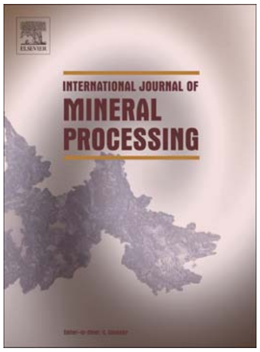

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P. Patra, T. Bhambhani, M. Vasudevan, D.R. Nagaraj, P. Somasundaran

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Transport of fibrous gangue mineral networks to froth by bubbles in flotation separation

P. Patra[a*], T. Bhambhani[b], M. Vasudevan [b], D. R. Nagaraj[b], P. Somasundaran[a]

[a] Department of Earth and Environmental Engineering
Columbia University,
New York, USA 10091

[b] Cytec Industries Inc
Stamford Technology Center,
1937 W Main St, Stamford, CT USA 06907

Abstract

Flotation beneficiation of ores containing fibrous minerals is highly problematic due to transport of such gangue minerals from pulp to the froth phase. Earlier studies have attributed such transport to the entrainment of fibrous minerals. In this work, this problem is investigated for the case of flotation of ultramafic Ni ore with fibrous serpentines (Mg silicates) interfering with their separation. Serpentines are proposed to form large (~1-2 cm) networks in pulp and thus unlikely to be transported by entrainment. Various simulation based studies suggest that the networks are stable under the dynamic flotation conditions. Furthermore, the pores in the networks are relatively small (e.g. < 20 microns – SEM studies) for the bubbles (1-2 mm) to penetrate through the network of fibers in the pulp. This leads to the hypothesis that bubbles which cannot penetrate through the network accumulate below the network in the pulp with the buoyancy force of the bubbles thrusting the network to the froth phase. Model system studies were carried out with nylon fibers of size similar to that of serpentines. The phenomenon, of bubble-flux driven transport of fibrous serpentines was clear from the model system studies, and is proposed to be the key mechanism of transport of fibrous serpentines to flotation concentrate.

Key Words: Serpentines, fibrous, network, pore size, bubble flux

*corresponding author:

Partha Patra

Earth & Environmental Engineering
500 W. 120th Street
918 SW Mudd, MC 4711
New York, NY 10027
Phone: (212) 854-2905
Fax: (212) 854-7081
E-mail: pp2295@columbia.edu
Phone: +12128542926

1. Introduction

Economic beneficiation of the Ni ores containing large amounts of serpentines (Mg silicates) has been a longstanding challenging problem in the mineral industry (Claridge and Tenbergen, 1975; Edwards et. al., 1980; Eltham, J. A. and Tilyard, 1973). Typically, large amounts of serpentines are transported to the froth phase resulting in Ni grade dilution, affecting the smelter efficiency and lifetime. Serpentine minerals are alteration products of parent silicates, such as peridotite and pyroxene (Hess, 1933; Hoatson et. al., 2006). The alteration products have varying physicochemical properties which impact the separation of the value minerals from their ores in froth flotation in various ways. For example, talc is naturally hydrophobic and floats readily, competing with the value minerals in the froth phase and resulting in lower concentrate grades. Serpentines, on the other hand, are hydrophilic (Bremmel, 2005), so they do not report to the concentrate via *true* flotation. Various mechanisms for serpentine transport to the froth phase have been suggested such as: a) entrainment (Pietrobon, 1997), b) heterocoagulation (attachment of Mg silicates to Ni sulfides) (Edwards et. al., 1980) and c) transport of Mg silicates via composite particles having hydrophobic sites (Bremmell, 2005).

In this investigation, the transport behavior of serpentines, especially ultramafic ores containing fibrous minerals is examined. The transport rates of serpentines showed a linear trend irrespective of the reagent and condition schemes used in flotation tests. To understand such trends, the physicochemical aspects of the serpentines in the pulp and froth phase were studied using optical microscopy, SEM and EDX techniques. Model system studies were carried out with nylon fibers in a micro-flotation cell to phenomenologically simulate the trend observed in transport of serpentines to the froth phase.

2. Material and Methods

2.1 Materials

Ultramafic Ni ore samples were supplied by Vale Technical Services in Mississauga, Canada. Based on MLA (Mineral Liberation analysis) and XRD, the ore samples contained approximately 1% (by weight) pentlandite and 60% serpentine. Nylon fibers with dimension of 1cm long and approximately 15 micron in diameter were obtained from Nyconn Industries. The fibers were also subjected to size reduction to about 700 µ using a locally available fiber cutter. After size reduction of the nylon fibers the aspect ratios (d/l) of the fibers were estimated to be around 50 (based on average length and thickness observed under SEM) .

