Optimization of the UVP+PD Rheometric Method for Flow Behavior Monitoring of Industrial Fluid Suspensions

Reinhardt Kotzé[1], Johan Wiklund[2], and Rainer Haldenwang[2]

[1] FPRC – Flow Process Research Centre, Cape Peninsula University of Technology, P.O. Box 652, Cape Town 8000, South Africa
[2] SIK – The Swedish Institute for Food and Biotechnology, 402 29 Göteborg, Sweden

Corresponding author: kotzer@cput.ac.za

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Abstract:
Ultrasonic Velocity Profiling (UVP) is a powerful technique for velocity profile measurements in research and engineering applications as it is the only available method that is cost-effective, relatively easy to implement and applicable to opaque fluid suspensions, which are frequently found in industry. UVP can also be combined with Pressure Drop (PD) measurements in order to obtain rheological parameters of non-Newtonian fluids by fitting theoretical rheological models to a single velocity profile measurement. The flow properties of complex fluids are almost exclusively obtained today using commercially available instruments, such as conventional rotational rheometers or tube (capillary) viscometers. Since these methods are time-consuming and unsuitable for real-time process monitoring, the UVP+PD methodology becomes a very attractive alternative for in-line flow behavior monitoring as well as quality control in industrial applications. However, the accuracy of the UVP+PD methodology is highly dependent on the shape and magnitude of the measured velocity profiles and there are still a few problems remaining with current instrumentation and methods in order to achieve the robustness and accuracy required in industrial applications. The main objective of this research work was to optimize an UVP+PD system by implementing new transducer technology and signal processing techniques for more accurate velocity profile measurements as well as rheological characterization of complex fluids under industrial/realistic conditions. The new methodology was evaluated in two different pipe diameters (22.5 and 52.8 mm) and tested with three different non-Newtonian fluids in order to obtain a wide range of rheological parameters. Results were also compared to conventional rotational rheometry and tube viscometry. It was found that rheological parameters obtained from accurate velocity data across the pipe radius, especially close to pipe walls where the velocity gradient is high, showed better agreement to conventional rheometry than when compared to results obtained using profiles measured with conventional UVP instrumentation and commercial software (Met-Flow SA Version 3.0). The UVP+PD method is now more robust and accurate. The main challenge remaining is to successfully implement a complete non-invasive system in industrial processes that is able to achieve real-time and accurate complex flow monitoring of non-Newtonian fluid suspensions.

Zusammenfassung:
Ultrasonic Velocity Profiling (UVP) ist eine schlagkräftige Methode zur Messung von Geschwindigkeitsprofilen in der Forschung und Technik. Es stellt zurzeit die einzige Methode dar, welche kostengünstig und einfach zu implementieren ist und Messungen in opaken liquiden Suspensionen ermöglicht, wie sie in industriellen Anwendungen häufig vorkommen. UVP kann mit Pressure Drop (PD) Messungen kombiniert werden und dadurch können mittels eines Fits eines einzigen Geschwindigkeitsprofils an theoretische rheologische Modelle die rheologischen Parameter der nicht-newtonschen Fluide ermittelt werden. Die Fließeigenschaften von komplexen Fluiden werden aktuell fast ausschließlich mit kommerziellen Instrumenten gemessen, z.B. mit dem konventionellen Rotationsrheometern oder Kapillarviskosimeter. Da diese Methoden zeitaufwändig sind und sich nicht für eine echt-zeit Prozesskontrolle eignen, stellt die Kombination der UVP+PD Methoden sowohl eine sehr attraktive Alternative für die In-Line Kontrolle der Fließeigenschaften dar als auch zur Qualitätskontrolle in industriellen Anwendungsbereichen. Die Genauigkeit der UVP+PD Methoden ist jedoch stark von der Form und der Größe der gemessenen Geschwindigkeitsprofile abhängig, so dass bei der jetzigen Geräteausstattung noch einige Probleme überwunden werden müssen um den von der Industrie geforderten Anforderungen an Robustheit und Genauigkeit entsprechen zu können. Das Hauptanliegen dieser Studie war die Optimierung eines UVP+PD Systems durch die Implementierung einer neuen Messwertgebertechnologie und Signalverarbeitungsmethodologie, um Geschwindigkeitsprofile mit einer höheren Genauigkeit zu messen und die rheologischen Eigenschaften von komplexen Fluiden unter industriellen/realistischen Rahmenbedingungen zu ermitteln. Diese neue Methodologie wurde in zwei unterschiedlichen Rohr-Durchmessern (22.5 & 52.8 mm) und an drei unterschiedlichen nicht-newtonschen Fluiden getestet und eine große Auswahl an rheologischen Parametern ermittelt. Die Resultate wurden mit konventionellen Messungen an Rotationsrheometern und Viskosimetern verglichen. Die durch die neue Methodologie einer genaueren Geschwindigkeitsprofilmessung erhaltenen rheologischen Para-

