Design of a De–Inking Process for Recycling Mixed Waste Paper

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1. Introduction

Paper recycling in an increasingly environmentally conscious world is gaining importance. With rapid developments in deinking processes for the reuse of secondary fibers being made, the recycling process is becoming more and more efficient. The quality of paper made from secondary fibers is approaching that of virgin paper. The process is a lot more eco-friendly than the virgin-paper-making process.

Deinking is no longer just a laboratory success story. Today it is a commercially successful industry. Numerous plants have been set up in countries like Canada, United States, Germany, Sweden, etc. Extensive research is continuing at universities and other research centers to further improve the deinking process.

The process is very chemistry-intensive and has been studied extensively. Conventional processes use chemicals that are easily available and are cheap. Newer processes use specific combinations of enzymes that can be made cheaply too. The standards attempted to be met for the quality of the deinked pulp are the same as those for virgin paper pulp.

However, there are still a few rough edges in the processes being used commercially today that need to be smoothed out. Deinking processes, though far more eco-friendly than virgin-paper-making processes usually are, still use some chemicals that are harmful when released as effluents. Sludge disposal techniques leave a lot to be desired in most commercial ventures. Due to processes generally being highly proprietary, not all industries are being run at an optimal level. Besides, some very promising results obtained at the laboratory level, if incoprated into industrial processes, could be of great benefit.

Most industrial processes are designed to handle a particular type of input waste paper. There has not been much commercial success in handling mixed furnishes of paper. This communication is an attempt to assimilate promising laboratory results obtained and technologies that are currently in industrial use to design an optimal deinking process for commercial application. The objective is to achieve an eco-friendly and effective deinking process. Special attention is paid to sludge disposal techniques and effluent treatment. The material for the basic layout of the process has been culled from the reviews of deinking chemistry by Ferguson (1992A & 1992B). Results from other studies have been referenced at the appropriate places in the text.

2. Input Stream Composition

The process is designed to handle as general an input furnish of waste paper as possible. This input furnish includes old newspapcrs, old magazines, laser-printed papers, xerographic papers, and mixed office waste paper. Most commercial processes are designed to handle only specific parts of the above furnish. Conventional processes have been found to be quite effective in deinking an input furnish consisting of old newspapers and old magazines, while enzymatic deinking schemes have found success in treating non-impact printed toner paper like laser-printed paper and xerographic paper.

3. Process Flow

The designed process follows in most parts the route of conventional deinking processes. A few important modifications are made to incorporate techniques that make the process more efficient and also to handle sludge treatment and disposal. The process flow is illustrated in Fig. 1.

The deinking process that culminates in the separation of useful pulp for paper production is a five-step proccss:

- Pulping
- Ultrasonic treatmcnt
- Flotation Deinking
- Wash Deinking
- Sludge treatment

Of these, the pulping and the flotation deinking stages are by far the most important. They are often described as the "brain" and the "heart" of the deinking process, respectively.

A. Pulping

The function of the pulper in a deinking operation is to defiber the paper and to detach the ink particles from the fibers, while keeping the contrary materials large enough to be removed by cleaners and screens at later stages. The input furnish is converted into an aqueous medium with a consistency of about 45% here. This is the ideal consistency for effective chemical action. There are two alternate routes currently in use in commercial processes. One is the conventional route which involves the use of conventional chemicals. The other is the enzymatic deinking route.

Conventional Deinking

The principal chemicals used in this process in the pulper are sodium hydroxide, hydrogen peroxide, chelating agents, sodium silicates, and other collector chemicals. A careful balance of the chemicals here is the key to an efficient process. The amount of each chemical required depends on the nature of the furnish.

Sodium hydroxide is used in the treatment of wood-containing furnishes. Its main function is to adjust the pH of the aqueous medium so that it is alkaline. The alkalinity results in the softening and swelling of the paper fibers by saponification or hydrolysis. The amount of sodium hydroxide required is determined by the degree of alkalinity required, which has to be carefully determined for each furnish. The dependence of the brightness of the treated fibers on the pH can be seen in Fig. 2. As is shown, the brightness increases with increasing pH until a pH of about 10.2. For a pH greater than 10.2, there is a decrease in brightness. This phenomenon, called "alkalidarkening", has been determined as due to the formation of chromophores in lignin. Thus, a careful balance is required in maintaining the right pH so that the fibers soften and swell up, hydrogen peroxide performance is improved, formation of chromophores is minimized and contrary materials do not soften.

