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Improving recovery efficiency for pyrite from high sulfur gangue by collaborating vibration energy in fluidized bed

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Abstract: It is of great significance for economic development and environment protection to recover pyrite from high sulfur gangue in China. Due to problem of global water shortage, it is urgent to explore more efficient separation methods without consuming water in mineral processing field. This study has proposed an innovative method for pyrite recovery using vibration fluidized bed based on particle density difference. Detailed separation results depicted that sulfur content of -6+3 mm, -3+1 mm and -1+0.5 mm samples increased to ca. 37%, 33% and 27%. The highest comprehensive recovery rate reached ca. 72%. Compared with recent wet methods, separation results indicated that it was satisfied for pyrite recovery using vibrated fluidized bed. Thus, it is a feasible way for pyrite recovery from high sulfur gangue through the dry method of fluidized bed by collaborating vibration energy.

Keywords: Vibrated fluidized bed, pyrite recovery, density segregation, high sulfur gangue, dry beneficiation

1. Introduction

As one of primary energy sources in the world, coal accounted for about 30% of main energy, especially more than 65% in China (Dong et al., 2015). Due to requirements of environmental protection, it is necessary to conduct coal cleaning and improve efficiency of coal utilization. Coal beneficiation, as an effective method, could decrease ash content through reducing gangue in the coal. With the development of coal cleaning methods, the preparation proportion of coal is constantly increasing. As a result, gangue yield experiences upward tendency, and gangue has become the largest industrial waste (Querol et al., 2008). Recently, gangue pile has deleterious consequences on air pollution, spontaneous combustion and land occupation (Yu et al., 2013). Furthermore, many harmful elements, such as S and Hg, are existed in the gangue leading serious damage to land soil and air conditions (Hao et al., 2013). Government has put forward several policies of "green mining" in China (Xing et al., 2009; Zhang, et al., 2015). Therefore, gangue utilization becomes an important topic in the mineral field. Among different research areas of gangue utilization, extracting useful minerals has become one of hot topics (Ledin et al., 1996; Patra et al., 2004). Pyrite is an important mineral in gangue and is also an important raw material to produce rubber, paper, textile and matches (Bunkholt et al., 2013; Khataee, et al., 2015). Consequently, recovering pyrite from gangue is not only suitable to achieve goal of "green mining", but also beneficial to turn waste into treasure.

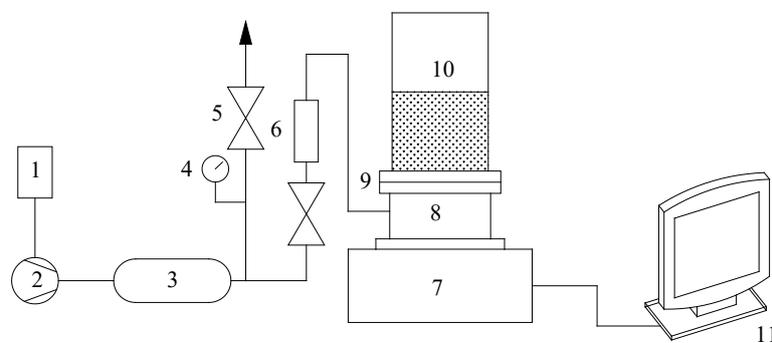
Recently, wet beneficiation processes with amount of water, like dense medium machine, cyclone and flotation, have been already used for pyrite separation (Brozek et al., 2013; Nakhaei et al., 2013; Pan et al., 2014; Deng et al., 2017; Kumar et al., 2017). However, coal mainly distributes in the arid area actually, such as Brazil, South Africa and Northwest of China. Wet separation methods would be under restrictions due to amount of water consumption (Oshitani et al., 2012; Sahu et al., 2013; Tan et al., 2017; Tang et al., 2017). In addition, traditional wet methods have complex slime water treatment system, which would increase system investment cost (Sekito et al., 2004), especially for recovering pyrite from

tailings. Compared to wet processes, dry methods could achieve suitable separation efficiency without water utilization and subsequent procedures. Since 1920s, many dry methods, such as compound dry separator, air jig separator and counter flow fluidized bed, have been used for +6mm mineral separation. In particular, air dense medium fluidized bed, designed by China University of Mining and Technology, has been realized industrialization with production capacity of 40 ~ 60 t/h. Meanwhile, the first dry coal beneficiation plant was built in Xinjiang Province, China. The probable error E could reach 0.05g/cm³ in industry, showing a satisfied separation efficiency (Zhao et al., 2016). However, pyrite mainly distributes in the gangue with small size (<6mm) and air dense medium fluidized bed is not suitable for fine particle separation. Therefore, many scholars have focused on fine particle beneficiation in the fluidized bed, like vibrated fluidized bed (Yang et al., 2013; Zhou et al., 2016). Based on above analysis, this study attempted to use vibrated fluidized bed for pyrite recovery from high sulfur gangue. In the study, gangue characteristics were firstly analyzed in detail. Effect of vibration intensity on the separation performance was investigated at different gas velocities. Separation efficiencies were compared between traditional and vibrated fluidized bed. In addition, separation results at the optimal conditions were analyzed by the Scanning Electron Microscopy (SEM). Meanwhile, we also compared separation efficiencies between this study and recent wet technologies.

