Scientific posters of MUDNET Conference 2021 (RHEOMUD)

RHEOMUD

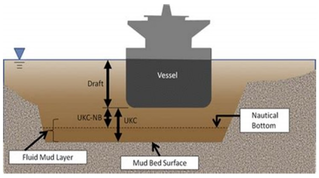
Rheological behaviour of marine sediments for assessing nautical depth

Ahmed BENAMAR, Anne PANTET, Mohamed-Tahar AMMAMI

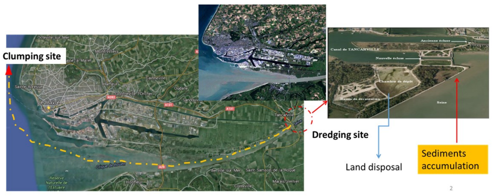
Université Le Havre Normandie, Laboratoire Ondes et Milieux Complexes (LOMC), UMR 6294 CNRS, 75 rue Bellot, Le Havre, France

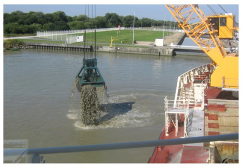
Nautical depth concept:

The costs of maintaining the nautical depths in the ports are significant, and authorities issued alternative solutions in order to avoid marine exclusive deposit. These costs will increase exponentially when deeper access channels are to be maintained. In this perspective the **nautical bottom concept** was developed and implemented in several major ports (Wurpts et al. 2005 – Mehta et al. 2013). This concept is valid because the top layer of the siltation material has, in general, such low strength characteristics that it does not avoid navigation. The expected nautical depth may be guaranteed without removing sediments (Fontein et al. 2006), by using a new concept of dredging system. As suggested for Emden port sediments (Wurpts *et al.*, 2005), the yield shear stress must be lower than 100 Pa for navigability concern.



In the top layer of siltation material, how making sediments navigable?





Dredging site

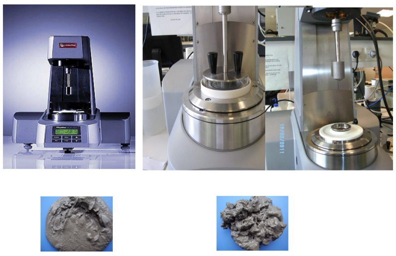
Site description:

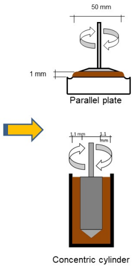
In France, the River Seine carries an average suspended load of about 200 mg/l in the water column, reaching up to 450 mg/l in tidal phases. This suspended material has the nature of quickly entering so-called calm zones as the entrance of Tancarville (France) channel located on the Seine estuary, where the largest retention occurs, leading to intensive dredging.

Nautical depth and Yield Point from rheometer tests:

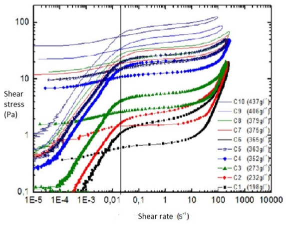
The main parameter assumed for navigational purposes is the initial resistance of the mud, when deformed, represented by the yield-strength. Rheological tests were performed in sediment samples collected from Tancarville waterway, involving different solid concentrations, indicated a non-linear increasing of the yield shear stress with the solid concentration from 400g/l to 800g/l ($\Phi = 0,13$ to $0,23$) by using two geometries (parallel plate and concentric cylinder). The density involving the suggested yield shear stress of 100 Pa is close to 1.4 t/m^3 whereas the threshold value of material flow is close to 1,2 t/m^3. So, Tancarville sediment can be considered navigable when its density does not exceed this latter value,

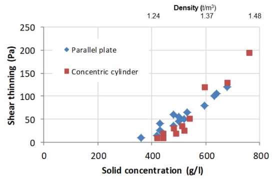
Rheometer tests





Results





Threshold parameters of material flow:
Solid Concentration = 400 g/l,
Density= 1.24 t/m^3

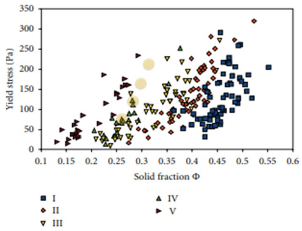
Analysis and matching with results from Marennes d'Oléron bay

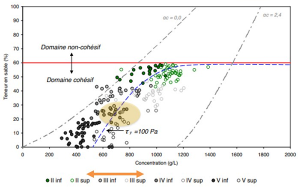
To precise the coarse particles effects within mud, the fine/solid fraction ψ is defined: $\Psi = \frac{V_f}{V_g + V_f}$ with Vf : volume of fine particles - (clay-silt) - Vg: grains volume (sand) - Vw: water volume (Pantet et al. 2010)

Tancarvile samples

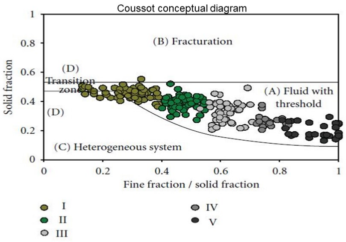
Table 2: Five types of sediments in MOb.

