An important criterion for good classifier design is that it will maintain good separation efficiency over a wide range of airflow rates. We define the 'effective range of airflow rates' as the range of airflow rates over which the separation efficiency is greater than 90%. Figure 8 shows the

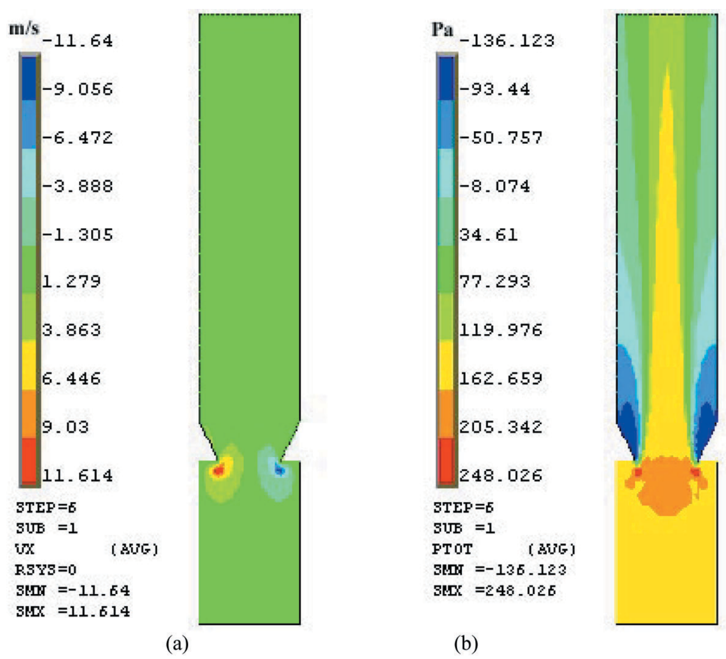


Figure 6—Velocity vector distribution in X direction and pressure distribution of classifier B

Table I

Separation efficiency of the air classifiers with different time intervals

Time (s)	E_f (G)%	E_f (C)%	E_f (D)%	E_f (E)%	E_f (F)%
10	82.01	91.26	89.72	85.97	85.08
20	86.60	94.50	95.26	92.72	92.37
30	89.02	95.02	96.96	93.80	92.87
40	90.00	95.94	97.36	94.27	92.50
50	91.10	96.45	97.62	94.27	92.10
60	91.79	96.84	98.12	94.51	91.94
70	92.06	97.10	98.25	94.63	91.67
80	92.47	97.22	98.62	94.75	91.38
90	92.74	97.35	98.75	94.87	91.38
100	93.01	97.61	98.87	94.87	91.38

