MAGNETIC SEPARATION FOR WASTEPAPER RECYCLE MILLS

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ABSTRACT

An alternative approach to the conventional washing and flotation techniques for de-inking of mixed office waste (MOW) is magnetic separation. The use of magnetic de-inking has great potential to improve the efficiency of ink removal due to the magnetic content of toners. It is shown experimentally that the magnetic susceptibility of toners typically found in MOW varies from weakly paramagnetic to ferromagnetic.

The magnetic de-inking of MOW in itself is not sufficient to achieve a high quality final product due to variations in the magnetic susceptibility of the toner particles. Nevertheless a combination of magnetic separation with flotation appears to be able to produce a final product of superior quality with 92.7% of the dirt removed. Considering these findings appropriate flowsheet modifications are suggested for improved plant performance.

INTRODUCTION

The world paper industry operates in a competitive market in which both quality and cost are of vital concern. Because of the cost of virgin fibers, papermakers are increasing the use of recycled fiber to fulfill their needs. A significant portion of recycled paper comes from mixed office waste (MOW). This type of waste is generated by non-impact printing processes such as laser printers and electrophotography. Usually, dry inks known as toners are employed by these printing processes and these inks consist of thermoplastic resins (e.g., copolymers of styrene and acrylate) usually mixed with magnetic pigments or carbon black.

During the printing process the toner particles are fused to one another and to the paper surface by the combination of heat and pressure. The resulting bond of the toners to the paper involves intermolecular adhesion between the two substances. Due to the stickiness of the toner ink at the paper surface the MOW needs to undergo de-inking prior to reuse in order to effectively compete with virgin fiber.

The MOW de-inking technology consists of detachment of the fused toner from the paper surface through the combined action of chemicals, heat, and mechanical agitation. Subsequently the toner particles must be separated from the fiber suspension. Common MOW ink separation techniques include washing and/or flotation. Both processes have certain disadvantages.

Washing often results in low yields and incomplete ink removal that results in dirty cellulose fibers. Flotation is essentially a physico-chemical process and thus its effectiveness is related to the composition of the wastepaper, type of binder, type of fibers, type and content of mineral fillers, and coating. Consequently, the quality of cellulose fibers obtained by flotation varies depending on the wastepaper source.

An alternative approach to these conventional techniques is magnetic separation. Of course this technique depends on the magnetic susceptibility of the toner particles, which must be at least paramagnetic for the successful separation from the non-magnetic cellulose fibers. The toner magnetic contents vary with the type of image development process used by the electrophotographic copy machine or laser printer. There are two major types of development systems the dual (or two) component and monocomponent.

The dual component systems are used for high speed machines. They are called dual component systems because the developer mix has two components, toner and magnetic carrier. Commonly, the toner is non-magnetic but copy machines such as the Xerox 50 series and the Xerox 1065 utilize toner with 15 to 25% magnetic pigment in order to improve the copy quality (1). In the case of monocomponent systems the magnetic

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carrier particles are eliminated with the use of toner rich in magnetic pigment content. The majority of the monocomponent toners contain from 25 to 60% magnetic pigment and are usually referred to as magnetic toners (1-3). Laser printers mainly use the monocomponent developer in its image process.

In 1991 the volume of dry toner consumed was estimated to be 85 millions pounds in the United States alone and 200 millions pounds world wide (1). From these 85 millions pounds close to 50% was magnetic toner. Therefore, the use of magnetic separation should be a very promising technique for MOW de-inking. In this regard, the magnetic character of toner particles has been examined in order to evaluate the potential of using wet high intensity magnetic separation to de-ink furnishes containing significant quantities of MOW.

EXPERIMENTAL

Material

Commercial toners used in these experiments were obtained from Xerox Corporation and Canon Inc.. Table I, shows the iron oxide content of selected toners as determine from the Material Safety Data Sheet (MSDS).

Two types of wastepaper were studied, one consisted of laser printed waste (LPW) only and the other wastepaper sample consisted of 50% laser printed waste and 50% electrophotographic copied waste. The laser printed waste was generated with the Hewlett Packard Laser jet III and the photocopied waste by Xerox copy machine 5052.

Magnetic Susceptibility

Magnetic susceptibilities of the commercial toners were measured by Susceptometer Kappabridge that makes use of the alternating current method. The susceptometer has high accurancy, fast measuring rate and is able to read magnetic susceptibility of materials that range from diamagnetic to ferromagnetic The measurements yield Kappabridge units that are normalized to mass magnetic susceptibility (χ_g).