Sediment type	Rheological type	Fraction (%)		
		Sand	Silt	Clay
Silty sand	I	75–60	21–34	4–6
Muddy sand	II	60–45	34–46	6–9
Sandy mud	III	45–29	46–61	9-10
Slightly sandy mud	IV	29–18	61–71	10-11
Mud	V	18–0	71–81	11–13





Coussot conceptual diagram



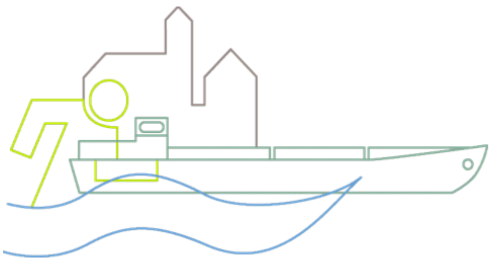
Summary:

Rheometric tests performed in laboratory allowed to assess the suitability of remoulded sediments to reach low shear resistance in order to be navigable. The flow curves show that this mud material will be able to flow when external shear stress exceeds about 30 Pa and the density close to 1,2 t/m^3. The dredging method which is applied must shows that the material can be navigable up to a yield point of 100 Pa if its density is lowered to less than 1.4 t/m3. Previous rheological measurement sensitivity allowed to identify five typical sediments that correlate with solid fraction and fine fraction. From the provided diagram, the Tancarville sediment falls in the area of a fluid with threshold,

To understand the relationship between the mud sedimented layer and the mud suspension layer, further experiments involving a chanel with cohesive sediments are under design to complete the rheological characterization.

References

Mehta A.J. Samsani F. Khare Y.P. , Sahin C. "fluid mud properties in nautical depth estimation " Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 140, No. 2, March 1, 2014. ©ASCE, ISSN 0733-950X/2014/2-210–222/$25.00.
Buchanan L (2005). *Difficulties of surveying in fluid mud, the effect on bathymetry of suspended sediments in the water column*. Hydro-International vol. 9, Nbr 6.
Wurpts R, Torn P (2005). *15 Years' Experience with Fluid Mud: Definition of the Nautical Bottom with Rheological Parameters*. Terra et Aqua – Number 99.
Benamar A, Pantet A, Brasselet S, Bourdin F (2015). *Rheological behaviour of marine sediments for assessing nautical depth*. C2M conf., Ferrare, Italy. Editions Paralia, pp. 107–110. https://doi:10.5150/cmcm.2015.022
Fontein W, Werner C, Wal J (2006). *Assessing nautical depth including direct viscosity measurements, Dredging and Sustainable Development CHIDA* - 2nd International Dredging Congress *May 17-18, 2006, Guangzhou, CHINA*
Pantet A, Robert S, Jarny S, Kervella S (2010). *Effect of Coarse Particle Volume Fraction on the Yield Stress of Muddy Sediments from Marennes Oleron Bay.* Advances in Materials Science and Engineering , https://doi.org/10.1155/2010/245398



Rheological measurements to improve the understanding of suspended sediment dynamics in the Ems estuary

MUDNET Conference – Delft
29.3. – 30.3.2021

Christine Borgsmüller

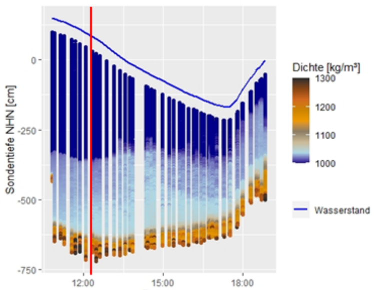
Department M3 - Fluvial morphology, Sediment dynamics and -management
Federal Institute of Hydrology, Koblenz

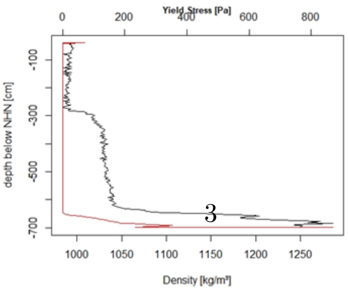
The Ems estuary

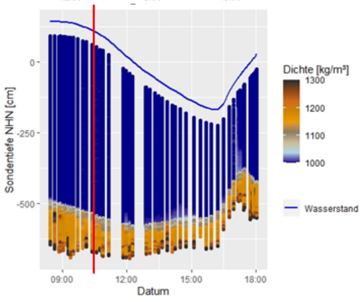
Quelle: BAW (2014);

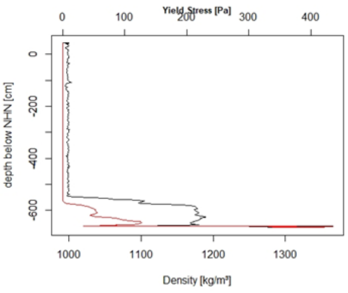
- the bed of the lower Ems estuary is temporarily covered with fluid mud layers up to serveral meters
- high variability of hydrodynamic conditions on different timescales lead to complex behaviour of fluid mud concerning formation, consolidation, entrainment and advective transport processes
- goal: to conduct further research to examine the rheological properties of estuarine muds under different hydrological conditions

Density and yield stress measurements in the estuary





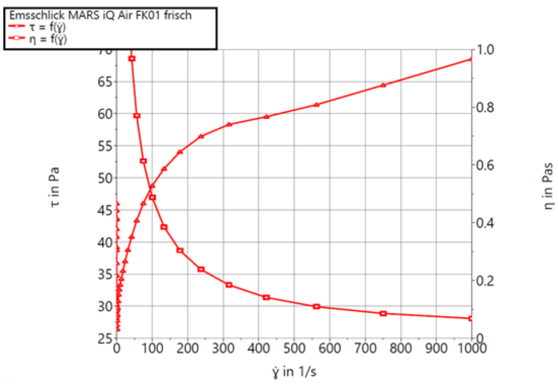




- Rheotune measurements at Emskm 7,2 (upper estuary) on 17.6. and 16.7.2020
- Multiple profiles with Stema Rheotune probe during ebb tide represent different hydrodynamic conditions
- Denisty (black line) and yield stress(red line) profiles differ significantly
- Question: how do sediment/mud samples differ concerning their (rheological) properties, especially thixotropic behaviour?