Hydrogen peroxide is primarily used as a bleaching agent in the fiber treatment process. The bleaching stage comes after the fiber has been separated and washed.

However, hydrogen peroxide serves a very important function in the pulping stage too. Here its bleaching action is used to offset alkali darkening that occurs due to the use of sodium hydroxide. The bleaching action of hydrogen peroxide is due to the formation of the perhydroxyl ion (HOO–) in an alkaline environment. The higher the degree of alkalinity, the greater the concentration of perhydroxyl ions formed. The effect of hydrogen peroxide on brightness is shown in Fig. 3. However, hydrogen peroxide is very sensitive to its environment. The presence of heavy metal ions such as those of copper, manganese, iron, etc., that are commonly found in inks, and enzymes such as camlase cause decomposition of the peroxide. These contribute to loss of brightness in the pulp. In order to stabilize the environment in which hydrogen peroxide works, various chemicals like chelating agents and sodium silicate are used. They act by forming soluble complexes with the metal ions which can then be washed away. Commonly used chelating agents include diethylenetriaminepentaacetic acid (DTPA) and ethylenediaminetetracetic acid (EDTA), with the former used more than the latter.

However, the biggest problem with using these chelating agents is that, when disposed off in the effluent stream of the process, they can be harmful to the environment. They can cause heavy-metal poisoning in rivers, streams, etc., and severely affect aquatic life. Hence, their usc should be avoided as far as possible.

The alternative is to use sodium silicate. Sodium silicate functions in much the same way as chelating agents. It also has the added advantage of acting as a buffering agent to maintain the pH of the pulp. However, it has its own problems of stability, and causes fouling of equipment, coating of fibers, harshness of paper, etc., due to the formation of silicates. Efforts are on to find a stabilizer for it and there is evidence available to suggest that a polymeric stabilizer would be effective.

Enzymatic Deinking

Enzyme-enhanced processes have been shown to have tremendous potential for application in deinking paper. They axe beginning to find acceptance as a viable alternative to conventional chemical processes at the industrial level. They have proven to be as cost-effective and more efficient in deinking than conventional processes. Most business concerns keep their enzyme combinations highly proprietary and finding information on the exact combination of enzymes used is difficult. However, information on some patented processes is available. Two of them axe presented now as examples.

The process patented by Wood (U.S. Patent # 4,666,558) is a three —— process step for deinking newsprint. Thc first step involves converting the newsprint to a pulp. In the second stage the pulp in an aqueous medium containing a deinking agent is agitated. The deinking agent comprises a mixture of (i) a water soluble C, to C_{16} alkanol ethoxylate component having an average of about 6.5 to 20 oxyethylene units per ethoxylate molecule, and (ii) an oil-soluble C, to C_{16} alkanol ethoxylate component having an average of about 0.5 to 3.5 oxyethylene units per ethoxylate molecule. The mixture contains the two components, (i) and (ii), in a relative weight ratio in the range 2:1 to 1:3, and is present in the aqueous dum in an amount between 0.1 to 0.5% by weight of oven dry pulp. The final stage involves recovering deinked pulp from the aqueous medium.

The process patented by Baret (US Patent # 5,364,501) involves a pH shift and addition of alkaline cellulase. The process requires pulping the papcr to a high consistency at a high pH first. Then alkaline cellulase is added and allowed to act during continued pulping and/or maccration. Besides resulting in better brightness of treated pulp, the cellulase treatment facilitates better operation of other equipment such as thickeners and better drainage of the pulp during paper making.

<u>B. Ultrasonic Chamber</u>

The use of ultrasound in this process to improve the efficiency of the deinking process is a novel idea and has not yet found acceptance in the industrial world. The study by Norman *et al.* (1994) however showed very promising results when used as a polishing step in the deinking process for mixed post-consumer wastes. It is most effective in handling laser printed and xerographic waste paper.

The action of ultrasound is to loosen the large toner particles from the fibers and break them up into smaller particles. The fraction of particles reduced in size can be considered as a measure of the efficiency of the process. The benefit of this reduction in size is seen in the later stages of flotation deinking and wash deinking.

