

Effect of anionic xanthan gum on the sedimentation of kaolinite

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ABSTRACT

This study looked at how a kaolinite suspension treated with xanthan gum settled. The sedimentation of kaolinite in solutions of xanthan gum biopolymer (0, 0.1, 0.5, 1.0, and 2.0 percent ratio in a mass of clays) was measured until the height of the sediment stayed the same. At the initial stage, XG forms kaolinite aggregates, forming an opaque suspension. The electrical force between the negatively charged XG molecules and the positively charged edge surface of the kaolinite binds the kaolinite together. Aggregated kaolinite flocs caused by XG settle faster due to a larger floc size (i.e., flocculated free settling) than untreated kaolinite (flocculated zone settling). In addition, x-ray CT scans taken at different heights from the bottom showed that the XG-induced aggregation made the sediment formation denser. The results of this study could lead to new attempts to speed up the way kaolinite clays settle by adding xanthan gum.

1. INTRODUCTION

Gravity and electrical forces cause the flocculation and subsequent sedimentation of clay particles in a solution (Kynch 1952). Sediment accumulation identification (Watabe and Saitoh 2015), land reclamation (Lee *et al.* 1987), mineral waste disposal (Zbik *et al.* 2008), river-floodplain morpho-dynamics (Lamb *et al.* 2020), colloidal chemistry (Lagaly and Ziesmer 2003) and wastewater treatment (Shaikh *et al.* 2017) are just some of the many academic applications of soil settling behavior.

Clay particle contact processes and settling behavior have been found using a variety of empirical and theoretical techniques (Kynch 1952; Imai 1980; Sridharan and Prakash 1999; Wang and Siu 2006). Particle size, sediment content, organic and chemical environment, and other variables all have a role in the settling behavior of clay particles in suspension (Berlamont *et al.* 1993). In general, sediments settle more

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quickly with larger particle sizes, containers of sediment, specific weight, and net particle attraction force, decreasing with increasing sediment concentrations and fluid viscosities in general (Imai 1980; Toorman 1996; Chamley 2013).

These forces (such as the van der Waals force and other net-interparticle forces) regulate the interaction and sedimentation behavior of clays because they have surface charge properties (Verwey 1947; van Oss *et al.* 1990; Missana and Adell 2000). Surface charge characteristics are affected by the pore-chemical fluid's parameters (e.g., pH, salinity), which in turn affects net forces between clay particles (Kotylar *et al.* 1996; Sridharan and Prakash 1999; Durán *et al.* 2000). The protonation-deprotonation of broken bonds in the alumina layer gives clay minerals their pH-independent and pH-dependent charges (Mohan and Fogler 1997; Tombácz and Szekeres 2006). Since clay particles prefer textures with a positively charged edge surface, when the pH is lower than the isoelectric point of the edge surfaces, they prefer the edge-to-face construction. In contrast, the double-layer repulsion dominates the clay contact when the pH of the edge surfaces is greater than the isoelectric point. As the pH of kaolinite suspensions was raised, Wang and Siu (2006) found that settling velocity decreased and ultimate sediment density increased. Furthermore, polyanions can form interparticle aggregates which enlarges and accelerates the settling velocity of clay particles. Various coagulants have been studied in a variety of previous research.

The goal of this research is to investigate the effects of xanthan gum biopolymer treatment on the fabric development of kaolinite suspensions. To effectively use kaolinites for wastewater treatment (Ruhsing Pan *et al.* 1999), sediment transport, and reservoir sedimentation (Cheng 1997), it is essential that these three properties be present: colloidal stability, coagulation, and flocculation. Given that biopolymers in geotechnical studies need a knowledge of the fabric interaction between kaolinite and the various xanthan gum biopolymers, this study suggests the xanthan gum biopolymer as a promising environment-friendly coagulant for kaolinite clays.

