Powder Technology 279 (2015) 185–195

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Feature extraction and early warning of agglomeration in fluidized bed reactors based on an acoustic approach

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ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form 30 March 2015
Accepted 7 April 2015
Available online 16 April 2015

Keywords:
Agglomeration monitoring
PCA
SVDD
Fluidized bed reactor
Polymerization

ABSTRACT

The potential use of audible acoustic emissions for monitoring particle agglomeration in ethylene polymerization fluidized bed reactors was investigated by the authors and reported in this paper. The offset in the power spectral centroid between normal and agglomeration signals was compared, and the energy distribution of the acoustic signals was confirmed to change under agglomeration conditions. On this basis, the acoustic signals were decomposed by wavelet packet decomposition (WPD) and the energy ratios of every sub-band were set as the voiceprint. Subsequently, principal component analysis (PCA) was introduced to reduce the dimensionality of the feature vector. Furthermore, based on normal signals, an agglomeration warning model could be created by support vector data description (SVDD) to avoid the decrease in description accuracy caused by the lack of agglomeration samples. Finally, a proper alarm rate (AR) parameter was designed to solve the problem of false alarms caused by the lack of repeatability and haphazardness of agglomeration in polymerization. According to the experimental results in a pilot plant, the proposed early-warning approach for agglomeration could provide a warning 20–50 min in advance of the traditional pressure and temperature monitoring methods.

1. Introduction

For its merits such as high heat and mass transfer efficiency and uniform mixing of reaction particles, the fluidized bed reactor (FBR) is well established and widely used in industry, especially for large-scale continuous production. However, in actual polymerization practice, the hydrodynamics may be changed drastically due to static electricity and the low heat exchange capacity, which will lead to particle aggregation, melting, sheeting, agglomeration, and even unscheduled shutdown of the plant. Therefore, the early-warning approach of gas–solid fluidized bed agglomeration has always been a research topic of great interest. Various authors have proposed a number of techniques to detect agglomeration, such as pressure fluctuations [1,2], temperature [3], electrostaticity [4], three dimensional X-ray imaging [5] and acoustic emission (AE) measurement [6], of which AE measurement has been considered as an attractive technique for monitoring fluidized beds due to its non-intrusiveness, rapidity, safety and low cost. Based on the use of piezoelectric acoustic emission sensors (with a resonance frequency of 30 kHz, 70 kHz or 150 kHz), Mark Whitaker et al. [7] reported a novel monitoring technique for a particle distribution measurement of a high shear granulation process and obtained the particle size distributions from the acoustic signals by the method of partial least squares (PLS). Hiroyuki Tsujimoto et al. [8] developed a high-frequency (140 kHz) acoustic emission sensor with narrow-band receptors for monitoring the particle fluidization in a fluidized bed granulator and further explored the direct correlations between the mean AE amplitude, the dimensionless excess gas velocity, and the dimensionless bed height. Maths Halstensen et al. [9–11] first used the PLS regression method for in-line monitoring of the particle size distribution of an industrial granulation production process based on high-frequency acoustic emission signals (0–250 kHz) and realized the discrimination of normal state vs. agglomeration state by principal component analysis (PCA). It can be seen that multivariate statistical analysis methods such as PCA and PLS are more popular in the existing literature for quantitative analysis of acoustic signatures. In addition to the multivariate statistical analysis methods, Yang Yongrong et al. [12, 13] studied the early-warning method of fluidized bed agglomeration based on multi-scale decomposition analysis of acoustic emission signals, and proposed the Hou-Yang Model of particle size distribution (PSD). This model expresses the relationship between the acoustic signal and the PSD. N. Salehi-Nik et al. [14] used high-frequency acoustic signals (50 kHz–1.5 MHz) for the determination of the hydrodynamic behaviour of fluidized beds and realized the hydrodynamic monitoring of FBRs using statistical analysis of acoustic emission signals. Different from high-frequency signals, there is also some literature focusing on

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http://dx.doi.org/10.1016/j.powtec.2015.04.009
0032-5910/