2. Material and methods

2.1. Apparatus

Separation system mainly contains air supplement apparatus, fluidized bed and vibration generator device, as shown in Fig. 1. Air supplement apparatus mainly includes blower, buffer tank, flow meter and controller. Fluidized bed is made of transparent plexiglass plate with diameter of 120mm and height of 300 mm. Vibration generator device consists of control device, vibration generator and vibrator platform. Vibration generator could afford vibration amplitude of 0~51 mm and vibration frequency of 5~5000 Hz. Meanwhile, it could provide fluidized bed with different kinds of vibration modes, such as sinusoidal vibration, frequency sweep vibration and random vibration. In this study, sinusoidal vibration is used for particle separation in vertical direction.



1. Air filter; 2. Roots blower; 3. Pressure tank; 4. Pressure gauge; 5. Valve; 6. Rotameter; 7. Vibrated bed; 8. Air chamber; 9. Air distributor; 10. Fluidized bed; 11. Vibration control system.

Fig. 1. Schematic diagram of vibration fluidized bed system

2.2. Materials

The gangue sample was chosen from Xintai, Shandong Province, China. Gangue basic characteristics were analyzed, as shown in the Table 1. The sulfur content (S%) of gangue was 19.18% measured by total sulfur analyzer machine. The moisture content was 0.84% which could provide favourable conditions for dry separation methods. The element compositions were further analyzed by X-ray Fluorescence Spectrometer (XRF). The results showed that chemical elements of Al, Si, S and Fe accounted for relatively higher proportion in the gangue, which indicated the gangue sample mainly consisted of pyrite, quartz and kaolin. Because pyrite basically distributes with fine granular, gangue was crushed for -6mm for the completely liberation and divided into -6+3mm, -3+1mm and -1+0.5mm

size fraction, which respectively accounted for mass fraction of 40.64%, 27.12% and 14.60%. Density composition of three samples were further analyzed using dense liquid, as shown in Fig. 2. The results showed that sulfur content of samples with +2.9 g/cm³ were considerably higher than that with other density levels, which were all beyond industry standard requirements, sulfur content (S%=35%).

Table 1. Basic industrial and element analysis of gangue

Sample	Ash / %	Moisture content / %	Sulfur content / %	Main chemical elements		
				Si / %	Fe / %	Al / %
Gangue	68.12	0.84	19.18	19.36	16.61	5.49

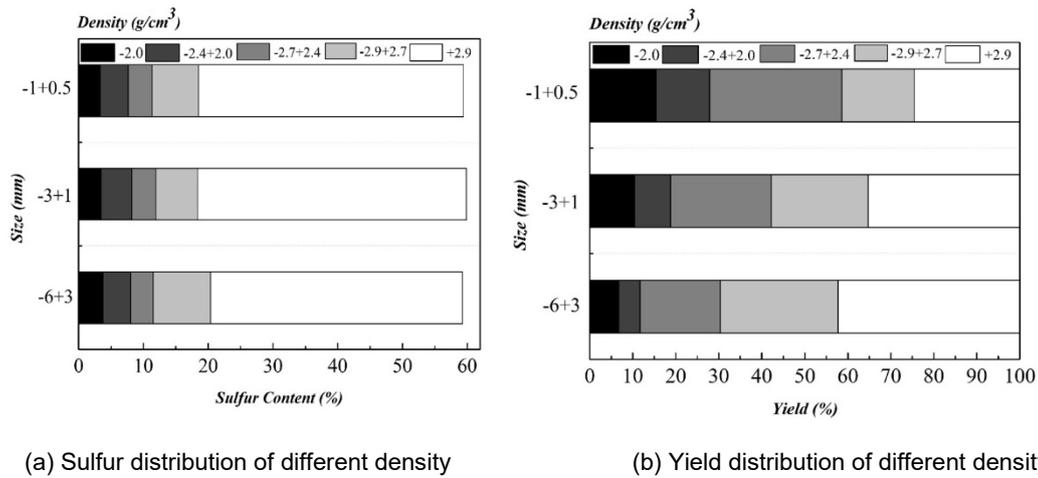


Fig. 2. Analysis of density composition for the samples

2.3. Evaluation index

Samples are generally divided into 5 layers to analyze distribution of sulfur content in the fluidized bed. As an experimental method for analysis of mineral characteristics, the repeated experiments were conducted for each sample in order to verify the results. Sulfur content of different samples would be measured more than twice. If variation of sulfur contents was lower than 1%, average value would be used as sulfur content of samples in the study. However, if variation of sulfur contents was more than 1%, repeated experiments would be conducted again to ensure data accuracy. In addition, segregation degree of sulfur content (D_{sulfur}) has been proposed for analysis of separation efficiency. The expression is defined as Eq. (1):

$$D_{sulfur} = \sqrt{\frac{\sum_{i=1}^n (S_i / S_0 - 1)^2}{n - 1}} \quad (1)$$

where S_i is sulfur content of i^{th} layer, %, S_0 is average sulfur content, %, and n is total number of layers. The index reflects that sulfur of each layer deviates from average sulfur content. No density segregation of particles is obtained at $D_{sulfur} = 0$ and higher D_{sulfur} value indicates higher degree of density segregation.