2. Materials and Methods

2.1 Materials

Kaolinite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), an aluminosilicate clay mineral, was employed in this investigation. It is a crucial mineral in the manufacturing process. Layers of silica (SiO_4) are sandwiched between octahedral alumina (AlO_6) and tetrahedral silica (SiO_4) in this layered silicate mineral. Without additional purification, a natural kaolinite from Bintang, Indonesia (CAS: 1318-74-7) was employed.

As a polysaccharide-type biopolymer, xanthan gum has several industrial applications, including as a common food ingredient. As an excellent thickener, emulsifying agent, and stabilizer, xanthan gum inhibits substances from dissolving into one another. Fermentation may be used to make xanthan gum from simple sugars, and it gets its name from the bacterium, *Xanthomonas campestris*, that makes xanthan gum. This study used a research-graded xanthan gum purchased from Merck & Co (CAS: 11138-66-2).

Using a laser scattering particle size analyzer (HELOS/KR, Sympatec GmbH, Germany), the size distribution of kaolinite and xanthan gum can be shown in Figure 1.

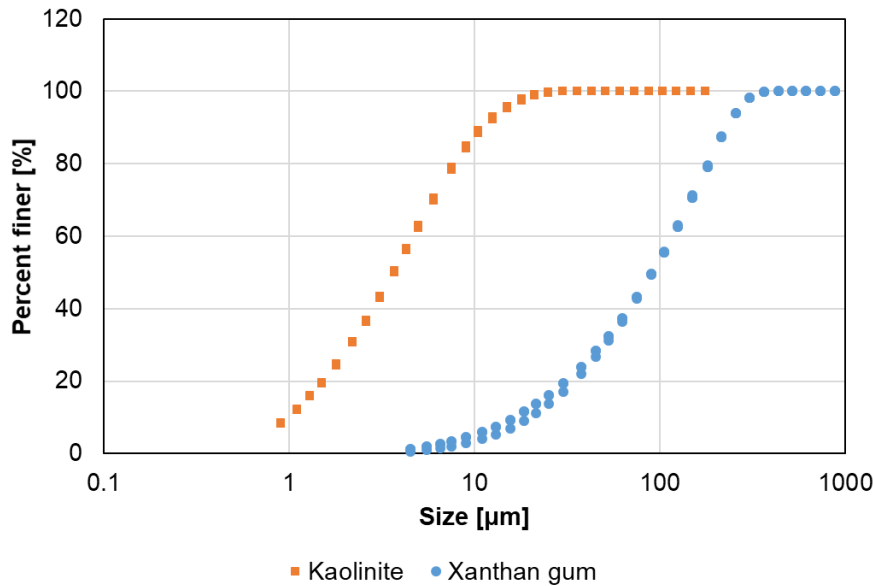


Fig. 1 Particle size distribution of kaolinite and xanthan gum used

2.2 Methods

Preparation of clay suspensions

Kaolinite sedimentation with high water content, 960 percent, was studied by observing the settling behavior of the XG-treated kaolinite suspension (0 %, 0.5 %, 1 %, and 2 % of XG-to-kaolinite ratio in mass) from the initial suspension stage until sediment reached a constant volume.

50 mL of the test fluid was placed in a 25 mm-diameter graduated cylinder with a maximum capacity of 100 mL. Xanthan gum was mixed with deionized water to mimic fluids with varying polyanion conditions. After that, a condensed suspension of kaolinite (10 g; 3.7 mL in volume) and test fluid (50 mL) was prepared in the cylinder. The cylinder was then filled to a final capacity of 100 mL with further test fluid. The XG-kaolinite suspension was gently combined by shaking upside down until a homogeneous suspension developed. For 24 hours, the prepared suspensions were allowed to rest in order to reach their maximum hydration potential. Cylinders were topped with a thermoplastic film (Parafilm M, USA) for sealing and wrapping.

