

## ABSTRACT

*Investigation of a closed cycle deinking facility showed that modification of the deinking process was necessary to minimize water and chemical usage. Changes to the effluent treatment system reduced total suspended solids and total dissolved solids. This allowed returning the effluent to the process as makeup water. Thermal oxidation destroyed solid wastes before fixation for disposal. The paper presents estimates for total investment costs and operating and maintenance costs.*

**Application:**

*It is possible to design a closed cycle deinking facility, although the costs are high.*

**T**HE CONCEPT OF A CLOSED cycle deinking facility is not new. In the past, however, both technology and costs made such technology impractical. Designing a closed cycle deinking facility does not allow any compromise in final product quality. This means maintaining the water quality for each process module. Treating both internal and external (effluent) streams and mixing these streams together achieves this water quality.

Raytheon Engineers & Constructors, Rust Div., started exploring the practicality of such a design several years ago. A client wanted to build a facility using the effluent for farm irrigation. Two years ago, Rust's Environmental Group extended that work<sup>1</sup> when the National Council for Air and Stream Improvement (NCASI) asked it to develop capital cost estimates. This work was preparation for the U.S. Environmental Protection Agency (EPA) issuance of the new Clean Water Act regulations and the Great Lakes Initiative.

## Cost implications for a closed cycle deinking facility

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The studies involved creating process flow diagrams and models; maximizing water recycling within the deinking process; and making predictions for total suspended solids (TSS), biochemical oxygen demand (BOD<sub>5</sub>), total dissolved solids (TDS), and pH. Information generated was shared with industry experts. There were six different deinking processes investigated. Some were combinations of floatation and washing while others were washing only.

This paper will discuss the combined systems. All the concepts are feasible. By applying all or part of the processes, it is possible to reduce greatly or eliminate process effluent from recycling facilities.

One must remember two factors:

- The facility is closed cycle not zero discharge. Even with elimination of the discharge of process effluent, there will still be discharges of sanitary wastes, short paper fibers (rejects and material commonly called sludge), and water vapor.
- Although the EPA did not specify in the draft cluster rules<sup>2</sup> that deinking facilities had to be zero discharge, it did specify in Subpart J of the Secondary Fiber Nondeinking Subcategory, Section 430.105, Paragraph a, that any new source used in the production of paperboard, etc., shall not discharge waste water to any waters in the United States.

## RECYCLING PROCESSES

Recovered paper recycling facilities have systems for repulping, trash removal, screening, and cleaning. Figure 1 shows a process designed to recycle old corrugated containers (OCC). Figure 2 depicts a deinking process to recycle a mixture of old newspapers (ONP) and old magazines (OMG). Figure 3 shows a deinking system designed to process mixed office waste (MOW). The differences in these systems are the feed furnish, additional processes such as washing and floatation, and the chemistry required to produce the final quality measured by brightness and dirt.