Rheological investigation of mud samples

Further investigation of van Veen grabber samples, Emskm 7,2 on 16.7.2020



First tests carried out in 2020 with Haake Mars Rheometer

Systematic investigation of fluid mud samples taken under different hydrological conditions will take place in 2021

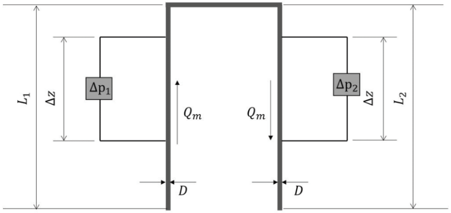
IHC Deltares Online Pipe Rheometer (IDRM)

The IDRM is an online **24/7 self-priming** pipe rheometer with an arrangement of U-tubes. It enables determination of the rheogram based on simultaneous measurements of pressure differentials and flowrates in vertically oriented tubes with a variety of diameters. Main output of the system is a rheogram, including Bingham parameters and density **every 10 minutes**!

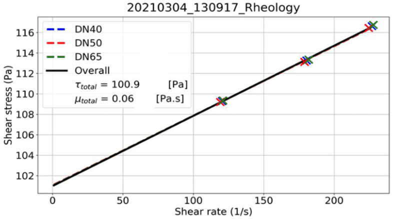

Water management thickener by rheological control of the underflow

BHP and EXPANDE
Mining Open Innovation Program of Fundación Chile

Rabinovich-Mooney Transformation



simulated output from IDRM



Authors and contacts
Jort van Wijk (Royal IHC)
Arno Talmon (Deltares)
Arno.Talmon@deltares.nl
Wiebe Boomsma (Royal IHC)
WBA.Boomsma@royalihc.com
Ebi Meshkati (Deltares)

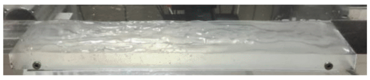
Rheological analysis of a model mud for laboratory erosion experiment

Pierre Lecostey[1], Guillaume Gomit[1], Sébastien Jarny[1], Lionel Thomas[1]
[1] Institut P', CNRS, Université de Poitiers, ENSMA,
Boulevard Marie et Pierre Curie, Futuroscope 86962, France
Email : pierre.lecostey@univ-poitiers.fr

Context and Purpose

Rheological properties of mud have a crucial impact on their erosion. To better understand this link, a local study of the erosion process is proposed. To make it possible, a clear model mud has been created with a mix of laponite and CarboxyMethylCellulose (CMC) (figure 1). Indeed erosion experiments, using optical technics like Particle Image Velocimetry (PIV) and sediment surface estimation, required clear mud. Furthermore, model mud takes advantage to be rheologicaly stable and reproducible.

Fig. 1 Model mud created with laponite and CMC



Rheological analysis

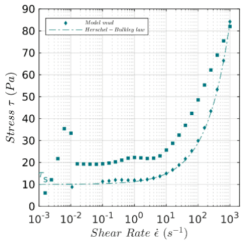
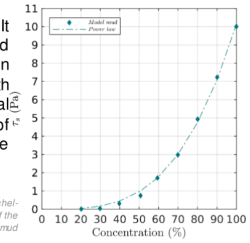


Fig. 2 Rheological flowing test of model mud and Herschel- Bulkley model fitted

Flowing rheological tests have been conducted on the model mud and its dilutions. It appears that the sediment can be modelized by an Heschel-Bulkley fluid with a yield stress τ_s (figure 2). Herschel-Bulkley model is often used to describe natural fine-grain sediment [1]. The clear mud has a yield stress around 10 Pa which is consistent with real fluidized mud. The dilution of the model mud will be used to create several laboratory sediments with different Herschel-Bulkley characteristics. Yield stress of each dilution have been represented on the figure 3. The growth of τ_s can be modelized by a power law which is in agreement with natural mud [2].

Fig. 3 Yield stresses of Herschel-Bulkley function of the concentration of model mud



Erosion experimentation

The study of the model mud diluted under turbulent flow has been performed in a squared closed channel (figure 4). Particle Image Velocimetry (PIV) coupled with a surface detection algorithm have been used. The use of the PIV allows the estimation of the bottom shear stress of the flow, important factor of sediment erosion [3], and the mud surface. In addition, the PIV could give more information on the flow like hairpin structure which is known to affect non-fine sediment erosion [4]. The correlation of velocity field data from the PIV with the surface detection allows the analysis of the relationship between the flow structures and the bed sediment motion.

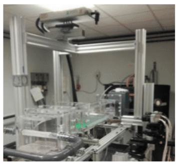


Fig. 4 Hydro-sedimentary channel

The figure 5 shows a example of the mud surface deformed by the flow just before erosion process. The surface detection code result is plotted in red and the white vectors represent the velocity calculated with the PIV technics.

