FLOW REGIME DETECTION IN PNEUMATIC TRANSPORT OF PARTICULATES USING NON-INTRUSIVE ACOUSTIC PROBES

Katherine Albion, Lauren Briens, Garret Book, Franco Berruti & Cedric Briens
Western Fluidization Group, Faculty of Engineering
The University of Western Ontario, London, Ontario, N6A 5B9

1. INTRODUCTION

Pneumatic transport is used to convey solids in many industrial plants. Changes in particle properties or operating conditions may cause particles to settle out and deposit on the bottom of horizontal sections of the transport line. Such deposits result in unsteady solids flow, pressure surges and eventually, blockage of the line. Early detection of deposits would allow for quick corrective action.

The objective of this paper is to present an early detection method for solids deposits at the bottom of the transport line using only non-invasive sensors. External microphones were selected as non-invasive sensors and their signals were processed with advanced filters and signal analysis methods.

1.1 Pneumatic Transport and Flow Regimes

In dilute phase horizontal pneumatic transport, particles do not move forward in a straight line, parallel with the pipe wall. Gravity pulls the particles toward the bottom of the pipe, but are ideally kept in suspension by turbulent gas eddies. As the gas flowrate is reduced or the solids flowrate increased, particles eventually deposit on the bottom of the pipe [1].

Flow patterns in horizontal transport vary depending on the solids concentration and superficial gas velocity. Different flow regimes occur at different transport conditions. At high superficial gas velocities and low solids fluxes, there is fully suspended dilute phase flow; increasing the solids flux or decreasing the superficial gas velocity results in dilute phase flow with a higher concentration of solids transported along the bottom of the pipe, and later as solids deposits as dunes or a stationary bed [2].

Flow patterns in an inclined line are similar. At high gas velocities and low solids fluxes, there is dilute phase flow. Increasing the solids flux or decreasing the superficial gas velocity eventually results in solids deposition on the bottom of the pipe [3].

1.2 Acoustics

Acoustic sensors are inexpensive and can withstand a wide range of process conditions. They can provide reliable, on-line and non-intrusive monitoring. Passive acoustics detect the acoustic emissions generated by the process. In processes involving the movement of solid particles, acoustic emissions are caused by particles colliding with each other, vessel walls or other objects [4].

1.3 Signal Analysis – Wavelet Residual and V Statistic

The wavelet residual is a method used for detecting outliers in the signal [5]. Wavelets can be used to denoise signals while preserving sharp, rapid variations in the signal. However, in the present work the rejected "noise" actually contains valuable information about the process. The V Statistic is used to detect cyclic, non-periodic behaviour.

2. METHOD

The pneumatic transport loop consisted of a 0.1 m inside diameter, stainless steel pipe. The gas-solids mixture flows through a 5.3 m vertical transport line, a 5.5 m horizontal pipeline or 5 m inclined pipeline, with a return line into a cyclone. Each acoustic measurement was recorded at a frequency of 40 000 Hz. Acoustic sensors were located on the bottom or side of the pipe, at measurement locations of 0.05, 0.20, 0.35, 0.90, 1.05, 1.20, 1.35, 1.50, and 1.65 m from the elbow in the horizontal line for glass beads or PVC powder, or at 0.50, 1.05. 2.50 and 3.3 m from the elbow in the inclined line for polyethylene pellets. An acrylic section of pipe in each section allowed for visual observations of the flow regimes. The flow regimes could easily be determined from high speed video files.

3. RESULTS & DISCUSSION

The V Statistic at 0.000425 s was calculated from the wavelet residual signal. At this subperiod length, there was a significant difference in the V Statistic which allowed for regime identification. Three flow regimes were identified: conveying over settled solids, dilute phase conveying and a transition region between the phases. Figure 1 shows that the narrow transition region could be detected from acoustic signals. This transition region occurred at $164 \pm 4\ s^{-0.5}$.

This method was applied to PVC powder in the same system, and resulted in a similar transition region of $169.5 \pm 5.5\ s^{-0.5}$.

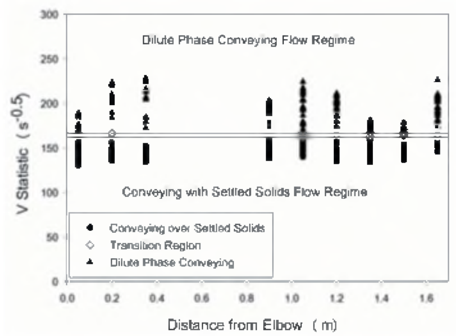

Fig. 1. V Statistic values for glass beads using wavelet residual of acoustic signals for all distances from the elbow, identifying two main flow regimes and narrow transition region.