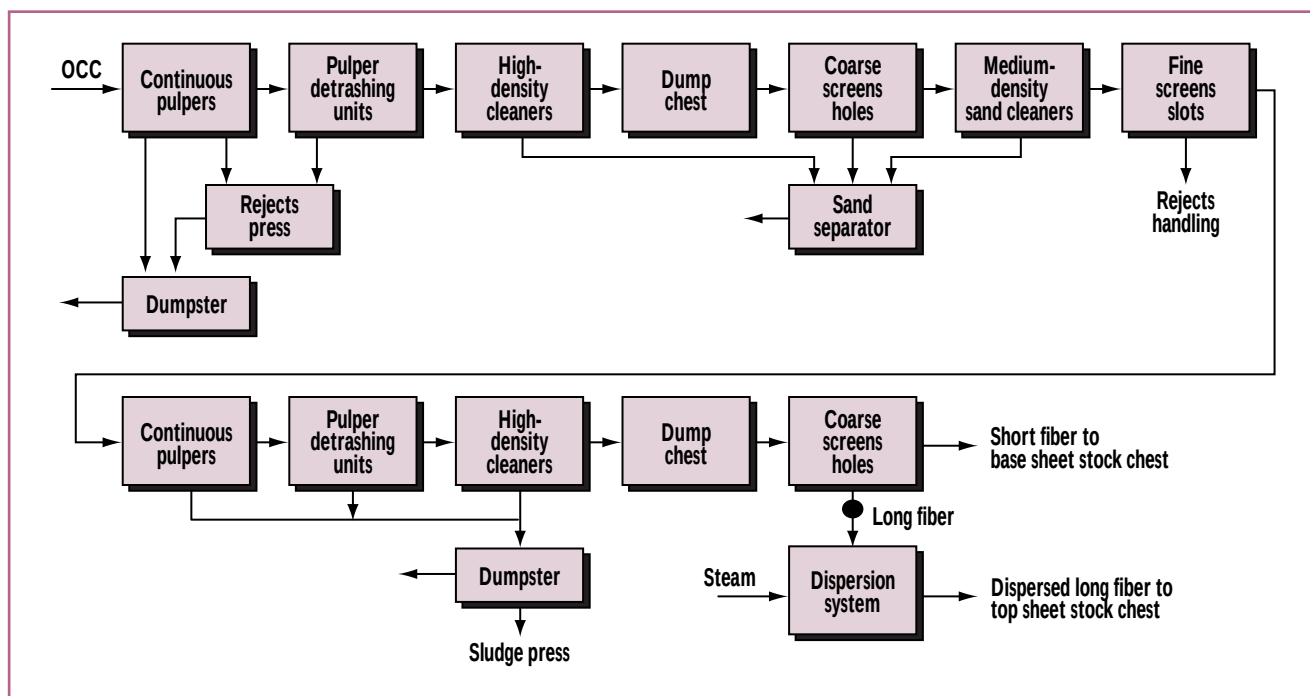
OCC systems are the easiest to achieve closed cycle. Unless designed to use quantities of wet-strength paper, such systems require no use of caustic soda and minimal use of other chemicals such as biocides and flocculants.

The deinking systems require extensive use of chemicals to ensure efficient ink removal in the washing stages and floatation cells. In addition, it is necessary to bleach the recycle fiber to achieve the desired brightness. Table I lists the chemicals used.

Sodium containing chemicals are integral components of the deinking process. They adjust pH to 9.5–11.0, saponify or hydrolyze the ink resins, disperse the inks, decolorize the chromospheres, and bleach the product. If sodium ion accumulates in a closed system, the system will become highly corrosive. If the effluent contains high amounts of sodium ion, it will not be suitable for farm irrigation. Excessive sodium would

<sup>1</sup>Bader, T., Hodge, G., and Shih, T.-H., NCASI Central Lakes Regional Meeting, NCASI, New York, 1993.

<sup>2</sup>Anon., *Federal Register*, 40 CFR parts 63 and 30, U.S. Government Printing Office, Washington, 1993.



1. OCC recycling

cause salt accumulation in land. The ion would also react with clays to deter water penetration.

A sodium absorption ratio (SAR) of less than 3 is necessary when using an effluent for farm irrigation. The following equation is a definition of SAR:

$$\text{SAR} = [\text{Na}^+]/([\text{Ca}^{+2} + \text{Mg}^{+2}]^{1/2})$$

In the equation, the bracketed values are in mmoles/L. This is the concentration in mg/L divided by the atomic weight shown as follows:

$$[\text{Na}^+] = \text{mg/L of Na}^+ / 22.9 = \text{mmoles/L}$$

#### Chemical alternatives for sodium

A Mexican mill uses ammonium hydroxide to achieve the required alkalinity. This is not a suitable alternative, however, because of the potential for the formation of amine color bodies, the requirement to scrub the vents from the pulping or

bleaching operation, and the possible waste treatment problems.

DuPont has developed a patented bleaching process using calcium hydroxide and magnesium hydroxide. It is not in commercial use, however.

Diethylenetriamine penta (methylenephosphoric acid) (DTPMPA) is a nonsodium peroxide bleach stabilizer. Its high cost and lack of extensive use eliminated it from consideration.

Formamidine sulfinic acid (FAS) is a reductive bleaching substitute for sodium hydrosulfite that is even more effective. Although it still requires an alkaline system, it does reduce the amount of sodium. It therefore has use for bleaching purposes.