Sedimentation test

By shaking and turning each sealed cylinder upside down for at least 10 minutes, the XG-kaolinite suspensions that were fully hydrated were stirred up thoroughly. After the last flip, the cylinders were put on a flat surface. This is considered the beginning of sedimentation (time = 0). The height of the sediment was watched over time until the final sediment height reached a constant volume with a rate of settling of less than 1.0 mL/day. The longest a single sedimentation could last be seven days.

X-Ray CT image

When a kaolinite sedimentation was done, X-ray CT images were captured on the XG-treated kaolinite suspensions, using the X-ray CT facility at the Korea Advanced Institute of Science and Technology, Daejeon, South Korea. From each scan, 1023 thin

slices of high-resolution images were made that covered the whole height of the final kaolinite sediment. So, each slice image was made up of 1024 pixels by 1024 pixels.

3. Experimental results

The sediment behavior of XG treated kaolinites are plotted in Fig. 2. The final volumes of kaolinite in different XG solutions were shown in Fig. 3.

Given that solid mutual interactions between positively charged edge and negatively charged face (Fam and Santamarina 1997), untreated kaolinite showed uniform sedimentation of large flocs (i.e., flocculated zone settling) (Imai 1980). Thus, kaolinite that hasn't been treated settles at the same rate, making a sharp line between the supernatant and flocculated suspensions. However, the XG in a fluid changed how the kaolinite in a suspension settled. During the process of sedimentation, the electrical force between the negatively charged XG molecules and the positively charged edge surface of the kaolinite brings the kaolinite particles together (Nugent *et al.* 2009; Chang *et al.* 2019). Therefore, according to Stoke's law, the flocs that have been brought together by XG settle first, and the smaller flocs settle after that (i.e., flocculated free settling).

The aggregation of particles induced by XG treatment resulted in a denser sediment formation. Figure 4 shows X-ray CT scans captured at different heights from the bottom. When 2 % of XG was added to kaolinite, larger aggregates formed at the bottom (Fig. 4a), and the size of the aggregates got smaller as they moved up. On the other hand, kaolinite that hadn't been treated was spread out evenly over the whole height (Fig. 4b). X-ray CT scanning showed that XG forms dense aggregates, and the larger pore sizes between aggregates could lead to faster drainage after settlements.

