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# Multi-resolution analysis of wavelet transform on pressure fluctuations in an L-valve

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**Abstract**

A novel diagnostic method to characterize the flow patterns in an 80 mm-i.d. L-valve had been developed by using multi-resolution analysis (MRA) of wavelet transformation on the pressure fluctuation signals which were acquired from the standpipe and the horizontal part of L-valve. Parameters including the aeration rate, aeration positions, riser gas velocity and composition of binary particle mixture (194-μm and 937-μm sand particles) were used to investigate the relationship of performance of L-valve and its pressure fluctuations. By means of MRA, the original pressure fluctuations were divided into multi-scale signals. They were macro-scale, meso-scale and micro-scale successfully described the structures of gas–solid flow in the L-valve, such as the gas bubbles/slugs, dune-ripple flow, suspension particle flow, etc.


*Keywords:* L-valve; Pressure fluctuations; Wavelet transform; Multi-resolution analysis

## 1. Introduction

L-valve is one of the most effective and frequently used non-mechanical valve for conveying solid flow in the fluidized bed systems. It mainly consists of a long vertical pipe (standpipe) and a horizontal pipe. The solid flow through the L-valve is controlled by injecting small amount of aeration gas near the bottom of the standpipe. Although its performance, flow dynamic and design procedures had been investigated and reported by some previous studies (Knowlton and Hirsan, 1978; Geldart and Jones, 1991; Ozawa et al., 1991; Loung and Bhattacharya, 1993; Smolders and Baeyens, 1995; Arena et al., 1998), the study of the pressure fluctuations in L-valve for different flow patterns is sparse and the relationship between the standpipe and the L-valve is seldom discussed. Ozawa et al. (1991) measured the fluctuations of static pressure at the lower part of the standpipe. They qualitatively discussed the relationship between the pressure fluctuations and the corresponding flow patterns (packed-bed, coexistence, oscillation and pseudo-bridge patterns) in the standpipe. However, no further discussion of the pressure fluctuations in the horizontal part of L-valve was proposed in their study. To understand the more detail characteristics of different flow patterns in an L-valve, it is necessary to integrate the study of the pressure fluctuations in the standpipe and the horizontal part of L-valve.

In recent years, a powerful signal processing tool, wavelet transform, has been applied to analyze various kinds of signal in scientific and engineering fields. It is especially adequate to deal with a signal which contains multi-scale features and unsteady characteristics, such as the pressure fluctuations in the gas–solid flow systems. So far, it has been shown to provide much significant information from the pressure signals measured in literatures. Lu and Li (1999) proposed that wavelet function analyzes the pressure fluctuation signals and indicated the scale 4 detail signal reflects the bubble behaviors in a fluidized bed. Ren and

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Li (1998) used wavelet transform to decompose the original pressure fluctuations into three scales corresponding to macro-, meso- and micro-scales. The first one characterizes the effect of the processing unit on the system behavior, the second one describes the interaction of clusters or bubbles and the third one mainly characterizes particle motion in clusters or dilute phase. They verified that a fluidized bed exhibits multi-scale behaviors causing multi-resolution components in original time series of pressure fluctuations. Park and Kim (2001) used wavelet and Fourier transforms to analyze the pressure fluctuations in a three-phase fluidized bed. They characterized two different flow regimes in the bed by the dominant scale of wavelet coefficients and the highest wavelet energy. Li (2000, 2002) employed wavelet multi-resolution analysis and statistic methods (root mean square, skewness factor and probability density function) to the pressure fluctuations of gas–solid flow in a horizontal pipe.

The aim of this paper is to investigate the pressure fluctuations in the standpipe and the horizontal part of the L-valve under different operation conditions by using the multi-resolution analysis (MRA) of wavelet transformation. According to this analytic method, the flow mechanism of the gas–solid flow in the L-valve was characterized by the energy distribution of the multi-scale signals.