#### Other process considerations

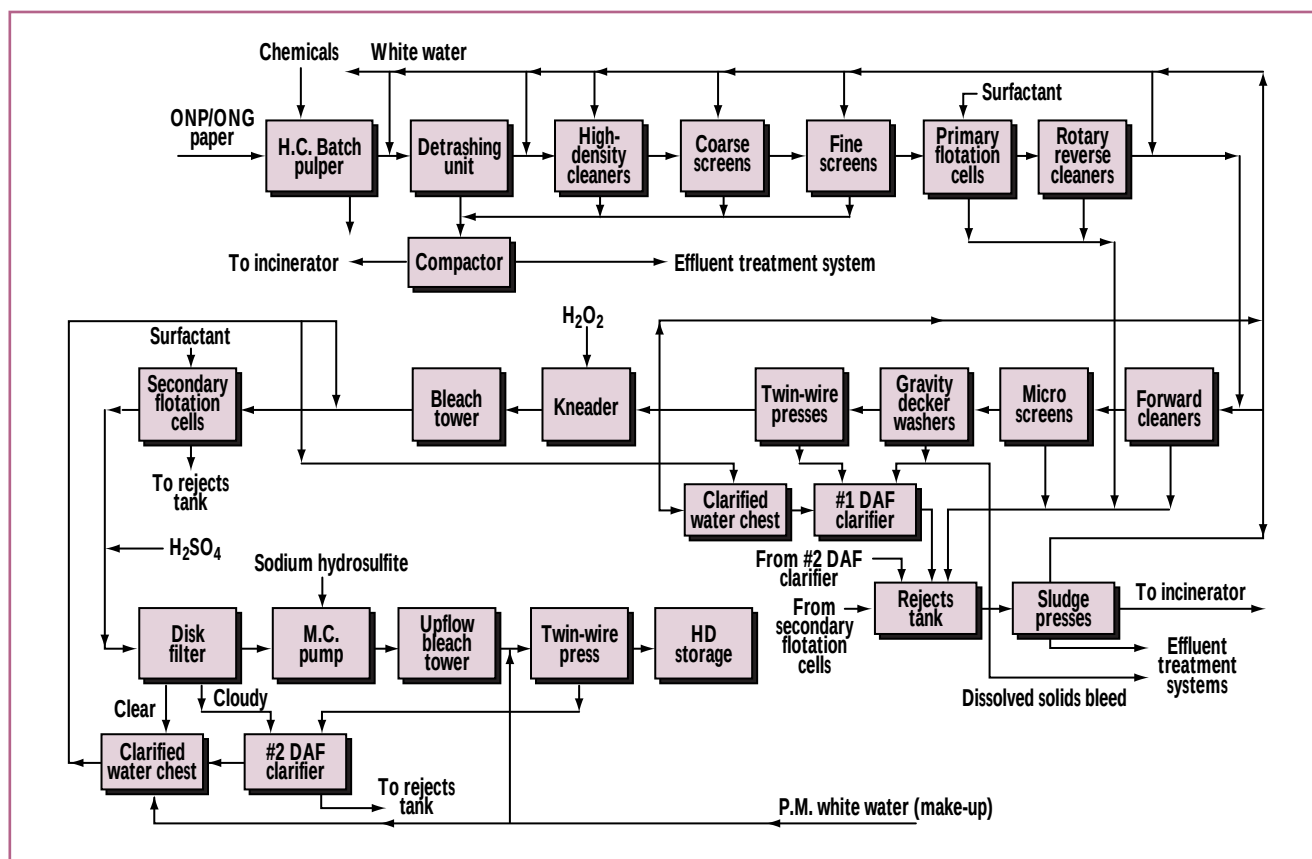
Any closed cycle deinking facility requires extensive treatment of effluents to reuse them within the deinking process. These flow based systems are expensive. Minimizing cost therefore requires the least flow. A

method used in process designs is the installation of twin-wire—or equivalent—presses between water loops. These presses achieve consistencies above 25%. This minimizes chemical carryover and water usage.