2.2 Flotation tests

Ore ground at 50% solids used for flotation tests. Flotation tests were carried out with ultramafic Ni ores at 25% solids in a Denver cell using a dithiophosphate-based collector (40 g/t) and MIBC (20 g/t) frother for 12 minutes. Flotation tests were adjusted to pH levels ranging from 4-5. Flotation tests were carried out at an impeller speed 1000 rpm and aeration rate of 3L/min. Concentrates were collected at 0.5, 1.5, 2, 3, and 5 mins.

2.3 Optical microscopy and the SEM of pulp phase and froth samples

Pulp phase samples were collected before and after the flotation test using a plastic dropper. Samples were also collected from the top half of the froth phase at regular intervals during the flotation test. Samples were immediately transferred to be observed under the optical microscope (Olympus BH-2). The samples viewed were as collected and also after 5 times dilution. For SEM studies the samples were collected in 10 ml glass vials and gently tumbled before placing a drop of the froth/pulp sample on a SEM stub. A technique known as acetone-replacement drying (Fitzpatrick, 1980) was used instead of conventional drying to maintain the structural integrity of the sample. After drying and carbon coating the SEM/EDX of the samples were obtained using the Zeiss DSH 982 Gemini SEM and the Princeton Gamma Tech EDX system using low electron beam voltage (3KeV) to obtain high resolution images.

2.4 Micro-flotation tests

Micro-flotation tests were carried out in 100 ml glass cells with a porous frit. Nylon fibers of aspect ratio 50 were used in these experiments. Nylon fibers micro-flotation tests were carried out at 3-5 % (w/w) solids and for less than 5 minutes. Air flow rate was maintained at 100 ml/min.

3. Results and Discussions

3.1 Flotation results

According to Figure 1 Ni recovery showed a parabolic trend which is typical for minerals reporting to the concentrate by *true* flotation. In contrast, the trend for serpentine recovery (as determined by MgO assay) is linear irrespective of the reagents and conditions used in flotation. Such a linear trend is uncharacteristic of true flotation. As serpentines are typically not hydrophobic, it is reasonable to consider that the serpentines transport to the froth phase is not via true flotation. The linear trend is typical of mechanisms such as entrainment (Pietrobon, 1997). If serpentines transport is via entrainment mechanism the a correlation between particle size of serpentines and their degree of entrainment (Maachar and Dobby, 1992) should exist. In order to determine the particle size of the serpentines, the sample in the pulp and froth phase was characterized using optical microscopy, SEM/EDX. Screens and automated particle size analyzers were found to be ineffective for fibrous mineral particles.

3.2 Particle size analysis of pulp and froth phase samples

It can be seen from the optical microscopic images (Figure 2 a-b) of pulp and froth phase that macro-networks as large as 1-2 cm were observed. SEM of the networks carefully separated is shown in Figure 2c. It can be observed from SEM images that the networks are comprised of fibrous as well as fine particles. EDX spectra of this network structure showed Fe, Mg, Si and O peaks which are typical of serpentines. The XRD of these samples also indicated that they are Lizardite and Chrysotile type of serpentines.

It is clear from the optical and SEM images that the serpentines do not exist as individual particles in the suspension but rather exhibit a macro-network like structure and their transport by entrainment is an unlikely mechanism. In fact it seems that it is indeed the network of serpentines that is transported through the suspension-bubble three phase system to the froth phase. To develop an understanding of the mechanism of transport of such a macro-network our approach was to study the impact of the pore size of the network and the effect of bubble buoyancy using systems comprising of either chrysotile fibers or nylon fibers. Results with nylon fibers are reported here.

3.3 Network pore sizes

SEM micrographs (Figure 2c), suggest that the pore sizes for the serpentine network were as small as 20 microns. Based on various simulation based studies reported in literature, the apparent pore sizes across the network bed is expected to be even smaller, as the macro-network is typically in the form of layers (Switzer, 2004) of many small networks. Based on rheological studies, the network is stable under high shear conditions typical of that observed in flotation cells (Vasudevan, 2010). It is also known from other simulation based studies (Lindström and Uesaka, 2008) that a network similar to that in this investigation can be quite sturdy and resistant to shear.

