Water/solid matter interactions in sewage sludge: Linking rheology and water activity

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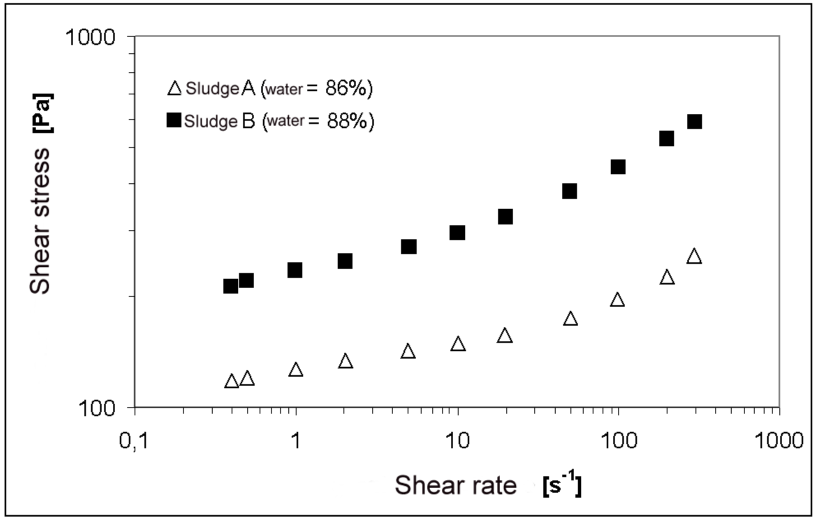
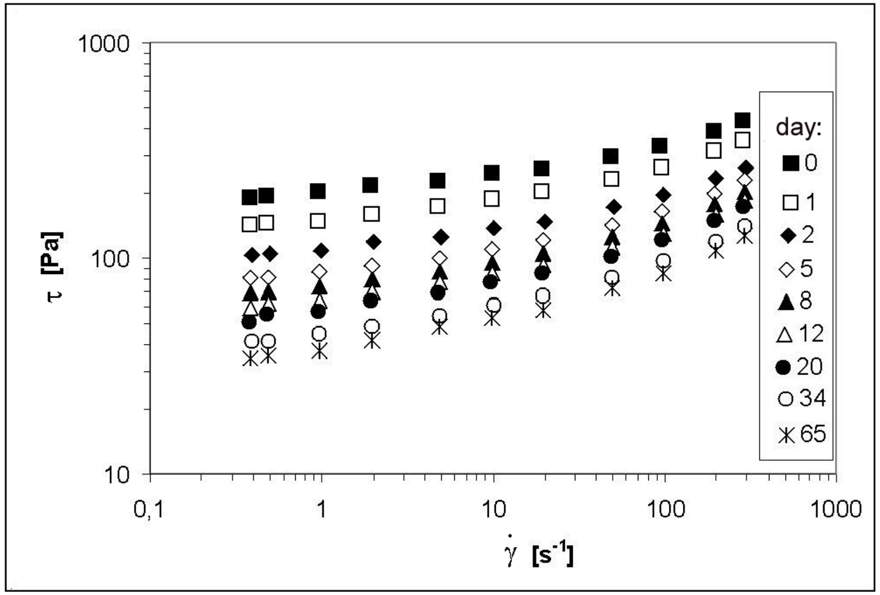
Context

Increasing amounts of sewage sludge

- Towards an added-value material
- Whichever the re-use mode, many treatments (dewatering, etc.)
- Need of flowing properties
- Need of quantitative descriptors: solid concentration not enough





Context

Role of water/solid matter interactions

Several studies. Four categories of water (Vesilind, 1994):

- Free water
- Interstitial water (trapped inside flocs)
- Vicinal water (adsorbed to particles surface)
- Bound water

Water cannot have different energy states. It is a continuum

- Water activity is largely used in food science and food engineering (Australian concept !)
  - *The concept of water activity and its relationship to the growth of bacteria, yeasts and moulds was developed in CSIRO during the 1950s by Dr W. J. Scott and his colleagues.*
  - *A variety of foods may have exactly the same moisture content and yet have quite different water activities*

Vesilind, P.A. (1994). The role of water in sludge dewatering. Water Environment. Research 66(1): 4-11.

