# DOES RHEOLOGY RESTRICT THE SECONDARY SETTLER CAPACITY?

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## ABSTRACT

Consideration of sludge rheology is very important for a proper solids transport and to obtain the necessary settler capacity. Although a true yield stress does not exist, large apparent viscosities at low shear rates inhibit an efficient sludge transport. Research indicates that the dimensionless ratio of gravity to viscous forces is an important operational parameter towards settler capacity. To improve solids transport scraper mechanisms are utilized that introduce extra shear to (i) overcome the pseudo-yield stress and (ii) liquefy the sludge.

## INTRODUCTION

Efficient transport of thickened sludge in secondary settling tanks largely depends on the low-shear rheological properties of the suspension as low shear stresses prevail in the solids blanket. Thickened sludge characterized as Bingham or Herschel-Bulkley fluids show a yield stress below which no solids move. Increased yield stresses thus prevent solids transport along the bottom floor (i.e. settler capacity); they impact the solids blanket height and velocity field in the settling tank (Lakehal *et al.*, 1999). The primary goal of this study is to experimentally investigate whether a yield stress exists for sludge as Barnes & Walters (1985) described how this stress only results from the sensor's insensitivity. The objectives were to set up an alternative rheological model that accurately describes low-shear rheology; to determine its impact on the internal sludge transport in secondary settlers by computational fluid dynamics simulations; and to identify the mechanisms of the scraper as sludge removal device.

## METHODS

Comprehensive rheology sampling was conducted with a sensitive rotational stress-controlled Bohlin CVO rheometer. Sludge at different solids concentrations and from different Belgian municipal wastewater treatment plants were investigated in terms of their rheological behavior. The extracted rheological model was subsequently imported in the computational fluid dynamics (CFD) software FLUENT (Fluent Inc., UK) enabling the computation of the solids concentration and flow velocity fields. The CFD model was validated for a circular secondary settler operating with a zeolite dosage to improve the sludge settling properties (De Clercq, 2003).

**RESULTS**

The rheological experiments clearly indicated the non-existence of a yield stress; large apparent viscosities prevail at shear rates below 1 $s^{-1}$ though (FIGURE 1). An alternative Herschel-Bulkley rheological model has therefore been proposed, i.e.

$$\tau = \tau_0\left(1 - e^{-m\dot{\gamma}}\right) + K\dot{\gamma}^n$$

where $\tau$ and $\dot{\gamma}$ are the shear stress and shear rate respectively. Further, $\tau_0$, K and n are the yield stress, fluid consistency index and flow behavior index respectively. The material parameter m has been introduced by Papanastasiou (1987) to control the growth of stress as the shear rate increases. Its original introduction to avoid numerical instabilities in CFD code now obtains a physical interpretation as well. Whereas the material parameter and flow behavior index appeared to be constants, the dependencies of yield stress and fluid consistency index on the solids concentration were described by a power and quadratic model respectively.

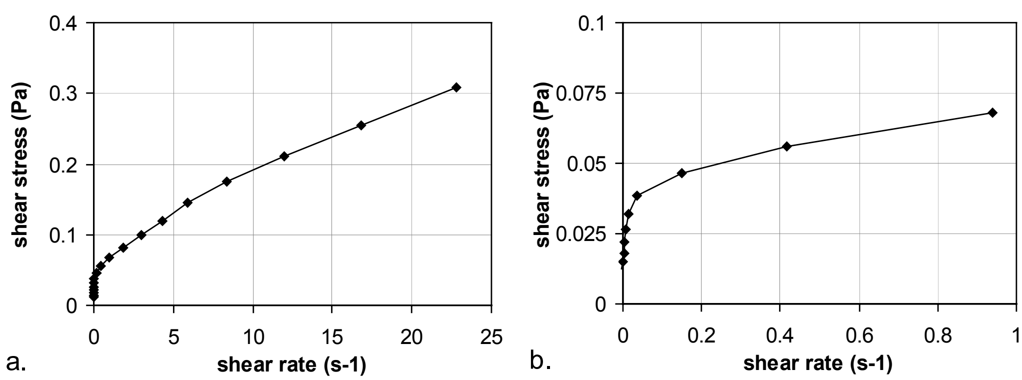


FIGURE 1. Typical rheogram for activated slude (a), and zoom-in (b).

