INFLUENCE OF RE-CIRCULATION DREDGING ON FLUID MUD DYNAMICS IN SEAPORT EMDEN

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6 authors, including:

Floris van Rees
Utrecht University

Ahmad Shakeel

Alex Kirichek
Delft University of Technology

INFLUENCE OF RE-CIRCULATION DREDGING ON FLUID MUD DYNAMICS IN SEAPORT EMDEN

J. Gebert[1], F. van Rees[2], A. Shakeel[3], A. Kirichek[4], J. Habdank[5] and B. Amman[6]

Abstract: Maintenance of the nautical depth in the seaport of Emden, Germany, is achieved by re-circulation of fluid mud using a trailing suction hopper dredger. Continued re-circulation has proven to maintain low settling rates and to keep yield stresses of re-circulated fluid mud below 50-100 Pa, in combination with densities of 1.15-1.2 t/m³ enabling safe navigation through these layers. It is assumed that low-density extracellular polymeric substances (EPS), produced by a highly adapted microbial community, are responsible for the desired effect of keeping fine-grained sediment in suspension and that the regular contact with the oxygenated water phase during recirculation dredging supports thriving of this community. Climate change models have indicated increased future discharge of fresh water from the hinterland into the saline port of Emden. It is hypothesized that increased freshwater discharge alters the composition and activity of the microbial community and hence changes the prerequisites for maintaining the currently favourable properties of fluid mud. In this paper we evaluate this hypothesis by elucidating the main factors governing the success of the current practice of re-circulation dredging in the Port of Emden by means of field and laboratory investigations. Initial results obtained in this ongoing research suggest that the low yield stresses of fluid mud in the Port of Emden are not the result of a specialized microbial community producing high concentrations of EPS, but can be solely attributed to a reduction in density as achieved by re-circulation dredging. Secondly, it appears that future possible increases in the share of freshwater do not affect the sediment's rheological response, settling behaviour and concentration of extracellular polymeric substances and will hence not adversely impact the maintenance of the nautical depth.

Key words: Re-circulation dredging, fluid mud, salinity, microbiology

[1] Delft University of Technology, the Netherlands, j.gebert@tudelft.nl
[2] Deltares, the Netherlands, floris.vanRees@deltares.nl
[3] Delft University of Technology, the Netherlands, a.shakeel@tudelft.nl
[4] Delft University of Technology, the Netherlands, o.kirichek@tudelft.nl
[5] Niedersachsen Ports GmbH & Co. KG, Germany, jhhabdank@nports.de
[6] Niedersachsen Ports GmbH & Co. KG, Germany, bamman@nports.de

1 INTRODUCTION

Maintenance of the nautical depth in the seaport of Emden, Germany, is achieved by re-circulation of fluid mud using a trailing suction hopper dredger, producing a material of low settling rates and yield stresses below 50-100 Pa, in combination with densities of 1.15-1.2 t/m³, enabling safe sailing through these layers. Wurpts and Torn (2005) assumed that low-density extracellular polymeric substances (EPS), produced by a highly adapted microbial community, are responsible for the desired effect of keeping fine-grained sediment in suspension, and that the contact with the oxygenated water phase during recirculation dredging supports thriving of this community. Climate change models have indicated increased future discharge of fresh water from the hinterland into the saline water of the port of Emden (Spiekerman et al., 2018), affecting the present seasonal patterns of salinity and water composition. Microbial activity is tightly connected to the availability of degradable organic matter. Settling and rheological behaviour of suspended sediments are related to salinity and to organo-mineral interactions (Deng et al., 2019; Mietta et al., 2009). To anticipate possible effects of increased freshwater discharge on fluid mud properties and hence maintenance of the nautical depth, it was of interest to investigate the effects of (1) the natural seasonal variability in salinity in the Port of Emden and (2) of changes in the ratio of freshwater to saline water on rheological properties, settling behaviour of fluid mud and the composition and activity of the microbial community. To this end, a field monitoring program with monthly sampling events in the two focus areas of maintenance and a laboratory mesocosm experiment involving dilutions of fluid mud with hinterland freshwater were carried out. It was hypothesized that increased shares of freshwater alter the composition and activity of the microbial community and hence change the boundary conditions for maintaining the currently favourable properties of fluid mud.