Context

Water activity is derived from fundamental principles of thermodynamics and physical chemistry. As a thermodynamic principle there are requirements in defining water activity that must be met. These requirements are: pure water (aw= 1.0) is the standard state, the system is in equilibrium, and the temperature is defined

– In the equilibrium state: $\mu = \mu_o + RT\ ln(f/f_o)$
where: **μ** is the **chemical potential** of the system i.e. thermodynamic activity or energy per mole of substance; μ_o is the chemical potential of the pure material at the temperature T; R is the gas constant ; **f** is the **fugacity** or the escaping tendency of a substance; and f_o is escaping tendency of pure material (van den Berg and Bruin, 1981).

The activity of species is defined as $a = f/f_o$. When dealing with water, a subscript is designated for the substance, $a_w = f/f_o$

– **a_w is activity of water, or the escaping tendency of water in system divided by the escaping tendency of pure water (with no radius of curvature).**

– For practical purposes, the fugacity is closely approximated by the vapor pressure (f ~ p) so $a_w = f/f_o \sim p/p_o$

– Water activity is defined as the ratio of the vapor pressure of water in a material (p) to the vapor pressure of pure water (p_o) at the same temperature.

Context

Water activity

- Thermodynamic parameter
- Estimation of free and bound (= not free) water
- $Aw = p/p_0$

Purpose of this study

Focus on the relationship between rheology (macroscopic behaviour) and water activity (representative of microscopic structure and water/solid matter interactions)

⇒ Determine if water activity evolution can be representative of rheological sludge behaviour for raw and flocculated sludge.

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Materials and methods

Sludge samples and preparation

Sewage sludge

Raw sludge

- Activated sludge (Varennes sur Allier, France)
- Raw sludge dry content: 19 g/L

Conditioning

- Polymer: Flopam EM840 (supplier: SNF)
- Optimal dosage: determined with CST measurements

Samples preparation with various solid contents

- Lab ultra-centrifuge (dewatering)
- 20℃, 5min, 4000 to 10000g for raw sludge
- 20℃, 5min, 2000 to 14000g for flocculated sludge

Materials and methods

Rheological and water activity measurements

Rheological measurements

Anton Paar MCR300 and MCR301

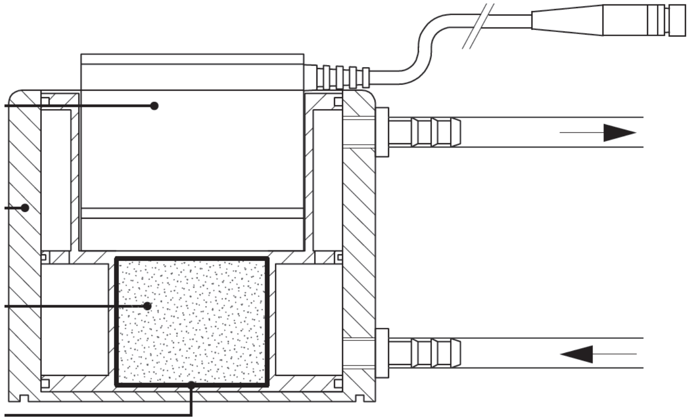
- Parallel plates geometry (radius=25mm, gap=1-2mm)
- Rough surfaces, 20°C
- Oscillatory tests: G' and G'' measurement