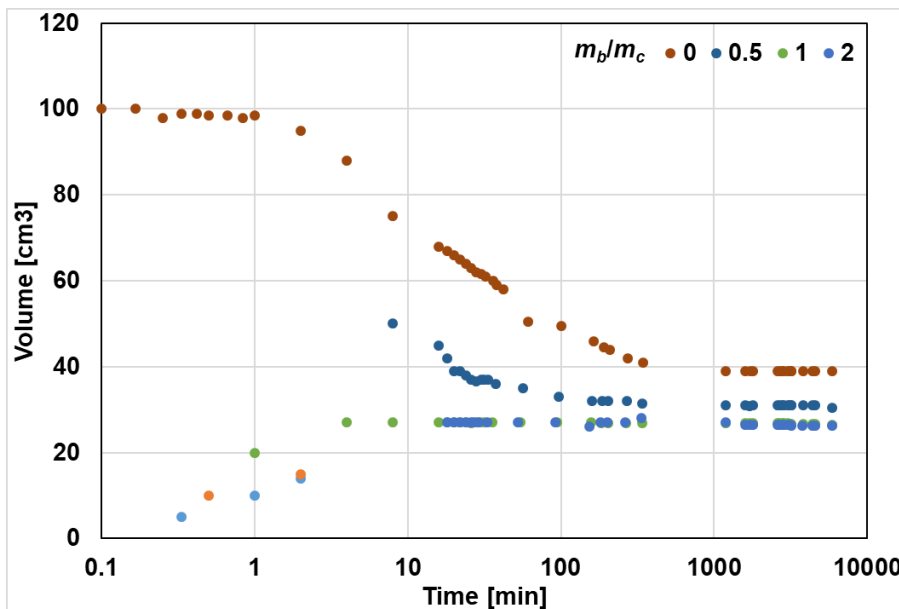


Fig. 2 The settling behavior of xanthan gum treated kaolinites

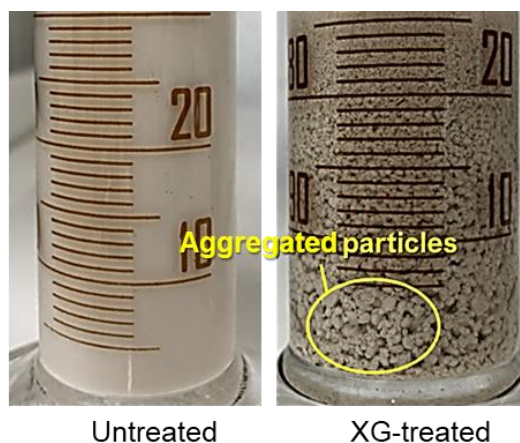


Fig. 3 Sediment formation after settling

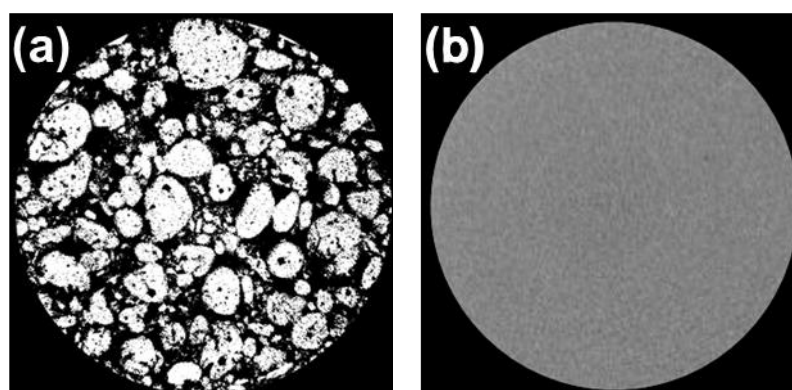


Fig. 4 The X-ray CMT scan images from the bottom of the sediment for (a) XG-2% treated kaolinite and (b) untreated kaolinite

3. Conclusions

This study looked at the connections between kaolinite particles and XG based on the settling behaviour of XG-treated kaolinite suspensions. When kaolinite is treated with XG, the particles stick together via electrical charge of XG molecules. This changes the way the particles settle from flocculated zone settling to flocculated free settling. When XG caused particles to stick together, they formed dense clusters that settled faster and had bigger spaces between them. So, adding XG to the sedimentation process can speed up the consolidation process that continues after sedimentation. This makes the sediment stronger, but more research is needed to do a consolidation experiment with samples after sedimentation.

