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RESEARCH ARTICLE

Introducing Jameson Cell flotation technology for deinking paper fibers

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Abstract

Deinking is the industrial process of removing printing ink from paper fibers of recycled paper to make deinked pulp. The process of deinking is literally demonstrated and factors associated with releasing ink from fibers as well as ink-bubble attachment / detachment are discussed. Froth flotation is known as a separation technology in which ink-laden bubbles are created and removed. A new flotation technology has been designed and manufactured and introduced in this paper to highlight the most effective features associated with pulp-paper deinking process. Some important aspects of ink particles attached to bubbles are also demonstrated.

Introduction

Paper recycling is the process of turning waste paper into new paper products. Today, 90% of paper pulp is created from wood. Paper production accounts for about 35% of felled trees and represents 1.2% of the world's total economic output (FAO, 2013). Energy consumption is reduced by recycling, although there is debate concerning the actual energy savings realized (EIA, 2013). A concern about recycling wood pulp paper is that the fibers are degraded with each cycle and after being recycled 4–6 times the fibers become too short and weak to be useful in making paper.

In order to remove ink from fibers there may be pulping, cleaning and screening before de-inking process. Centrifugal cleaning separates materials that are denser than pulp fibers. Screens, with either slots or holes, are used to remove contaminants that are larger than pulp fibers (Wills and Napier-Munn, 2006).
Washing and dewatering (thickening) is a filtration process, in which small particles (<5μm) are removed by passing water through the pulp. Bleaching is a post-processing activity that uses peroxides or hydrosulfites to increase the brightness of the pulp if white paper is desired. The goal in bleaching method is to make the fiber brighter.

The industrial process of removing printing ink from paperfibers of recycled paper is to make deinked pulp. The efficiency of ink removal flotation requires that three basic conditions are met i.e. the ink particles are separated from the fibers, they are hydrophobic, and are of an appropriate size (5–250 μm) (Zhao et al. 2004). The pulp suspension consists essentially of water as the carrier (98–99%), fibers as the clean fraction (1–2%), filler (<0.6%), the ink to be removed (<0.15%) and additive (<0.1%). In addition, the suspension contains negligible amounts of soluble and insoluble organic and inorganic compounds, which may, however, affect the flotation process and its results (Costa and Rubio, 2005).

Flotation deinking

The deinking process is based on the detachment of ink from the fibers. This is achieved by a combination of mechanical action and chemical means. The most common process is froth flotation deinking. Froth flotation is a method of generating bubbles and making them available for particles to attach to bubbles. It is a separation method based on particles surface chemistry as well as system hydrodynamics.

Some key parameters are bubble–particle size ratio and the degree of turbulence in the suspension. Ink particles are collided to bubbles and bubble-ink aggregates are created. The ink-laden bubbles can then be removed. Therefore, in flotation deinking one should deals with surface chemistry of ink particles and the mixing characteristics of process itself. The theory of removing ink from paperfibers by flotation is literally chemistry based, however there are some key physical aspects involved. Deinking is basically a two-stage process:

1. Detachment of ink from the fibers and fillers
2. Separation of ink particles from fibers and fillers

Both chemistry and physics theory are governing these two stages. In the ink detachment phase, alkali is added to the pulp slurry to detach ink from the fibers. The detached ink particles are dispersed in water. In the separation stage surfactant is added to render ink particles hydrophobic in order to attach to bubbles.

Chemicals used for deinking of recycled paper

The most common reagents used are Alkali (NaOH), Peroxide, Sodium Silicate, Soap and Lime. The key surfactant which affects the surface hydrophobicity of ink is a combination of soap (anionic) and synthetic non-ionic surfactants (e.g. ethoxylated fatty acids). It is often used in the form of a fatty acid emulsion. The water hardness is also important, thus the presence of Ca^{++} in the form of lime milk is a usual practice. In this stage the reaction between ink, soap and Ca^{++} is the adsorption of soap to the ink particles which may affect the flotation efficiency, too. Therefore, hardness, emulsion dosage, pH and sodium silicate dosage are likely the determining factors in deinking (Mo and Roring, 2013).

The role of surfactant is to reside at the ink-air and air-water interface changing the surface characteristics. The affinity of air bubbles to ink particles relative to that of fibers is dependent on the role of surfactant. Some surfactants are found less harmful to the environment than others. Therefore, there is tendency for using biodegradable surfactants in paper deinking process (Venditti, 2013). Flotation technology has been used as primary means in paper deinking over the last decades and encountered considerable developments. Later in this paper, one of the latest developments in flotation technology which has resulted in the use of the system to the deinking process will be discussed.

