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Dissolution of starch and its role in the flotation separation of quartz from hematite

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ABSTRACT

Corn starches are cheap and eco-friendly flotation depressants for iron oxides, but their solubilities in water at ambient temperature are low. Starches are often treated by alkali or thermal gelatinization to enhance their dissolution before being used in iron ore flotation. Despite its importance, little is known about the fundamentals of starch dissolution and its role in iron ore flotation. In this paper, four corn starches (waxy, normal, G50 and G80) differing in the mass ratio of amylopectin to amylose were used to investigate the starch solubility as a function of solution preparation temperature and pH. It was found that the starch solubility increased with increasing the solution preparation temperature, pH, or the mass ratio of amylopectin to amylose. Three stages of starch dissolution (swelling – rupturing – releasing starch molecules/ghost) were observed, and the tendency for the rupturing followed the order of waxy starch > normal starch > G50 > G80, indicating that a starch with higher amylopectin content could be more readily dissolved. Micro-flotation tests were carried out for pure hematite and quartz and their mixture with these four starches dissolved at different temperatures and pHs. The results suggest that there is a strong correlation between starch solubility and the depressing ability. Among these starches tested, waxy starch and normal starch, which have relatively high amylopectin contents, are preferred for being used in the flotation separation of quartz from hematite as depressant after proper solution preparation.

1. Introduction

Iron ores are important feedstock materials for ironmaking and steelmaking [1]. Most iron ores in the earth crust are in the form of hematite (Fe_2O_3) or magnetite (Fe_3O_4). These valuable minerals are often associated with gangue minerals such as quartz and silicate minerals [2]. Low grade iron ores cannot be used directly in the blast furnaces and need to be beneficiated to reduce its gangue content and increase its iron content. The common iron ore beneficiation methods used in practice include gravity separation and magnetic separation [3,4]. With the rapid depletion of relatively simple iron ores that can be readily beneficiated, the recovery of iron minerals from complex and finely grained iron ores requires efficient fine particle separation methods such as froth flotation [5–7]. In the flotation of iron ores, it is possible to allow gangue minerals to be floated and discharged as reject, with the valuable iron oxides remaining in the machine to be removed as product. This process is referred to as reverse flotation, which often requires the addition of a depressant to inhibit the flotation of iron oxides. A group of widely used depressants for iron oxides are natural starches that are cheap and eco-friendly [8–11].

Starch when dry is in the form of granule. Starch granule has a concentric semi-crystalline multiscale structure (see Fig. 1) [12]. The basic components of starch are amylose (a helical polymer made of α-D-glucose units) and amylopectin (a branched polymer in which the main chain is linked to the branches) [13,14]. Amylopectin branches partially crystallize to form successive alternating crystalline-amorphous lamellae. Amylose molecules are present as amorphous conformations in the amorphous layers or interspersing among the amylopectin crystallites.

Starch granules exhibit low solubility in water at room temperature. Starch granules in water can have unique and complicated phase changes [15]. At room temperature, water can slightly hydrate and swell starch granules. When treated with heat or alkali, starch granules keep imbibing water and swelling, and they eventually burst and collapse [16].

Starches are often treated by alkali or thermal gelatinization to enhance their dissolution before being used in iron ore flotation [17]. Starch solutions can be prepared with hot water alone or in sodium hydroxide solution at room temperature or elevated temperatures [21–24]. Although the preparation conditions greatly affect the behaviour of starch [18,19], to date, no standards for starch dissolution have been developed.

The type and size of starch granules, starch age, cooking time and temperature, time and temperature of storage after cooking and the