Wet High Intensity Magnetic Separator - (WHIMS)

A batch type wet high intensity magnetic separator, model 3X4L from Carpco was used to separate magnetic toners from non-magnetic cellulose fibers. The principle of operation has been described in the literature (4, 5) and is illustrated in Figure 1. The pulp is fed into the chamber with a ferromagnetic matrix (steel balls) in-place and coil current at the desired setting. Magnetic material will be retained in the chamber after flushing with water while non-magnetic material will be washed through the chamber. The magnetic fraction can then be washed from the ferromagnetic matrix after the coil current has been turned off.

The WHIMS unit was operated with soft iron balls, 19 mm diameter. The pulped wastepaper was fed continually into the WHIMS at a consistency of 1%. Both fractions magnetic (toner particles) and non-magnetic (cellulose fibers) were collected filtered and stored for analysis.

Wastepaper Pulping

Pulping consists of two steps: disintegration of the wastepaper structure and creation of a suspension. The pulping was accomplished by conditioning 250 grams of wastepaper, under moderate agitation, in the presence of hot steam (84 to 90 °C), de-ionized water and reagents. After disintegration the pulp is dispersed in a high speed blender. All pulping, including both LPW and MOW, was done at the same consistency of approximately 12% solids by weight and subsequently diluted to 1% solids by weight.

Flotation

De-inking flotation was carried out under identical conditions to produce results with the same treatment but not necessarily optimal removal conditions. The pulped wastepaper at a consistency of 1% was conditioned for 2 minutes with the collector, LIONSURF 768 (0.4 pounds/ton of dry paper) from Lion Industries. The LIONSURF 768 is a nonionic surfactant/fatty acid blend. The flotation was then carried out for 15 minutes at a stirring speed of 1400 rpm. Subsequently, the float (toner particles) and non-float (cellulose fibers) products were carefully filtered, dried and stored for analysis.

Image Analysis

A PC-based image analysis system developed at the University of Utah (6) was used to measure the cleanness of the cellulose fibers. The measurement was done by placing a hand sheet of the product to be examined beneath a high resolution video system to capture and to digitize the image from the microscope. The image is transmitted to a microcomputer and analyzed by the software. All measurements were achieved under identical conditions including a magnification of 0.84X and a gray level of 90. For each product, the analysis was done for both sides of the hand sheet and the results reported are an average of these two values. The cleanness of the hand sheet was defined by the extent of dirt removal, expressed as a percentage.

$$\text{Dirt Removal} = 100\left(1 - \frac{\text{Area covered by ink after treatment}}{\text{Area covered by ink before treatment}}\right)$$

RESULTS AND DISCUSSION

The Magnetic Behavior of Toner Particles

Magnetic susceptibility

The specific (mass) magnetic susceptibilities of commercial toners are presented in Table II. As can be noted, the magnetic susceptibility increases as the content of iron oxide increases. The variation of magnetic susceptibility is not only due to iron oxide content but also due to the presence of different magnetic pigments.

As mentioned before, depending on the type of image development process, different toners with special magnetic proprieties are required. The magnetic powder (< 0.5 µm) which can be used to formulate the toner is not limited, and any appropriate magnetic substance can be employed. Suitable magnetic pigments include metals, such as iron, cobalt, and nickel; alloys of these metals; metal oxides, such as Fe_3O_4, α–Fe_2O_3, γ–Fe_2O_3, and co-doped iron oxide; and various ferrites, such as MnZn ferrite and NiZn ferrite (7, 8).

The magnetic phases present in the toners was determined by X-rays diffraction (XRD). Table III shows the phases identified in each of the toners. According to the XRD results different magnetic pigments are employed which account for some of the variation in the magnetic susceptibilities.

Therefore, comparison of magnetic susceptibility of toners can be a complex task if the magnetic pigment varies not only in content but also in type.

In general, it should be noted that toners with more than 10 percent iron oxide have sufficient magnetic character to be separated by WHIMS.

WHIMS - toner systems

In order to study the WHIMS response of toner particles only two toners were selected; the 0% iron oxide (Xerox 5052) a typical toner used by the 5052 Xerox copy machines and the 30% iron oxide (Canon EP-S) frequently used by laser printers.

Figure 2, shows the magnetic weight recovery of these toners as a function of applied magnetic field. Due to the difference in magnetic susceptibility between those toners, the weight recovery of EP-S toner (30% iron oxide) is significantly greater than for 5052 toner (0% iron oxide). These results suggest that laser printer toner likely to be present in MOW will be separated efficiently by the WHIMS.

Of course at higher field strengths and /or field gradients it should be possible to improve the recovery of the weakly paramagnetic toners. However, such a separation might require a superconducting magnet in order to achieve sufficient field strength.

Toner particle size

An important factor that limits the applicability of conventional de-inking techniques is the ink particle size. Washing de-inking is more effective in the removal of ink particles smaller than 20 µm while flotation de-inking has optimal ink removal for ink particles in the size range of 10 to 100 µm (9).