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REFERENCES

- Berlamont, J., Ockenden, M., Toorman, E. and Winterwerp, J. (1993), "The characterisation of cohesive sediment properties", *Coastal Engineering*. **21**(1), 105-128.
- Chamley, H. (2013), *Clay sedimentology*, Springer, Berlin, Heidelberg
- Chang, I., Kwon, Y.-M., Im, J. and Cho, G.-C. (2019), "Soil consistency and interparticle characteristics of xanthan gum biopolymer-containing soils with pore-fluid variation", *Can Geotech J.* **56**(8), 1206-1213.
- Cheng, N.-S. (1997), "Effect of concentration on settling velocity of sediment particles", *Journal of Hydraulic Engineering*. **123**(8), 728-731.
- Durán, J.D.G., Ramos-Tejada, M.M., Arroyo, F.J. and González-Caballero, F. (2000), "Rheological and Electrokinetic Properties of Sodium Montmorillonite Suspensions: I. Rheological Properties and Interparticle Energy of Interaction", *J Colloid Interf Sci.* **229**(1), 107-117.
- Fam, M. and Santamarina, J.C. (1997), "A study of consolidation using mechanical and electromagnetic waves", *Geotechnique*. **47**(2), 203-219.
- Imai, G. (1980), "Settling behavior of clay suspension", *Soils and Foundations*. **20**(2), 61-77.
- Kotylar, L.S., Sparks, B.D. and Schutte, R. (1996), "Effect of Salt on the Flocculation Behavior of Nano Particles in Oil Sands Fine Tailings", *Clay Clay Miner.* **44**(1), 121-131.
- Kynch, G.J. (1952), "A theory of sedimentation", *Transactions of the Faraday Society*. **48**(0), 166-176.
- Lagaly, G. and Ziesmer, S. (2003), "Colloid chemistry of clay minerals: the coagulation of montmorillonite dispersions", *Adv Colloid Interfac.* **100-102** 105-128.
- Lamb, M.P., de Leeuw, J., Fischer, W.W., Moodie, A.J., Venditti, J.G., Nittrouer, J.A., Haught, D. and Parker, G. (2020), "Mud in rivers transported as flocculated and suspended bed material", *Nature Geoscience*. **13**(8), 566-570.
- Lee, S.L., Karunaratne, G.P., Yong, K.Y. and Ganeshan, V. (1987), "Layered clay-sand scheme of land reclamation", *Journal of Geotechnical Engineering*. **113**(9), 984-995.
- Missana, T. and Adell, A. (2000), "On the applicability of DLVO theory to the prediction of clay colloids stability", *J Colloid Interf Sci.* **230**(1), 150-156.
- Mohan, K.K. and Fogler, H.S. (1997), "Effect of pH and layer charge on formation damage in porous media containing swelling clays", *Langmuir*. **13**(10), 2863-2872.
- Nugent, R.A., Zhang, G. and Gambrell, R.P. (2009), "Effect of exopolymers on the liquid limit of clays and its engineering implications", *Transp Res Record*. **2101**(1), 34-43.
- Ruhsing Pan, J., Huang, C., Chen, S. and Chung, Y.-C. (1999), "Evaluation of a modified chitosan biopolymer for coagulation of colloidal particles", *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. **147**(3), 359-364.
- Shaikh, S.M.R., Nasser, M.S., Hussein, I., Benamor, A., Onaizi, S.A. and Qiblawey, H. (2017), "Influence of polyelectrolytes and other polymer complexes on the

- flocculation and rheological behaviors of clay minerals: A comprehensive review", *Separation and Purification Technology*. **187** 137-161.
- Sridharan, A. and Prakash, K. (1999), "Influence of clay mineralogy and pore-medium chemistry on clay sediment formation", *Can Geotech J.* **36**(5), 961-966.
- Tombácz, E. and Szekeres, M. (2006), "Surface charge heterogeneity of kaolinite in aqueous suspension in comparison with montmorillonite", *Appl Clay Sci.* **34**(1), 105-124.
- Toorman, E.A. (1996), "Sedimentation and self-weight consolidation: general unifying theory", *Géotechnique*. **46**(1), 103-113.
- van Oss, C.J., Giese, R.F. and Costanzo, P.M. (1990), "DLVO and Non-DLVO Interactions in Hectorite", *Clay Clay Miner.* **38**(2), 151-159.
- Verwey, E.J.W. (1947), "Theory of the Stability of Lyophobic Colloids", *The Journal of Physical and Colloid Chemistry*. **51**(3), 631-636.
- Wang, Y.H. and Siu, W.K. (2006), "Structure characteristics and mechanical properties of kaolinite soils. I. Surface charges and structural characterizations", *Can Geotech J.* **43**(6), 587-600.
- Watabe, Y. and Saitoh, K. (2015), "Importance of sedimentation process for formation of microfabric in clay deposit", *Soils and Foundations*. **55**(2), 276-283.
- Zbik, M.S., Smart, R.S.C. and Morris, G.E. (2008), "Kaolinite flocculation structure", *J Colloid Interf Sci.* **328**(1), 73-80.