3.4 Bubble-network interaction

Typical bubble size in flotation is 1-2 mm and this is larger than the pore size of the network. It is thus unlikely that the bubbles will penetrate through the network. This suggests that bubbles will accumulate at the network-water interface, and it is likely that large accumulation of bubbles will provide enough buoyancy force to thrust the network upward through the pulp phase and final reaching the froth phase. We have developed a phenomenological model to test this concept.

3.5 Model system studies using nylon fibers:

The transport of nylon fibers was studied in a micro-flotation. It was observed that layers of nylon fibers reported to the froth phase (Figure 3). A schematic of the whole transport process as observed is illustrated in Figure 3. Figure 3a shows network of nylon fibers under turbulent conditions of the flotation cell. Figure 3b shows a schematic accumulation of air bubbles at the layers of network of nylon fibers. We observed that for the first 5 seconds there was neither transport of fibers nor formation a froth (Figure 3b) phase indicating the need for accumulation of bubbles at the nylon network-water interface developing a thrust due to the bubble-flux at the interface. Development of froth phase was observed after 5 seconds. Figure 3c shows that the entire network is transported to the froth phase.

Even though bubble entrapment in the fibrous network phenomenon has been widely studied, bubble flux driving a network from pulp to froth phase is largely unknown. Based on the above, the predominant mechanism in transport of the serpentines is proposed to be the bubble-flux-driven upward flow of the network of serpentines.

4. Conclusions

Bubble-flux driven lift of the fibrous serpentine network contributes significantly to the transport of serpentines to the froth phase. The fibers entangle and form a network with an effective pore size much smaller than the bubble size which restricts percolation of the bubbles through the network. Thus, a swarm of bubbles is proposed to build up at the base of the network in the pulp, resulting in enough buoyancy thrust to enable the network to be transported from the pulp to the froth phase. It is also important to note that other non-fibrous minerals can be expected to be trapped in the network and transported to the froth phase.

5. Acknowledgements

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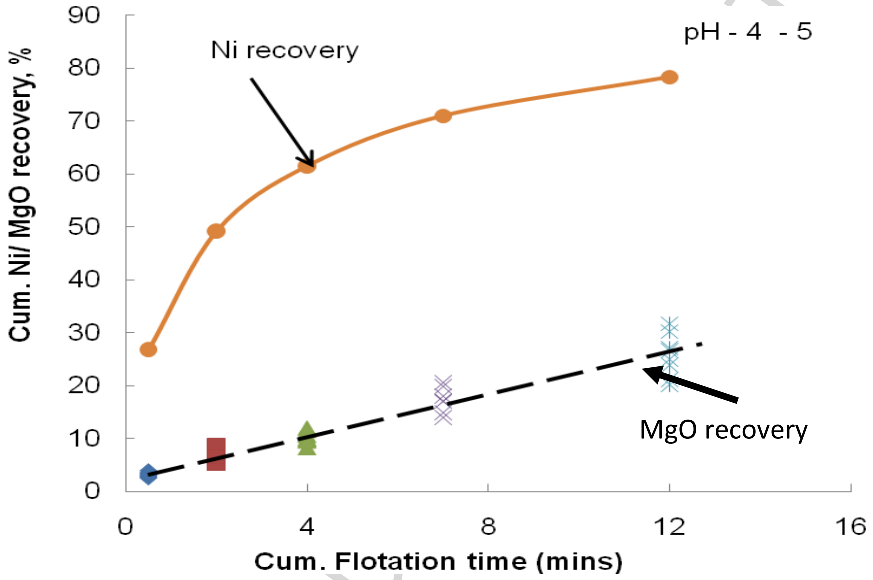
Figure 3. Schematic of various steps in transport of fibrous network from flotation pulp to froth phase. The white colored material in the micro-flotation cells are nylon fibers. The fibers are represented as irregular lines in the schematic of micro-flotation cells. Gray colored circles are represented as air bubbles**.**



