Molecular weight effects in interactions of guar gum with talc

Claudio A. Garcia Vidal, Marek Pawlik *

The University of British Columbia, Norman B. Keevil Institute of Mining Engineering, 517-6350 Stores Road, V6T 1Z4 Vancouver, BC, Canada

A B S T R A C T

Interactions between talc and four non-ionic guar gum samples of different molecular weights (from 160,000 to 1.40 million) were evaluated through adsorption, flotation, and stability measurements. It was found that the effect of molecular weight on adsorption was insignificant and all four guar gums produced similar adsorption densities on the talc particles. Turbidity data also showed that all four polymers were strong flocculants of fine talc particles. However, higher molecular weight samples were more powerful than lower molecular weight samples. Higher doses of the polymers led to steric re-dispersion of talc, and lower molecular weight polymers were more efficient in dispersing talc than higher molecular weight polymers. Finally, all four polymers were equally effective as depressants of talc flotation. Most interestingly, it was found that the strongest depression of talc flotation was accompanied by very strong flocculation of the fine talc particles. Implications of these phenomena to the entrainment of fine talc during the froth flotation process were also discussed.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Talc is a magnesium phyllosilicate composed of three repeating sandwich-like layers: a brucite-like ($Mg(OH)_2$) layer of octahedrally coordinated magnesium-hydroxyl ions between two silica-like layers of tetrahedrally coordinated silicon–oxygen ions. The brucite layer and two silica layers are held together by strong ionic bonds while the entire sandwich structures are linked by weak oxygen–oxygen van der Waals forces (Fuerstenau et al., 1988). In some cases, small amounts of titanium or aluminum can substitute for silicon in the tetrahedral layer, while calcium may substitute for magnesium in the octahedral brucite layer. The level of substitution of aluminum for silicon varies depending on the source of the mineral and falls between 0.01 and 3.04% (Deer et al., 1978, 1992). By breaking talc particles, two different types of surfaces can be formed: the basal plane (or face); and the edge. The basal plane results from the cleavage of the weak bonding between silica layers. The basal plane has traditionally been considered to be electrostatically uncharged in aqueous solutions. However, recent studies on the subject showed that even low levels of substitution of Si by Al and Ti are sufficient to impart a detectable negative charge to the basal plane of talc (Burdukova et al., 2006, 2007). The low level of substitution and weak bonds exposed to the surrounding water also make the basal planes quite hydrophobic. Wettability studies on the basal planes of talc reported contact angle values ranging from 60° (Fuerstenau and Huang, 2003) to 90° (Kaggwa et al., 2006). On the other hand, the edge forms from the rupture of strong ionic and covalent bonds of the silica and brucite layers. As such, the edges are electrostatically charged with high polarity, and are therefore strongly hydrophilic (Chander et al., 1975).

The guar gum macromolecule consists of $(1 \rightarrow 4)$-linked β-D-mannopyranose units with α-D-galactopyranose units randomly connected to the main mannose chain through $(1 \rightarrow 6)$ glycosidic linkages, at a mannose-to-galactose ratio of 1.8–1.0 (Painter et al., 1979; Whistler and Hymowitz, 1979). Guar gum plays an important role in base metal and platinum group metal (PGM) ore processing, where the occurrence of the naturally hydrophobic and problematic talc is common. In flotation processes, guar gum is used to adsorb selectively onto talc particles, rendering them hydrophilic and depressing their natural floatability.

The basic model of polymer adsorption (Scheutjens and Fleer, 1979, 1980) with some additions and modifications (Fleer et al., 1993; Fleer, 2010), predicts that a polymer with a high molecular weight should give a higher adsorption density compared to a polymer with a low molecular weight. Considering the large volume of adsorption data, in general, very few studies systematically investigated the effect of the molecular weight of a polysaccharide on its adsorption on talc, and the experimental results sometimes do not agree with the theoretical predictions. Shortridge et al. (2000) studied the effect of the molecular weight of carboxymethyl cellulose (CMC) on depression of talc using four samples with molecular weights ranging from 205,000 to 552,000 (estimated through intrinsic viscosity measurements in 0.01 M KNO_3). There was no effect of molecular weight on depression of talc. Parolis et al. (2005) also found that there was no effect of the molecular weight of CMC on the adsorption density onto talc. These authors used three of the four CMC samples used previously by Shortridge et al. (2000), with molecular weights ranging between

* Corresponding author.
   E-mail address: mpp@mining.ubc.ca (M. Pawlik).