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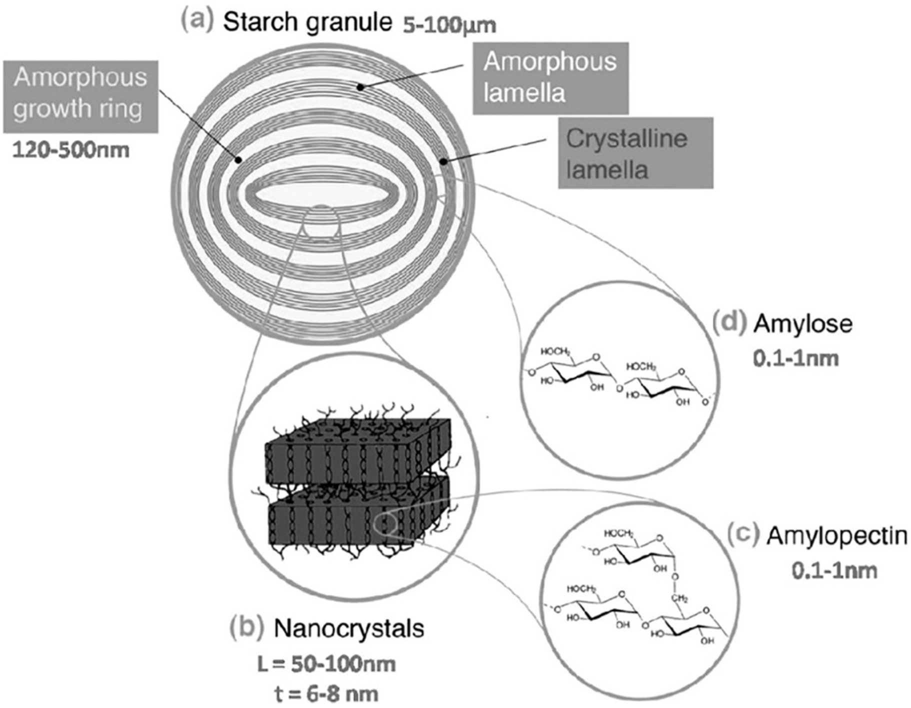

Fig. 1. Structure of starch granules, adapted from Ref. [12].

added ingredients all affect the formation of the starch gel and its characteristics [20]. The main factors are summarized as follows:

i. Mass ratio of amylopectin to amylose - amylopectin is more difficult to be dissolved than amylose in alkaline solution with vortexing [21], while amylose is more difficult to be dissolved at high temperature [22].
ii. Temperature - starches with high amylose content is less likely to be dissolved in hot water [22]. After cooling, the dispersed starch molecules go through a reassociation process called retrogradation [23]. Amylopectin retrogrades very slow while the retrogradation of amylose occurs quickly within a few hours [24].
iii. pH - starches undergo hydrolysis and become simpler sugars in the presence of acids [25]. On the other hand, high pH accelerates the progress of starch gelatinization [26].
iv. Size of starch granules - larger starch granules require more time for gelatinization. Normally, a duration of 30 min is enough for starch gelatinization [24].
v. Ingredients of aqueous medium, including water reactivity and salt [27,28].

Overall, the dissolution/gelatinization of starch granules is complicated and is affected by multiple factors.

There are various starches that are produced from corn, rice, tomato, potato and other sources. Among them, corn starch is the common depressant for iron bearing minerals due to its wide availability and low price [29]. In the present work, four corn starches (waxy, normal, G50 and G80) differing in the mass ratio of amylopectin to amylose were investigated. The degree of starch gelatinization was evaluated by starch solubility. Images were taken to study the phase transition of starch granules. The role of starch solubility in the flotation of hematite and quartz was investigated. The results have significant implications for flotation and other processes such as flocculation [30,31], where starches are used.

2. Experimental

2.1. Materials and reagents

Hematite and quartz samples were purchased from GeoDiscovery, Australia. Table 1 and Fig. 2 show the X-ray fluorescence and X-ray diffraction results of these two mineral samples, respectively. As shown, these hematite and quartz samples were highly pure. All mineral samples used in the experiments were crushed, ground and wet-sieved to prepare the flotation feed samples whose particle size fell into the range of 38–74 μm.

Four types of corn starches with different amylose/amylopectin contents (Waxy Starch: 0/100; Normal Starch: 27/73; Gelose 50: 50/50; Gelose 80: 80/20) were used in the present work to study their dissolving process. Table 2 shows the characteristics of four corn starches with different amylose/amylopectin contents as reported in literature [22]. Normal corn starch (NS) was purchased from Sigma-Aldrich while the other starches, waxy starch (WS), Gelose 50 (G50) and Gelose 80 (G80), were obtained from Penford Australia Ltd. (Lane Cove, NSW, Australia). Only fresh starch solutions prepared using a hotplate and a magnetic stirrer were used to minimise possible impact from retrogradation. Dodecyl ammonium chloride (DAC) was chosen as collector in this study as it is one of the most popular cationic collectors in iron ore flotation, and many new synthetic cationic amine collectors were investigated through the comparison with DAC in iron ore flotation [6,17]. DAC, sodium hydroxide (NaOH), absolute ethanol, sodium acetate and

Table 1
Chemical analysis of the hematite and quartz.

Sample Name	Fe_2O_3 (%)	Si (%)	Al_2O_3 (%)
Hematite	95.19	0.96	1.61
Quartz	–	99.9	–