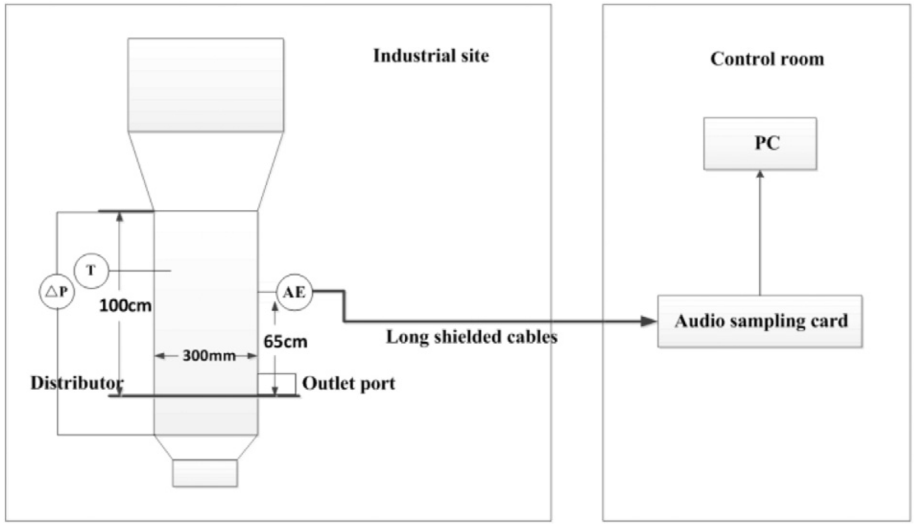

Fig. 1. Schematic diagram of the experimental apparatus.

the audible acoustic signals (20–20 kHz) and lower frequency signals (0–400 Hz). Lauren Briens et al. [15] showed that audible acoustic emissions had potential as a technique for end-point detection in high-shear wet granulation, and PLS-DA discriminant analysis together with experiments in a laboratory-scale plant verified the potential of the method. Javier Villa Briongos et al. [16] applied low frequency (0–400 Hz) accelerometry signals for detecting regime transitions in a gas–solid FBR. J.R. van Ommen et al. [17] investigated the potential of both passive acoustic emission and vibration measurements (both recorded at a frequency of 400 Hz) for monitoring gradual process changes in comparison with pressure fluctuation measurements and showed that the acoustic and vibration measurement techniques were not as robust as pressure fluctuation measurements in terms of reproducibility and sensitivity. To sum up, the main research topics of the above literature are fluidized bed dryers or granulators, and the reactions involved are mainly physical reactions, including heat transfer, drying, film covering and granulation. Pilot plants or laboratory-scale plants are the main reactors, and the purpose is to create an association between acoustic signals and PSD.

Fig. 2. The acoustic sensor on the FBR.

In this paper, polyethylene was prepared through ethylene polymerization by virtue of fluidized bed reactors, and an advanced signal processing method was developed to monitor the agglomeration in the polymerization reaction based on audible acoustic signals. In comparison with high-frequency acoustic emission signals, audible acoustic signals can reduce the signal bandwidth, simplify the signal processing circuit and facilitate real-time measurement and fault detection. In actual polymerization, agglomeration occurs occasionally and repeatedly, and sometimes these masses may disappear during the reaction. In view of this, the sensitivity of the agglomeration alarm needs to be considered. If the sensitivity of the alarm is too high, the chances of false alarm will increase; otherwise, it will be difficult for the acoustic method to avoid missing the alarm. Furthermore, when using the acoustic method to detect agglomeration in an FBR, false alarms caused by high sensitivity, low signal-noise ratio and difficult feature extraction must be dealt with as a matter of urgency.

To solve the problems mentioned above, this paper analysed the voiceprint extraction technique and the pattern recognition method for an acoustic signal. Based on the analytical results of the power spectral centroid, wavelet packet decomposition was used, considering the high-frequency band as well as the low-frequency band, and the PCA method was adopted to solve the high-dimension problem of the

Table 1
Parameters of the hardware system.

Hardware	Parameter	Value
Acoustic sensor	Type	Piezo buzzer
	Driving mode	Piezoelectric
	Energy sources	Passive
	Material quality	Brass
	Diameter of brass	27 mm
	Thickness of brass	0.11 mm
	Ceramic diameter	16.2 mm
	Total thickness	0.28 mm
	Resonant resistance	<300 Ω
	Resonant frequency	3.6 kHz ± 0.5 kHz
Soundcard	Channel number	Mono channel
	Model	Creative sound blaster 5.1 VX
	Input voltage peak value/resistance	50 mVpp/600 Ω
	Sampling parameter	≤24 bits/(ADC)/≤96 kHz