#### WASTE TREATMENT PROCESSES

The detraging unit, high-density cleaners, and initial screening systems remove major contaminants or rejects from the recycling process. These rejects go to a compactor for dewatering and disposal. Incineration of solid materials reduces the volume before disposal in a landfill. The effluent system processes water removed by the compactor.

Dissolved air floatation (DAF) clarifiers in the water loops minimize accumulation of solids and contaminants. Contaminants removed from the later cleaning and screening systems, flotation cells, and DAF collect in a rejects tank. The rejects undergo dewatering in a press. The solids are incinerated. The water is



2. Newsprint deinking

processed for reuse in the effluent system.

Consider now the various processes of the effluent system shown in Fig. 4.

#### Bar screen

The deinking effluent in a basin goes through a bar screen to remove large debris. Mixed with polymer to improve settling, the water then proceeds to the primary clarifier.

#### Primary clarifier

The reactor-type clarifier promotes flocculation of TSS that soon settle to the bottom. The settled material goes to a press for dewatering and disposal. The overflow goes to secondary or biological treatment.

#### Secondary treatment

Nutrients, anhydrous ammonia, and phosphoric acid, are added before treating the effluent biologically in sequencing batch reactors (SBR).

SBR are activated sludge systems that combine aeration and settling.

The SBR process operates on a fill and draw principle. It normally follows the basic steps of fill, react, settle, and decant. The cycle time varies with the quality of effluent desired. Treated effluent typically has 30 mg/L of TSS and BOD<sub>5</sub>. Clarified water goes to the multimedia filters. Excess sludge goes to a press for dewatering.

#### Multimedia filters

Pressure-type multimedia filters reduce TSS to 1–3 mg/L. Approximately 55% of the filtered water returns to the deinking process without further treatment. The remaining effluent undergoes further processing to control the accumulation of (TDS). This portion goes to the micro filters.