In addition, recovery rate is also used to reflect efficiency of pyrite recovery, as Eq. (2):

$$\varepsilon = \frac{\gamma S_c}{100 S_0} \times 100\% \quad (2)$$

where S_c is the concentrate grade, %; γ is the yield of concentrates, %. The higher recovery rate, the higher efficiency of pyrite recovery is acquired.

2.4. Separation process and principle

In this study, samples with different size and density would be firstly fed into the fluidized bed. When gas velocity is beyond minimum gas velocity, particles would reach fluidization state in the traditional fluidized bed. Extra gas flow would be coalesced for bubbles and bubble diameter increases in the vertical direction. In addition, bubbles also cause particle mixing in the traditional fluidized bed. Fig. 3 shows detailed separation process and principle of pyrite recovery in vibrated fluidized bed. When vibration energy is introduced to the fluidized bed, it is beneficial to strengthen movement and collision of particles, which could effectively break up bubbles through particle squeeze effect. As a result, extra gas would merge into a dilute area for particle segregation. The dilute area would spread from bottom to top of fluidized bed and density segregation of particles would generate due to difference of settling velocity. In addition, size ratio of feed particles should be controlled due to the relationship between settling velocities and particle density or size.

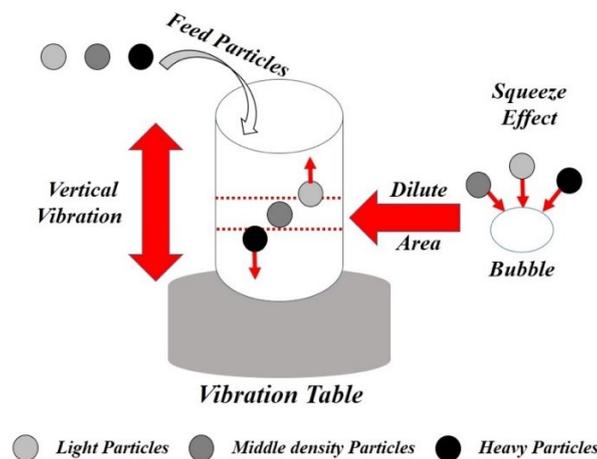


Fig. 3. Principle for pyrite recovery using vibrated fluidized bed

3. Results and discussion

3.1. Analysis of separation efficiency in vibrated fluidized bed

Vibration intensity, Γ , is used to express how much vibration energy introducing to the fluidized bed in this study, described as $\Gamma = A\omega/g$, where A is vibration amplitude, (mm); $\omega = 2\pi f$ is angular velocity, (rad/s); f is vibration frequency, (Hz); g is acceleration of gravity, 9.8 m/s^2 . In the study, minimum gas velocities, U_{mf} , were 1.25 m/s , 0.78 m/s and 0.27 m/s for $-6+3 \text{ mm}$, $-3+1 \text{ mm}$ and $-1+0.5 \text{ mm}$ gangue. Firstly, comparison of vibration frequency and vibration amplitude has been analyzed on separation efficiency under the same vibration intensity and $1.20 U_{mf}$. Fig. 4 depicted that D_{sulfur} were 0.40 , 0.51 and 0.67 for samples with $-6+3 \text{ mm}$, $-3+1 \text{ mm}$ and $-1+0.5 \text{ mm}$ size fraction at $\Gamma=3.22$ ($f = 20 \text{ Hz}$, $A = 2 \text{ mm}$). When Γ was 3.22 ($f=40\text{Hz}$, $A=0.5 \text{ mm}$), D_{sulfur} were 0.37 , 0.51 and 0.63 for samples with $-6+3 \text{ mm}$, $-3+1 \text{ mm}$ and $-1+0.5 \text{ mm}$ size fraction. When Γ was 6.45 , D_{sulfur} were 0.27 , 0.31 and 0.34 for the samples with $-6+3\text{mm}$, $-3+1 \text{ mm}$ and $-1+0.5 \text{ mm}$ size fraction, when f was 20Hz and A was 4mm . D_{sulfur} were 0.23 , 0.25 and 0.37 for samples with $-6+3 \text{ mm}$, $-3+1 \text{ mm}$ and $-1+0.5 \text{ mm}$ size fraction, when f was 40Hz and A was 1mm . The separation results were relatively similar with different combinations of vibration amplitude and frequency. Therefore, vibration amplitude and frequency both have important effect on improving separation efficiency under suitable vibration intensity. This is because that vibration amplitude is directly related to improve expansion ratio. During separation processing, suitable vibration amplitude could increase particle movement distance in the vertical direction, which is conducive to increasing of bed voidage. Therefore, suitable vibration amplitude could strengthen uniformity of gas distribution, which could contribute to generating appropriate fluidizing conditions for sample beneficiation through eliminating the channeling in the bed. Meanwhile, vibration frequency could promote frequency of particle collision, which could optimize bubble behavior by strengthening interaction of emulsion phase and bubble phase. As a result, appropriate vibration frequency could break up bubbles to strengthen extra gas distribution and form a dilute area for particle segregation. Therefore, it's

effective to obtain satisfied separation performance through adjusting combinations of vibration amplitude and frequency.

