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Rheology of Microfibrillated Cellulose Suspensions in Pressure-driven Flow

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Abstract:
Rheology of Microfibrillated Cellulose (MFC) suspensions is useful for designing equipment to transport, mix, or process them. Pressure-driven flow behavior is particularly important for MFC suspensions if they are to be pumped, extruded or coated. Herein, we report use of slot and pipe geometries for determination of MFC suspension rheology and compare the results to boundary-driven flows. MFC flow behavior in a slot with varying gaps was studied at mass concentrations of 1, 2, and 3 % and up to shear rates of 100 000 s^{-1}. The suspensions exhibited yield stress and were highly shear thinning (pseudo-plastic) with apparent power law indices of 0.22 – 0.43. The shear thinning behavior can be explained by a microstructural picture in which a non-yielding center plug is surrounded by a yielded layer and a fiber-depleted water rich boundary layer.

Key words:
Microfibrillated cellulose, high shear rheology, suspensions, pressure-driven flow, slot geometry

1 INTRODUCTION

Microfibrillated Cellulose (MFC) is currently a material of high interest due to its unique properties such as biodegradability, mechanical robustness, barrier properties, large surface area [1 – 7], and complex rheology [8]. MFCs can be isolated from wood or plant cell wall, and have lateral dimensions in nanometer scale (≤ 100 nm) and length reaching several micrometers [4]. The fibrils may differ in physical properties depending on the production method and/or raw material source. The suspensions produced using only the mechanical treatment differ in size and morphology from nanocellulose suspensions produced using chemical, enzymatic, or carboxymethylation pretreatments followed by mechanical treatment [1, 9, 10]. Mechanically produced MFC tends to flocculate, and it is less water binding and swollen than chemically pre-treated ones [9]. Others in the literature use various terminologies for this similar material such as cellulose nanofibers or nanofibrillated cellulose.

It is crucial to be able to process MFC suspensions into end-use products in economic and environmentally friendly ways for fully exploiting the capabilities of this material. The possibility of continuous processing of MFC suspensions combined with additives has been discussed by Rantanen et al. [11]. Kumar et al. [12] have reported roll-to-roll coating of pure MFC suspensions recently. Håkansson et al. [13] and Iwamoto et al. [14] have investigated the potential to draw the material into a filament. One of the main challenges in processing MFC suspensions is their complex rheological behavior [8]. The scientific interest on the rheology of MFC suspensions is growing rapidly and has been a subject of discussion in many previous works [15 – 30]. Rheology of pulp fiber suspensions is also well known [31 – 35]. However, the distinctive behavior of MFC suspensions due to the high aspect ratio of fibers and strong interfibrillar forces makes it challenging to produce reliable information on their rheology using conventional rheometers. Most of the previous work on the rheology of MFC suspensions has been limited to boundary-driven flow at low shear rates (ca. up to 1000 s^{-1}). The rheological determinations based on pressure-driven flow have been sporadic [15, 19, 36]. To the authors' knowledge, a detailed investigation on high shear rate (> 10000 s^{-1}) rheology of MFC suspensions has not yet been reported. The comparison of pressure-driven flow to boundary-driven flows has also not been reported

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