The process involves moving the pulp from the pulper to the ultrasonic chamber. Here, the consistency of the pulp is lowed to about 0.5-1%. Experimental results show that, for higher consistencies, the effectiveness of ultrasound decreases very rapidly. The chamber is next irradiated with ultrasound. An operation time of about 10 minutes has been found to be ideal for this process as seen in Fig. 4. The frequency used is in the 22 Khz to 54 Khz range, with greater efficiency being associated with higher frequency, as illustrated in Fig.5, and correspondingly higher electricity costs. A balance between the two, frequency of operation and energy consumed, has to be reached based on the nature of the input furnish. Another advantage of this process over conventional processes is that it eliminates the need for use of toxic surfactanta in the pulper, thus aiding to create a more eco-friendly process.

The "heart" of the deinking process involves the use of a flotation cell to remove the ink that has been released from the fiber during the pulper and ultrasonic chamber stages. collector chemicals are added to the pulp either at the pulper or just before the flotation cells. Non-toxic, naturally occurring collector chemicals can be used in this process. These are mainly fatty acid soaps. The collector chemicals are designed to bring together the freed ink particles such that they can be removed by air bubbles. The ideal size of particles that can be removed in this stage is in the range 10-100 μm diameter. For ink removal to occur, the ink particles must come into contact with the collector chemicals which, in turn, must come into contact with the air bubbles so that the ink agglomerates can be removed, as is illustrated in Fig. 6. The injectors and mixing section have to be carefully designed to maximize turbulence and the random collisions of all three components. It is crucial that the bubbles have sufficient surface tension strength to carry the ink through the flotation cell to the surfax, and yet still break once the bubble reaches the weir.

The fatty acid soap added is a sodium soap and needs to be converted to a calcium soap before it can be effective. The source of the calcium is usually the furnish itself since it contains calcium carbonate used as fillers and coatings. If needed, calcium can be added by adding calcium chloride to the flotation cells. The microprecipitates that the calcium soap forms with water associate with the ink particle and the air bubble and all thee get carried to the surface where they are removed. However, with the increased level of calcium in the medium, the problem of fouling and scaling of equipment arises. This is taken care of by adding talc (Keselica 1993).

To further improve the efficiency of this process, displectors and surfactants are used. Displectors are a combination of dispersants and collectors. They are synthetic liquids that are often blends of many components. When combined with fatty acid soaps, they effect an increase in brightness of the pulp. An added advantage is that they reduce the possibility of fouling and scaling of equipment.

Another feature that improves the efficiency of the functioning of the flotation cell is bubbling carbon dioxide through the flotation cell rather than use air or oxygen (Marchildon 1993). The resulting increase in brightness and luminosity and decrease in yellowing of the pulp is attributed to the acidity induced in the pulp by the carbon dioxide. There, however, is a detrimental effect in that the strength of the pulp fibers is reduced. This situation is remedied by incorporating an alkaline wash stage after flotation.

The wash deinking process is the final stage in the deinking of fibers. Dispersant chemicals such as blends of Eo/Po copolymers and glycols, and fatty alcohol ethoxylates are used. Their function is to take the ink and dirt particles that have been freed during the pulping and ultrasonic chamber stages and keep them in suspension so that they can be removed while washing and thickening. The objective is to keep the particles small enough so that they can be moved through screens and hydrophilic enough so that they drain easily. Thus the dispersant combines the features of wetting, emulsification and dispersion. Particles of sizes less than 10 μm are removed in this stage. The mesh sizes are kept small enough so that fiber losses are minimized.

The wash deinking process is illustrated in Fig. 7. The more the stages of washing and screening, the better the efficiency of the process. But again, the trade-off is in processing time. The optimal number of wash stages depends on the quality of the initial furnish.

After the wash deinking stages, the pulp is filmed off and passed through screw extractors to remove as much water as possible before being sent off to the bleacher, storage tank or the papermill.

E. Sludge Treatment

Sludge treatment has so far been one of the blind spots in the deinking industry. There have been several studies performed to find ways to treat and dispose the sludge. Options include composting the sludge with forced aeration and letting the cellulosic fraction degrade (Brouillette 1996), bioconversion of the cellulosic fraction of the sludge to ethanol which is then used as fuel (Borchardt 1993), or incineration of the sludge in a fluidized bed combustor.