Likewise, particle size is an important factor in magnetic separation. Generally, the WHIMS particle size ranges can vary from 0.1 to 1000 µm depending on the magnetic susceptibility of the particulate material. The limits on the particle size range are determined by the forces that act in the separator. These forces are the magnetic attraction force (F_M), hydrodynamic drag force (F_D) and the gravitational force (F_G).

Each of these forces has a different dependence on particle size. The gravitational force depends on the third power of the particle size which means that the gravitational force will be more significant for larger particles. The drag force, which in the Stokes region depends on the first power of the particle size, will be important for small particles. When the magnetic field gradient is matched to the particle size the magnetic force varies as the square of the particle size. Therefore, the attractive magnetic force may be greater than the competing forces only in a limited range of particle sizes.

The effect of the toner particle size on magnetic de-inking can be predicted by calculation of the magnetic, drag and gravitational forces for a typical toner particle size distribution. Figures 3 and 4 show the results for EP-S and 5052 toner particles passing through a theoretical magnetic field of induction of 2 T, at an interstitial velocity 0.1 m s^{-1} with the field gradient generated by the matched steel ball matrix.

For the Xerox 5052 toner the drag force dominates over the magnetic and gravitational forces for all particle sizes considered. This theoretical prediction is in agreement with the experimental WHIMS results for the 5052 toner (Figure 2), a poor separation response was observed. On the order hand, the EP-S toner has a magnetic force significantly greater than the other forces for most of the particle size range considered. This results is also in total agreement with the WHIMS results for the EP-S toners (Figure 2).

Clearly in the case of magnetic de-inking, the toner particle sizes are not a factor that limits its applicability but rather the separation is limited by the magnetic susceptibility of the toner particles.

Although these simple force calculations do not take into consideration the kinetics of the particle motion in the pulp and their mutual interaction, it does give useful information regarding the utility of magnetic separation for de-inking of wastepaper containing magnetic toners

Magnetic De-inking of Wastepaper

In order to make a realistic evaluation of the WHIMS for the de-inking of waste paper, two sorts of waste were investigated; laser printed waste and mixed office waste. These wastes vary with regard to the uniformity of the toner magnetic susceptibility.

Laser printed waste

Figure 5 shows the results from a single-stage wet high intensity magnetic separation for laser printed waste. This is an impressive separation to observe, because close to 89% of the dirt is removed in a single-stage and also due to the fact that the magnetic product leaves the wet separator with almost no cellulose fiber.

It is well known that flotation de-inking has a fiber loss of 20 to 25 percent. The amount of fiber loss during flotation de-inking can be related to two different factors. First, not all toner particles are released during pulping. Toner particles may not be totally free of fibers -"hairy" particles (10) and the flotation of such particles is difficult. Second, short fibers (fibrils) may be carried to the toner product due to the hydrodynamics of the system.

In the case of magnetic de-inking the fiber loss due to the fibrils is significantly reduced. Marwah, et. al. have shown that magnetic separation of MOW using magnetic carrier material leads to high fiber yields (10-11). In our work, the fiber loss for the magnetic de-inking was not quantified, but appeared to be less than 1%.

The results from a test using a combination of flotation and single-stage WHIMS is shown in Figure 6. Flotation alone is able to remove only 67.9% of the dirt. After a single-stage WHIMS the quality of the final product has been improved significantly with the extent of dirt removal being 89.3%. As can be noted, a single-stage process is sufficient to produce a high quality fiber product.

In order to improve the cleanness of the cellulose product a two-stage wet magnetic separation has also been done. Results on dirt removal are presented on Figure 7. As shown, dirt removal close to 97% was achieved.

Because the magnetic susceptibilities of the toner particles are fairly uniform, successful ink removal of the laser printed waste by magnetic de-inking was achieved. But in the case of mixed office waste, the toner particles are completely dissimilar with respect to magnetic content and thus a different magnetic de-inking response can be expected.

Mixed office waste

Results from the magnetic de-inking of mixed office waste using single-stage wet separation is shown in Figure 8. The efficiency of separation is low. Only 51% of the dirt is removed. The drop in the separation efficiency is due to the variation in the magnetic susceptibility of the toners present in the furnish.

The effectiveness of MOW magnetic de-inking in conjunction with flotation is presented in Figure 9. This combined process gave greater ink removal (92.7%) than either flotation (85.6%) with no magnetic separation or single-stage wet magnetic separation (51.0%). It can be noted from these results that the use of WHIMS for the de-inking of office waste paper is a feasible technique for the recovery of a high quality fiber product.

An additional advantage with regard to the use of magnetic de-inking, besides the improvement of the final product, is the possibility for the removal of any paramagnetic mineral fillers and coating such as anatase (TiO_2) and rutile (TiO_2).