2 INVESTIGATION AREA, APPROACH AND METHODS

2.1 Investigation area and field sampling

Since March 2021, fluid mud is sampled monthly from the two focus maintenance areas IH (Wendekreis Industriehafen) and GS (Große Seeschleuse), the latter close to the main lock of the inner port to the outer port and river Ems (Figure 1). Before sampling, the upper (lutocline) and lower depth of the fluid mud layer are identified by high- and low-frequency echosounding, respectively. Using a Beeker sampler, the upper, middle and lower part of the fluid mud layer, usually located between 8 and 12 m below the water surface, are sampled with three subsamples per layer. All nine subsamples are united to create one mixed sample, which is then subdivided into five aliquots for analysis of:

1. Amount and composition of extrapolymeric substances (EPS)
2. Abundance and composition of the microbial community
3. Rheological properties and settling rates
4. Anaerobic and aerobic degradation of organic matter
5. Standard solids and pore water properties.

Figure 1. Investigation area and sampling locations IH and GS (left, © Google Earth), Beeker sampler (right)

2.2 Laboratory experiments

To investigate the effect of freshwater addition on sediment properties, fluid mud from location GS was collected in March 2021 and used to prepare four mixtures with freshwater from the Ems-Jade channel in shares of 10%, 20%, 30% and 50% by volume. To the reference sample, no fresh water was added. After admixture of the freshwater, the original density was re-established by withdrawing the corresponding volume of water. The mixtures were incubated in the laboratory at 20 °C in the dark in 15 l buckets and sheared with a vane for several hours per week to mimic the field recirculation practice (Figure 2). The rotational speed was adjusted as to set the entire fluid mud volume into motion. At five points in time between March and December 2021, all mesocosms were sampled for analysis of the parameters 1 to 5 listed in section 2.1.

Figure 2. Fluid mud and fresh water sample (left), shearing with vane (right)

To assess the role of density versus the hypothesized role of EPS for the rheological properties of fluid mud, additional samples were collected with a grab sampler from three locations (TB, D and B) within the port that are not subject to recirculation dredging and experience build-up of more consolidated sediment layers. This material was diluted with water from the sampled site to achieve the range of densities found for the fluid mud layers at locations GS and IH. Subsequently, rheological properties ad settling rates were determined.

2.3 Selected methods

2.3.1 Extrapolymeric substances (EPS)

Total EPS was isolated according to Wingender et al. (2001), with a few modifications, determination of proteins, carbohydrates, uronic acids and lipids was performed according to Frølund et al. (1996), Dubois et al. (1956), Filisetti-Cozzi & Carpita (1991) and Hara & Radin (1978), respectively.

2.3.2 Rheology and settling rates

Stress ramp-up tests were performed with a HAAKE MARS I rheometer (Thermo Scientific, Germany) with concentric cylinder (Couette) geometry (gap width = 1 mm) and yield stresses computed based on the protocol presented by Shakeel et al. (2020), adapted from the protocol described by Wurpts & Torn (2005). Based on the changes in viscosity with increasing stress (Figure 3), static (SYS) and fluidic yield (FYS) stress values were derived.

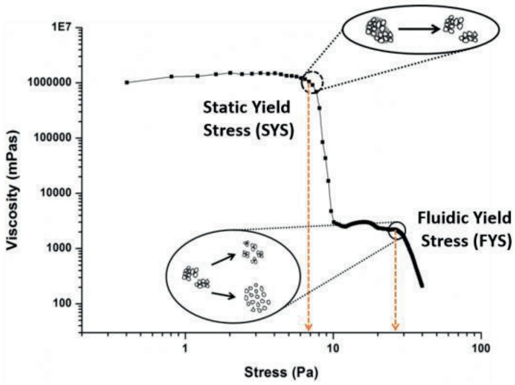

Figure 3. Example of two-step yielding in a stress sweep test according to Shakeel et al. (2020)

Settling rates were determined by transferring a homogenised sample into 1000 ml graduated glass cylinders and observing the subsequent depth development of the fluid mud-water interface over a period of minimum 24 hours with an automated camera system. The settling rate, valid for a temperature of 20 °C, was calculated from the time that had passed for every 10 ml incremental change of interface depth, as also described by Shakeel et al. (2021).