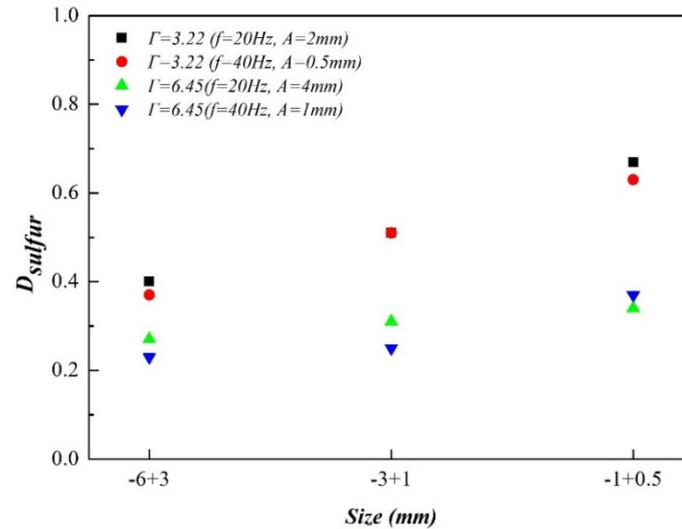


Fig. 4. Comparison of separation efficiency between vibration frequency and amplitude

Detailed effect of vibration conditions was investigated on pyrite recovery at $1.20 U_{mf}$, $1.30 U_{mf}$ and $1.40 U_{mf}$. As shown in Table 2, for the samples with -6+3 mm, -3+1 mm and -1+0.5 mm, the highest D_{sulfur} increased to 0.67, 0.65 and 0.75 when Γ was 1.81, comparing to the lowest D_{sulfur} = 0.40, 0.45 and 0.53. As shown in Fig. 5, the highest sulfur content increased to 37.43%, 32.95% and 26.79%, depicting considerably satisfied separation efficiency. Meanwhile, Table 2 showed that D_{sulfur} mainly increased firstly and then decreased with the increasing vibration intensity. The reason is that bubble would be firstly compressed by distributor and particles during bubble formation in the vertical direction. Due to lower surface tension, extra gas would be dispersed uniformly. Because gas would be flowed to the area with least resistance, dilute area would be generated for particle separation based on different terminal velocities of particles when diameter of dilute area is roughly equivalent to that of bed. When Γ is 0.40, vibration intensity is lower and bubbles plays the crucial role on particle segregation. Because the samples belong to Group D particle, many negative phenomenon, like gas channeling, could cause relatively poor fluidization quality in the bed. Meanwhile, bubbles may also facilitate particle mixing. Therefore, it is difficult to form ideal dilute area for particle separation only rely on gas when vibration intensity is low. When vibration intensity increases to 3.22, higher vibration intensity would disturb particles movement behavior and strengthen particle mixing. Particle circulation flow would be also observed near the wall when vibration intensity is higher. As a result, higher vibration intensity would also decrease separation efficiency.

Table 2. Separation results at different vibration conditions

Vibration Intensity, Γ	Gas Velocity	D_{sulfur} (-6+3mm)	D_{sulfur} (-3+1mm)	D_{sulfur} (-1+0.5mm)
0.40	1.20 U_{mf}	0.48	0.57	0.73
1.81		0.58	0.65	0.71
3.22		0.40	0.51	0.67
0.40	1.30 U_{mf}	0.53	0.53	0.71
1.81		0.63	0.62	0.75
3.22		0.49	0.45	0.63
0.40	1.40 U_{mf}	0.52	0.57	0.68
1.81		0.67	0.60	0.67
3.22		0.41	0.45	0.53

