In-Line Rheometry Based on Ultrasonic Velocity Profiles: Comparison of Data Processing Methods

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Abstract :
Ultrasonic Velocity Profiling with Pressure Drop (UVP+PD) is a technique, which allows the measurement of the shear rate dependent viscosity non-invasively in a laminar pipe flow. To assess the performance of different data processing approaches for the extraction of the rheometric values, model fluids are characterized under well defined flow conditions created with a piston setup. Considering the shear rate range available in the pipe flow, a good quantitative agreement is found between the in-line measurements and the off-line measurements made with a rotational rheometer.

Zusammenfassung :
Ultraschall basierte Strömungsgeschwindigkeitsmessung kombiniert mit Druckdifferenz (UVP+PD) ist eine nicht invasive Methodik, welche die Messung der Viskosität in Funktion der Schergeschwindigkeit in einer laminaren Rohrströmung ermöglicht. Um die verschiedenen Möglichkeiten der Berechnung der rheometrischen Werte zu vergleichen, wurden Modell-Fluide unter definierten Strömungsbedingungen mit einem Kolben Apparat gepumpt. Unter Berücksichtigung der Schergeschwindigkeit in der Rohrströmung, wurde eine gute quantitative Übereinstimmung zwischen den Resultaten der in-line Messungen und der off-line Messungen, die mit einem Rotationsrheometer durchgeführt wurden, gefunden.

Résumé :
Le profil de vitesse obtenu par vélocimétrie ultrasonore combinée avec la mesure de différence de pression (UVP+DP) est une technique qui permet la mesure non inclusive de l'évolution de la viscosité en fonction du taux de cisaillement pour un fluide pompé dans un tuyau sous écoulement laminaire. Afin d'évaluer les performances de différentes approches de traitement du signal utilisé pour l'extraction des données rhéologiques, des fluides modèles sont caractérisés dans des conditions d'écoulement bien définies avec une pompe à piston. Compte tenu de la gamme de taux de cisaillement disponible dans l'écoulement tubulaire, un bon accord quantitatif est trouvé entre les mesures en ligne et les mesures réalisées hors ligne avec un rhéomètre rotatif.

Key words: in-line rheometry, velocity profile, pipe flow, UVP+PD, polymer suspension

1 INTRODUCTION

The shape of the velocity profile and the pressure drop in a fully developed, laminar pipe flow are a function of the fluid type: A parabolic velocity profile is obtained in a Newtonian fluid, for a shear thinning fluid the velocity gradient is steeper towards the pipe wall and flattened in the center. Thus, the measurement of the flow velocity profile and the pressure drop allows to derive rheometric information directly from the pipe flow. Mainly three techniques have been developed to measure the velocity profile for rheometry (i) laser Doppler velocimetry (LDV) [1–3] and (ii) nuclear magnetic resonance imaging (MRI) [4–7] and (iii) ultrasonic velocimetry [8]. Compared to LDA and MRI based techniques, ultrasound has the advantages to work for opaque systems, being relatively low cost and able to penetrate different pipe wall materials including stainless steel.

The first publication demonstrating the use of the ultrasonic velocity profile for in-line rheometry comes from Warshaw [9], where they already used a model fitting approach for the evaluation of the suspension and emulsion measurements. Probably independent of that, the next publication came about 17 years later from Erlangen [10, 11] and after that from the ETH Zurich [12 - 14]. UC Davis was active in the field since 2003 [15, 16] with know how from using MRI for the velocity profile measurement. Around the

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