3 SELECTED RESULTS AND DISCUSSION

3.1 Basic properties of fluid mud

The average particle size distribution of fluid mud in the Port of Emden comprised 59.7 % clay (< 2 µm), 38.7 % silt (2-63 µm) and 1.3% sand (63-2000 µm). Salinity varied seasonally (Figure 4), with lower values after a period of elevated freshwater discharge in the winter (higher precipitation in combination with low evapotranspiration) and higher values in summer (less precipitation, high evapotranspiration). Plausibly, salinity was consistently higher at sampling location GS near the lock to the Ems and much higher compared to the freshwater Port of Hamburg. Total organic carbon varied between 3.5 and 4 %. Fluid mud density varied between 1.07 and 1.13 t/m^3, which is in the lower range of values reported for other ports (overview in Shakeel et al., 2020). Particle size distribution, density and TOC were very similar to average values described for fluid mud in the Port of Hamburg (Zander et al., 2020).

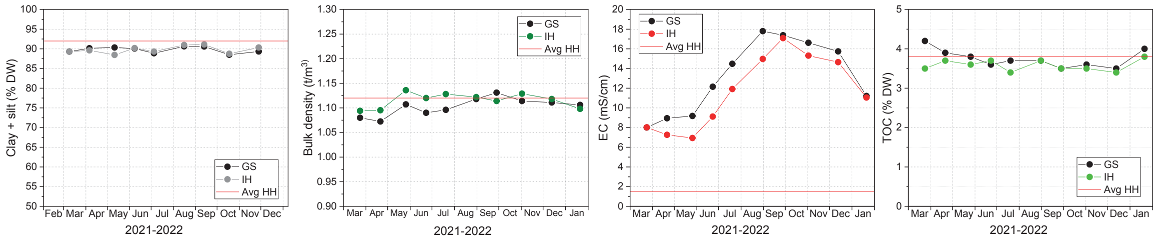

Figure 4. Particle size fraction < 63 µm, bulk density, electrical conductivity (EC) and total organic carbon (TOC) at locations GS and IH in 2021. Red line = average value for fluid mud in the Port of Hamburg.

3.2 Rheological properties and settling rates

Fluid mud from the port of Emden showed very low yield stresses with values below 3 Pa for the static yield stress and below 11 Pa for the fluidic yield stress (Figure 5), which is in the lower range of values found for fluid mud in the Port of Hamburg (data not shown). The ratio between fluidic (FYS) and static (SYS) yield stress averaged around 3 for both sites, similar to fluid mud from Port of Hamburg (Shakeel et al., 2020), with more consolidated material mostly showing a higher ratio. SYS and FYS at both sites were strongly related to fluid mud density (Figure 5, left and middle panel). The original more consolidated sediment sampled at non-maintained sited TB, D and B showed densities ranging between 1.16 and 1.22 t/m^3. Upon dilution to the density range of fluid mud, the relationship between density and yield stresses followed the same slope as found for fluid mud from sites GS and IH (Figure 5, right panel). These data strongly suggest density as the sole driver for yield stress in the investigated system.