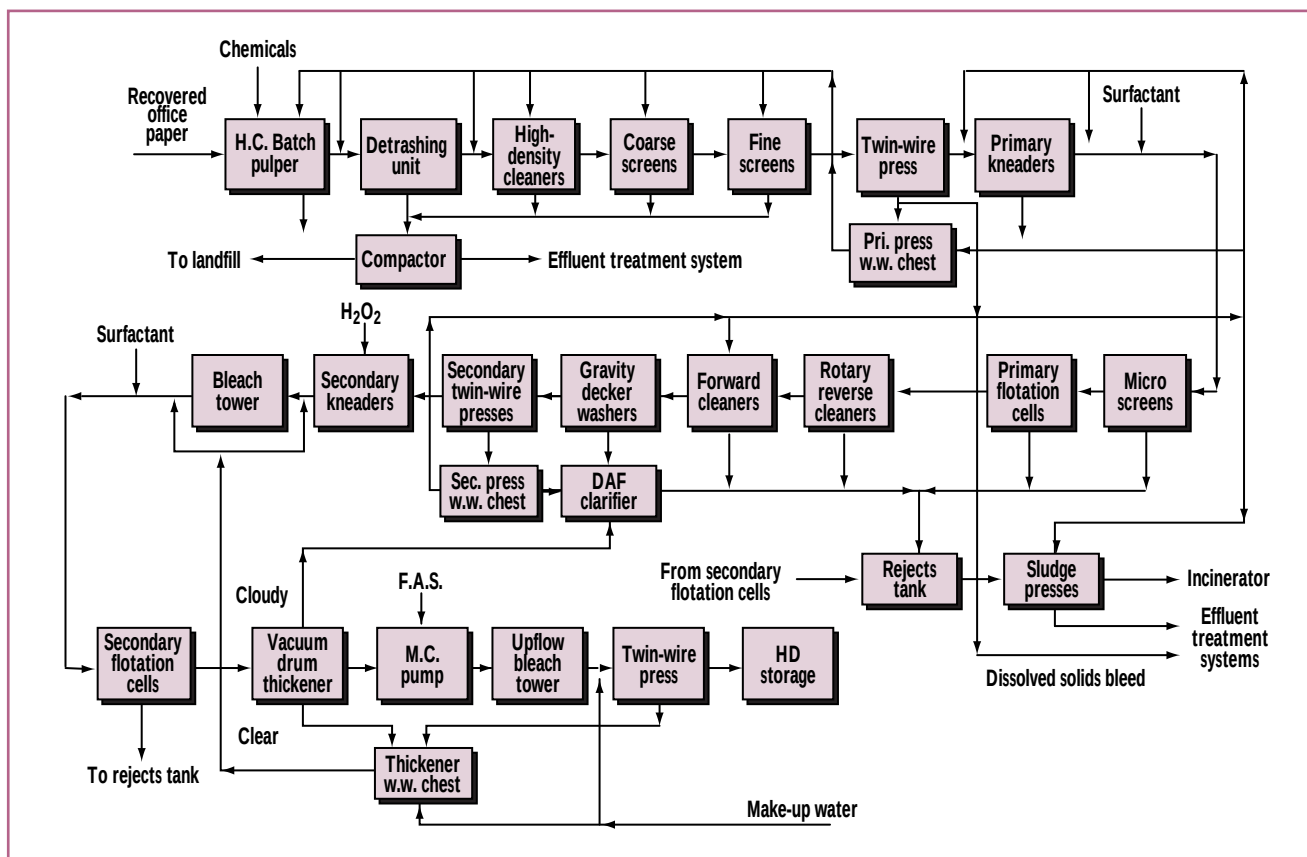
#### Micro filters

Micro filters further reduce the TSS to below 1 mg/L before processing by reverse osmosis (RO).

#### Reverse osmosis

The purpose of RO is to remove and separate TDS from the water. Water from the micro filters is pumped through the RO membrane at approximately 400–450 psi. The membranes are the “desalination type” and provide approximately 80% sodium and 85% TDS removal. The filtered water then returns to the deinking process. Volume of the recycled stream is 20–25% of the feed. The concentrated rejected material or brine is collected and sent to an evaporator for concentrating.

Although pulp and paper applications have used ultrafiltration, it is not a satisfactory alternative to RO. It



3. Fine paper deinking

Sodium hydroxide  
Sodium silicate  
Chelating agents  
Hydrogen peroxide  
Surfactants  
Collectors  
Agglomeration agents

Calcium chloride  
Dispersants  
Sodium hypochlorite  
Sodium hydrosulfite  
Formamidine sulfinic acid  
Contaminant controls  
Clarification polymers

#### 1. Chemicals used in deinking systems

does not remove appreciable quantities of sodium or chloride ions.

##### Evaporator

The TDS rejected by the RO are concentrated from 2% to 75% by evaporation. This equipment is similar to that used at one Canadian mill. The volume of low-pressure steam is approximately twice the amount of rejects being concentrated. Heat exchanging condenses the vapor for return to the deinking process. The

TDS produced undergo further treatment in a crystallizer.

##### Crystallizer

Although it would be possible to recover the chemicals, their low economic values dictate fixation and disposal in a landfill. It typically takes one ton of cement to fixate 8 tons of ash.

##### Clean water storage

An integral part of any closed cycle facility is the need for adequate water storage. This allows stable