Process Design Consideration

One of the major requirements for successful magnetic separation of toner from recycled fiber furnish is proper toner particle sizing during pulp pretreatment prior to magnetic separation. Additionally, pulp consistencies must be low enough to reduce the interaction between pulp fibers and toner particles during magnetic separation. Although with a suitable magnet of high field strength it may possible to process pulp at a high consistency.

The pulp consistency required for effective magnetic separation is available either before or after flotation separation. The even lower consistency used for fine centrifugal cleaning would also be appropriate for magnetic separation and could yield higher toner removal.

Effective magnetic separation could reduce the number of processing steps required to produce clean recycled fiber. Pulp yield could also be improved due to the low fiber losses associated with magnetic separation. Thus a recycled fiber mill employing magnetic separation could have lower capital and operating costs for producing recycled fiber from wastepaper furnishes containing toners than that which could be achieved using only conventional de-inking technologies.

SUMMARY AND RECOMENDATIONS

Toner magnetic susceptibility varies from weakly paramagnetic to ferromagnetic. The variation in magnetic susceptibility is not only due to the iron content but also to the type and nature of the magnetic pigment used in the toner formulation.

In the case of magnetic de-inking the toner particle size is not a factor that limits its applicability but rather the magnetic susceptibility of the toner particles.

Toners with more than 10% magnetic pigment are paramagnetic enough to be separated by wet high intensity magnetic separation.

Single-stage magnetic de-inking of laser printed waste can result in a dirt removal of 89% while two-stage processing results in a dirt removal of 97%.

A combination of flotation with magnetic separation was found to be an effective procedure for de-inking mixed office waste. A dirt removal of 92.7% was achieved with such a processing strategy.

The use of magnetic separation not only produces a high quality cellulose product but also improves the recovery of fibers.

From an environmental quality standpoint the use of magnetic de-inking can lead to a reduction in the cost of flotation and washing reagents and consequently to a reduction in water treatment cost.

Also, based on environmental considerations the use of magnetic toners should be encouraged in order to improve the efficiency of wastepaper recycling operations.

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Table I. Iron Oxide Content of Commercial Toners

Commercial Toners	Iron Oxide Content (%)
5052	0
5775	< 10
5090	15-20
4635mx	25-30
EP-S	30-40
4213	40-45
5012	45-50

Table II. Magnetic Susceptibility of Commercial Toners

Commercial Toners	Iron Oxide (%)	Specific (Mass) Magnetic Susceptibility (m^3/kg)	Magnetic Susceptibility
5052	0	1.40×10^{-8}	Weakly Paramagnetic
5775	< 10	3.05×10^{-5}	Paramagnetic
5090	15-20	1.05×10^{-4}	Ferromagnetic
4635mx	25-30	1.23×10^{-4}	Ferromagnetic
EP-S	30-40	1.74×10^{-4}	Ferromagnetic
4213	40-45	2.05×10^{-4}	Ferromagnetic
5012	45-50	2.82×10^{-4}	Ferromagnetic

Table III. X-Ray Diffraction Analysis of Commercial Toners

Commercial Toners	Iron Oxide (%)	XRD Analysis
5052	0	—
5775	< 10	Magnetite (Fe_3O_4)
5090	15-20	Magnetite (Fe_3O_4)
4635mx	25-30	Maghemitite (γ– Fe_2O_3)
EP-S	30-40	Magnetite (Fe_3O_4)
4213	40-45	Maghemitite (γ– Fe_2O_3)
5012	45-50	Maghemitite (γ– Fe_2O_3)