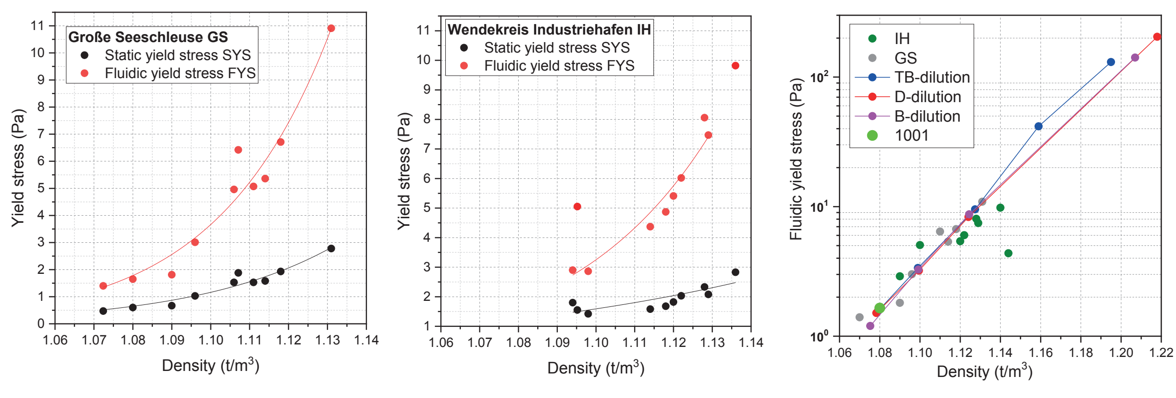

Figure 5. Relationship between density and static and fluidic yield stresses at locations GS (left) and IH (middle) and for material from sites TB, D and B diluted to different densities (right). Sample 1001 = sampled in March 2021 from site GS

In the laboratory mesocosm experiment, fluid mud sampled from location GS in March 2021 was diluted with fresh water to various extents, re-adjusted to the same density (~ 1.07 t/m^3) and then regularly sheared over a period of several months. As a result of the freshwater addition, the salinity range between the control and the most diluted sample amounted to almost factor 2 (4.5 mS/cm vs. 8 mS/cm). However, no effect of fresh water addition on the rheological properties could be detected. As seen in Figure 6, even after four months (subsampling event t4), no differences in the rheological response between the different shares of freshwater admixture were detected.

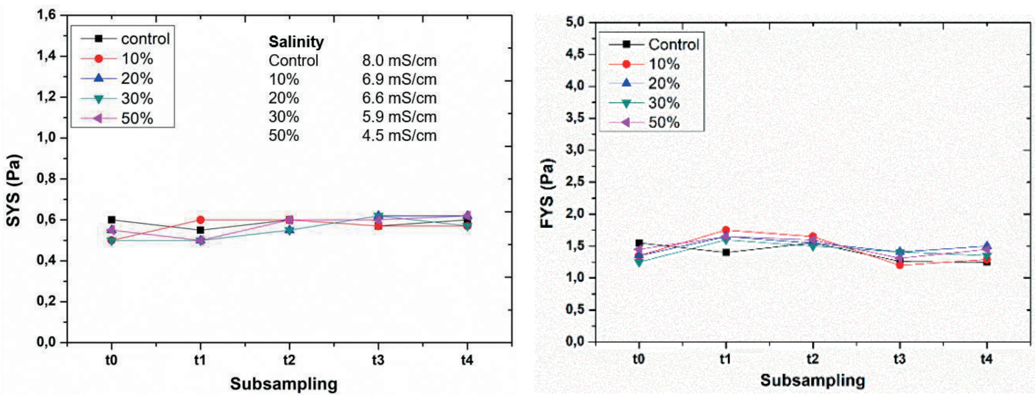

Figure 6. Effect of different shares of fresh water admixture on static and fluidic yield stress over time of laboratory incubation. t1-4 = sampling events with t4 approximately 4 months after start of experiment

The development of the fluid mud-water interface over time within the first 24 hours of the settling experiment was usually linear (Figure 7, left panel), enabling the calculation of the settling rate from the slope. Settling rates of fluid mud at both locations were inversely related to density (Figure 7, right panel), i.e. the denser the mud, the lower the settling rate, leading to near hindered-settling phenomena at the higher densities. To optimise the effect and cost-efficiency of re-circulation dredging on the stability of fluid mud layers, the positive correlation of yield stresses and density (Figure 5) can be balanced with the inverse effect of density on settling rates to define a 'density window' that allows for both, the desired low yield stresses and low settling rates.

