Some Applications of Acoustic Emission in Fluidized Bed

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Abstract

The hydrodynamic parameters, including fluidized velocity, particle size distribution (PSD), agglomeration, flow pattern and so on, can be detected in fluidized bed, by utilizing wavelet analysis, wavelet packet analysis and frequency spectrum analysis, on basis of the mechanism that acoustic emission (AE) signals with different frequencies were emitted when the particles with different size impacted on the wall. The acoustic signals of particles were investigated in a fluidized bed with ϕ150 in diameter containing polyethylene powders. In those experiments, we found that the analysis of wave signals based on the wavelet packet analysis could be applied to the discrimination of the initial fluidization velocity and the initial turbulent velocity. The quantitative relationship was explored between PSD and AE signals' energy fraction in all scales on basis of the mechanism of particles impaction on the local wall area of the gas-solid fluidized bed by the AE-PSD model. And the mean relative errors were all less than 10%. Based on 7 scales wavelet analysis, a relationship was found between formation of agglomeration and the d6th, d7th scales that represent large size particles. A multi-circulation flow pattern of a gas-solid fluidized bed was experimentally obtained for the first time by acoustic emission technique. The results indicate that the hydrodynamic parameters of fluidized bed can be quickly and exactly detected online by acoustic emission technique.

Keywords: Acoustic emission, fluidized bed, flow pattern, PSD, fluidized velocity, agglomeration, wavelet, wavelet packet, frequency spectrum

1 Introduction

The hydrodynamic parameters are significant to the fluidized bed reactor. And some parameters require online technique to detect the variables. The measurement of the initial fluidization velocity and the initial turbulent velocity is important, as it is the basic parameter of fluidized bed. The detection of PSD and agglomeration is crucial, which relates to the stability of production in fluidized bed. Also the flow pattern is vital, once obtained, we can improve the reactor in order to increase output. However, most available techniques, such as pressure fluctuation, pressure drop and γ-ray, are intrusive or hurtful [1~3].

This paper presents a novel technique, Acoustic Emission (AE), to detect the hydrodynamic parameters in fluidized bed, and some applications of AE in detecting the hydrodynamic parameters of fluidized bed. Acoustic emission is presented as an interdisciplinary approach, covering diverse fields including applied engineering, electronics, signal analysis and chemo-metrics [4]. It is based on the fact that AE signals with different frequencies were emitted when the particles with different size impacted on the wall [5~6]. Particle-wall friction and collisions generate AE waves. The transmitted acoustic bulk waves along the chamber are detected by an AE sensor system based on passive piezoelectric transducers. However, Most AE research has concentrated on fault detection (e.g. pipe leakage, bearing failure, etc.) and has been well reviewed elsewhere [7~8]. Difficulties in extracting the information from the acoustic signal have been one possible reason why process AE monitoring is not more widespread.

In this paper, by utilizing many mathematical methods, such as wavelet, wavelet packet, frequency

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spectrum and so on, the AE signals will be completely decomposed into information of fluidized velocity, PSD [9], agglomeration, flow pattern and so on. Moreover, the parameters can be quickly and exactly detected online. The AE technique and the methods mentioned above will be illustrated by experiments with a 0.15m diameter fluidized bed containing polyethylene powders.

2 Experiment and Principle

2.1 Experimental Section

As it is shown in Fig. 1, the experiments were performed in a gas-solid fluidized bed with ϕ150 in diameter and 1.4 m in height. The distributor was a perforated stainless steel plate with 0.002 m orifice diameter and 2.6% orifice ratio. The fluidizing gas was transmitted by air in normal condition. Three kinds of polyethylene powders (M1, M2 and M3) were used as fluidized particles. And details of polyethylene particles are described in Table 1. An online measurement and analysis system (UNILAB AE2003) were used, including the AE sensor, narrow-band receptors (SR-15), pre-amplifier, signal conditioning system, together with data acquisition and computer. The AE sensor was easily installed on the wall of bed with the help of coupling agent. The frequency of AE wave was measured up to 500 kHz. Each measurement lasts one minute and the values listed in this study are obtained as the arithmetic average over one minute. Blank experiment shows that the sounds of background have no effect on the measurement of particles collision or friction in fluidized bed.