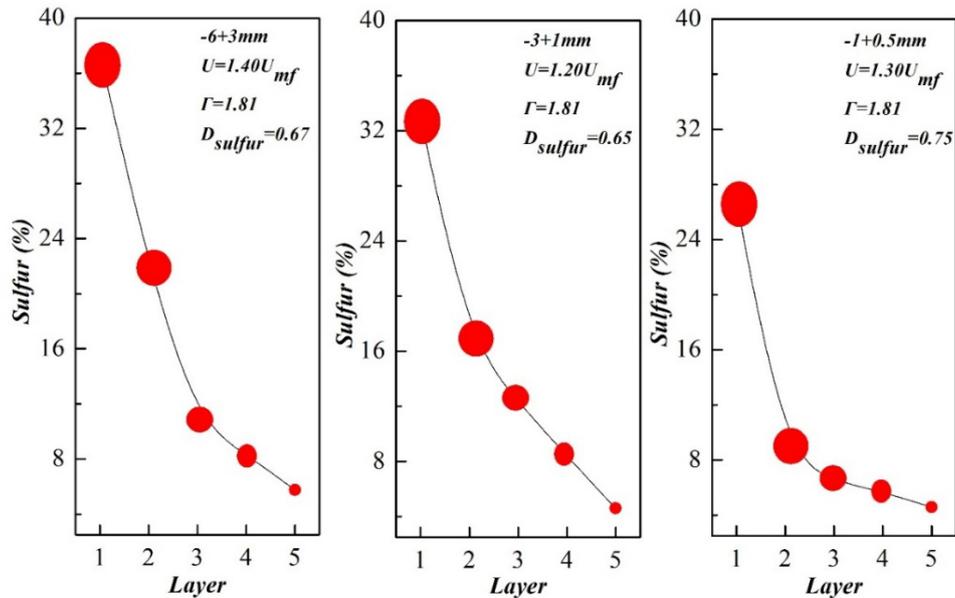


Fig. 5. Separation performance at different vibration intensity

3.2. Analysis of bed expansion in vibrated fluidized bed

In order to reveal segregation mechanism of vibrated fluidized bed, expansion ratios were compared between vibrated fluidized bed and traditional fluidized bed. Expansion ratio, $\varepsilon = (H - H_{mf}) / H$, was used to reflect gas voidage and solid holdup, where H is bed height after expansion and H_{mf} is minimum bed height. Images were captured by Olympus i-SPEED 3 high-speed camera to observe the variation of bed heights. Fig. 6 showed that expansion ratio was relatively higher in the vibrated fluidized bed than that in the traditional fluidized bed. When vibration intensity was 0, expansion ratio was relatively lower than 2%. When vibration intensity increased to 1.81, expansion ratios were 2.45%, 3.09% and 3.80% for samples with -6+3 mm, -3+1 mm and -1+0.5 mm size fraction. Meanwhile, when vibration intensity reached 3.22, expansion ratio presented the highest value. Generally, fluidization quality of Geldart D particles traditionally is relatively poor with some undesirable phenomenon, such as channeling in the fluidized bed. Therefore, expansion ratio is lower in the traditional fluidized bed. When the vibration energy is introduced, bubbles could be effectively broken up due to particle squeeze effect, which could improve uniformity of particle distribution and increase bed expansion ratio. As a result, extra gas would merge into a dilute area for particle segregation in the vibrated fluidized bed, as showed in Fig. 7.

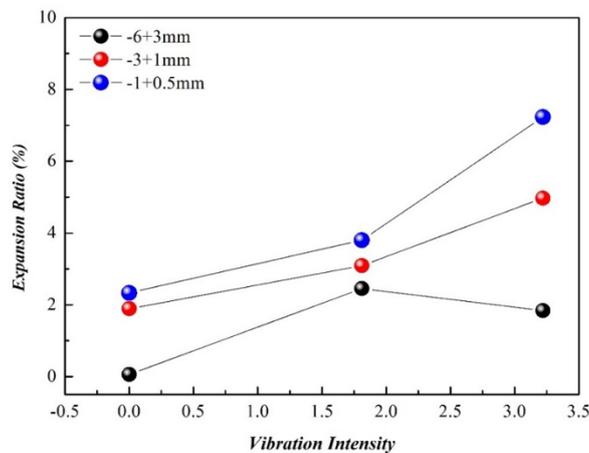


Fig. 6. Comparison expansion ratio between traditional fluidized bed and vibrated fluidized bed