114,000 and 277,000. Using the same CMC samples as those studied by Parolis et al. (2005), Khraisheh et al. (2005) found that CMC adsorption onto talc increased with increasing CMC molecular weight. The molecular weight ranged from 108,000 to 194,000.

Shortridge et al. (2000) also studied the effect of guar gum molecular weight on the depression of talc floatability. A number of anionic, cationic, and unmodified guar gum samples were used. The molecular weights of the samples were not reported but the order was inferred from intrinsic viscosity estimations. Shortridge et al. concluded that talc recovery from micro-flotation tests decreased with increasing molecular weight of guar gum. Somasundaran et al. (2005) found that unmodified guar gums with molecular weights of 1.45 million and 242,000 did not show a marked difference in the depression of talc in microflotation tests. Maximum depression was achieved at concentrations below maximum polymer adsorption. A related study by Wiese et al. (2008) concluded that low molecular weight starch (21,000) can be an effective depressant of naturally floatable gangue. The performance of starch was compared with the action of high molecular weight CMC and modified guar gum (MW of 325,000 and 230,000, respectively). The results showed that guar gum was a superior depressant compared to starch and CMC, with the latter two producing similar results.

The main objective of the present study is to determine any significant correlations between guar gum adsorption, talc depression, and aggregation/dispersion phenomena in the talc–guar gum system as a function of the molecular weight of the polymer.

2. Materials and methods

2.1. Materials

Talc samples were obtained from Ward's Science (Rochester, NY). The mineral was received as large pieces, approximately 5 cm by 5 cm. The mineral pieces were crushed below about 20 mm and separated into two sub-samples (A and B). Talc A was dry-ground below 38 μm, and this sample was used for adsorption and turbidity tests. Talc B was dry-ground below 106 μm, and this size fraction was used for flotation tests. Both samples were then characterized in terms of the particle size distribution and the specific surface area. The BET (Brunauer, Emmett, Teller) specific surface areas were determined by nitrogen adsorption using an Autosorb-1MP BET analyzer (Quantachrome). The specific surface areas were 10.8 m^2/g and 6.6 m^2/g for Talc A and Talc B, respectively, and these values were used for calculating the adsorption densities of the tested polymers. The particle size distributions of the talc samples were measured with the use of a Malvern Mastersizer 2000. The volume-average particle sizes were 14.1 μm and 24.4 μm for Talc A and Talc B, respectively.

An x-ray diffraction analysis (Rietveld refinement) of this sample revealed the presence of 85% of talc, along with approximately equal quantities of other magnesium silicates, such as tremolite (Ca$_2$Mg$_5$Si$_8$O$_{22}$(OH)$_2$), anthophyllite (Mg$_7$Si$_8$O$_{22}$(OH)$_2$), and lizardite (Mg$_3$Si$_2$O$_5$(OH)$_4$). The mineral was used "as-received" without any purification or cleaning. According to Burdukova et al. (2007), talc samples supplied by Ward's Science can be characterized by a level of substitution in the basal plane (Al and Ti for Si) of 0.3%, which is at the lower end of the known substitution values mentioned earlier (Deer et al., 1978, 1992).