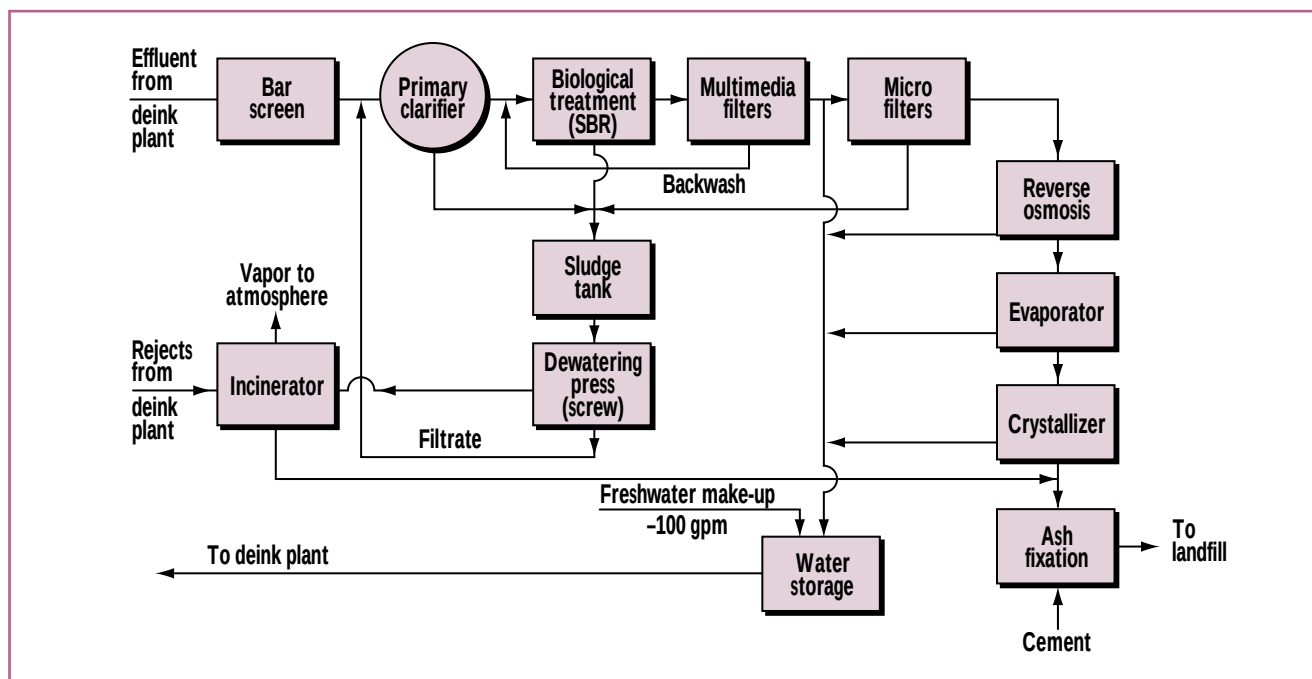
operations during periods of high water that occurs during startup and upset conditions.

##### Sludge press

Rejects from the primary clarifier, SBR, and filters are collected and then dewatered in a screw press. The filtrate returns to the primary clarifier. The solids—typically about 30% consistency—are mixed with the burnable rejects from the deinking process and conveyed to an incinerator for disposal.

##### Incinerator

Disposal of the rejects and sludges is by burning in an incinerator or thermal oxidizer. A simple incinerator is adequate. Sludge goes into the top of the combustion chamber. Preheated air is supplied to the bottom of the unit. Natural gas burners supply the heat for incineration startup and maintaining operating temperature.



4. Closed cycle wastewater treatment system for 300 tons/day fine paper deinking plant

Gas use is minimal during operation. After preheating the incoming combustion air, flue gas is scrubbed to remove  $\text{SO}_x$  and other emissions. A bag house follows the scrubber to control fly ash. Disposal of the fly ash and bottom ash is in a landfill.

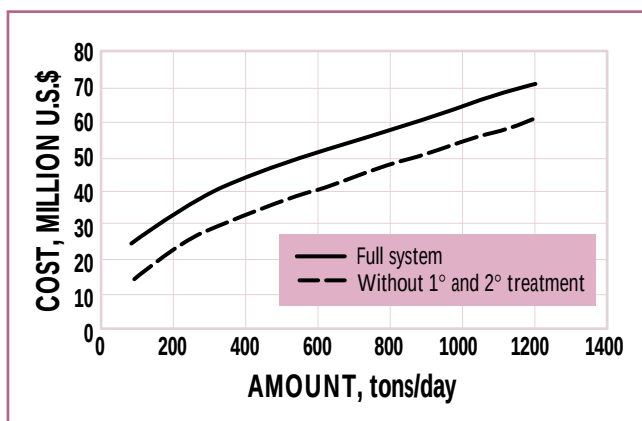
An alternate solid waste disposal technique is destructive distillation. Destructive distillation of sludge involves reducing sludge to its component gases and char residue by the indirect application of heat without oxygen. It is a process similar to the distillation of coal to produce coke. Excess heat from the distillator dries the incoming sludge. The 200–300 Btu/ft<sup>3</sup> gas produced is burned in a boiler to produce steam. Since it is partially activated carbon, the char has a variety of uses. Distillation units come in modules of 25–35 o.d. tons per day of solid waste. Capital cost is approximately US\$ 90,000–110,000 per o.d. ton processed.