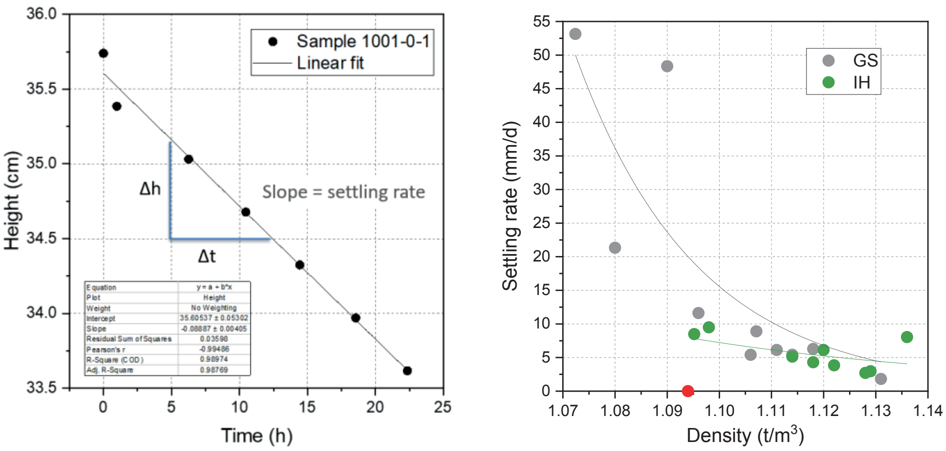

Figure 7. Development of the fluid mud-water interface over 24 hours in a settling experiment (left) and relationship between fluid mud density and settling rate at locations GS and IH (right). Red point = outlier.

3.3 Concentration and composition of extracellular polymeric substances

Total EPS concentration varied seasonally with peaks in June and July 2021 (Figure 8, left). The overall level of EPS concentrations was in parts two orders of magnitude lower than for example detected in fluid mud samples from the Port of Hamburg (data not shown). After the lipids with concentrations of up to 17 g/kg DM (not shown), acid polysaccharides constituted the largest share, followed by proteins, neutral polysaccharides, DNA and uronic acids proteins (Figure 8, middle and right). Concentrations at both sites were similar.

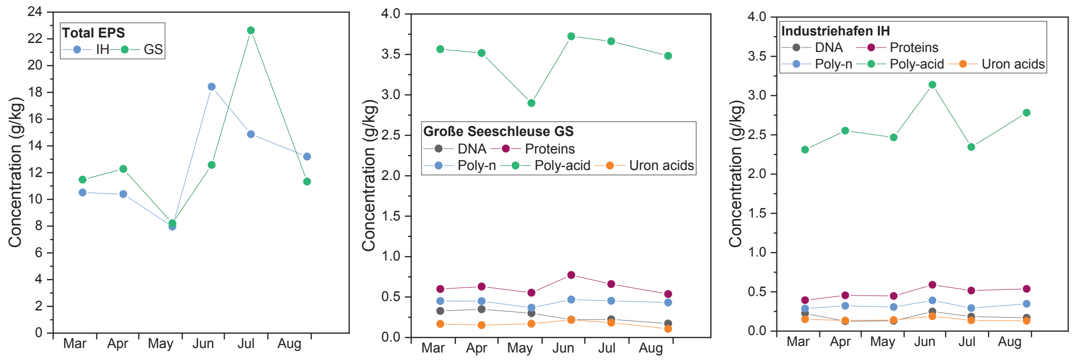

Figure 8. Concentration of total EPS (left) and of EPS components (middle, right) per unit dry matter at locations GS and IH in 2021

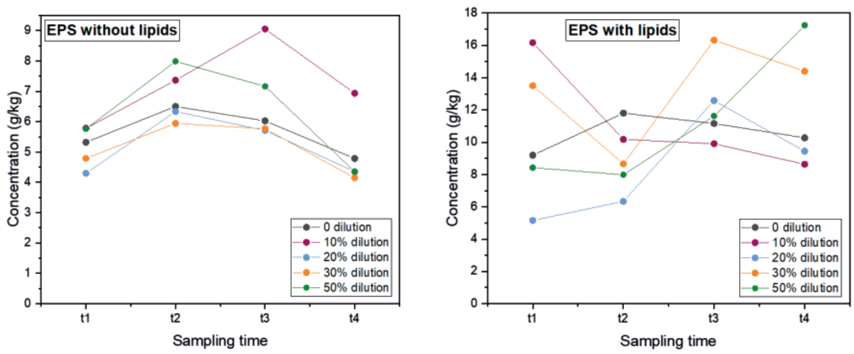

Figure 9. Effect of different shares of fresh water admixture on the concentration of EPS (with and without lipids) during laboratory incubation. t1-4 = sampling events with t4 approximately 4 months after start of experiment.