To demonstrate the impact of the large pseudo-yield stress, i.e. large viscosities at small shear rates, on sludge transport in settlers, steady-state CFD simulations were run for the rheology of water (Newtonian liquid without yield stress) and the modified Herschel-Bulkley model (EQUATION 1); zeolite-treated sludge was utilized. CFD simulations as shown in FIGURE 2 clearly show that no hydraulic transport limitation to the hopper occurs as the solids blanket stayed low. However, fundamental studies indicated that the sludge flow velocity on a slope should increase drastically by gravity in case of the water rheology. As observed in FIGURE 2 though, the bottom sludge flow is clearly maintained at a low velocity by boundary conditions, i.e. boundary-related forces counteract the gravity force. At low velocities it can be demonstrated that the yield stress becomes very important to the sludge transport efficiency. In FIGURE 2, however, the gravity force is large enough to overcome this stress thanks to the sludge density increase from zeolite dosing. When no zeolite is present, the gravity force reduces, and both a clarification and capacity failure exists for the modified Herschel-Bulkey rheology though (FIGURE 3).
The study indicated that increasing solids concentration at the settler's bottom enhances both gravitational and viscous forces, but the latter increases more than

proportional compared to the gravitational force. Hence, the flow velocity reduces for the modified Herschel-Bulkley model. In case of water, higher solids concentrations only enlarge the density difference since the viscosity is fixed. Consequently, the velocity increases as long as it is not restricted by the underflow velocity. Simulations also demonstrated that a significant increase of the fluid consistency index does not result in a blanket rise; the yield stress, or the large viscosity at small shear rates, is the sole reason for the clarification and capacity failures. The zeolite though increases the density and, thus, the gravity force to such an extent that viscous forces negligibly counteract it. This indicates that the ratio of gravitational to viscous forces B is crucial for proper sludge transport inside the solids blanket and along the bottom floor; it may be quantified by the ratio of the dimensionless Reynolds number Re to the Froude number Fr, i.e.

$$B = \frac{F_{gravity}}{F_{viscous}} = \frac{Re}{Fr} = \frac{\rho UL}{\mu}\frac{gL}{U^2} = \frac{\rho g L^2}{\mu U}$$

where $\rho$, g, L and U are the bulk density, gravitational acceleration, a characteristic length and velocity scale respectively; $\mu$ is the apparent viscosity defined as $\mu = \tau/\dot{\gamma}$. Large values of B obviously induce a sludge flow in the solids blanket. In this respect, the working principle of a solids removal mechanism like a scraper can now be easily explained as a device introducing extra shear to overcome this pseudo-yielded region. The introduced shear also breaks down the particulate structure of the sludge such that it liquefies, i.e. the apparent viscosity decreases, and easily transports to the hopper (data not shown).