The Jameson Cell flotation technology

Jameson cell originally was invented by Professor Graeme Jameson from the University of Newcastle, NSW, Australia the late 1980s, and since then been used extensively in the mineral processing, solvent extraction and industrial wastewater treatment fields (Yan and Jameson, 2001; Mozaffari, 1998; Hall, 1991; Harbort et al, 1994).

In this paper some prime features of the Jameson cell are discussed and its innovative potential for effective deinking introduced. The Jameson cell is an innovative flotation process driven by fluid mechanics. The principle of using air bubbles to recover particles is the basis of the technology. The advantages of modern Jameson cells are generating small bubble size. The air is self-induced and an external compressor or blower is not required. It also occupies small footprint and offers operator-friendly designs. Fig 1 shows a schematic view of Jameson cell. As can be seen there is no mechanical part fixed for agitation, which is an unavoidable part in conventional flotation devices. The fine bubbles are consistently generated through imparting intense mixing which brings about rapid flotation and high throughput. It is simple operation and is extremely energy efficient. The way air bubbles are generated and their interaction with particles in the Jameson cell is the key for achieving high efficiency. The energy for flotation is delivered by conventional pump power consumption, and is therefore significantly lower than the equivalent mechanical flotation cell (Gorain et al, 1999). Optimal Jameson cell performance is maintained by delivering a constant volumetric flowrate of pulp to the downcomer.

The downcomer, the middle column shown in Fig 1, is the heart of the Jameson cell where intense contact between air bubbles and particles occurs. Feed is pumped into the downcomer through the slurry lens orifice creating a high-pressure jet. The jet of liquid shears and entrains air from the atmosphere. Removal of air inside the downcomer creates a vacuum, causing a liquid column to be drawn up inside the downcomer. The jet plunges into the liquid column where the kinetic energy of impact breaks the air into fine bubbles which collide with ink particles. The very high interfacial surface area and intense mixing result in rapid particle attachment to the air bubbles, and high cell carrying capacities. The downcomer is where bubble-particle collision, attachment and collection occur. The different hydrodynamic regions of the downcomer are the free jet, induction trumpet, plunging jet, mixing zone and pipe flow zone. The tank pulp zone, external column shown in Fig 1, is where ink-laden bubbles are disengaged from the downcomer. The tank, also known as separation cell, is designed to ensure an efficient, quiescent zone for separation of ink-laden bubbles from the cleaned pulp (Atkinson et al, 1993). Such a design maximises safe removal of ink-bubble aggregates into the froth zone at the top of the tank and a clean ink-free pulp discharged from the bottom of the tank.

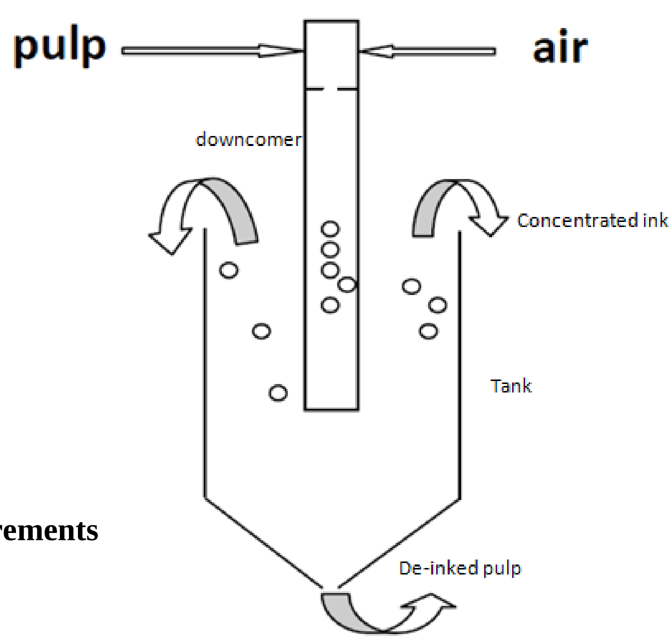
The Jameson cell, from ore refining to wastewater treatment and paper pulp deinking

The Jameson cell process (also known as Induced Air Flotation) utilises the energy of the fluid to induce air into the process rather than requiring an external compressor or blower (Armatec, 2013). It has been primarily designed and used in coal and mineral processing (Hall, 1991). Later, Australian companies have introduced it to wastewater treatment and run pilot plant of Jameson cell to remove blue-green and green algae from affected wastewater streams. From these tests, the system demonstrated high efficiency algae, phosphorus and suspended solids removal (Garden, 2005). A great lesson may be learnt from the application of flotation for treatment of algae bearing municipal waters, where algae cells are usually very small in size (3–7µm). Here, Jameson cell technology is found to be capable of removing very different types and forms of algae cells using cationic polymer flocculants (Yan and Jameson, 2001). Also used in treatment of oily pollutants, the Jameson cell has shown efficient recovery. Other researchers presented results of a rapid emulsified oil-removal from water by flocculation followed by flotation in a modified Jameson cell (Santander et al, 2011). Parameters studied were flocculation (type and concentration of polymer), oil concentration, oil droplets size distribution and flotation cell design. The oil removal increased up to 85% in the Jameson cell.