  ⇒ viscoelastic properties

Water activity

Rotronic HygroLab 2

- Relative humidity captors
- 20°C
- Aw values

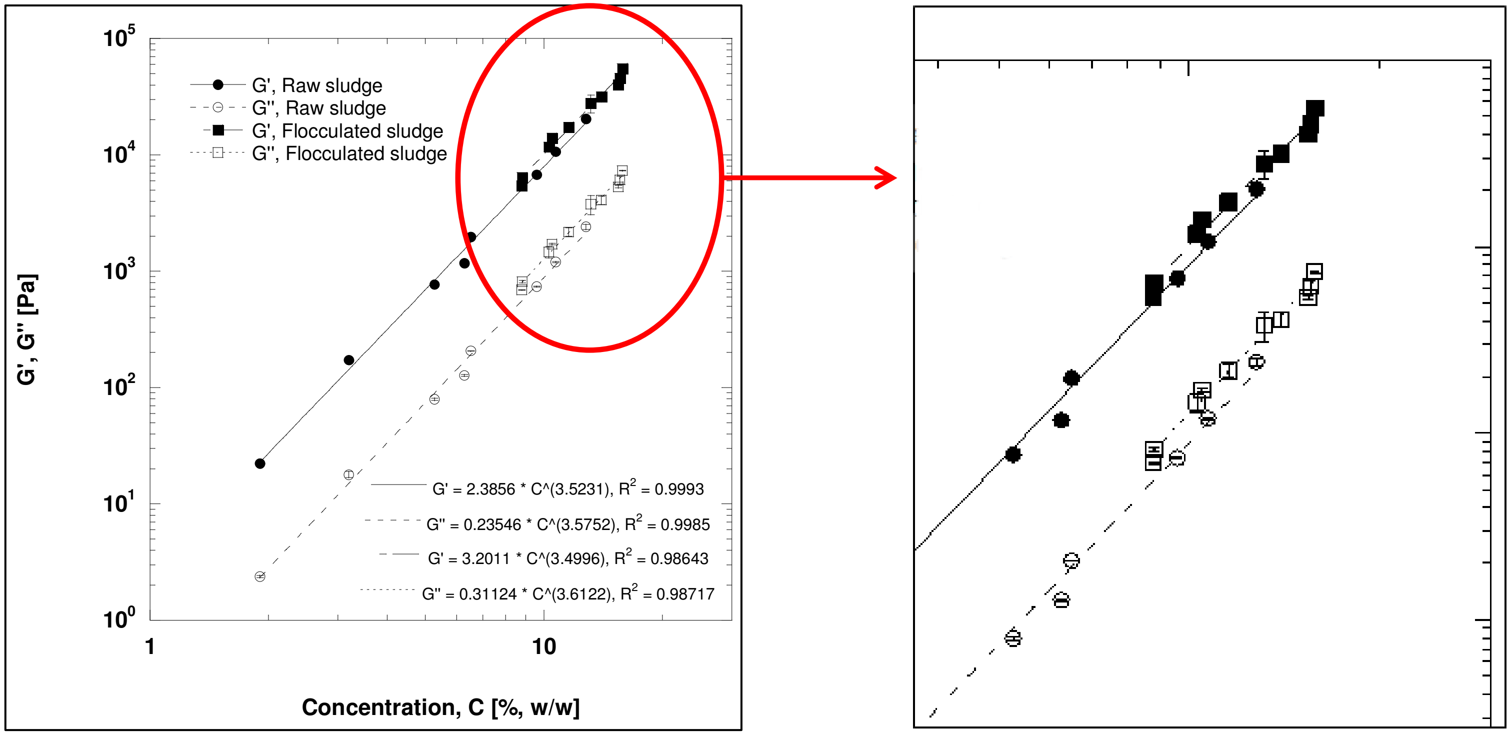


Results

Impact of solid concentration

For both raw and flocculated sludge samples

- G' and G'' increase with total solid content
- Following power-law model
- Flocculation increases G' and G'' values

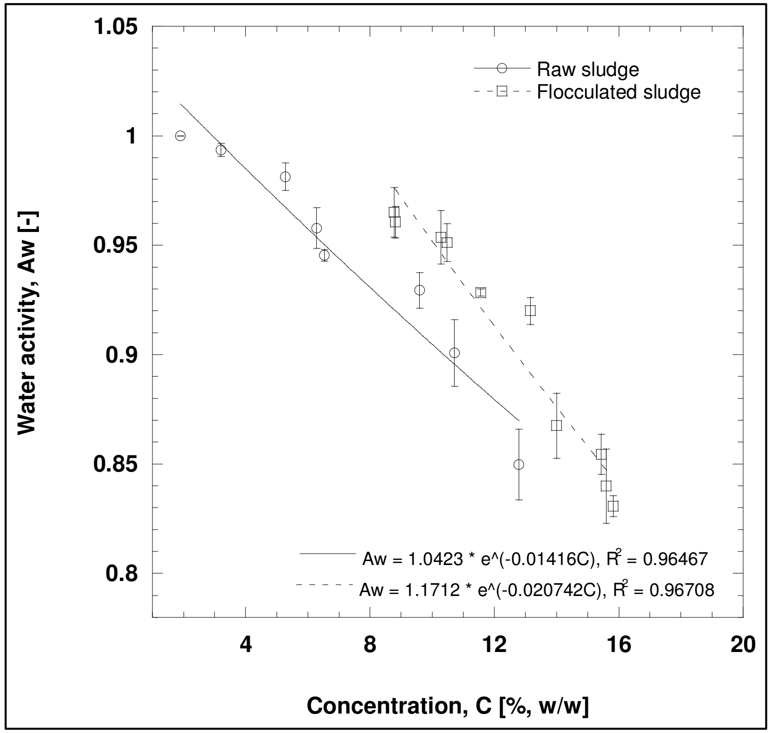


Results

Impact of solid concentration

For both raw and flocculated sludge samples

- Aw decreases with total solid content
- Following an exponential model
- For a given solid content, Aw is higher when sludge is flocculated