## 2. Experimental setup and procedure

Experiments were conducted in a Plexiglas. L-valve which had an 80-mm-i.d. × 380-mm-long horizontal section and its vertical section was connected with an 80-mm-i.d. × 1760-mm high Plexiglas standpipe. The 52-mm-i.d. riser was used for recirculation of solid particles from L-valve to the storage tank equipped at the top of the standpipe. Three aeration taps (labeled as A1, A2 and A3) were located at 0.17 m, 0.27 m and 0.37 m above the centerline of the horizontal section of the L-valve respectively. Fig. 1 shows the scheme of the experimental setup. Ambient air was supplied by Roots blower to lift the solid particles in the riser. The aeration gas injected into the L-valve was supplied by a compressor and the aeration rate was measured by a rotameter. Two different sizes of sand particles were employed as bed materials and their properties are listed in Table 1. The solid flow rate of the sand particles was obtained by timing the solid particle velocity at the standpipe wall between two marks (0.1 m apart) at steady-state operation and calibrated by the solid flow rate determined by collecting the solids in a container over a measured time interval as proposed by Knowlton and Hirsan (1978).

Several pressure taps were installed in 0.1-m interval apart along the horizontal and vertical sections of the L-valve. To avoid the blockage by fine particles, the tip of each pressure probe was covered with screen of 400 mesh, and was flushed with the inside wall of the L-valve. In each run of experiments, the pressure fluctuation signals were recorded by an AD/DA card at a rate of 100 Hz with 81.92 s of sampling duration. The multi-resolution analysis of wavelet transformation was carried out off-line by using the wavelet toolkit of S-PLUS software.

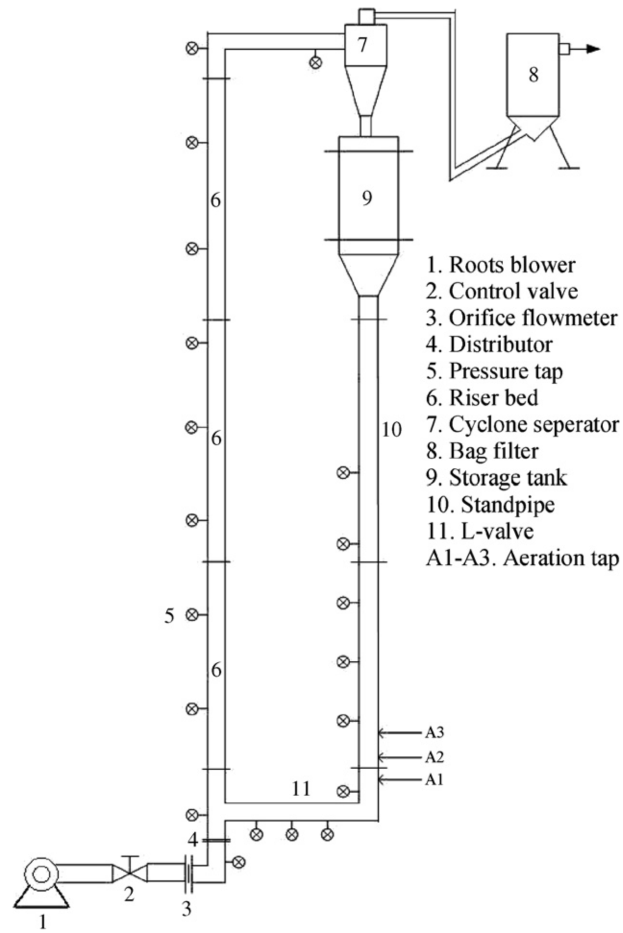


Fig. 1. Experimental setup.

Table 1
Properties of solid particles

| | Geldart's classification | |
|---|---|---|
| | *B* | *D* |
| $d_p$ (μm) | 194 | 937 |
| $\rho_s$ (kg/m$^3$) | 2635 | 2635 |
| $U_{mf}$ (m/s)[a] | 0.0382 | 0.582 |
| $U_{ms}$ (m/s)[b] | 0.096 | 0.64 |

[a] Estimated from Wen and Yu (1966).
[b] Estimated from Stewart and Davidson (1967).

## 3. Signal processing of experimental data

### 3.1. Wavelet transformation

Wavelet transform is a relatively novel mathematical tool for signal processing. Similar to a windowed Fourier transform, a wavelet transform can measure the time–frequency variations of spectral components, but it provides