Table 1- Velocity and total residence time of tracer in the downcomer and tank (frother: MIBC)

MIBC (ppm)	Average Velocity of Colour Tracer (Ink) in the Downcomer (cm/s)	Average Velocity of Colour Tracer (coal) in the Downcomer (cm/s)	Total Residence Time (R.T.) (sec.)	R.T. in the Tank (sec.)	R.T. in the Downcomer (sec.)
20	26.2	22	18.1	7.6	10.5
35	25.8	22.5	17.3	6.5	10.8

Fig 1 - Schematic view of the Jameson cell



Retention time measurements

A lab scale Jameson cell machine was manufactured in mineral processing lab at Imam Khomeini International University. Experimental work carried out with the Jameson cell is demonstrated to highlight the effective potential of the device for deinking application. Experiments were carried out in the lab scale Jameson cell with the following arrangements:

Tracer monitoring in the downcomer

As a medium in a two phase system, liquid in the downcomer can be well monitored using iron gall ink. The gall ink product of Conservation by Design Ltd was used. The ink is generally prepared by adding some iron(II) sulfate ($FeSO_4$) to a solution of tannic acid ($C_6H_2(OH)_3COOH$). By mixing tannin with iron sulfate, a water-soluble ferrous tannate complex is formed. This ensures that no attachment to bubbles will occur and therefore the liquid phase in the downcomer can be monitored. Ink is introduced at a point about 20 cm below the orifice plate to make sure that the tracer is added into the bubbly zone. The velocity of the contaminant part is considered as the actual liquid velocity in the downcomer. This was measured by tracing the centre of the coloured volume unit as it descends within the downcomer. A similar technique of colour monitoring, using coal particles, was applied for the gas phase velocity measurement. The coal particles, which are naturally hydrophobic will attach to bubbles when finely ground and conditioned with kerosene in an aqueous solution (Vapur et al, 2010).

Table 1 shows the average velocity and total residence time of tracer in the downcomer and tank. A total residence time of approximately 20 sec. is found to be shorter than that of other flotation devices, whose residence time is reported to be around a few minutes (Lapierre et al, 2004).

Bubble size measurement

The bubble diameter distribution inside the tank was measured at the top of the tank. Arrangements were made for taking samples of the two-phase mixture from inside the column (Mozaffari, 1998). A photographic technique used to capture the images of the bubbles was found reliable using a camera with 1:125 sec. shutter speed. Bubble size measurements were carried out using image analysis for different frother concentrations (MIBC, Methyl Isobutyl Carbinol: 35, 20, 10 and 5 ppm); mean bubble diameters of 0.3 mm, 0.5 mm, 1 mm and 2.5 mm were measured respectively.

Recommendations and Conclusions

The Jameson cell can be a competent device for paper deinking process. It is expected that the machine will be capable of treating paper pulp with higher yields and ink removals. This is because of higher probability of particle bubble collision / attachment prevails in the downcomer (Clayton et al, 1991). It has shown good performance in removing blue-green and green algae from affected wastewater streams (Yan and Jameson, 2001), and for the treatment of oily effluent (Santander et al, 2011). The separation cell (tank) also performs adequately providing good environment for disengagement of particle-laden bubbles and clean discharged liquid. Shorter residence time brings about higher throughput making it capable of treating more pulp in shorter time. Conventional flotation technologies produce larger bubbles with less gas hold-up and carrying capacity (Gorain et al, 1999). In the Jameson cell, bubbles are smaller in size and gas hold up is higher, by which the removal of ink by flotation is governed. From algae and oil removal applications introduced here, it can be inferred that chemical, physicochemical and operating process parameters are the key aspects in the Jameson cell. These parameters are controlled by the very high air hold-up and mixing conditions prevail in the downcomer, which bring about a very high-rate separation efficiency as a result of capture of oil droplets by bubbles at low residence time. The next program is to bring adequate amount of paper pulp from Latif Paper Ltd and introduce it to the flotation machine to test its efficiency. The machine is capable of working in a semi-batch form that is to return the tailings (the cell discharge) to the feed and let the ink particles get more chance to be removed by bubbles (Harbort et al, 1994).

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