The process chosen here is based on the one proposed by Dorica & Simandl (1995). This process is used to remove suspended solids from spent deinking liquor and then recycle the fiber content of the solids. The filmed liquid is either recycled in the plant or is treated for the presence of effluents before being released (see Fig. 1).

The objective of the solid treatment process is to recover as much of the fiber content of the solids as possible and to free the fiber of the attached clay and ash, as seen in

Fig. 8a. The process involves a modified flotation process that has a quiescent stage in the flotation cell followed by screening of the collected fiber to reduce the ash content. The fiber is then either sent through this process again or is sent to the pulper. Centrifugation of the underflow from the modified flotation cell follows and the resulting centrifugation cake is landfilled. The ash content of the fibers can be reduced to as low as 6% by this process (see Fig. 8b).

Incorporaton of this stage goes a long way in increasing the eco-friendliness of the process since it carries recycling to the maximum possible limit and at the same time reduces the release of harmful effluents. The overall efficiency of the deinking process can be increased by 13-27% by this technique.

4. Conclusion

The deinking process detailed above is an attempt to incoprate promising results at the laboratory stage into existing conventional processes in order to achieve an eco-friendly and efficient deinking process. The work is subject to the limitations of a paper-design and hence may not be practical in every respect. However, it does provide food for thought towards redesigning the process for green engineering.

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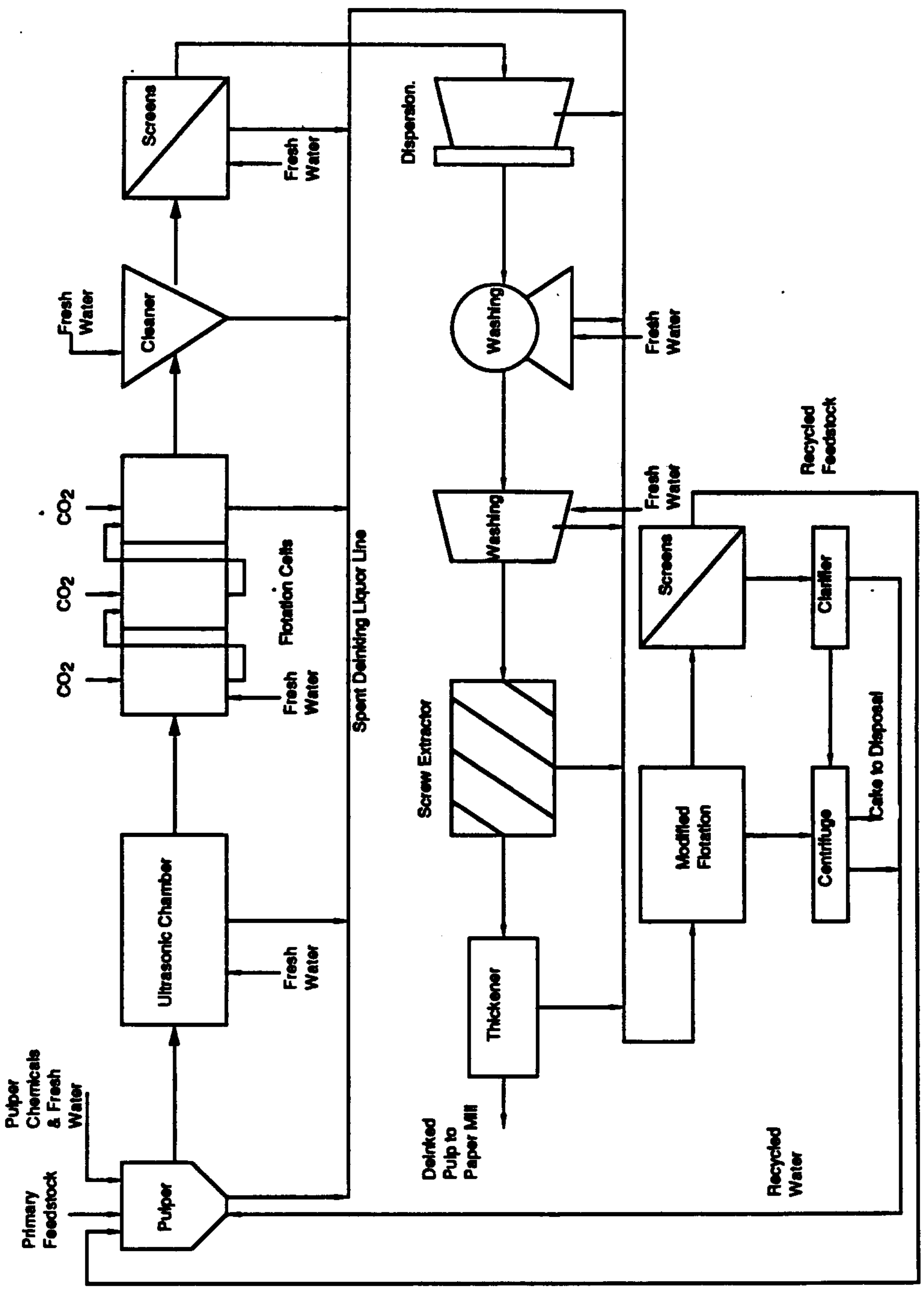