Four guar gum samples were supplied by Rantec Corporation (Ranchester, WY, USA) under the code names KP4000, RX5048, RX5051, and RX5055. According to the manufacturer, the RX5051 and RX5055 were produced by breaking the RX5048 to obtain polymers with shorter chains and consequently with lower molecular weights (MW). For the purpose of further discussion, the samples were renamed with more intuitive acronyms. Thus the KP4000 is HMW1 (High Molecular Weight 1), RX5048 is HMW2, RX5051 is MMW (Medium Molecular Weight) and RX5055 is LMW (Low Molecular Weight). Each sample contained a significant amount of insoluble material. The content of insoluble matter (seed and plant residue from extraction of the polymer) was 13.2% for HMW1, 11.3% for HMW2 and MMW, and 9.0% for LMW, as determined by centrifuging 1 g/L solutions of these polymers at an acceleration of 10,000 g, and assaying the solution for total organic carbon (TOC) content. More details on TOC analysis are given in Section 2.3. Therefore, all stock guar gum solutions in this study were centrifuged before experiments in order to remove the insoluble matter, and their concentrations in solution were corrected accordingly.

All four samples were non-ionic uncharged guar gums, as confirmed by Fourier-transform infrared spectroscopy of polymer films prepared at pH 3 and at pH 6. This approach allows peaks originating from carboxylic groups to be more readily identified in the infrared spectra as the carboxylic group becomes protonated (pH 3) or dissociated (pH 6), and the corresponding peaks shift to different wavenumbers (Ma and Pawlik, 2007).

The intrinsic viscosities of the samples were determined from dilute solution viscometry at pH 9.0 in dilute (0.01 mol/L) potassium chloride solutions using Cannon-Fenske capillary viscometers (Schott-Geräte, GmbH, Germany), and a Lauda PVS1 photo-timing and processing system. The detailed experimental conditions are given elsewhere (Garcia, 2013). In short, after measuring the kinematic viscosities and calculating the reduced viscosities, the intrinsic viscosities were obtained by extrapolating plots of the reduced viscosity as a function of polymer concentration to zero polymer concentration using the Huggins equation (Huggins, 1942):

$$\eta_{red} = [\eta] + k[\eta]^2 c \tag{1}$$

where η_{red} is the reduced viscosity, $[\eta]$ is the intrinsic viscosity, k is the Huggins constant, and c is the polymer concentration. As a general rule, the highest polymer concentration that can be used in dilute solution viscometry should not exceed a value of $1 / [\eta]$ to avoid the formation of inter-chain entanglements. The obtained intrinsic viscosity values were subsequently used for calculating the molecular weights of the samples. The graphical evaluation of the raw viscosity results to obtain the intrinsic viscosity and the calculation of the molecular weights of the guar gum samples will be presented in Section 3.

The ionic strength in all the tests was maintained using a 0.01 mol/L potassium chloride (KCl) solution. Potassium chloride was an ACS-certified chemical from Fisher Scientific.

2.2. Flotation of talc

The floatability of talc was studied in the guar gum concentration range from 0 to 500 mg/L (0 to 5000 g/t, grams of guar gum per ton of talc). A 0.01 mol/L KCl solution was used as the background electrolyte. An Agitair LA-500 flotation machine with adjustable air flow rate and a 500 mL flotation cell was used in these experiments. The solution and talc masses were proportionally increased from those of the adsorption tests in order to keep the same solids-to-liquid ratio in the flotation test. First, 50 g of Talc B was mixed with 500 mL of the background solution and the suspension was conditioned in the cell for 6 min at 700 rpm. Then, a small volume of a guar gum stock solution in 0.01 mol/L KCl was added to the cell and the entire mixture was conditioned for a further 6 min. Finally, a small amount of methyl isobutyl carbinol (MIBC) was added as a frother to achieve a dosage of 40 g/t. The natural pH of the flotation pulp was about 9.0 and was left unadjusted. The air flow rate was set at 4 L/min and the flotation time was 5 min.

At the end of each flotation test, a sample of the aqueous phase was taken for measuring the residual concentration of guar gum in the pulp, which could also be used for calculating the amount of guar gum adsorbed on talc under the flotation conditions. The amount of guar gum was assessed through total organic carbon (TOC) analysis, and a TOC correction had to be taken for the presence of residual MIBC as determined from a blank test in the absence of guar gum.