In spite of the variation in salinity following dilution with freshwater (Figure 6), no systematic differences between the different mixtures with respect to EPS concentrations could be detected (Figure 9). If lipids were subtracted from the total EPS concentrations, a trend of first increasing and then decreasing concentrations over time of incubation could be detected (Figure 9, left panel). These effects likely reflect the growth of the microbial population after transfer of samples from the cool field conditions (March 2021) to the laboratory conditions (20 °C).

4 CONCLUSIONS AND OUTLOOK

Combining the insights from the analyses of the rheological behaviour, settling rates and extracellular polymeric substances in field and laboratory samples, the following conclusions can be drawn:

- Yield stresses and settling rates in the Port of Emden are strongly density driven. The responses are of opposite nature and can be used to define a ‘window of optimum density’ that allows for the desired low yield stresses in combination with low settling rates.
- Freshwater admixture does not impact the rheological response, nor the concentration of EPS, provided that the same density is maintained. This implied that future possible increases in shares of hinterland freshwater will not impede maintenance of the nautical depth as practiced currently.
- Contending the assumptions by Wurpts & Torn (2005), these findings suggests that the low yield stresses of fluid mud in the Port of Emden are not the result of a specialized microbial community producing high concentrations of EPS, but can be solely attributed to a reduction in density as achieved by re-circulation dredging.

This study is ongoing and also includes the analysis of stability of sediment organic matter and of the composition of the microbial community composition, which will further understanding of the behaviour of fluid mud in the port of Emden.

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REFERENCES

Deng Z., He Q., Safar Z. & Chassagne C. (2019). The role of algae in fine sediment flocculation: In-situ and laboratory measurements. *Marine Geology* 413, 71–84.

Filisetti-Cozzi T.M. & Carpita N.C. (1991). Measurement of uronic acids without interference from neutral sugars. *Anal. Biochem.* 197, 157-62.

Frølund B., Palmgren R., Keiding K. & Nielsen P.H. (1996). Extraction of extracellular polymers from activated sludge using a cation exchange resin. *Water Res.* 30, 1749-1758.

Hara A. & Radin N.S. (1978). Lipid extraction of tissues with a low-toxicity solvent. *Analytical Biochemistry* 2697(78)90046-5.

Mietta F., Chassagne C., Manning A.J. & Winterwerp J.C. (2009). Influence of shear rate, organic matter content, pH and salinity on mud flocculation. *Ocean Dynamics* 59, 751-763. DOI 10.1007/s10236-009-0231-4.

Shakeel A., Kirichek A., & Chassagne C. (2020). Rheological analysis of mud from Port of Hamburg, Germany. *Journal of Soils and Sediments* 20, 2553-2562.

Shakeel A., Kirichek A., & Chassagne C. (2021). Rheology and yielding transitions in mixed kaolinite/bentonite suspensions. *Applied Clay Science* 211, 106206

Spiekermann J., Ahlhorn F., Bormann H. & Kebschull J. (2018). KLEVER: Klimaoptimiertes Entwässerungsmanagement im Verbandsgebiet Emden. Report. Accessible from https://uol.de/fileadmin/user_upload/proj/klever/KLEVER/KLEVER-Ergebnisbroschuere.pdf

Wingender J., Strathmann M., Rode A., Leis A. & Flemming H.C. (2001). Isolation and biochemical characterization of extracellular polymeric substances from Pseudomonas aeruginosa. *Methods Enzymol.* 336, 302-314.

Wurpts R. & Torn P. (2005). 15 years experience with fluid mud: Definition of the nautical bottom with rheological parameters. *Terra et Aqua* 99, 22-32.**3**

Zander F., Heimovaara T. & Gebert J. (2020). Spatial variability of organic matter degradability in tidal Elbe sediments. *Journal of Soils and Sediments*. DOI: https://doi.org/10.1007/s11368-020-02569-4