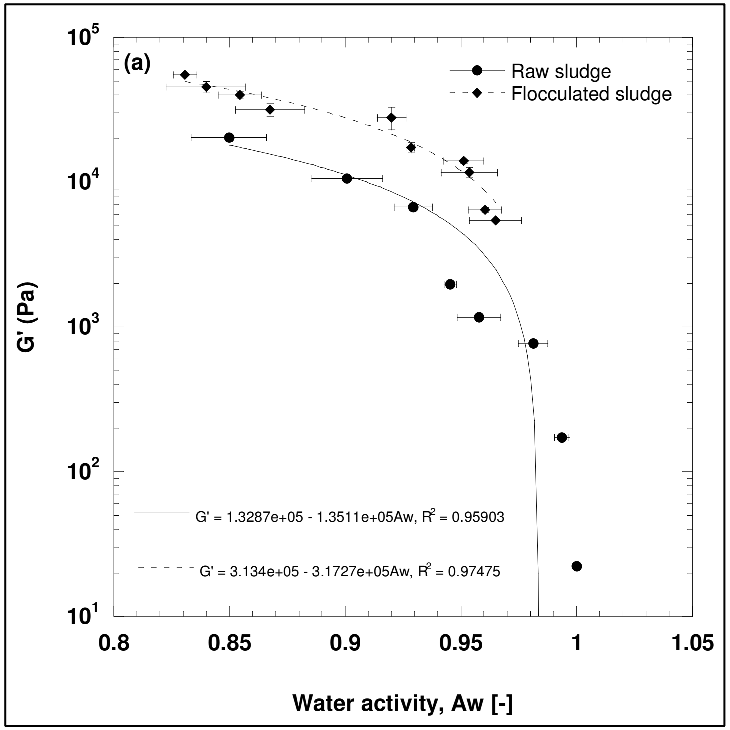
Results

Impact of solid content

- Impact of flocculation: polymer addition increases G', G" and Aw

⇒ Flocculation strengthen particles network but release water

- Rough decrease of rheological viscoelastic properties when Aw tends towards 1

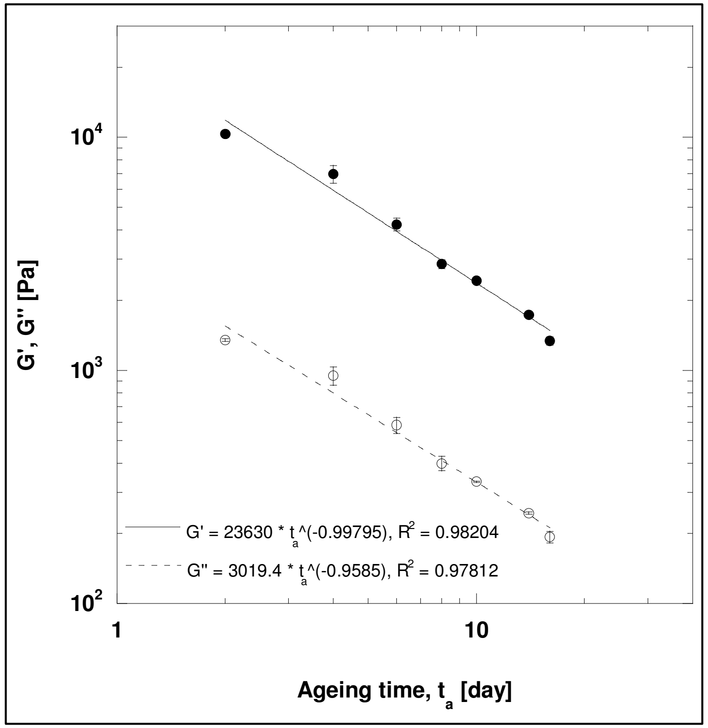


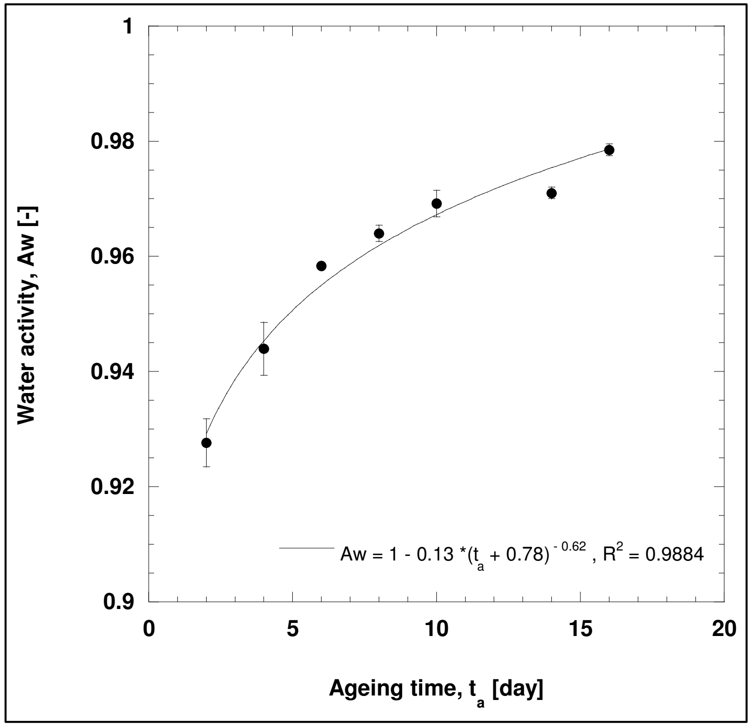
Results

Impact of ageing time

Raw sludge behaviour was studied during ageing time

- G' and G'' decrease with the inverse of time
- Aw increases with ageing time



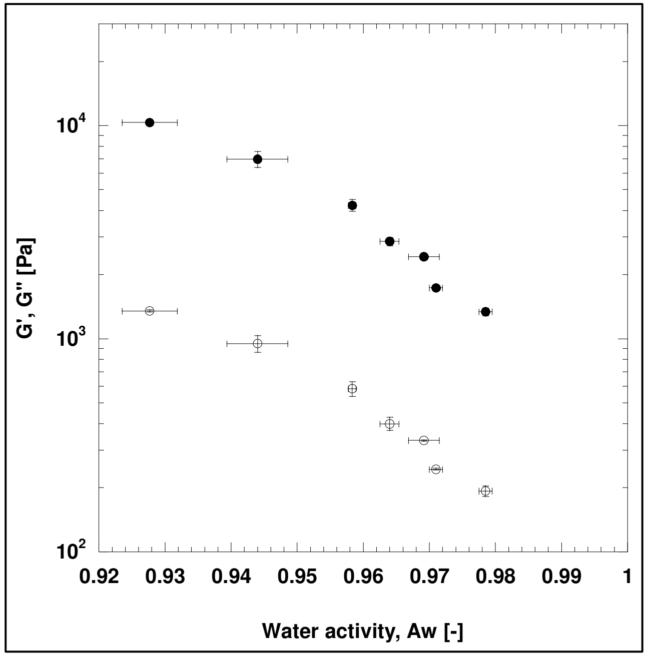


Results

Impact of ageing time

Ageing time = natural fermentation

- Organic matter degradation and fatty acids production
- Macromolecule hydrolysis ⇒ water consumption
- Increase of Aw ⇒ increase of water mobility
- Role of fatty acids production?



Conclusion

Conclusions

Impact of solid content

- With and without conditioning, G’ and G’’ increase with the solid content (i.e. during centrifuge lab dewatering) whereas Aw decreases
