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Flow noise identification using acoustic emission (AE) energy decomposition for sand monitoring in flow pipeline

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ABSTRACT

In pipelines used for petroleum production and transportation, sand particles may be present in the multi-phase flow of oil and gas and water. The Acoustic Emission (AE) measurement technique is used in the field of sand monitoring and detection in the oil and gas industry. However, as the AE signals recorded are strongly influenced by flow conditions in the pipe, identification of sand particle related signals or events remain a significant challenge in interpretation of AE signals. Therefore, a systematic investigation of sand particle impact AE energy measurements, using a sensor mounted on the outer surface of a sharp bend in a carbon steel pipe, was carried out in the laboratory to characterise flow signals using a slurry impingement flow loop test rig. A range of silica sand particles fractions of mean particle size (212–710 μm) were used in the flow with particle nominal concentration between (1 and 5 wt.%) while the free stream velocity was changed between (4.2 and 14 ms^{-1}).

A signal processing technique was developed in which the total AE energy associated with particle-free water impingement was divided into static and oscillated parts and a demodulated frequency analysis was carried out on the oscillated part to identify major spectral components and hence the sources of AE signals. A simple theoretical model for water impingement AE signals was then developed to show the dependence of AE energy components on different flow speeds. A similar decomposition of AE energy into static and oscillatory components was used to analyse AE signals for particle-laden flows. The effect of flow speed on the spectral AE energy for different sand concentrations and particle size fractions was investigated and the results show that the 100 Hz band is attributed to mechanical noise, the 42 Hz band is due to fluid turbulence and the dominant band is broad oscillated component.

The AE energy decomposition method together with the water impingement model and coupled with spectral peaks filtering enable isolation of AE energy associated with particle impact from other AE sources and noise and, hence, the proposed decomposition approach can enhance the interpretation of AE data in pipeline flows.

1. Introduction

During petroleum production, sand particles may be present in hydrocarbon flow due to drilling, formation damage, well ageing, reservoir fracturing and use of proppants [1]. The sand can cause serious problems in wear of pipelines and valves and the integrity of the production facilities [2]. Therefore, methods of identifying and quantifying sand production are needed. Methods of sand management include inspection techniques after production and involving disrupting production. Faster, non-disruptive, on-line monitoring techniques for sand production are needed to enable hydrocarbon production optimization. An on-line technique needs to identify the onset of sand production, assess the extent of damage to pipelines and production facilities, enable actions to be taken when excessive sand is produced and provide timely information for sand management measures.

Existing sand monitoring techniques can be broadly classified as intrusive and non-intrusive methods. Electrical Resistance (ER) sensing elements, radio-active probes and optical measurements [3] use intrusive mechanism to monitor the presence of sand flow streams. This type of device can be inefficient as they are not robust and need replaced after establishing the sand presence. Although such methods provide a reasonable assessment of the cumulative sand production, they are not effective in providing the real time or instantaneous indication of sand production [4]. Therefore, there is a need for a non-intrusive, fast, easily and cheaply maintained technique that can monitor large structures or pipelines from a single sensor location. Non-intrusive methods involve "listening" to the sound generated by a stream of solid particles impinging on a pipe wall. Vibration analysis is

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Nomenclature

List of symbols and abbreviations:

AE	acoustic emission
C	solids concentration in flow loop (expressed as weight percentage)
d_p	diameter of impacting particle
RMS AE	root-mean-square of the acoustic emission time series, often used as a time-series itself, of lower effective sampling rate)
wt.%	percentage, by weight (for example mass of particles as a percentage of total mass of particles plus carrier fluid)
v	fluid speed in flow loop
E^w	measured AE energy associated with particle-free water impingement, V^2 sec
E^w_{st}	static AE energy associated with particle-free water impingement, V^2 sec
E^w_{osc}	oscillated AE energy associated with particle-free water impingement, V^2 sec
E^{sl}_{tot}	measured AE energy associated with particle-laden flow, V^2 sec
E^{sl}_{st}	static AE energy associated with particle-laden flow, V^2 sec
E^{sl}_{osc}	oscillated AE energy associated with particle-laden flow, V^2 sec
E^{sl}_{sp1}	oscillated AE energy associated with particle-laden flow for 100 Hz harmonic series, V^2 sec
E^{sl}_{sp2}	oscillated AE energy associated with particle-laden flow for 42 Hz band, V^2 sec
E^{sl}_{broad}	remaining oscillated AE energy associated with particle-laden flow, V^2 sec
E^P	AE energy associated with particle impacts, V^2 sec
E^p_{st}	static AE energy associated with particle impacts, V^2 sec
n	curve fit power index, as in $y = Ax^n + B$
n_i	curve fit power index for a particular independent variable