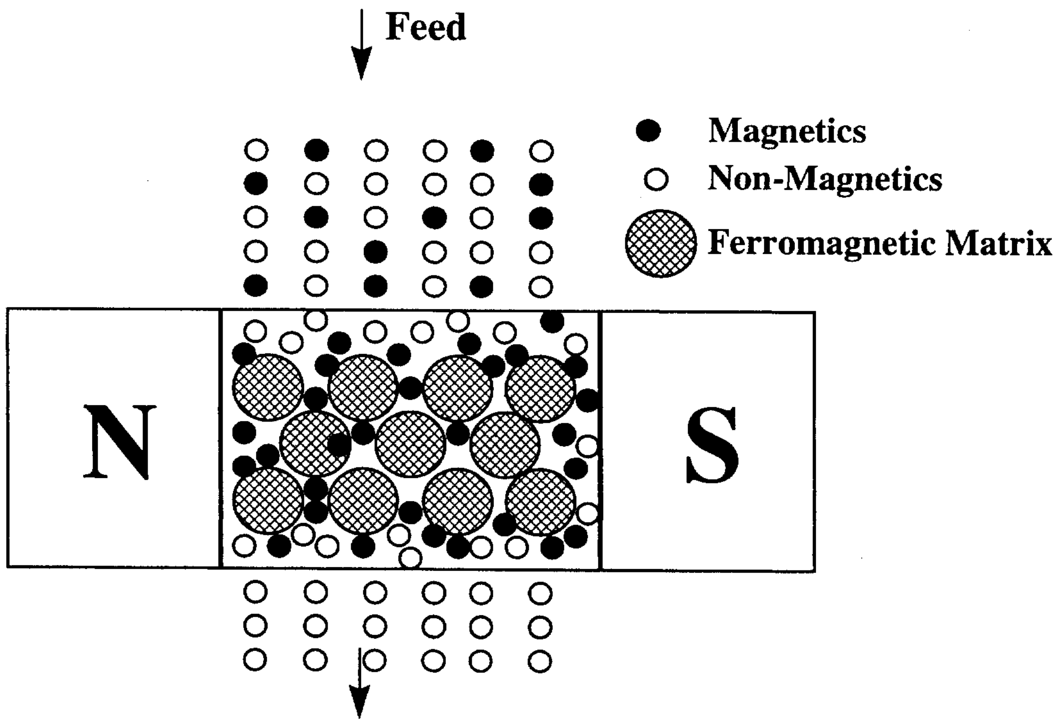

Fig. 1. The general principle of the Wet High-Intensity Magnetic Separator (WHIMS).

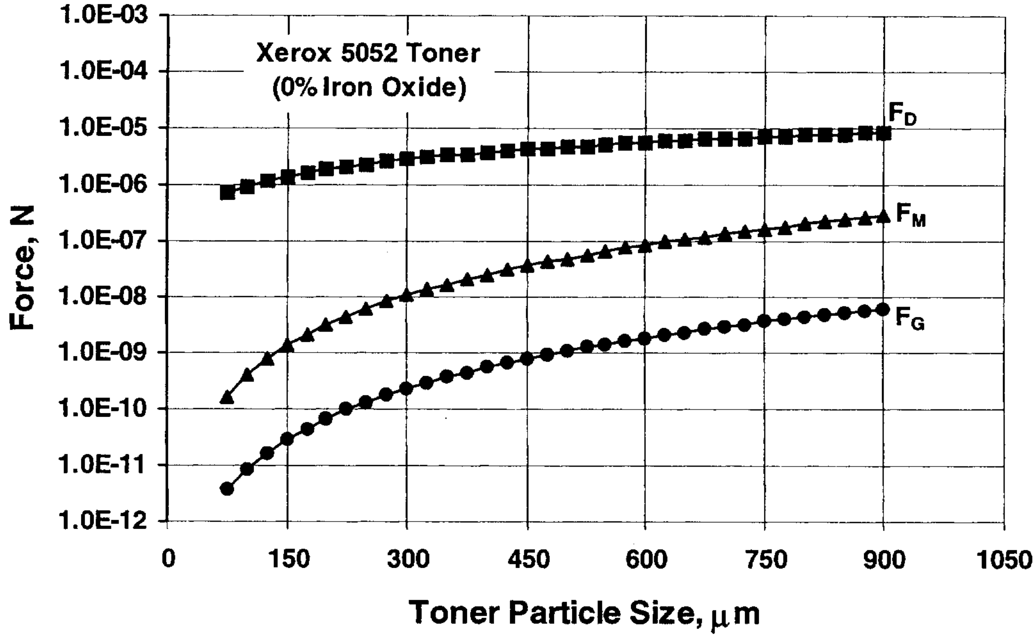

Fig. 3. Plot of magnetic force (F_M), gravitational force (F_G) and drag force (F_D) versus particle size for Xerox 5052 toner particles flowing through the steel ball matrix placed in a magnetic field of 2 T at interstitial velocity 0.1m/s.