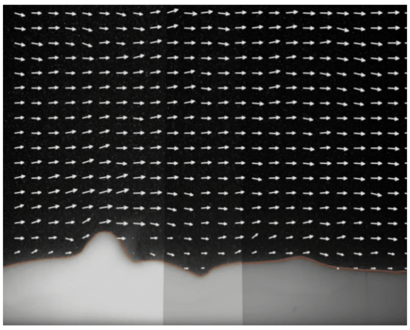


Fig. 5 PIV vector coupled with surface detection on the model mud

Prospects

- Link rheological constants with flow characteristics
- Correlate surface movement to flow structures
- Analyse surface oscillations preceding the erosion of the mud
- Study model mud in an open channel

Bibliography

[1] MELINGE Y. *et al*, Etude du comportement visqueux-visco-plastique de suspensions sédimentaires multi-echelle, 2015
[2] MIGNIOT C., Étude des propriétés physiques de différents sédiments très fins et de leur comportement sous des actions hydrodynamiques, 1968
[3] GYR A. and HOYER K., Sediment Transport: A Geophysical Phenomenon, 2006
[4] LE LOUVETEL-POILLY J.,Etude expérimentale du rôle de la turbulence de paroi dans le transport de particules, 2008

CNRS • Université de Poitiers • ENSMA • UPR 3346
SP2MI • Téléport 2 • 11, Boulevard Marie et Pierre Curie • BP 30179
F86962 FUTUROSCOPE CHASSENEUIL Cedex
www.pprime.fr

A rheological model for mud which avoids the use of a yield stress

Johanna Schmidt[1], Andreas Malcherek[1]

[1]Chair of Hydromechanics, Institute of Hydro Sciences, Universität der Bundeswehr München

Abstract

1.

A Cross model has been applied to mud samples from the Ems Estuary with different sediment volume fractions ϕ_s. It yields excellent approximations in the area where shear is low. This model represents a transition from a high to a low viscosity and avoids the use of a yield stress. The model parameters strongly depend on ϕ_s. For CFD simulations, the dependency on ϕ_s can be included into the model. The model can then be applied for water, fluid mud and immobile mud.

Introduction and Motivation

2.

Mud samples show a shear-thinning, thixotropic behavior with two-step yielding [1]. Figure 1 shows the scheme of a flow curve and viscosity curve for a mud sample. A Bingham or any other model that consists of a yield stress, e.g. $\tau = \tau_{y,B} + \mu_\infty \dot{\gamma}$ results in an infinitely large viscosity for $\dot{\gamma} = 0$. Modern rheometers detect small movements below the yield stress $\tau_{y,s}$, which indicates a high but not infinite viscosity.

Thus, the approximation of mud data with a Bingham model is weak at areas of low shear and leads to a possible division by zero in numerical simulations. In natural channels, the velocity shear is typically low, especially when the sediment concentration is high. An improvement is possible with a model which describes a transition from a high to a low viscosity instead. Suitable models are the Cross model or Carreau-type models.

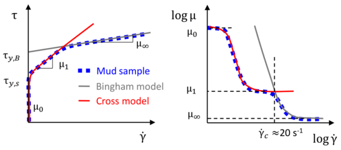


Figure 1. Flow curve (left) and viscosity curve (right) of a mud sample with Bingham and Cross model.

Materials and Methods

3.

Stress sweep tests were performed with four mud samples (ϕ_s = 0.16 0.13 0.10 and 0.07, see Figure 2) using the stress-controlled mode of the rheometer.

The Cross model follows the equation

$$\mu = \frac{\mu_0 - \mu_\infty}{1 + (t_r \dot{\gamma})^n} + \mu_\infty \quad (1)$$

where $\mu \rightarrow \mu_0$ for $\dot{\gamma} \rightarrow 0$ and $\mu \rightarrow \mu_\infty$ for $\dot{\gamma} \rightarrow \infty$ [2]. We wish to apply the model up to an intermediate viscosity μ_1 instead of μ_∞:

$$\mu = \frac{\mu_0 - \mu_1}{1 + (t_r \dot{\gamma})^n} + \mu_1 \quad (2)$$

The parameter t_r has the unit seconds. The value $\frac{1}{t_r}$ is the value where the transition from μ_0 to μ_1 starts. The parameter n indicates how quick the transition occurs.

For evaluation, the data between $0 \leq \dot{\gamma} \leq \dot{\gamma}_c$ was used. The measurement data was then fitted to Equation (2).

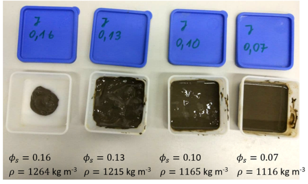


Figure 2. Mud samples from the Ems Estuary (Jemgum). Rheological experiments were performed using a Physica MCR301 rheometer. A parallel plate geometry with a gap of 1 mm was used.

Results and Discussion

4.

The results of Equation (2) with the parameters for the four mud samples are shown in Table 1 and Figure 3. The parameters μ_0, μ_1 and t_r increase with increasing ϕ_s. As the parameter n was close to 1 for all samples, the value was set to 1. The model is in excellent agreement with the measurement data. A dependency for the parameters $\mu_0(\phi_s)$, $\mu_1(\phi_s)$ and $t_r(\phi_s)$ can be found. The model is valid for $0 \leq \dot{\gamma} \leq \dot{\gamma}_c$.

Table 1. Results of the parameters for the Cross model for different mud samples. *There is an interesting relation between μ_0 and t_r: The value of the yield stress $\tau_{y,s}$ can be analytically derived as $\tau_{y,s} \approx \frac{\mu_0}{t_r}$.

Sample	μ_0 [Pa s]	μ_1 [Pa s]	t_r [s]	$\tau_{y,s} \approx \frac{\mu_0 *}{t_r}$ [Pa]	R^2
J 0.16	$3.0 \cdot 10^5$	5	2420	124	0.9887
J 0.13	$9.0 \cdot 10^4$	2	1765	51	0.9798
J 0.10	$2.5 \cdot 10^4$	1	1470	17	0.9964
J 0.07	$6.0 \cdot 10^2$	0.3	600	1	0.9971

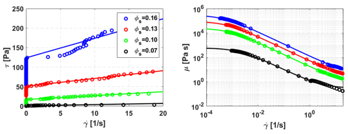


Figure 3. Measurement data and Cross model for the mud samples. The viscosity curve (right) is calculated with Equation (2). The flow curve (left) is then calculated with $\tau = \mu\dot{\gamma}$.

