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The effect of acrylamide-*co*-vinylpyrrolidinone copolymer on the depression of talc in mixed nickel mineral flotation

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ABSTRACT

Copolymers of acrylamide and vinylpyrrolidinone with varying compositions have been synthesised and employed to depress talc in a model flotation system with process plant operation conditions. Adsorption isotherms indicated that the hydrophilic acrylamide homopolymer has a very low affinity for the hydrophobic talc surface, whereas vinylpyrrolidinone homopolymer strongly adsorbs onto the talc surface. Micro-flotation experiments revealed that the copolymer system can induce stronger talc depression than the homopolymer variants, with the most effective copolymer depressant having 25–30% vinylpyrrolidinone incorporation. The copolymer system is observed to have inherited the strong talc affinity of vinylpyrrolidinone polymer and the strong hydrophilic property from polyacrylamide. This combined effect facilitates the desired strong talc depression in single mineral flotation. However, this copolymer system has similar adsorption affinity on both the talc and pentlandite, hence depressing both talc and pentlandite in the mixed mineral flotation system. This research shows that a sufficient hydrophobic balance on the polymer is necessary for the adsorption and subsequent depression for talc. However, polymer with high adsorption selectivity is required to be a successful synthetic talc depressant for mixed mineral system.

1. Introduction

Talc is a common gangue mineral found closely associated with many complex valuable mineral ores. The natural hydrophobicity of talc means that it tends to be collected with the valuable minerals during the froth flotation process. As talc is essentially a magnesium silicate mineral (Deer et al., 1992), high talc content in flotation concentrates causes complications during the downstream smelting process and imposes financial penalties upon the concentrate seller. The depression of talc in flotation processes has therefore been the focus of a great deal of research.

Guar gum is one of the most widely used industrial depressants for hydrophobic talceous gangue minerals in flotation of nickel bearing ores. However, guar is a natural product and is subject to seasonal variation. Thus, there is a lack of control over its microstructural properties such as the galactose:mannose ratio and distribution, a problem which can lead to fluctuations in depressant performance.

Other polymers have been used to depress talc in flotation. The basic concept is to employ polymers with particular functional groups to render the gangue mineral hydrophilic and hence prevent the flotation of the gangue mineral (Chen et al., 2003). Previous researches in the field have focused on the use of polysaccharides such as dextrin (Liu et al., 2000; Rath et al., 1997; Sedeva et al., 2010) and carboxymethyl cellulose (Burdukova et al., 2008; Cuba-Chiem et al., 2008; Khraisheha et al., 2005; Shortridge et al., 2000), as well as polyacrylamides (Beattie et al., 2006a,b; Chiem et al., 2006; Morris et al., 2002) as synthetic depressants for talc with limited success.

This paper presents an approach in employing a copolymer of acrylamide (Am) and vinylpyrrolidinone (VPD) as a synthetic depressant in froth flotation system. The concept of this synthetic depressant is to develop a polymer with balanced hydrophobic/hydrophilic nature to overcome the natural hydrophobicity of talc and hence to prevent it from attaching to the air bubbles in the froth flotation process. However, the acrylamide homopolymer does not adsorb strongly onto talc and hence has a weak talc depression because of the opposing hydrophobicities of the polymer (hydrophilic) and talc (hydrophobic). This paper investigates a solution to this problem by incorporation of less hydrophilic monomer into the acrylamide polymer, thus providing anchor points for the hydrophilic copolymer to adsorb onto the hydrophobic surface of talc and to reduce its floatability. Micro-flotation and laboratory-scale flotation devices, as well as isotherm adsorption experiments, have been employed for the study of flotation and adsorption selectivity respectively in this research.

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2. Experimental

2.1. Materials

Talc sample for single mineral flotation was sourced from the Mt. Fitton mine site in South Australia with XRF analysis showing more than 99% purity. The sample was milled and wet-screened, before being collected for use in the flotation study. The volume weighted mean diameter, $D[4,3]$, was 234 μm as determined using a Malvern Mastersizer and the BET surface area was measured as 2.29 m^2/g. Brucite sample used in the single mineral flotation was sourced from CSIRO with a volume weighted mean diameter, $D[4,3]$, of 81 μm and a BET surface area of 2.94 m^2/g.

Talc sample used in the adsorption studies was purchased from Unimin Australia (>95% purity) with a volume weighted mean diameter, $D[4,3]$, of 30 μm and a BET surface area of 3.69 m^2/g. This talc sample was not use in flotation experimentation since its particle size is too fine for froth flotation.

Pentlandite sample used in the adsorption studies was sourced from CSIRO with a volume weighted mean diameter, $D[4,3]$, of 107 μm and a BET surface area of 1.06 m^2/g.

For the mixed mineral experiments, high grade sample of talc was obtained from Steetley Minerals and was crushed to pass a sieve mesh size of 1.65 mm and screened to reject the material passing 200 μm. The pentlandite was concentrated from a high grade sample from Kambalda, WA. Non-sulphides were first rejected by hand sorting and the upgraded portion was then crushed to pass a sieve mesh size of 700 μm. The −300 μm fraction, which was low grade, was rejected and the +300 μm fraction was split into closely sized fractions. These size fractions were upgraded individually in a laboratory magnetic separator to reject pyrrhotite.