a non-intrusive technique which has gained interest in recent years. For example, Wang et al. [5] have used a vibration technique for sand detection in sand-oil-water multiphase flow. A multiphase flow comprising a mixed liquid of 80 wt.% water and 20 wt.% oil with average speed of 2.14 ms^{-1} and sand content from 0.03 wt.% to 0.09 wt.% with sand fractions between 80 and 325 μm was used in a multiphase flow loop. A broad band vibration sensor was installed at two locations, a down-stream bend pipe wall and on an impact cell which was designed to amplify the vibration signals caused by solid particle impacts. They observed a good correlation between power spectrum amplitude of recorded vibration signals and sand concentration with different sizes of particles. In another work by the same authors, Wang et al. [6] have used the vibration measurement technique for sand detection in sand-gas multiphase flow. Using the same vibration sensor to acquire the vibration signals generated by sand impinging on horizontal and vertical down-stream bend pipe wall, they observed a correlation between vibration energy and sand mass flow rate. Also, Wang et al. [7] carried out a more applied field study on four typical wells in Bohai oil production platform. They observed a difference in the time-frequency domain and power spectrum between sand and non-sand producing wells and claimed a correlation between the recorded vibration signal power spectrum amplitude and sand production volume.

Another non-intrusive technique is monitoring of particle impact using Acoustic Emission (AE) which exploits the fact that, when a hard, solid particle strikes a target, a fraction of the incident energy dissipates as elastic waves, which will propagate through the target material according to its geometry and elastic properties before being detected by a suitable AE sensor. Because of this, and the very high temporal resolution available from AE, the potential of AE to monitor particle impact energy has attracted many investigators. A detailed review on the application of AE in monitoring particle impacts and in wear studies is beyond the scope of this paper and has been presented in the author's previous works [8–11].

The characteristics of the observed signal from the AE sensor will depend not only on the particle impact dynamics, the propagation of waves into the target medium and the type of sensor used but also on

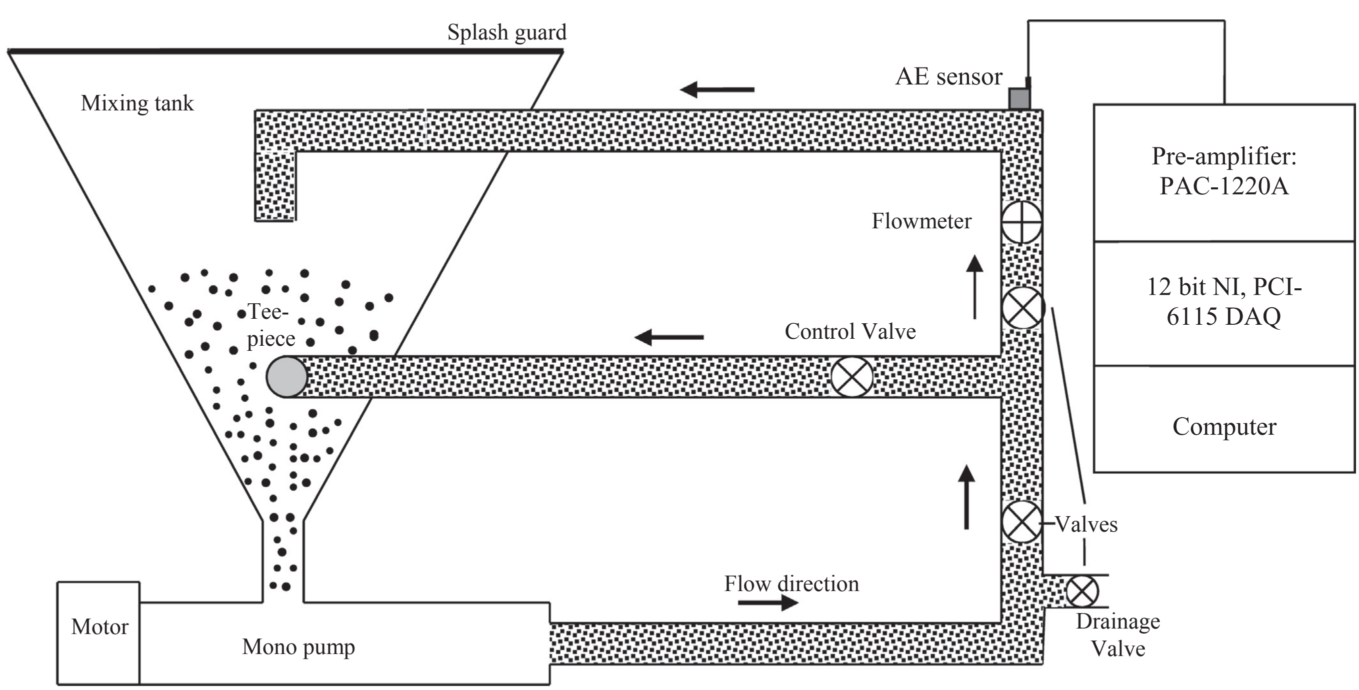

Fig. 1. Experimental setup (slurry jet test apparatus) and measurement system.