Conclusions

5.

This study shows a simple rheological model for mud which avoids the use of a yield stress and is valid in areas of low shear rate. The model was successfully applied to mud samples with different sediment volume fractions. In CFD simulations, such a yield stress-free model has the advantage that it avoids the possible division by zero. Furthermore, it includes the rheological measurement data at very low shear rates which is usually neglected.

Acknowledgements
This work was funded by the German Federal Waterways Engineering and Research Institute (BAW).

References
[1] Shakeel, A., Kirichek, A., Chassagne, C. (2019), Rheological analysis of mud from Port of Hamburg, Germany, *Journal of Soils and Sediments*, 20
[2] Cross, M.M. (1965), Rheology on non-Newtonian fluids: a new flow equation for pseudoplastic systems, *Journal of Colloid Science*, 20, 417-437.

Universität der Bundeswehr München
Institut für Wasserwesen – Professur für Hydromechanik und Wasserbau
Prof. Dr.-Ing. Andreas Malcherek

Rheology of cohesive suspensions:
A preliminary approach towards the sediment transport

Bougouin, A., Jarno A., Bénamar A., Marin F. and Pantet A.

Laboratoire Ondes et Milieux Complexes (LOMC) - Université Le Havre Normandie, UMR 6294 CNRS,
76063 Le Havre, France

Introduction

The sediment transport is of major importance as it contributes in the morphology of riverbeds and it may be associated to risks (e.g., floods, scouring). One of the main challenges is to relate the sediment transport rate to the hydraulic conditions applied to the granular bed. However, a fine proportion of cohesive materials may strongly affect the sediment transport by increasing the particle threshold of motion [2, 4]. The present work aims to combine both the rheological measurements and the laboratory experiments on the sediment transport in a flume with clay-sand mixtures to highlight the relationship between the rheology and the transport of such materials. **Here, we present the preliminary results on the rheology of pure illite and kaolinite suspensions over a wide range of volume fractions, using both a cone-plane and a novel vane geometry**.

Setup and validation

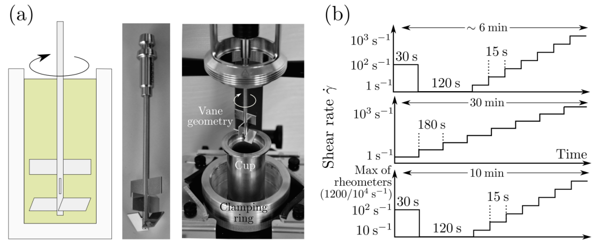


Figure 1: (a) Vane geometry and (b) measurement protocols.

The **rheological measurements** are performed using both a Physica MCR 501 rheometer and a RheolabQC rheometer from Anton Paar, equipped with a cone-plane and a novel vane geometry [Fig. 1(a)], respectively. Three different protocols are used to ensure the reliability of measurements [Fig. 1(b)]. **Cohesive suspensions** are made of illite or kaolinite clay suspended in tap water, and they are prepared at least one day before the rheological measurements. The masses of water m_w and of clay m_c are weighted accurately to estimate the volume fraction of suspensions as

$$\phi = \frac{\rho_w m_c}{\rho_w m_c + \rho_c m_w}, \tag{1}$$

where $\rho_w = 1000\text{kg.m}^{-3}$ is the water density, and $\rho_c = 2600$ and 2800kg.m^{-3} are the densities of kaolinite and illite, respectively. The volume fraction is varied in the range $\phi = [0 : 0.269]$ with the cone-plane, and $\phi = [0.147 : 0.399]$ with the vane geometry.

Preliminary results. The volume fraction ϕ mainly controls the flow curve $\tau = f(\dot{\gamma})$ of suspensions [Fig. 2(a)]. Moreover, the different protocols do not affect significantly the rheological behavior of suspensions (from light to dark gray symbols), unlike the geometry considered (circles vs. triangles). Indeed, the estimate of τ using the vane geometry is larger than that measured by the cone-plane, probably due to different internal structures of the sample [3]. In both cases, the flow curve is described using the Herschel-Bulkley model $\tau = \tau_y + K\dot{\gamma}^n$, with τ_y the yield stress, K the consistency, and n the index (solid and dashed lines). The comparison of the values τ_y estimated with both geometries shows that the bias of measurements for the yield stress may be easily corrected here [dotted line, in Fig. 2(b)].

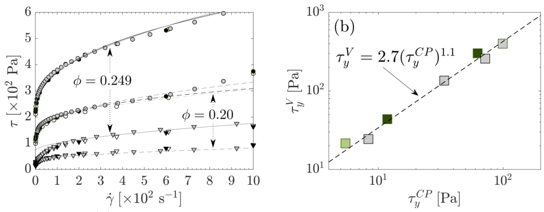


Figure 2: (a) Shear stress τ as a function of the shear rate $\dot{\gamma}$ for kaolinite suspensions with different ϕ, measured by the cone-plane (triangles) and the vane (circles) geometry with different protocols (light to dark gray). The solid lines are the best fits of the Herschel-Bulkley model. (b) Yield stress τ_y^V measured by the vane geometry as a function of the yield stress τ_y^{CP} measured by the cone-plane with different protocols (from light to dark colors), for illite (green) and kaolinite (gray) suspensions.