Polyfroth H57 (Huntsman), acrylamide (Am) (Merck, 98%), 1-vinyl-2-pyrrolidone (VPD) (Sigma–Aldrich, ⩾99%), 2,2′-azobis(2-methylpropionamidine) dihydrochloride (AMPA) (Sigma–Aldrich, 97%), NaCl (Chem-Supply, 99%), $CaCl_2$ (Merck, ⩾99%), KCl (Ajax Chemicals, 99%), $NaHCO_3$ (Sigma–Aldrich, ⩾99%), $MgSO_4{\cdot}7H_2O$ (Sigma–Aldrich, ⩾99%), guar (Sigma–Aldrich) and sodium ethyl xanthate (SEX) (CSIRO) were used as received.

2.2. General procedure for synthesis of P(Am-co-VPD) copolymers

Copolymers of Am and VPD (see Fig. 1) were synthesized by copolymerizing Am and VPD in water at 100 °C under argon for 2 h using AMPA as initiator. The composition of the final copolymer was controlled by varying the initial Am to VPD monomer ratio (see Table 1). The resulting polymers were precipitated into acetone, collected via filtration and dried under vacuum and stored in a desiccator at room temperature. The corresponding VPD composition of each copolymer was evaluated by ^{1}H-NMR spectroscopy.

For example; Am (12.0 g, 168.8 mmol), VPD (6.0 mL, 56.3 mmol) and AMPA (2.0 g, 7.5 mmol) were dissolved in MilliQ water (270 mL, 18 MΩ cm) and heated at 100 °C under an argon atmosphere for 2 h. After cooling to room temperature the solution was diluted with water (130 mL) and precipitated into acetone (4 L) with rapid stirring. The resulting precipitate was collected by filtration and dried *in vacuo* for 48 h to afford a fluffy white solid, 18.7 g (92%); ^{1}H-NMR spectroscopic analysis provided a VPD composition of 25%; GPC: M_w = 624 900, PDI = 2.58.

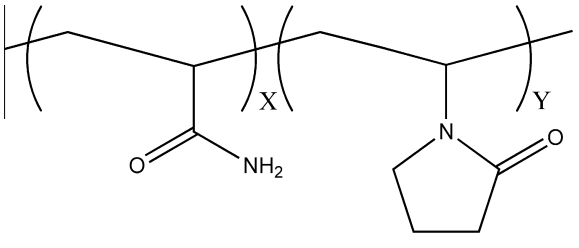

Fig. 1. Structure of the P(Am-*co*-VPD) copolymer.

Table 1
Characteristics of the synthetic depressant.

Polymer	% Am[a]	% VPD[a]	Mw (Da)[b]	PDI[b]
P(Am)	100	0	306 500	3.14
P(Am-*co*-VPD5%)	95	5	423 100	3.10
P(Am-*co*-VPD8%)	92	8	507 700	2.29
P(Am-*co*-VPD11%)	89	11	423 300	1.57
P(Am-*co*-VPD25%)	75	25	624 900	2.58
P(Am-*co*-VPD37%)	63	37	316 200	2.45
P(Am-*co*-VPD50%)	50	50	328 800	1.94
P(Am-*co*-VPD63%)	37	63	496 500	1.67
P(Am-*co*-VPD75%)	25	75	241 700	1.36
P(Am-*co*-VPD90%)	10	90	353 000	1.35
P(VPD)	0	100	247 000	1.11

[a] Am and VPD composition measured by ^{1}H-NMR.
[b] Molecular weight (M_w) and polydispersity (PDI) measured by GPC.

2.3. Polymer molecular weight and composition measurements

The molecular weight characteristics of the polymers were determined via size exclusion chromatography performed on a Shimadzu liquid chromatography system fitted with a Wyatt mini-DAWN TREOS laser light scattering detector (690 nm, 30 mW) and a Shimadzu RID-10A differential refractometer (690 nm), and using three phenogel columns in series (500, 10^4 and 10^6 Å porosity, 5 μm bead size). An aqueous solution (50 mM $NaNO_3$, 0.02% w/v of NaN_3) was used as the eluent at a flowrate of 1 mL/min and with the column temperature set at 50 °C.

The corresponding composition of each polymer was analysed using proton nuclear magnetic resonance (^{1}H-NMR) spectroscopy on a Varian Unity + 400 in D_2O at 400 MHz.

2.4. Hallimond tube flotation tests

Micro-flotation tests were performed using a modified Hallimond tube. Hyper saline solution used was 0.825 M NaCl, 0.011 M $CaCl_2$, 0.028 M KCl, 0.003 M $NaHCO_3$ and 0.099 M $MgSO_4$ in distilled water. 20 mL of the hyper saline solution was added to 2 g of the Mt. Fitton talc in a 28 mL polypropylene container. The pH was adjusted to pH 4.5 with the addition of 80 μL of 0.25% v/v H_2SO_4. Then, 0.75 mL of 2 mg/mL depressant prepared in distilled water was added into the talc sample to make a final depressant concentration of 750 g of depressant per tonne of mineral (750 g/t). The talc sample was conditioned by mixing on a rotator for 10 min. For the flotation experiment, the talc sample was then transferred to the Hallimond tube followed by addition of the top-up solution, which consisted of 0.001% v/v of H57 frother in 200 mL of hyper saline solution at pH 4.5. The talc sample was agitated by a custom made mechanical impeller at a stirring rate of 500 rpm and high purity nitrogen gas was delivered at the rate of 10 mL per minute. After a set flotation time of 3, 5 and 8 min, the concentrate and the tailing were separately collected, filtered by Whatman Grade 541 filter paper, dried and weighed. The recoveries are expressed on a weight basis. The experimental error was measured to be ±2.5%.

2.5. Isotherm adsorption studies

Preliminary time-dependent adsorption experiments indicated that maximum adsorption was attained within 15 min. For all adsorption tests shown in this study, the time of equilibration