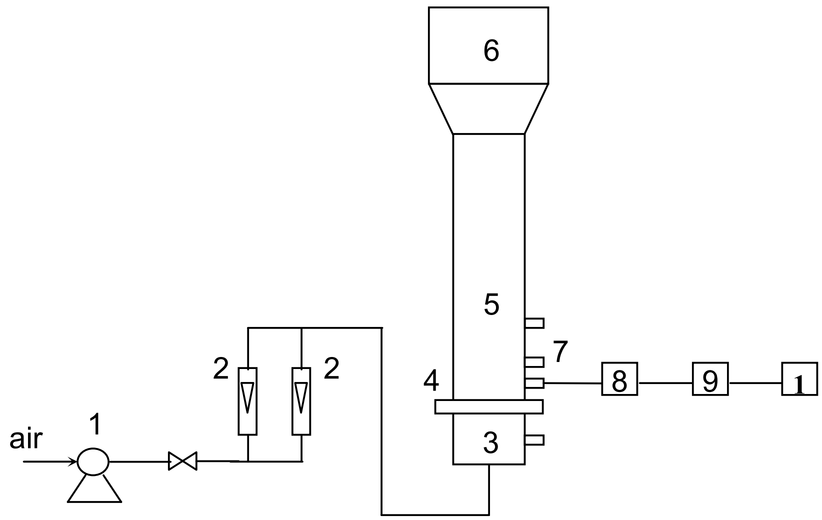


Fig.1 Schematic diagram of experimental apparatus
1 –Fan 2- Flow meter 3- Mixing room 4 -Distributor 5-Fluidized bed 6-Expanding section 7- AE sensor 8- Preamplifier 9- Signal conditioning 10- Computer

Table1 Property and PSD of M1, M2 and M3

Resin	Melt Index (g/10min)	Density (kg/m^3)	$\overline{d_p}$ (μm)
M1	9.6	944	460
M2	15.9	961	671
M3	6.0	946	365

2.2 Principle

Solid fluidization generally releases various AE signals, which are consisted of particle-particle or particle–chamber collisions impact sound, particle-particle or particle-chamber friction sound, along with air turbulence in fluidized bed. Therefore, the measurement and analysis of AE energy can reflect the real-time particle activity, or even reveal the flow pattern, mixing of particles in fluidized bed. Meanwhile, different scales decomposed by wavelet reflect different frequent signals. To be more exact, the small particles correspond to the high frequent signals in small scales, while the big particles correspond to the low frequent ones in big scales. So it is reliable to measure the particle size distribution and agglomeration, utilizing the multi-scale analysis of acoustic signals.

3 Results and Discussion

3.1 Measuring of Fluidized Velocity

The initial fluidization velocity and the initial turbulent velocity were experimentally investigated with variation of the gas velocity in fluidized bed. The energy distribution of particles was found in regular change. Based on that, the theory of energy redistribution was presented. When the gas velocity was increased, some small particles were pushed in the bed and began to gain the energy from the gas and then fluidized, then some big particles were pushed by fluidized small particles and gas. With further increase of the velocity, the big particles began to fluidize and pushed the bigger particles. In the process, the energy distribution of each scale changed with the variation of the gas velocity, as different particles led to different energy distribution. When every energy distribution reached equilibrium temporarily, the first energy redistribution was achieved, which is named as the first theory of energy redistribution. And the gas velocity of the moment was the initial fluidization velocity. As the gas velocity was increased again, the bubbles appeared in the bed. As the gas velocity kept increasing， the obvious bubbles in the bed disappeared, and the bed surface became vague. At that time, the particles would not restrict in somewhere, their fluidization would expanded to the whole bed, which resulted in the variation of the energy distribution of every scale in the fluidized bed. At even higher gas velocity， when the particles in the bed were mixed completely, the energy distribution of each scale would reach equilibrium again, which was named as the second theory of energy redistribution. From that time on, when the gas velocity was increased, the energy ratio of each scale would keep constant, in the interval the fluidized bed was considered well mixing and stably fluidizing. In this velocity area it was called well-mixing fluidization. The minimum velocity of the well-mixing region was the initial turbulent velocity. When the velocity reached the carry-over velocity, the energy equilibrium would alter because of the carry-over of the particles. And the energy ratio of each scale changed again, from high frequency to low frequency the energy ratio decreased scale by scale till zero.

According to the criterion of the initial fluidization velocity and the initial turbulent velocity obtained basing on the energy redistribution theory, the initial fluidization velocity and the initial turbulent velocity were gained by the energy redistribution theory analysis and the complexity measurement analysis of wave signals from the high density polyethylene particles with mean particle size equals to 0.51mm, 0.64mm, 0.76mm, 1.02mm, 1.24mm on a gas-solid fluidization bed with inner diameter equals to 150mm. Compared with the initial fluidization velocity measured by the classical pressure drop method and the initial turbulent velocity published by enterprise the mean relative errors were 5.18% and 6.78%. The details are described in Table 2. So the analysis of wave signals based on the wavelet packet analysis could be applied to the measurement of the initial fluidization velocity and the initial turbulent velocity.