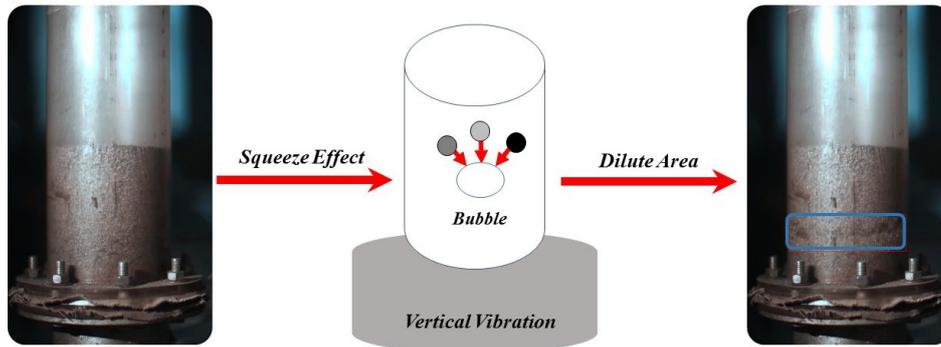


Fig. 7. Particle separation behavior in the vibrated fluidized bed

3.3. Comparison of separation efficiency of traditional fluidized bed and vibrated fluidized bed

In this study, experiments for pyrite enrichment were then conducted in the fluidized bed with and without vibration energy. Fig. 8 showed that the highest D_{sulfur} were 0.43, 0.48 and 0.57 for the samples with -6+3 mm, -3+1 mm and -1+0.5 mm in the fluidized bed without vibration, dropping from D_{sulfur} =0.67, 0.65 and 0.75 in the fluidized bed with vibration. The results showed that separation efficiency was lower for gangue with -6+3 mm, -3+1 mm and -1+0.5 mm size fraction in the traditional fluidized bed. Fig. 9 showed the difference of particle behavior in the traditional fluidized bed and vibrated fluidized bed. As shown in Fig. 9 (a), particle segregation only relies on the bubble behavior without vibration energy introduced. Due to the higher density of gangue samples, frequency of bubble coalesce is relatively higher based on the minimum energy principle. Although particles could be separated due to the density difference, the local bubble behavior could not achieve particle separation completely in the bed. In addition, a wake area would be existed behind the bubble to improve degree of solid mixing. As shown in Fig. 9 (b), vibration energy could effectively facilitate uniformity of gas distribution and increase bed expansion ratio to avoid some negative phenomenon, such as gas channeling. As a result, it is efficiency in optimizing the bubble behavior through promoting interaction of emulsion phase and bubble phase. A dilute area would be then generated for particle beneficiation. In the dilute area, particles with higher density tend to sink preferentially over the lighter particles, which could increase separation efficiency for pyrite recovery from high sulfur gangue.

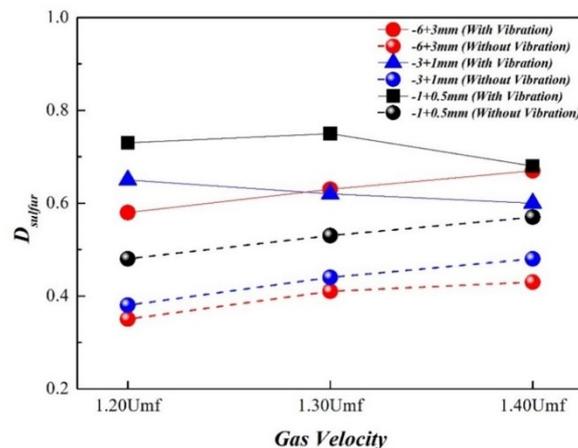


Fig. 8. Comparison of separation efficiency between traditional fluidized bed and vibrated fluidized bed

3.4. Comparison of separation efficiency of narrow-size samples and mixed-size samples

Effect of size distribution was then investigated on the separation efficiency. Samples of mixed size range (-6+0.5 mm) and narrow size range (-6+3 mm, -3+1 mm and -1+0.5 mm) were used for pyrite recovery at $1.30U_{mf}$. Mixed size samples would be sieved after separation experiments by a standard set of screens to obtain -6+3 mm, -3+1 mm and -1+0.5 mm samples. Fig. 10 depicted that the highest D_{sulfur}

of mixed samples were decreased to 0.48, 0.50 and 0.41 for -6 + 3 mm, -3+1mm and -1+0.5mm respectively. Meanwhile, when narrow size range samples were used for the separation experiments, D_{sulfur} of different size samples have relatively higher values compared to that of mixed size samples. The results showed that D_{sulfur} was directly related to distribution of particle size. Therefore, decreasing size distribution is conducive to improving separation efficiency.

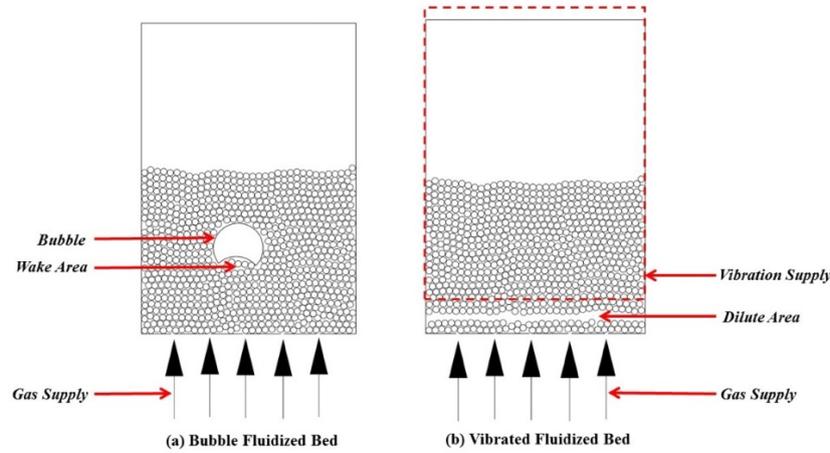


Fig. 9. Comparison of particle behavior between traditional fluidized bed and vibrated fluidized bed