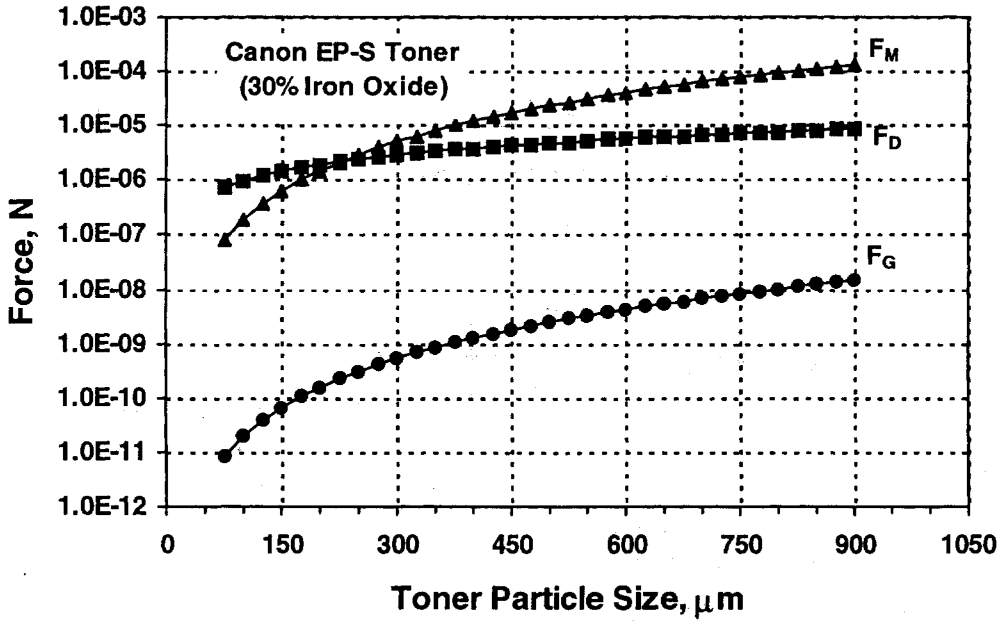

Fig. 4. Plot of magnetic force (F_M), gravitational force (F_G) and drag force (F_D) versus particle size for Canon EP-S toner particles flowing through the steel ball matrix placed in a magnetic field of 2 T at interstitial velocity 0.1m/s.

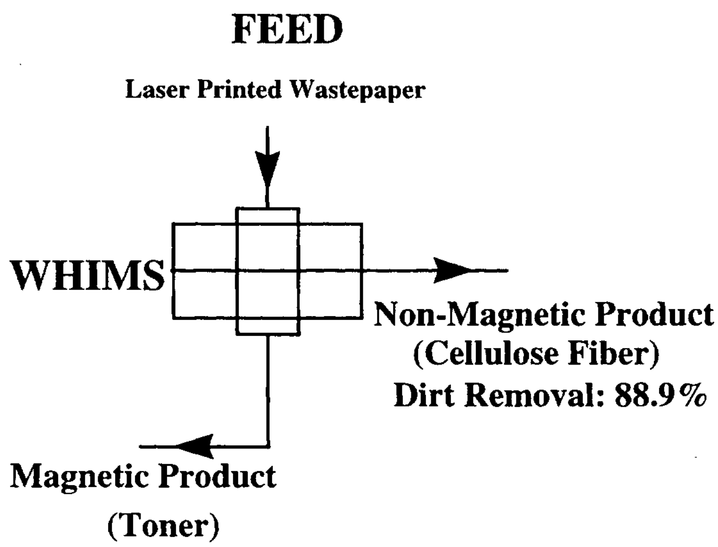

Fig. 5. Single-stage WHIMS for laser printed wastepaper flowing through the ferromagnetic matrix, (19 mm steel balls) for a magnetic field of 0.3 T.

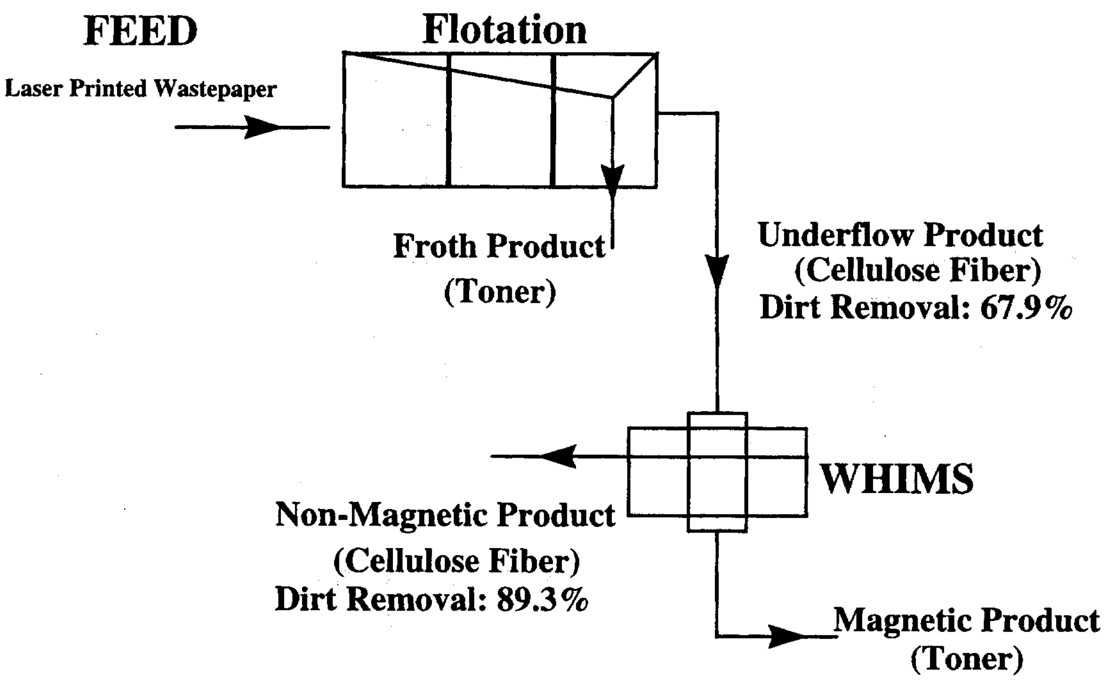

Fig. 6. Flotation of laser printed wastepaper followed by a single stage of WHIMS.

