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Deinking selectivity (*Z*-factor): a new parameter to evaluate the performance of flotation deinking process

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Abstract

This study proposes a deinking selectivity concept that considers both ink removal and fiber yield in determining the performance of deinking operations. The defined deinking selectivity, or *Z*-factor, is expressed by the ratio of ink removal expressed by the International Standards Organization (ISO) brightness gain or the reduction in relative effective residual ink concentration (ERIC) and the relative fiber (oven-dry basis) rejection loss. For most flotation processes, typical brightness *Z*-factor is on the order of unit value and ERIC *Z*-factor is on the order of 10 units. Therefore, the *Z*-factor weighted brightness gain and ERIC reduction have relevance to ISO brightness and ordinary ERIC reduction. Pilot-scale flotation deinking experiments showed that *Z*-factor weighted brightness gain and ERIC reduction are good indicators of deinking process efficiency. The period or stage *Z*-factors are good indicators of the efficiency of the periods or stages of a deinking process. The ERIC *Z*-factor can be directly related to the separation factor defined in chemical engineering science. A simple criterion developed using the stage *Z*-factor concept was applied to both pilot-scale experiments and an industrial recycling mill operation for determining the economics of a given period or stage in a flotation deinking operation.

Keywords: Flotation deinking; Paper recycling; Secondary fibers; Deinking sensitivity; Fiber yield; Fiber loss

1. Introduction

Since its introduction in the 1980s, flotation deinking has been adopted as a standard practice for removing ink from wastepaper in paper recycling operations. Inks are detached from fibers through the pulping process before flotation. The objective of the flotation process is to remove the detached inks from the fiber suspension by injecting air bubbles, with the assumption that the hydrophobic ink particles will stick to air bubbles on collision. Ink is removed when the ink-attached bubble froth floats to the top of a flotation cell and is rejected. An increase in froth rejection rate results in an increase in ink removal. Unfortunately, the bubble froth rejection process also rejects fibers, primarily as a result of the entrainment of fiber into the bubble network [1–5]. Furthermore, fiber rejection loss is increased with an increase of froth rejection [3]. It is apparent that increased ink removal and fiber yield are two contradictory requirements in flotation operations, which makes flotation deinking so different from mineral flotation.

Because the primary concerns in most paper recycling mill operations are machine or process runnability and meeting the ink removal specifications of mill customers without additional processing (e.g., bleaching or washing), most studies on flotation deinking have primarily focused on removal of contaminants. These studies include understanding pulping chemistry and process [6–10] to achieve good ink separation from the fibers for removing ink, removal of wax or stickies through flotation [11,12], and flotation chemistry to improve ink removal [13–19]. Typical gains of pulp brightness around 10% ISO standard [20] and effective residual ink concentration (ERIC) reduction of 75% through flotation are common in laboratory or mill operations. Pulp ISO brightness is defined as the ratio of the radiance of wavelength 457 nm of a

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paper specimen made from the pulp sample in question to that of a perfect reflecting diffuser (e.g., magnesium oxide). ERIC is defined as the ratio of the absorption coefficient of the paper specimen to that of ink at wavelength of 950 nm (normally assumed to be 10,000 m^2/kg if measurements are not available). It can measure the amount of ink on paper through calibration. Little attention has been paid to the improvement of fiber yield through flotation. After studying the fiber entrapment mechanism of fiber loss in flotation deinking [5,21], water spray was used to reduce the fiber trapped in the bubble network and thereby increase yield in a laboratory study [21].

A frothing agent spray concept was proposed to obtain separate control of froth stability to increase fiber yield and optimize ink removal in deinking of toner printed papers in a laboratory column flotation cell [4]. This concept was later successfully demonstrated using a mixture of old newsprint (ONP) and old magazine (OMG) furnish in a pilot-scale commercial flotation cell [22]. However, a limited number of commercial trials of the frothing agent spray concept have been conducted. Typical yield losses in recycling mill operations are about 10–25%, which contributes to the higher cost of recycled fibers compared with that of virgin fibers. Because loss in fiber yield is mainly caused by the same process used for removing ink in flotation, i.e., the froth rejection process, it is logical to take an integrated approach to study flotation deinking and to evaluate flotation deinking process performance. That is, the flotation process has to be optimized in terms of both high ink removal rate and fiber yield.

The objective of our study was to define a deinking selectivity concept that takes into consideration both ink removal and fiber yield loss in a deinking process. The deinking selectivity concept was then applied to a set of flotation deinking experiments conducted in a laboratory pilot-scale facility to demonstrate its usefulness in evaluating the performance of the flotation process under various experimental conditions. Note that deinking selectivity is completely different from the flotation selectivity used in mineral flotation. It is a measure of the effectiveness of a deinking process to selectively remove ink. The selectivity used in mineral flotation is to measure the selective separation of various grades of minerals. The goal of the present study was to develop a balanced evaluation technique to assess the performance of industrial deinking operations.

2. Definitions

In chemical engineering science, the degree of any separation process is defined by the separation factor [23]. For a two-stream process (accept and reject) in flotation deinking with two components of fiber and ink, the separation factor can be expressed as follows:

$$\alpha = \frac{x_{\text{ink}}^{\text{reject}}/x_{\text{fiber}}^{\text{reject}}}{x_{\text{ink}}^{\text{accept}}/x_{\text{fiber}}^{\text{accept}}} \tag{1}$$

Table 1
ISO brightness gain and fiber loss in flotation deinking experiments

Experiment number	Fiber loss (%)	Brightness gain (ISO, %)	Selectivity
1	5.3	8.75	1.64
2	5.9	9.80	1.67
3	10.0	9.97	1.00
4	12.1	8.52	0.70

where x can be the mole or mass fractions, or mole or mass flow rates. Unfortunately, pulp brightness, which has been accepted as a standard to measure the cleanness and visual quality of fibers in the pulp and paper industry, the commercial market for recycled fibers, and the academic research community, has no relation to the material mass quantities required in the definition of separation factor (Eq. (1)). Moreover, the definition in Eq. (1) also requires to evaluate the material quantities in both the accept and reject streams, which makes the separation factor even more difficult to use.

In a previous study [22], the ratio of pulp brightness gain after deinking and percentage of relative fiber loss was used to describe flotation deinking selectivity. We found that selectivity was effective in differentiating the overall performance of several flotation experiments under various conditions. Table 1 lists the experimental data presented in Figs. 4 and 5 of our previous study [22] to illustrate the effectiveness of selectivity. The data clearly show that experiment 2 was optimal in terms of low fiber loss and high brightness gain. While experiment 3 resulted in the highest brightness gain, it suffered from very high fiber loss, 40% more than that incurred in experiment 2. Experiment 1 showed the lowest fiber loss, but brightness gain was also lowest among the three experiments. The selectivity data clearly show that the best results were obtained with experiment 2. The initial success of the term “deinking selectivity” in evaluating deinking performance led us to define deinking selectivity in general terms, including selectivity based on another deinking parameter, ERIC, a standard to measure the degree of ink removal in industrial deinking operations and academic deinking research. Because ERIC can be a measure of the amount of ink remaining on the fibers in the accept stream through calibration, we will relate the ERIC based deinking selectivity to the separation factor later in the text.

2.1. Instantaneous selectivity

Instantaneous deinking selectivity, $Z(t)$, is defined as

$$Z(t) = \frac{\mathrm{d}G}{\mathrm{dFrj}} \tag{2}$$

where G is the relative percentage of change of any ink removal parameter, e.g., ISO brightness gain, relative effective residual ink concentration (ERIC) reduction, etc., and Frj is the percentage of fiber rejection loss. Therefore, instanta-