Fig. 1 Process Flow Chart

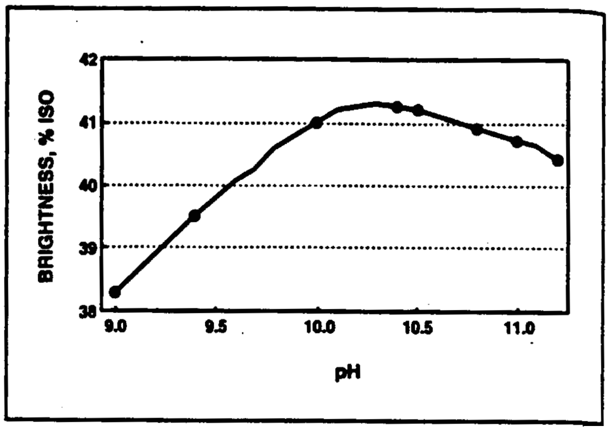

Fig. 2 Effect of pH on Brightness

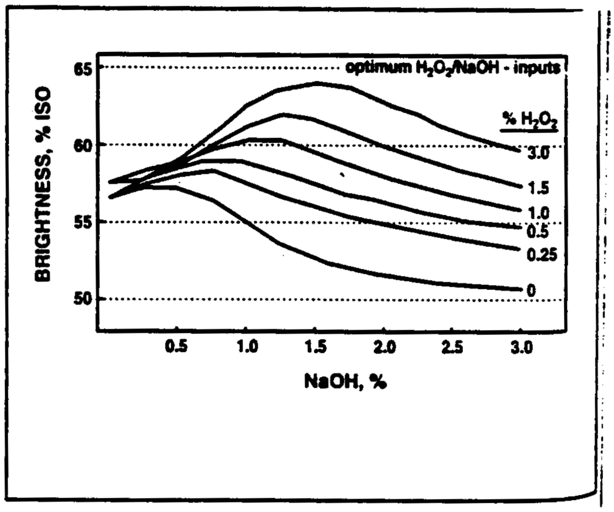

Fig. 3 Effect of Caustic Soda & Peroxide on Brightness