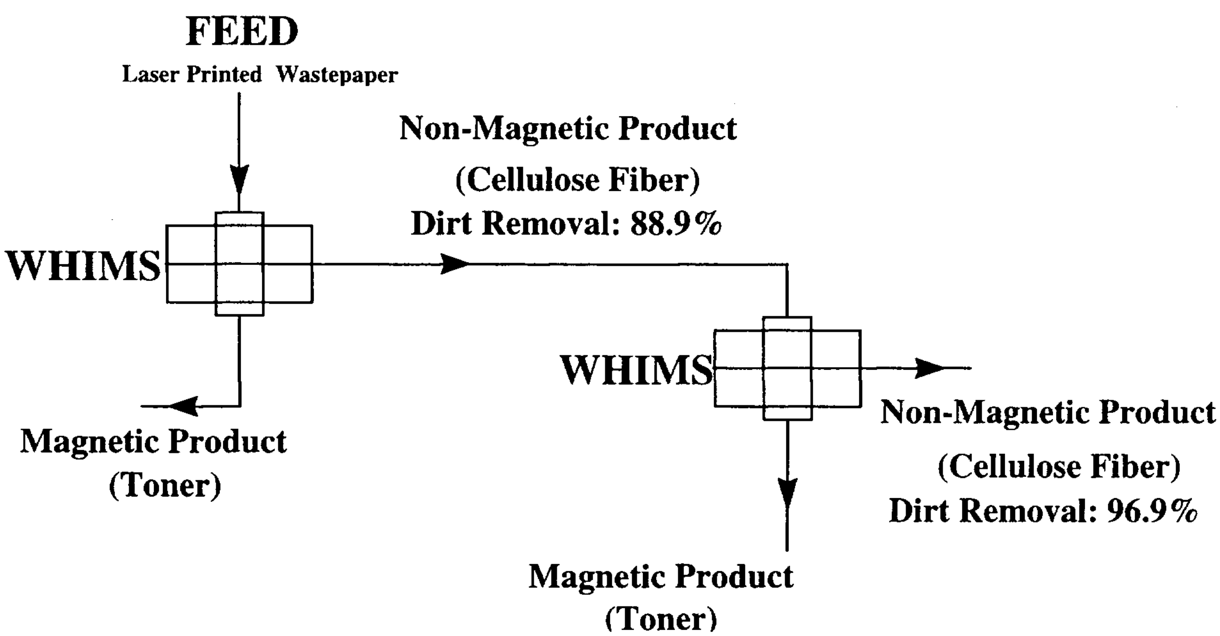

Fig. 7. Two-stage WHIMS for laser printed wastepaper flowing through the ferromagnetic matrix, (19 mm steel balls) for a magnetic filed of 0.3 T

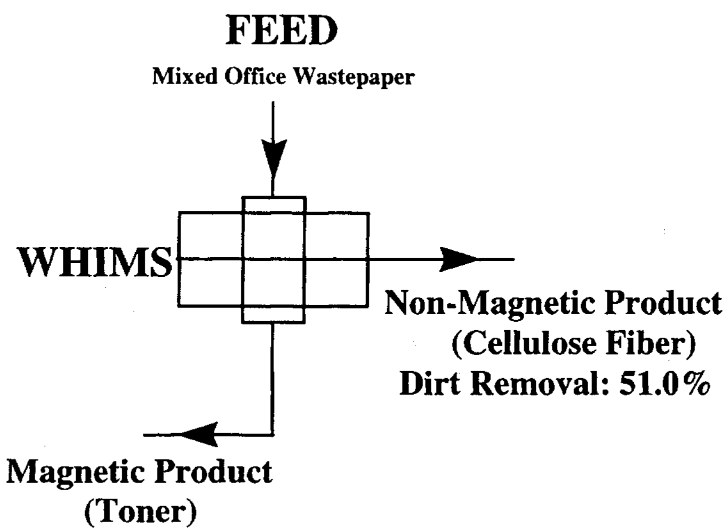

Fig. 8. Single-stage WHIMS for mixed office wastepaper (50% Laser Printer + 50% Xerox) flowing through the ferromagnetic matrix, (19 mm steel balls) for a magnetic field of 0.3 T