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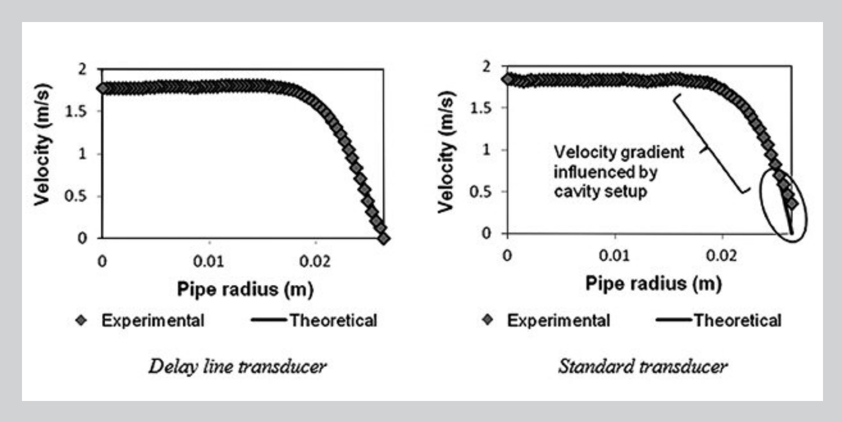

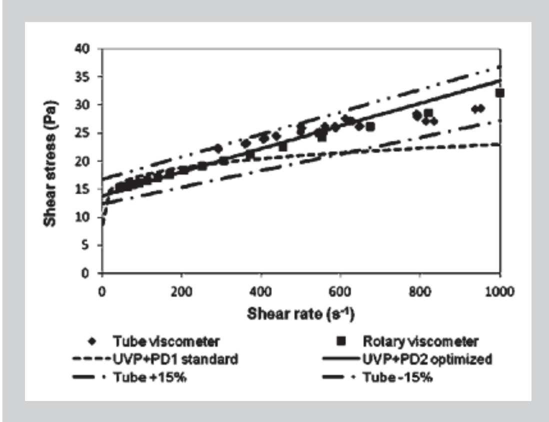

Figure 12 (left): Experimental and fitted theoretical velocity profile for delay line and standard transducers (52.8 mm pipe, bentonite 8 % w/w)

Figure 13: Rheogram for bentonite 8 % w/w (52.8 mm pipe)

5 CONCLUSIONS AND RECOMMENDATIONS

This article presents an optimized UVP+PD methodology for accurate and independent characterization of complex fluids in industrial applications. This was achieved by using delay line transducers in combination with optimized signal processing techniques capable of several velocity estimation methods and a deconvolution procedure, which lead to more accurate velocity gradients in the near wall region. Rheological parameters obtained from more accurate profile gradients close to pipe walls showed better agreement with conventional rheometric methods (within 15 %).

In comparison, a conventional set-up with flush-mounted standard transducers and small cavities in front of the transducer prevented measurements in attenuating fluids as the fluid filled up the entire cavity and absorbed the ultrasonic energy, as found with the kaolin suspensions in the 22.5 mm pipe. The delay line transducers eliminated this problem and showed that this methodology (combination of new transducer technology and advanced signal processing techniques) is essential for accurate monitoring of non-Newtonian fluid behavior as well as in-line rheology in industrial applications, where complex fluids with attenuating properties are encountered frequently.

The presented results show that the UVP+PD in-line rheometric method in combination with an invasive set-up with delay line transducers is now more versatile (applicable in wide range of pipe diameters and fluids), robust (measurements in attenuating fluids) and accurate (no knowledge of rheology initially is required). However, there are still a few limitations remaining. The delay line material used here absorbs ultrasonic energy and prevents measurements in larger pipe diameters in attenuating fluids. Although the signal processing techniques ensured accurate velocity data, the current setup produced rheograms and velocity profiles after about 30–60 seconds of calculation time. The data processing scheme and software (see Figure 3) need to be improved in order to obtain results in real-time for monitoring and control of dynamic processes. Limitations with the current delay line technology such as, temperature, pressure, high attenuation and wear resistance must also be addressed. New transducer development is required so that maximum energy transfer into the fluid medium is possible which will increase the penetration depth and applicability in industrial applications where large diameter pipelines are used.

The main remaining challenge is to find an optimal sensor setup for industrial applications. A non-invasive clamp-on set-up is an attractive alternative solution as industrial processes constantly run day and night and it is often not possible to stop these for installation and calibration of UVP equipment. Another significant advantage is that these transducer setups would not be directly exposed to high pressures, temperatures and harsh conditions found in industry. However, this setup could lead to new installation (mounting of sensors and pipe vibrations) and calibration (acoustic coupling) problems. Clamp-on systems have existed for more than 20 years and so far it has only been successful for accurate transit-time (bulk flow rate) and not Doppler measurements. The reasons for this are due to ultrasonic beam refraction, loss of energy, unknown sample volume shapes and wall interface positions after material layers that complicate measurements and results in inaccurate flow profile measurements [22]. New optimized sensor solutions are needed in order to completely implement the UVP+PD method in a dynamic and robust industrial environment.

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