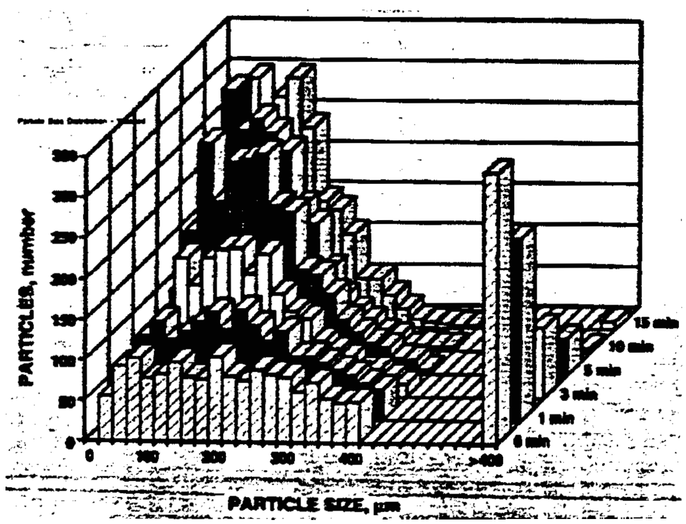

Fig. 4 Particle Distribution - Process Time: for ultrasonic treatment

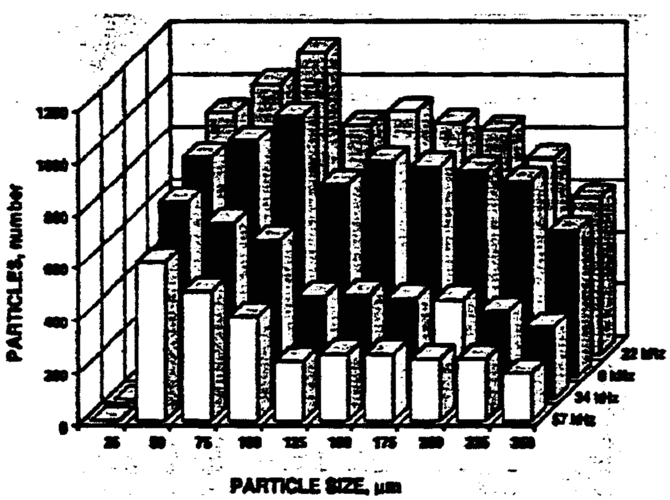

Fig. 5 Particle Distribution - Washed: for ultrasonic treatment