Figure 2 is a flow regime map that was developed from the acoustic signals using the criteria shown in Figure 1. Each curve on the map represents the average value of the transition region, as it occurs relative to all solids fluxes and superficial gas velocities, and corresponds to a given distance from the elbow. The area located above each line represents the conveying with settled solids flow regime, whereas the area located below each curve represents dilute phase conveying. At 0.05 m from the elbow, the settled solids regime predominated. At distances further from the

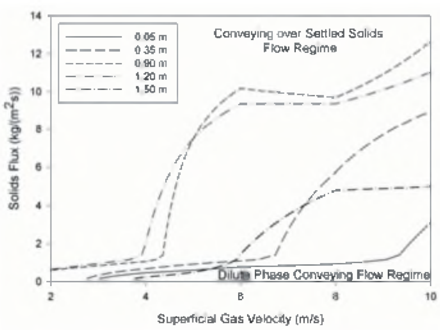

Fig. 2. Flow regime map for glass beads at various distances from the elbow.

elbow, 0.35 m and 0.90 m, the position of the line changed, and there were more conditions where dilute phase flow occurred. The majority of dilute phase flow occurred at 0.90 m and 1.20 m, where the shapes of the curves were nearly identical. Further from the elbow, at 1.50 m, there was less dilute phase flow, and the shape of the curve was similar to the curves closer to the elbow. This variation in the flows indicated where dunes existed rather than locations of a stationary bed. At 0.90 m and 1.20 m, there were breaks in the stationary bed, forming distinct dunes, existing at these locations and conditions, whereas at locations further from the elbow, a settled bed was detected.

This flow regime method was applied to an inclined line transporting polyethylene pellets. Figure 3 shows the V Statistic values for the wavelet residual acoustic signal at 0.000425 s. Two regimes were identified, conveying over settled solids and dilute phase flow. There was no detectable transition region: minute changes in either gas

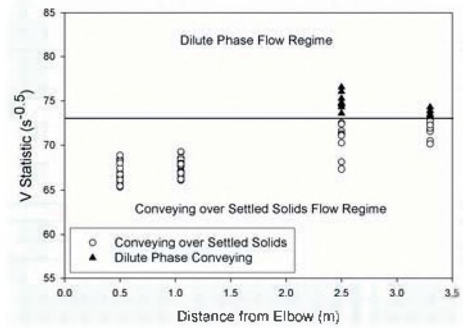

Fig. 3. V Statistic values for polyethylene pellets from the wavelet residual acoustic signal for all distances from the elbow, identifying the two flow regimes.

velocity or solids flowrate were sufficient to switch from one regime to another. The boundary between the two regimes occurred at 73 $s^{-0.5}$.

4. CONCLUSIONS

Flow regimes in pneumatic transport can be detected by applying a wavelet filter to the raw acoustic signal and calculating the V Statistic at 0.000425 s on the residual signal.

There was a narrow transition region between the dilute phase regime and conveying with settled solids regime for horizontal transport of glass beads and PVC powders. There was a sharp boundary between the two flow regimes for inclined transport of polyethylene pellets.

This acoustic monitoring method is useful for process control. It allows for easy, rapid and non-intrusive on-line monitoring of flow regimes in pneumatic transport lines. It can help maintain the pneumatic transport line at conditions that maximize product quality and system efficiency.

REFERENCES

[1] L.S. Fan, C. Zhu, Principles of Gas-Solids Flows: Cambridge Series in Chemical Engineering, Cambridge University Press, United Kingdom, 1998.

[2] G.E. Klinzing, R. Marcus, F. Rizk, L.S. Leung, Pneumatic Conveying of Solids, 2nd Edition, Chapman and Hall, New York, 1997.

[3] J G.E. Klinzing, N.D. Rohatgi, C.A. Myler, S. Dhodapkar, A. Zaltash, M.P. Mathur, Pneumatic transport of solids in an inclined geometry, Can. J. Chem. Eng. 67 (1989) 237 - 244.

[4] J.W.R. Boyd, J.Varley, The uses of passive measurement of acoustic emissions from chemical engineering processes, Chem. Eng. Sci. 56 (2001) 1749 - 1767.

[5] J. Trygg, N. Kettaneh-Wold, L. Wallbacks, 2D wavelet analysis and compression of on-line industrial process data, J. Chemometrics 15, (2001) 299 - 319.

ACKNOWLEDGEMENTS

The authors would like to thank the National Sciences and Engineering Research Council of Canada for their financial support of this research.