Possible reasons can attribute for the terminal velocity of different particles. The net forces of particles mainly include gravity, buoyancy and gas drag in the dilute area, as followings:

$$m \frac{du}{dt} = F_f + F_d + F_g \tag{3}$$

$$\frac{1}{6} \pi d \rho_p \frac{du}{dt} = \frac{1}{6} \pi d (\rho_p - \rho_g) g + \frac{1}{8} C_D \pi \rho_g v^2 \tag{4}$$

where F_f is the buoyancy, F_d is drag force produced by gas, F_g is particle gravity, m is particle mass, u is particle velocity, t is separation time, d is particle size, ρ_p is particle density, ρ_g is gas density, C_D is the resistance coefficient, v is the relative velocity between gas and particles. The Eq. (4) could be simplified as Eq. (5):

$$\frac{du}{dt} = \frac{(\rho_p - \rho_g)}{\rho_p} g + \frac{3C_D \rho_g v^2}{4d \rho_p} \tag{5}$$

Eq. (5) depicted that the settling velocity of particles is mainly depend on particle size and density. If particle A is heavy-small and particle B is light-big, namely $\rho_a > \rho_b$ and $d_a < d_b$, the settling velocities of particles may be equal with similar movement behavior. Therefore, for samples with wide size range in the study, small-heavy gangue may be well mixed with big-light gangue due to equal terminal velocity. In addition, when particle size ratio is much large, light-big gangue may sink to the bottom as the jetsam, according to the Nienow's research (Chiba et al., 1980). Hence, the results showed that mixed-size samples are more likely to increase degree of particle mixing and decrease separation efficiency.

3.5. Detailed analysis of separation results

Based on above analysis, the detailed separation results were chosen at optimal separation conditions. The highest sulfur content of -6+3 mm, -3+1 mm and -1+0.5 mm samples increased to 37.43%, 32.95% and 26.79% after separation experiments. As shown in Fig. 11, element analysis were investigated for -6+3 mm, -3+1 mm and -1+0.5 mm samples from bottom layer by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometer (EDS). The results showed that peak values of S and Fe were obviously higher in each curve. Meanwhile, S and Fe also accounted for relatively larger area, which indicated S and Fe were main elements and pyrite was the primary mineral in the concentrates.

Separation results were then analyzed based on two kinds of product distribution plans, as shown in Fig. 12. Separation efficiencies were satisfied using vibrated fluidized bed through one or two times separation processing. The results showed that pyrite would be obtained with the highest $S=34.07\%$, rising from 19.18% in the raw sample. Meanwhile, the highest comprehensive recovery rate, $\varepsilon\%$ was 72.19% . In order to evaluate the application feasibility in future, separation results of wet methods were collected for comparison with this study results, as shown in Table 3. The results showed that the results of sulfur content and recovery rate were both close to wet methods, showing the dry method could obtain similar separation performance to wet methods do. However, wet separation methods generally need two times separation processing, which may limit the development of these methods in industry. Due to the similar separation efficiency and simple work processing, it is feasible to use vibrated fluidized bed for pyrite recovery from high sulfur gangue.

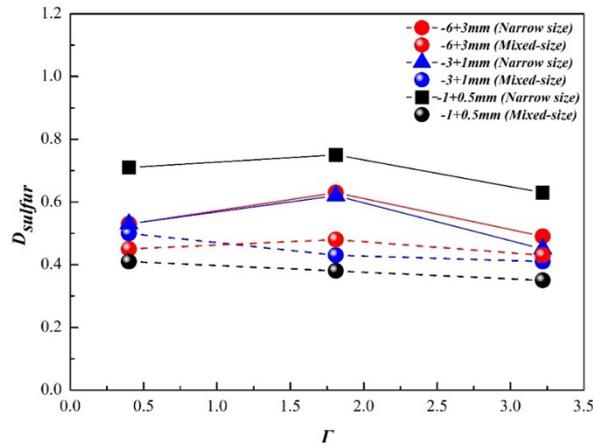


Fig. 10. Comparison separation efficiency of samples between narrow size and mixed-size range fraction