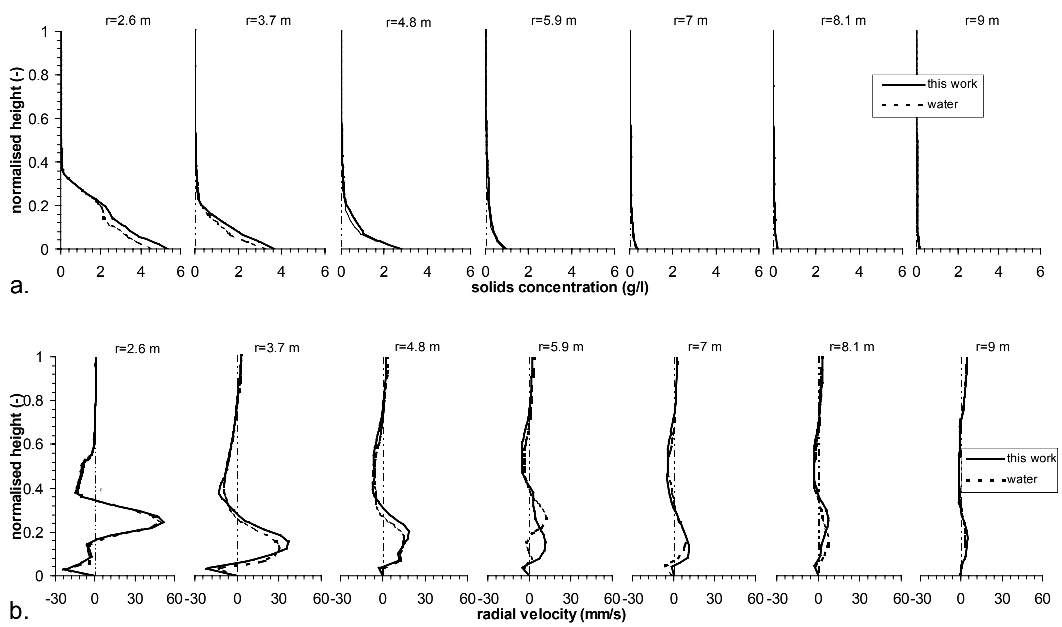


FIGURE 2. Comparison of two rheological models, i.e. water (Newtonian) and the modified Herschel-Bulkley model, for zeolite-treated sludge by means of solids concentration (a) and radial velocity (b) profiles obtained from CFD simulations. The profiles are shown at seven radial distances r measured from the center of the tank. They all situate outside the feed well. The height above the bottom floor is normalized by the local depth.

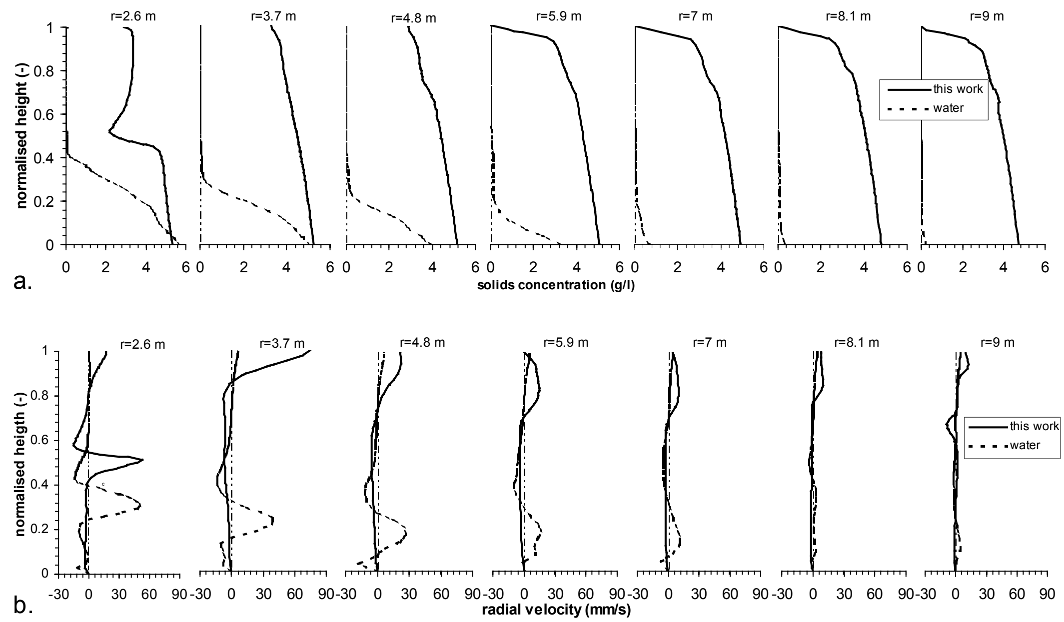


FIGURE 3. Comparison of two rheological models, i.e. water (Newtonian) and the modified Herschel-Bulkley model, for sludge with a reduced dry solids density (from 1750 to 1450 kg/m$^3$) by means of solids concentration (a) and radial velocity (b) profiles obtained from CFD simulations. The profiles are shown at seven radial distances r measured from the center of the tank. They all situate outside the feed well. The height above the bottom floor is normalized by the local depth.

## CONCLUSIONS

Consideration of sludge rheology is very important for a proper solids transport and to obtain the necessary settler capacity. Although a true yield stress does not exist, large apparent viscosities at low shear rates inhibit an efficient sludge transport. Research further indicated that the dimensionless ratio of gravity to viscous forces is an important operational parameter towards settler capacity. To improve solids transport scraper mechanisms are utilized that introduce extra shear to (i) overcome the pseudo-yield stress and (ii) liquefy the sludge.

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