Role of the volume fraction

As mentioned above, the rheological behavior of cohesive suspensions is mainly controlled by the volume fraction ϕ (Fig. 3), as already reported by previous studies [1, 2]. The increase of ϕ promotes larger shear stresses τ and apparent viscosities η, for a given shear rate $\dot{\gamma}$. Additionally, the flow curve of suspensions is well described using the Herschel-Bulkley model (dashed lines). The evolution of rheological parameters with ϕ can therefore be addressed, and in particular, the yield stress τ_y quantifying the mobility of mixtures for the purpose of investigating the sediment transport.

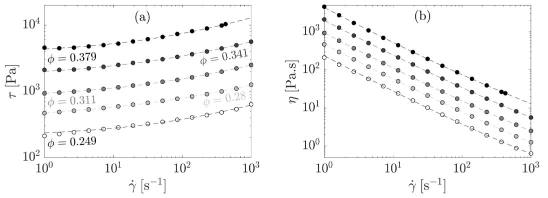


Figure 3: (a) Shear stress τ and (b) apparent viscosity η as a function of the shear rate $\dot{\gamma}$ for kaolinite suspensions with different ϕ. The dashed lines are the best fits of the Herschel-Bulkley model.

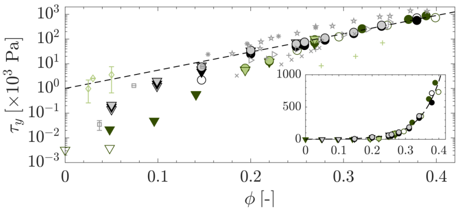


Figure 4: Yield stress τ_y as a function of ϕ for illite (green) and kaolinite (gray) suspensions, measured by the cone-plane (triangles) and the vane (circles) geometry with different protocols (light to dark colors). Opened symbols are data from the literature. The dashed line is $\tau_y = a\exp(b\phi)$, with $a = 1$ and $b = 17$.

As expected, τ_y increases over several decades with increasing ϕ (Fig. 4). At large ϕ, the experimental data may be described by the empirical law $\tau_y = a\exp(b\phi)$ [1], with $a = 1$ and $b = 17$ (dashed line), regardless of illite and kaolinite suspensions. At low ϕ, however, the yield stress is overestimated by the empirical model. Finally, our experimental data are included in the scatter of results from the literature (see opened symbols).

Conclusion

- Rheological measurements on pure illite and kaolinite suspensions with various volume fractions are performed using both a cone-plane and a novel vane geometry.
- The rheological behavior of cohesive suspensions is mainly controlled by the volume fraction, while the geometry used causes a bias of measurements.
- The yield stress increases with ϕ, in agreement with empirical laws and data from the literature.

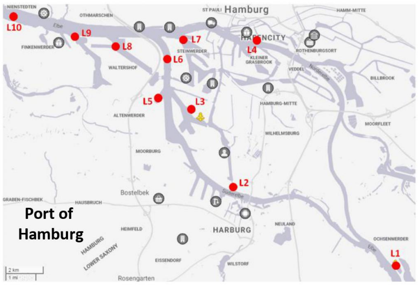
References

[1] P. Coussot and J.-M. Piau. *Rheol. Acta*, 33, 1994.
[2] A. Pantet *et al.* *Adv. Mater. Sci. Eng.*, 2010, 2010.
[3] A. Shakeel *et al.* *Mar. Pet. Geol.*, 116, 2020.
[4] L. C. Van Rijn. *J. Hydraul. Eng.*, 146, 2020.

Rheology of mud from Port of Hamburg, Germany

Ahmad Shakeel[1]; Alex Kirichek[1,2]; Claire Chassagne[1]
[1]Faculty of Civil Engineering and Geosciences, Department of Hydraulic Engineering, Delft University of Technology, The Netherlands,
[2]Deltares, The Netherlands

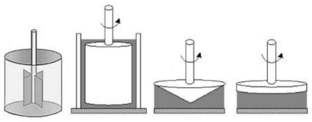
Mud Sampling

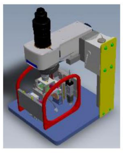


Frahmlot

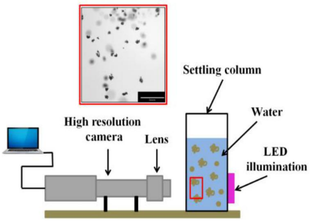
Experimental

HAAKE MARS I Rheometer



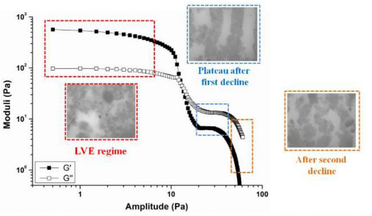


Modified RheOptiCAD



Floc-camera settling setup

Results

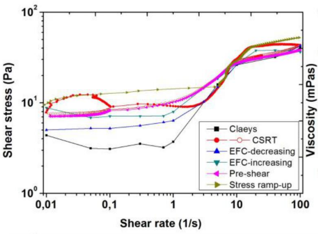


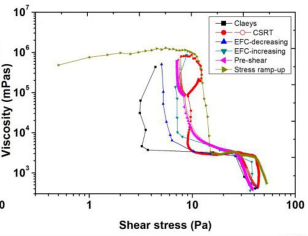
Two-step yielding behavior

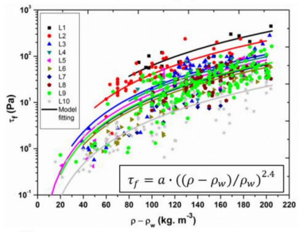
Collapse of floc network (i.e., first yield)