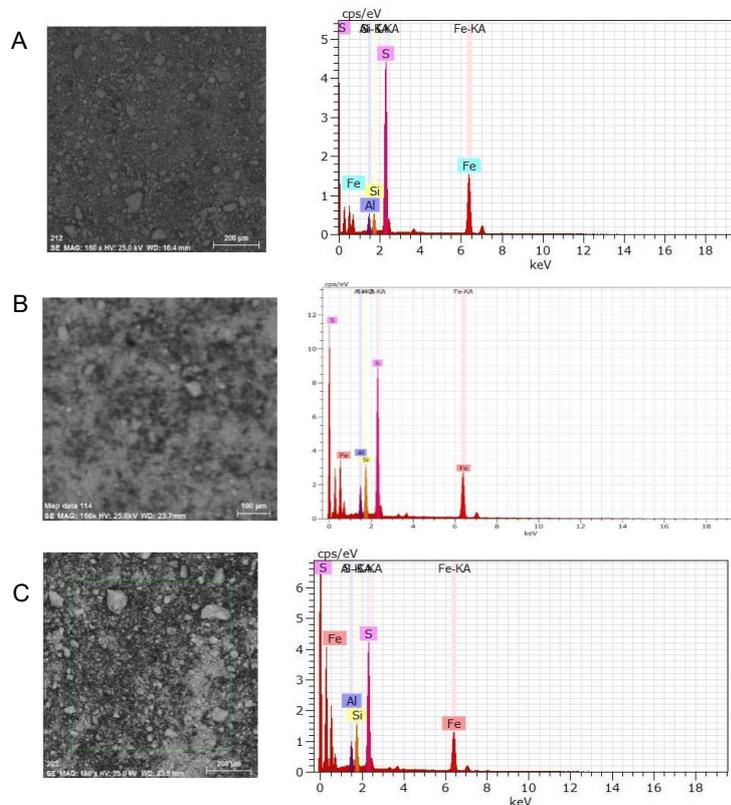


Fig. 11. Element analysis and images by SEM: (a) -6+3mm size sample;
(b) -3+1mm size sample; (c) -1+0.5mm size sample

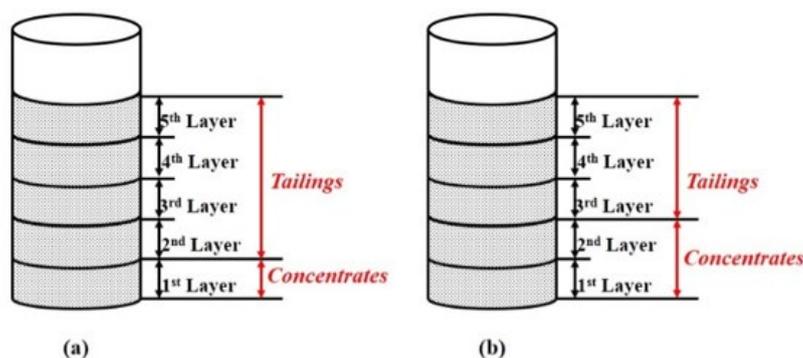


Fig. 12. Two kinds of production distribution plans

Table 3. Comparison separation efficiency between recent technologies

References	Separation technologies	Detail separation results
Pan et al., 1997	Shaking table separator (Two times separation)	S%:40.10% Recovery rate, ϵ %: 80.20%
Wang et al., 2002	Shaking table separator (One time separation)	S%:37.89% Yield%: 44.80%
Liao et al., 2006	Flotation method (Two times separation)	S%:37.19% Recovery rate, ϵ %: 87.37%
Huang et al., 2008	Cone dense- medium cyclone (Two times separation)	Yield%: 24.32% S%:13.06%
He et al., 2008	Cone cyclone (Two times separation)	S%:36.65% Recovery rate, ϵ %: 71.90%
Huang et al., 2010	Cone cyclone (Two times Separation)	S%:29.79% Recovery rate, ϵ %: 73.86%
Li et al., 2010	Shaking table separator (Two times separation)	S%:32.26% Recovery rate, ϵ %: 83.21%
Li et al., 2010	Shaking table separator + Cone cyclone (Two times separation)	S%:32% Recovery rate, ϵ %: 75%
Li et al., 2011	Shaking table separator + Cone cyclone (Two times separation)	S%:34.24% Recovery rate, ϵ %: 71.63%
Pan et al., 2014	Cone cyclone (Two Times Separation)	S%:30.76% Recovery rate, ϵ %: 16.91%
Our research	Vibrated Fluidized bed Product distribution plan(a) (One time separation)	S%:34.07% Recovery rate, ϵ %: 50.20%
Our research	Vibrated Fluidized bed Product distribution plan(b) (One time separation)	S%:30.75% Recovery rate, ϵ %:72.19%

4. Conclusions

This study presents a new dry method for pyrite recovery from high sulfur gangue using vibrated fluidized bed. Based on analysis of gangue characteristics, separation principle was introduced in detail. Effects of vibration intensity was analyzed on the pyrite recovery at $1.20U_{mf}$, $1.30U_{mf}$ and $1.40U_{mf}$. The results indicated that D_{sulfur} were 0.67, 0.65 and 0.75 for -6+3 mm, -3+1 mm and -1+0.5 mm samples, obtaining highest separation efficiencies when $\Gamma=1.81$. Separation efficiencies were then compared

between traditional and vibrated fluidized bed. The results were showed that -6+3 mm, -3+1 mm and -1+0.5 mm size fraction samples have higher separation efficiencies in the vibration fluidized bed. Samples with narrow size distribution would have higher separation efficiency compared to samples with mixed-size range. The detailed separation results depicted that the sulfur content of -6+3 mm, -3+1 mm and -1+0.5 mm samples respectively increased to 37.43%, 32.95% and 26.79% at optimal conditions. Based on analysis of Scanning Electron Microscopy (SEM), S and Fe were the main elements with highest proportion in the samples after separation. Compared to the results of wet methods, separation efficiencies were relatively satisfied using vibrated fluidized bed through one time or two times separation processing. The results showed that pyrite would be obtained with highest S%=34.07% and highest comprehensive recovery rate, $\varepsilon\%$ = 72.19%. Therefore, it is feasible to use the vibrated fluidized bed for pyrite recovery from high sulfur gangue.

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