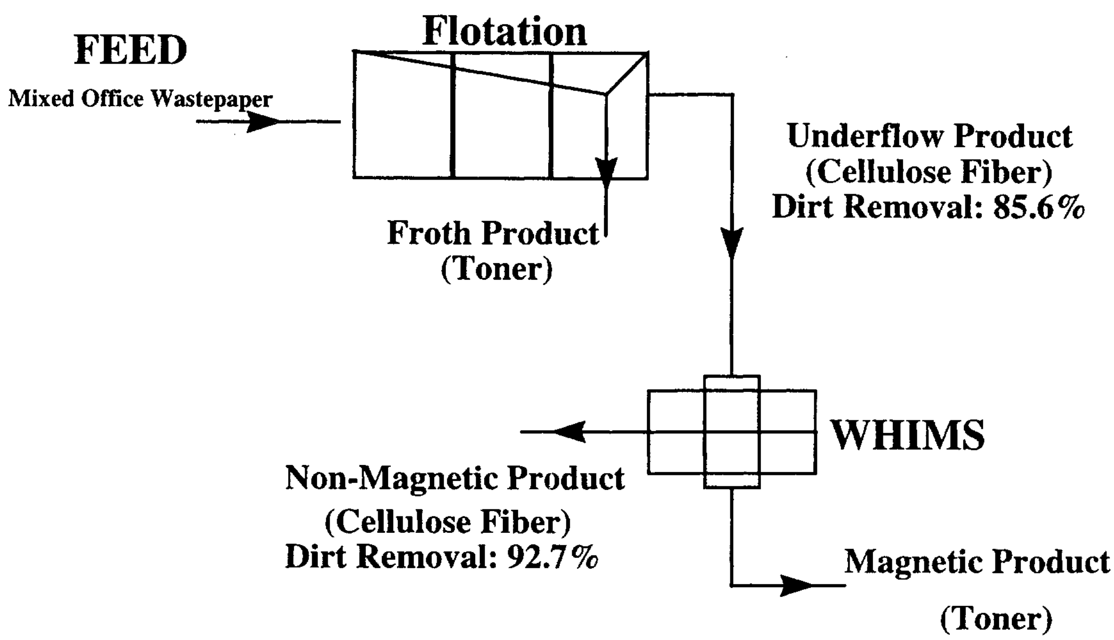

Fig. 9. Flotation of mixed office wastepaper (50% laser printer + 50% Xerox) followed by a single stage of WHIMS.

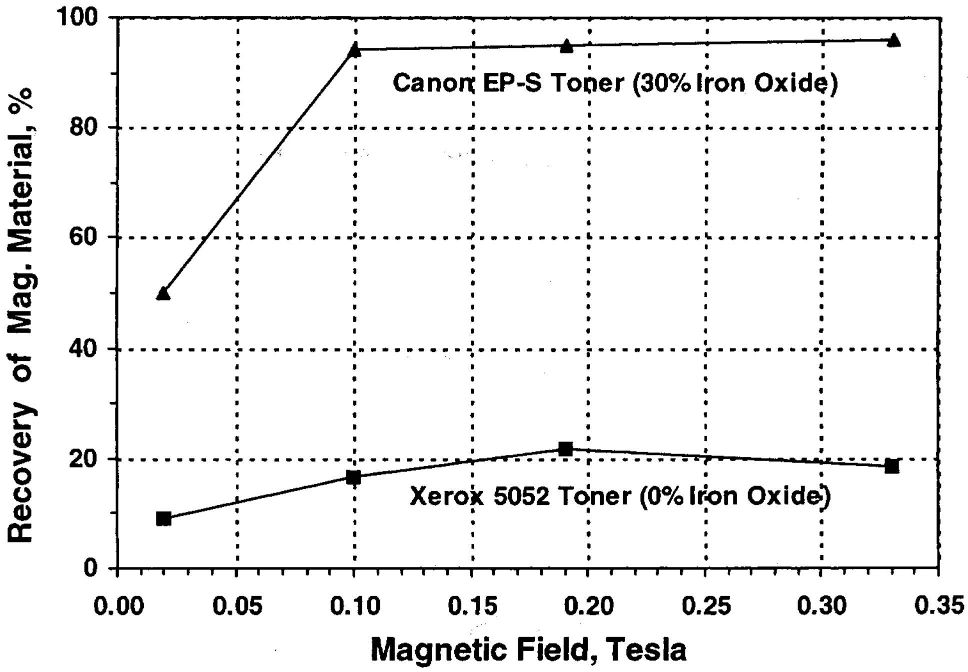

Fig 2. Separation of Xerox 5052 and Canon EP-S toners only by WHIMS. Ferromagnetic matrix of steel balls 19 mm in diameter.