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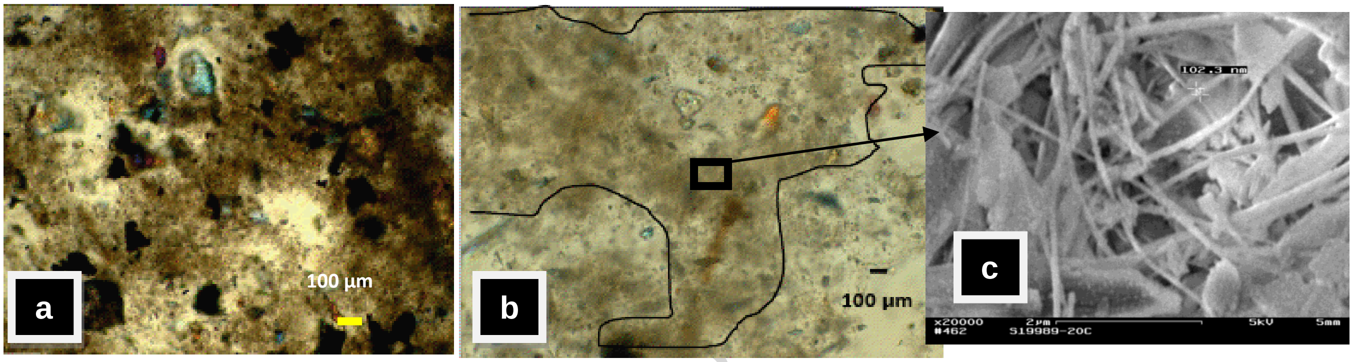

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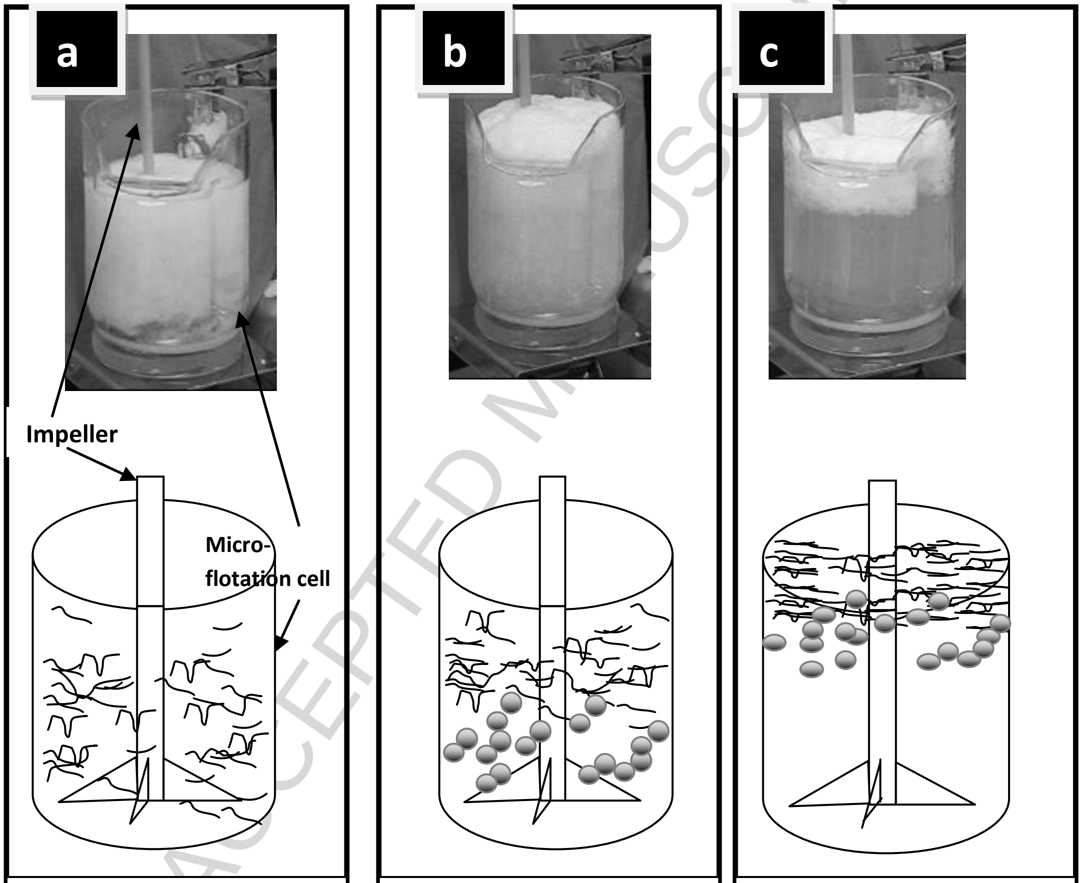