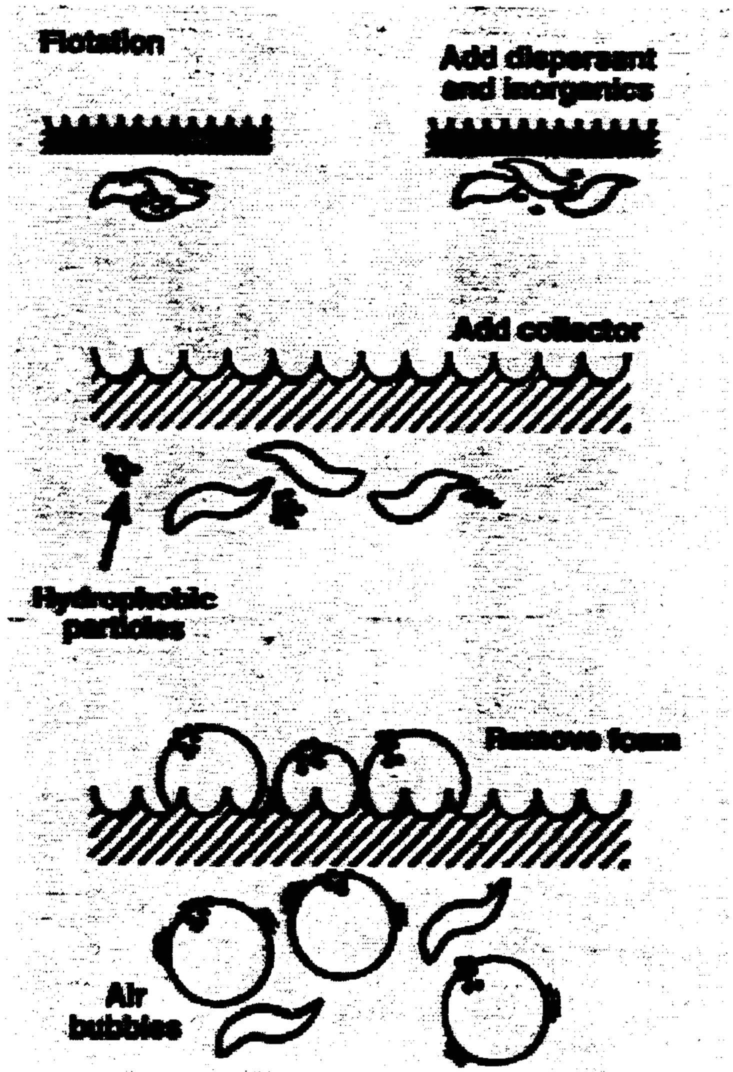

Fig. 6 Flotation Deinking

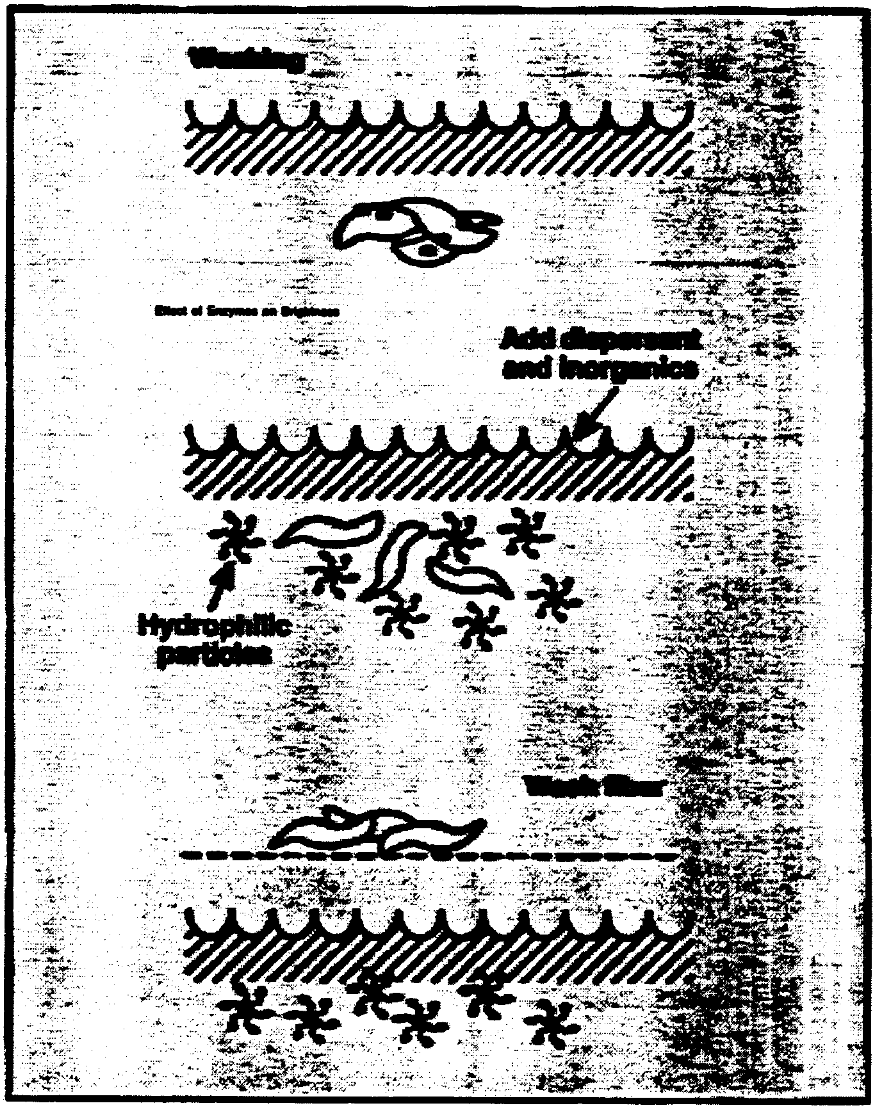

Fig. 7 Wash Deinking

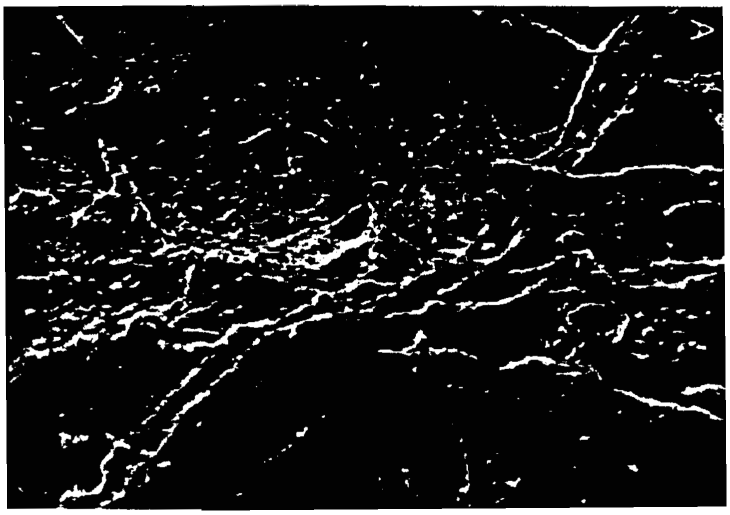

Fig. 8a Fibers before washing

Fig. 8b Fibers after 5 washes