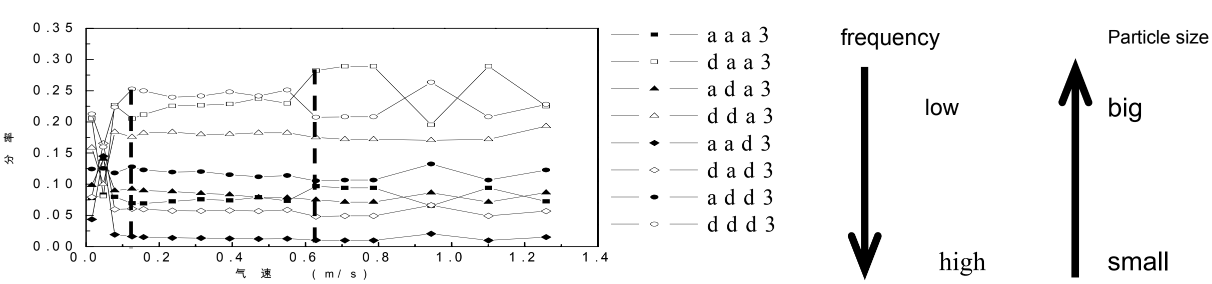


Fig.2 The energy percentage of wavelet packet analysis profile with the gas velocity

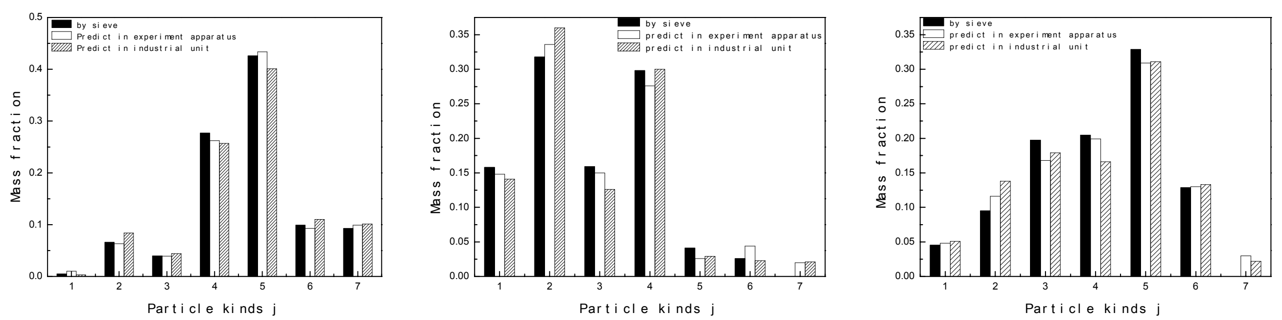
（sensor location Hp=150mm, d_p＝0.64mm）

Table 2 The Minimum fluidization velocity and the optimal operating gas velocity

d_p (mm)	Umf, m/s			optimal operating gas velocity, m/s		
	pressure drop	AE	AARD(%)	empirical value	AE	AARD(%)
0.51	0.10	0.089		0.42	0.480	
0.64	0.14	0.140		0.60	0.655	
0.76	0.17	0.158	5.18	0.75	0.800	6.78
1.02	0.24	0.229		1.05	1.080	
1.24	0.31	0.300		1.32	1.330	

3.3 Detecting of PSD

The changes of acoustic energy distribution in every scale reflect the changes of acoustic main frequency. In detail, since the acoustic energy produced by particles in different sizes distributes variously in all scales, the acoustic energy distribution is different in all scales. Moreover, it is possible to predict the PSD by multi-scale analysis of acoustic energy distribution. The AE-PSD Model [9] was on the basis of the principles mentioned above (2.2). This study was devoted to determine the PSD in the fluidized bed with three different polyethylene powders of M1, M2 and M3 respectively. The experiments were carried out in experimental apparatus and industrial fluidized beds. The comparison between the value by AE-PSD model and the value by sieving about the three kinds particles were shown in Fig. 3(a)~(c). The kind of particle sizes j=1~7 stand for 2.00mm, 1.19mm, 0.71mm, 0.50mm, 0.36mm, 0.18mm and 0.14mm respectively. It was found the corresponding deviations between AE-PSD method and sieves method are 3.2%, 5.3%, and 8.8% respectively. When using AE-PSD Model to predict PSD in the industrial fluidized bed, the average deviations are 6.2%, 8.3% and 15.8% respectively. The results indicate that AE-PSD Model may successfully be used to monitor the PSD in gas-solid fluidized beds.