Step (a) – 0 secs

Nylon fibers suspended in pulp and without air bubbles

Step (b) – at 5 secs

Nylon fibers in pulp and after air bubbles were introduced

Step (c) – 5 secs onwards

Nylon fibers collected by bubble flux at the froth phase

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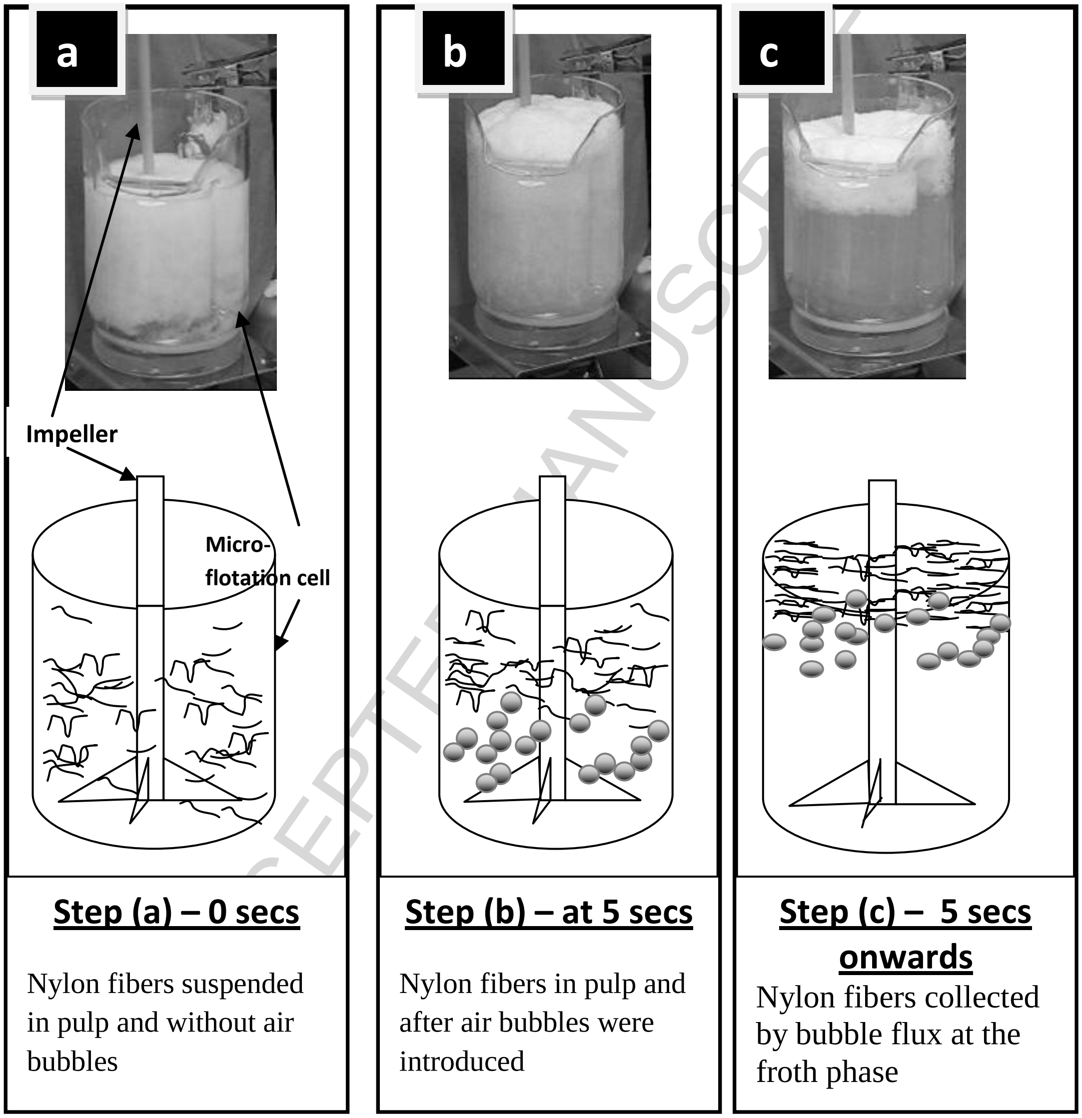
Graphical abstract



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Schematic of various steps in transport of fibrous mineral network from flotation pulp to froth phase. The white colored material in the micro-flotation cells are nylon fibers. The fibers are represented as irregular lines in the schematic of micro-flotation cells. Gray colored circles are represented as air bubbles.

Highlights:

- Transport of gangue to flotation froth is problematic with fibrous ores
- Entrainment/true flotation are proposed mechanisms by earlier researchers
- Fibers entangle and form network in pulp with pore sizes less than bubbles
- Bubbles percolation is restricted and thus accumulates at the network
- Bubbles accumulation results enough buoyancy thrust for network transport