Formation of cylinder-like structures

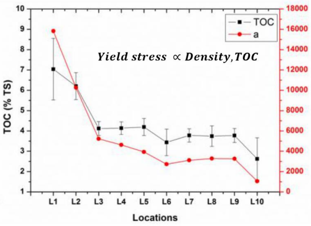
Collapse of these structures into smaller flocs (i.e., second yield)



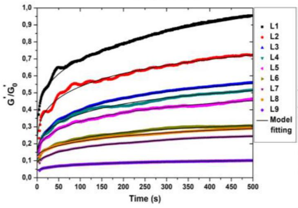


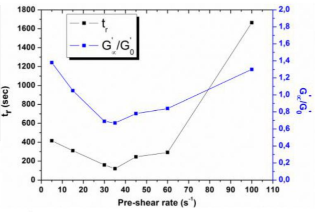


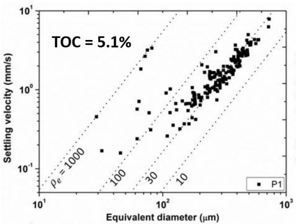
$$\tau_f = a \cdot ((\rho - \rho_w)/\rho_w)^{2.4}$$

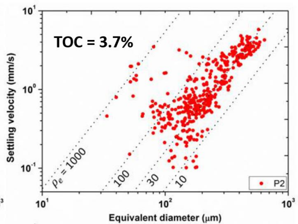


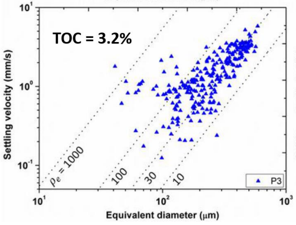
Yield stress ∝ Density, TOC

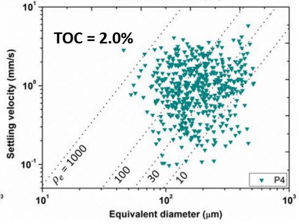












Conclusions

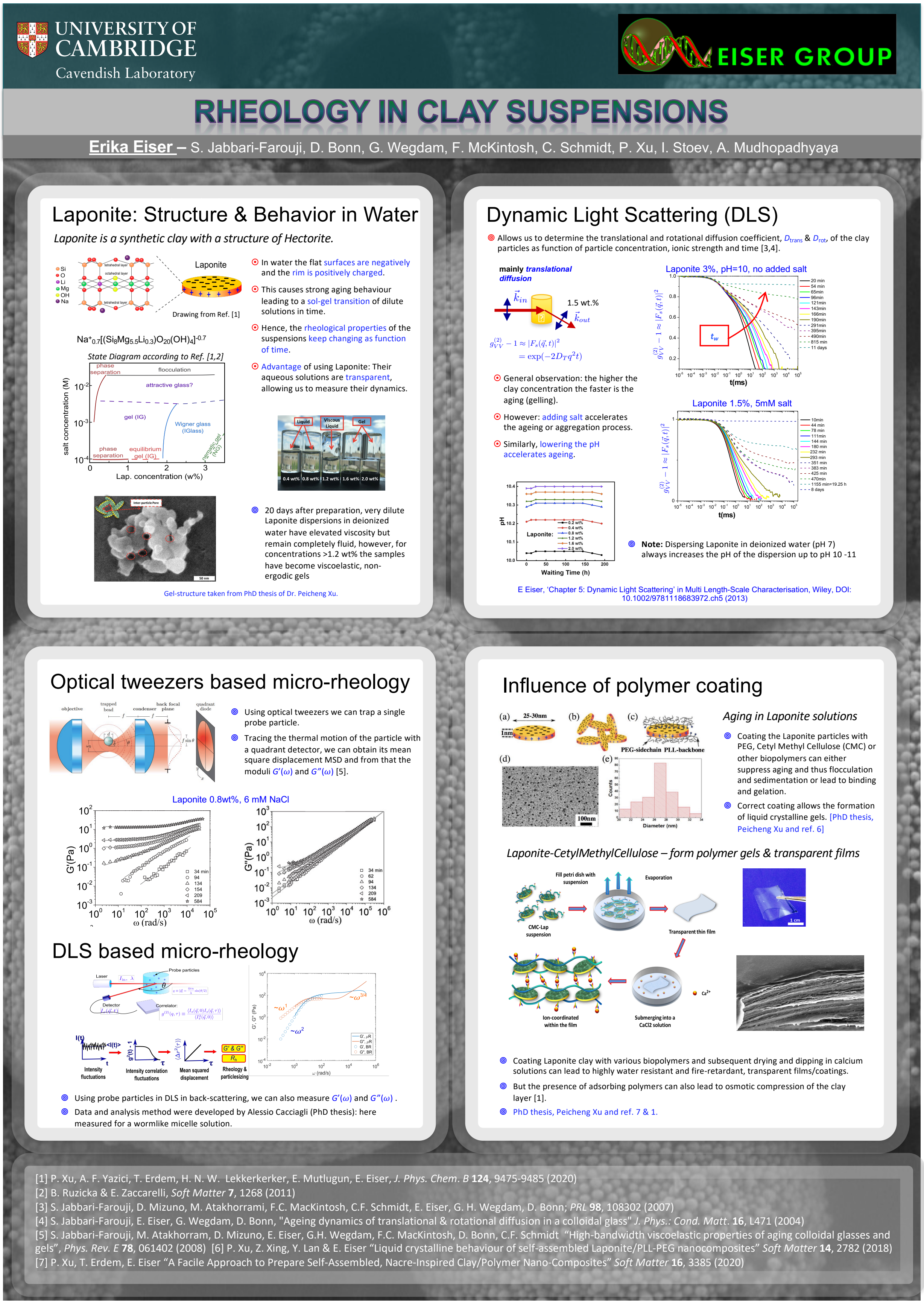
Stress ramp-up test with Couette geometry proves to be a fast and reliable test for yield stress measurement of mud samples.