（a） LLDPE（U=0.6m/s，ρ_s= 944kg/m^3） （b） HDPE（U=0.6m/s，ρ_s= 961kg/m^3） （c） Biomodal PE（U=0.4m/s，ρ_s= 946kg/m^3）

Fig. 3 The comparison between the value by PSD model and the value by sieving about the three kinds particles

3.3 Monitoring of Agglomeration

As the main frequency of the signals, which was caused by particles impacting on the chamber, decreased sharply when agglomerates began to appear in the fluidized bed. The agglomerating evolvement was presented in the bed based on multi-scale wavelet analysis. While the small particles polymerized into big particles even agglomeration, the main frequency transferred from high frequency to low frequency and the energy ratio of the acoustic signals increased level by level from low-scale to high-scale. In this study, the signals were decomposed into 7 scales. The d6th, d7th scales, which represented large size particles, increased suddenly, the agglomeration was formed. Fig.4 and Fig.5 illustrates that the energy ratio of each acoustic scale obtained from the decomposition of 7 scales wavelet analysis varies in the agglomerating evolvement of particles in an industrial fluidized bed between 17:30 and 19:30. According to the principle above, it can be discovered from Fig.5 that some big particles begin to agglomerate and form bigger particles, even block at 18:10. And at 18:51, it means the big agglomeration is formed as the energy ratio of the d7th scale increase suddenly. Meanwhile, the γ-ray was also used in this agglomerating process to detect the particle variation online. An agglomeration with the diameter of 150mm and length of 400mm was found. The results indicate that the energy ratio of the d6th, d7th scales decomposed by wavelet analysis can be the monitoring of agglomeration.

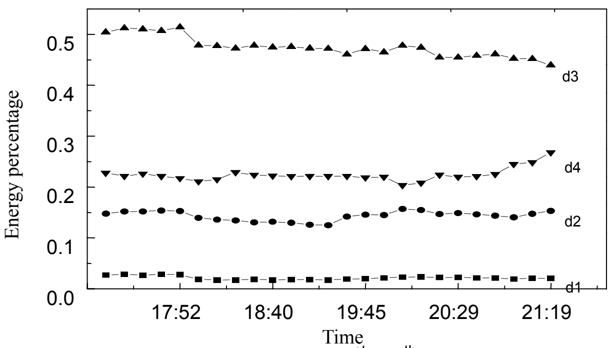


Fig.4 Variation of energy ratio in d1st~d4th scales in industrial bed

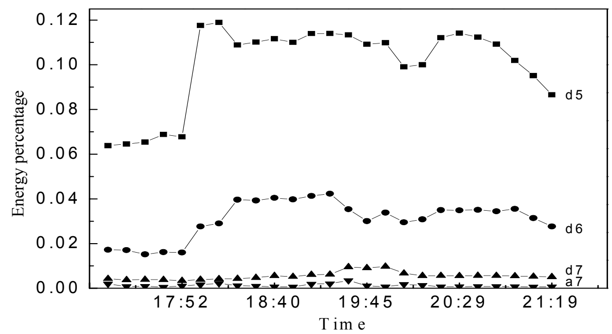


Fig.5 Variation of energy ratio in d5th ~d7th and a7th scales in industrial bed

3.4 Surveying of Flow Pattern

The acoustic energy could be calculated as the time average of square of amplitude of acoustic signals. For the M1 particles with average diameter 460 μm, the profile of acoustic energy along with the height of fluidized bed is illustrated in Fig.6, in which a minimum peak exists above the distributor. According to the bubbles theory [10], bubbles above the distributor rise up with radial uniformity. Along with the wakes of rising bubbles, particles accordingly move upwards and some particles from bubble breakup or coalescence will flow downward, thus many flow circulations cells form evenly across the bed above distributor. On the contrast, bubbles become to coalesce and grow in size and tend to rise up in the core area beyond a point of bed height. An amount of particles in wakes of the bubbles are followed to move upwards in the core region. When bubbles burst at the bed surface, particles in wakes are released and flow downwards along the wall region. A solid circulation with large size thus appears just above the circulation cells dispersed on the distributor. In this way, multi-circulation flow pattern zones have been verified in the fluidized bed by means of acoustic energy profile along with the height of bed. As shown in Fig. 6, there are solid circulations cells with smaller size and solid circulation with larger size (main circulation zone). The movement of particles with low AE energy will be more inactive at the interconnection due to counterwork of two circulation flows with opposite flow direction on the wall area. The region is named as stagnant zone at the position of height 0.17 m above the distributor. It can be anticipated that worse transfer of heat and then agglomeration will be appeared at the stagnant zone near the wall. Many experiences from commercial operators confirmed this prediction.