- Flocculation leads to higher moduli and Aw values without changing global behaviour
- Globally, water activity evolution indicates sludge rheological behaviour

Impact of ageing time

- Contrary to solid content effect, G’ and G’’ decrease and Aw increases with ageing time
- Fatty acids production is supposed to be linked to water mobility improvement

Water activity was shown to be an interesting indicator of rheological behaviour during centrifuge lab dewatering and ageing.

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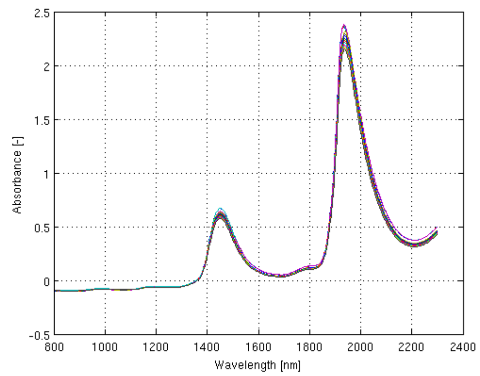
Conclusion

Prospects

- Analysis of other types of sludge samples to determine if the relationships can be widen
- Coupling rheological and water activity measurements to other techniques to deepen the knowledge of moisture distribution ⇒ NIR (near infrared spectroscopy) or NMR (nuclear magnetic resonance spectroscopy) would be efficient tools to analyse changes in water bonding.



Thank you for your attention