Two-step yielding behaviour is evident for mud samples due to the formation of cylinder-like structures.

Yield stress of mud samples is strongly dependent on both density and TOC.

Structural recovery after pre-shearing is higher for mud samples having lower TOC and pre-sheared at lowest or highest pre-shear rate.

The larger flocs are observed for the mud sample having higher TOC.



UNIVERSITY OF CAMBRIDGE
Cavendish Laboratory

RHEOLOGY IN CLAY SUSPENSIONS

Erika Eiser – S. Jabbari-Farouji, D. Bonn, G. Wegdam, F. McKintosh, C. Schmidt, P. Xu, I. Stoev, A. Mudhopadhyaya

Laponite: Structure & Behavior in Water

Laponite is a synthetic clay with a structure of Hectorite.

Drawing from Ref. [1]

$Na^{+}_{0.7}[(Si_8Mg_{5.5}Li_{0.3})O_{20}(OH)_4]^{-0.7}$

State Diagram according to Ref. [1,2]

- In water the flat surfaces are negatively and the rim is positively charged.
- This causes strong aging behaviour leading to a sol-gel transition of dilute solutions in time.
- Hence, the rheological properties of the suspensions keep changing as function of time.
- Advantage of using Laponite: Their aqueous solutions are transparent, allowing us to measure their dynamics.

- 20 days after preparation, very dilute Laponite dispersions in deionized water have elevated viscosity but remain completely fluid, however, for concentrations >1.2 wt% the samples have become viscoelastic, non-ergodic gels

Gel-structure taken from PhD thesis of Dr. Peicheng Xu.

Dynamic Light Scattering (DLS)

- Allows us to determine the translational and rotational diffusion coefficient, D_{trans} & D_{rot}, of the clay particles as function of particle concentration, ionic strength and time [3,4].

mainly *translational diffusion*

$$g^{(2)}_{VV} - 1 \approx |F_s(\vec{q},t)|^2 = \exp(-2D_T q^2 t)$$

- General observation: the higher the clay concentration the faster is the aging (gelling).
- However: adding salt accelerates the ageing or aggregation process.
- Similarly, lowering the pH accelerates ageing.

- **Note:** Dispersing Laponite in deionized water (pH 7) always increases the pH of the dispersion up to pH 10 -11

E Eiser, 'Chapter 5: Dynamic Light Scattering' in Multi Length-Scale Characterisation, Wiley, DOI: 10.1002/9781118683972.ch5 (2013)

Optical tweezers based micro-rheology

- Using optical tweezers we can trap a single probe particle.
- Tracing the thermal motion of the particle with a quadrant detector, we can obtain its mean square displacement MSD and from that the moduli $G'(\omega)$ and $G''(\omega)$ [5].

DLS based micro-rheology

- Using probe particles in DLS in back-scattering, we can also measure $G'(\omega)$ and $G''(\omega)$.
- Data and analysis method were developed by Alessio Cacciagli (PhD thesis): here measured for a wormlike micelle solution.

Influence of polymer coating

Aging in Laponite solutions

- Coating the Laponite particles with PEG, Cetyl Methyl Cellulose (CMC) or other biopolymers can either suppress aging and thus flocculation and sedimentation or lead to binding and gelation.
- Correct coating allows the formation of liquid crystalline gels. [PhD thesis, Peicheng Xu and ref. 6]

Laponite-CetylMethylCellulose – form polymer gels & transparent films

- Coating Laponite clay with various biopolymers and subsequent drying and dipping in calcium solutions can lead to highly water resistant and fire-retardant, transparent films/coatings.
- But the presence of adsorbing polymers can also lead to osmotic compression of the clay layer [1].
- PhD thesis, Peicheng Xu and ref. 7 & 1.

[1] P. Xu, A. F. Yazici, T. Erdem, H. N. W. Lekkerkerker, E. Mutlugun, E. Eiser, *J. Phys. Chem. B* **124**, 9475-9485 (2020)
[2] B. Ruzicka & E. Zaccarelli, *Soft Matter* **7**, 1268 (2011)
[3] S. Jabbari-Farouji, D. Mizuno, M. Atakhorrami, F.C. MacKintosh, C.F. Schmidt, E. Eiser, G. H. Wegdam, D. Bonn; *PRL* **98**, 108302 (2007)
[4] S. Jabbari-Farouji, E. Eiser, G. Wegdam, D. Bonn, "Ageing dynamics of translational & rotational diffusion in a colloidal glass" *J. Phys.: Cond. Matt*. **16**, L471 (2004)
[5] S. Jabbari-Farouji, M. Atakhorram, D. Mizuno, E. Eiser, G.H. Wegdam, F.C. MacKintosh, D. Bonn, C.F. Schmidt "High-bandwidth viscoelastic properties of aging colloidal glasses and gels", *Phys. Rev. E* **78**, 061402 (2008) [6] P. Xu, Z. Xing, Y. Lan & E. Eiser "Liquid crystalline behaviour of self-assembled Laponite/PLL-PEG nanocomposites" *Soft Matter* **14**, 2782 (2018)
[7] P. Xu, T. Erdem, E. Eiser "A Facile Approach to Prepare Self-Assembled, Nacre-Inspired Clay/Polymer Nano-Composites" *Soft Matter* **16**, 3385 (2020)