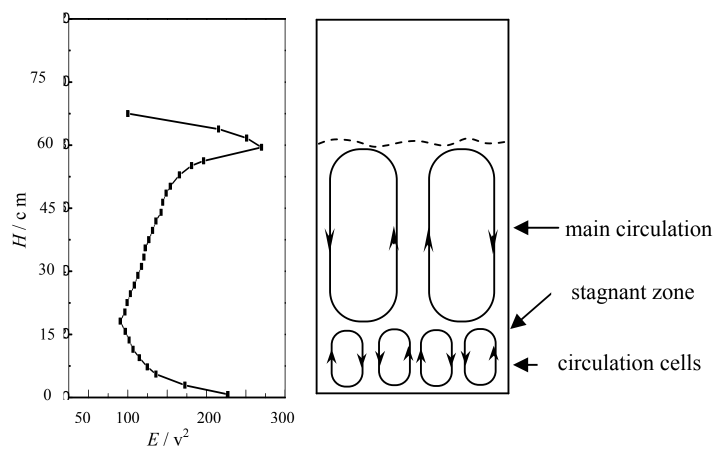


Fig.6 AE energy profile and multi-circulation

(M1, U=0.4 m/s, ϕ150, H=0.45 m)

At bed surface (about the height of 0.60 m as shown in Fig.6), the acoustic energy attains the maximum value because a lot of bubble burst and particles splash.

The results will obviously facilitate the intensification of polymerization reactor by appropriate design of conducting device as an internals of reactor [11].

4 Conclusions

The evolvement of the energy rate of AE signals from the granulation effect of the fluidization bed basing on the wavelet packet analysis principles was found. The criterion of the initial fluidization velocity and the well-mixing velocity was obtained. Online measurement of PSD was carried out both in the experiment apparatus and in the industrial unit with the AE-PSD model. Based on multi-scale wavelet analysis, a novel criterion was presented to detect the agglomeration real-time and online in the fluidized bed by acoustic emission technique. The flow pattern of a gas-solid fluidized bed was experimentally investigated by acoustic emission technique. A multi-circulation flow pattern was obtained for the first time in experiment.

Acknowledgements

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References

[1] Jaap C Schouten, Cor M van den Bleek. Monitoring the quality of fluidization using the short-term predictability of pressure fluctuations, *AIChE JOURNAL*, 1998, **44**(1): 48-60

[2] J. Ruud van Ommen, Robert-Jan de Korte, Cor M. van den Bleek. Rapid detection of defluidization using the standard deviation of pressure fluctuations, *Chemical Engineering and Processing,*2004, **43**: 1329-1335

[3] Gauthier, D., Zerguerras, S. and Flamant, G. Influence of the particle size distribution of powders on the velocities of minimum and complete fluidization. *Chemical Engineering Journal*, Volume 74, Issue 3, July 19, 1999, Pages 181-196

[4] Kim H. Esbensen, Maths Halstensen, ThorbjornTonnesen Lied and so on. Acoustic chemometrics—from noise to information, *Chemometrics and Intelligent Laboratory Systems*, 1998, 44: 61-76

[5] Cody, G. D., Goldfarb, D. J., Storch, G., V., Jr, Norris, A. N. Particle granular temperature in gas fluidized beds, *Powder Technology,* 1996, **87**(4): 211～232

[6] Cody G. D., Bellows R. J., Goldfarb D. J., et al. A novel non-intrusive probe of particle motion and gas generation in the feed injection zone of the feed riser of a fluidized bed catalytic cracking unit, *Powder Technology.* 2000, **110** (1-2): 128-142

[7] Fowler, T. J.. Chemical industry applications of acoustic emission, Materials Evaluation, 1992, 875-882

[8] Sundt, P.T.. Monitoring acoustic emission to detect mechanical defects, *InTech*, 1979, 43-44

[9] Yang Yongrong, Hou Linxi, Wang Jingdai. The study on particle size distribution in gas-solid fluidized beds based on AE measurement, *Prog. Nat. Sci.* (China), 2005, **15**(3): 380-384

[10] Cheremisinoff N. P., Encyclopedia Fluid Mechanics (Volume 4): Solids and Gas- Solids Flows, Gulf Publishing Company, Texas, USA.

[11] Meier GB, Weickert G, van Swaaij WPM, FBR for Catalytic Propylene Polymerization: Controlled Mixing and Reactor Modeling, *AIChE JOURNAL*, 2002, **48**(6): 1268-1283