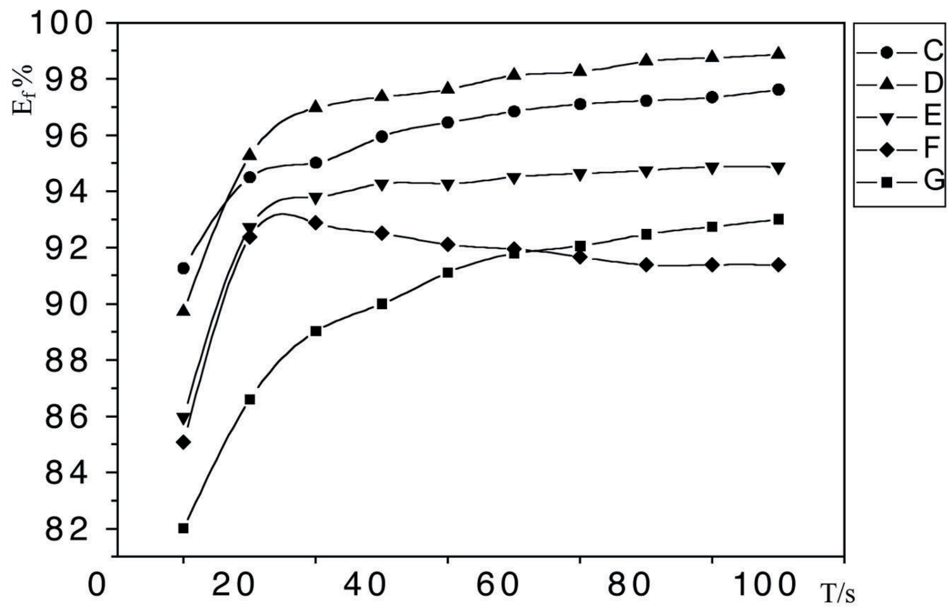


Figure 7—Efficiency-time curves of the air classifiers

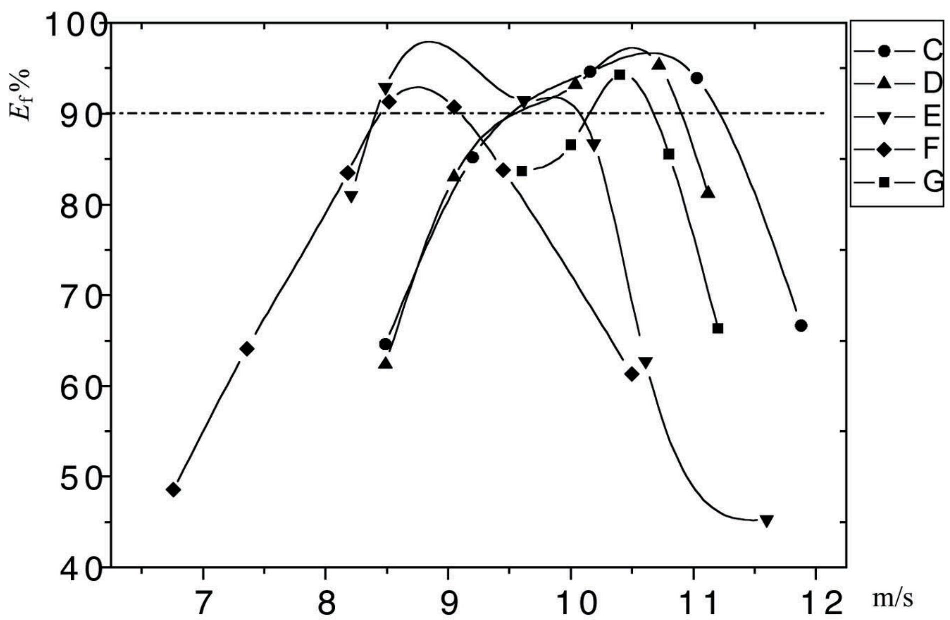


Figure 8—Effect of air velocity on separation efficiency

relationship between separation efficiency and separation airflow velocity for different air classifiers. It indicates that the effective range of airflow rates for the standard non-pulsing air classifiers is 0.52 m/s, while effective range of airflow rates is 1 m/s or more for passive pulsing air classifiers fitted with dampers. The effective range of airflow rates of the air classifier labeled C reaches 1.72 m/s. According to this result, we understand that the effective range of airflow rates of passive pulsing air classifiers are wider than that of the non-pulsing air classifiers. Therefore, the design is more robust in that it can maintain good separations over a wider range of airflow rates.

Conclusions

- ➤ Standard air separation is based on differences of the particles' terminal velocities under the influence of aerodynamic drag. The terminal velocity depends in turn upon the sizes, shapes and densities of the particles. Theoretically, it is impossible to achieve a purely density-dominant separation in steadily rising air streams.
- ➤ Passive pulsing air classifiers cause the airflow to accelerate by introducing constricting dampers in certain regions. The accelerating airflow not only makes the particles change their ascending or descending order in the raising and falling process, but also favours the density-dominant separation of particles.
- ➤ The flow patterns inside passive pulsing air classifiers were analysed to show that the damping regions create very strong acceleration/deceleration phenomena. The simulation tests show there is an eddy-current phenomenon around the dampers. These phenomena are conductive to particle separation by density and to the dispersal of material.
- ➤ The results of actual material separation show that passive pulsing air classifiers are superior to standard air classifiers in separation performance and have a wider operable airflow velocity range.

References

1. STESSEL, R.I. and PEIRCE, J.J. Separation of Solid Waste with Pulsed Airflow[J]. Journal of Environmental Engineering, 1985, 111(6): pp. 833–849.
.2. JACKSON, C.R., STESSEL, R.I., and PEIRCE, J.J. Passive Pulsing Air-Classifier Theory. *Journal of Environmental Engineering*, 1988, vol. 114, no. 1, pp. 106–119.
3. STESSEL, R.I. and PEIRCE, J.J. Particle Separation in Pulsed Airflow. *Journal of Engineering Mechanics*, 1987, vol. 113, no. 10, pp. 1594–1607.
4. WANG, H.F. Study on the Separation Mechanism and Airflow Pattern of Pulsed Air Classifiers. Master's thesis China University of Mining and Technology, 2004. pp. 54–68.
5. CROWE, P.B. and PEIRCE, J.J. Particle Density and Air-Classifier Performance. *Journal of Environmental Engineering*, 1988, vol. 114no. 2 pp. 282–399.
6. PEIRCE, J.J., STESSEL, R.I., and VESILIND, P.A. Quantifying the Performance of N-way Separators. *Resource and Conservation*, 1983,vol. 10: pp. 243–247.
7. DUANG, C.L., HE, Y.Q., WANG, H.F., and WEN, X.F. Separation Mechanism of Passive Pulsing Air Classifier. *Journal of China University of Mining and Technology*, 2003, vol. 32, no. 6, pp. 725–728. ◆