| Area description                | FINE PAPER |     | TISSUE |     | NEWSPRINT |     |
|---------------------------------|------------|-----|--------|-----|-----------|-----|
|                                 | TIC        | (%) | TIC    | (%) | TIC       | (%) |
| Primary treatment               | \$6.8      | 17  | \$7.3  | 17  | \$7.0     | 18  |
| Secondary treatment             | 5.3        | 13  | 5.5    | 13  | 5.3       | 14  |
| Filtration                      | 1.7        | 4   | 1.7    | 4   | 1.7       | 4   |
| Reverse osmosis                 | 3.6        | 9   | 3.6    | 9   | 3.6       | 9   |
| Evaporation and crystallization | 7.2        | 18  | 7.4    | 18  | 7.3       | 19  |
| Clean water storage             | 1.5        | 4   | 1.5    | 4   | 1.5       | 4   |
| Sludge dewatering               | 4.8        | 12  | 4.8    | 11  | 4.6       | 12  |
| Incineration and ash fixation   | 9.2        | 23  | 10.0   | 24  | 7.5       | 19  |
| Total                           | 40.1       | 100 | 41.8   | 100 | 38.5      | 99  |

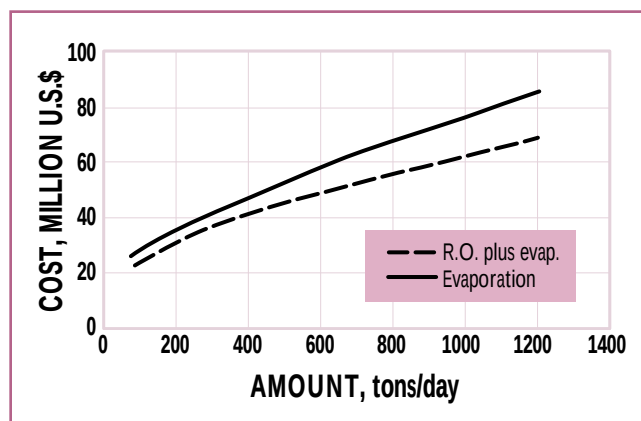
II. Total installed cost estimates in millions of US\$ for waste water treatment for 300 tons/day closed cycle deinking facilities

| Area                  | Cost/day | Cost/ton | Total % |
|-----------------------|----------|----------|---------|
| Personnel             | 1,007    | 3.36     | 11      |
| Materials             | 1,451    | 4.84     | 16      |
| Electricity           | 3,276    | 10.92    | 35      |
| Water                 | <1       | nil      | <1      |
| Minor maintenance     | 33       | 0.11     | <1      |
| Major maintenance     | 930      | 3.10     | 10      |
| Laboratory            | 20       | 0.07     | <1      |
| Landfill and fixation | 2,516    | 8.39     | 27      |
| Total                 | 9,234    | 30.78    | 100     |

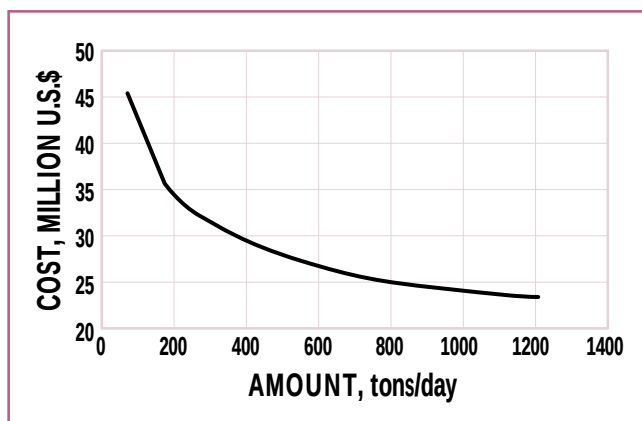
III. Estimated increased operating and maintenance costs in US\$ for 300 tons/day fine paper closed cycle deinking facility



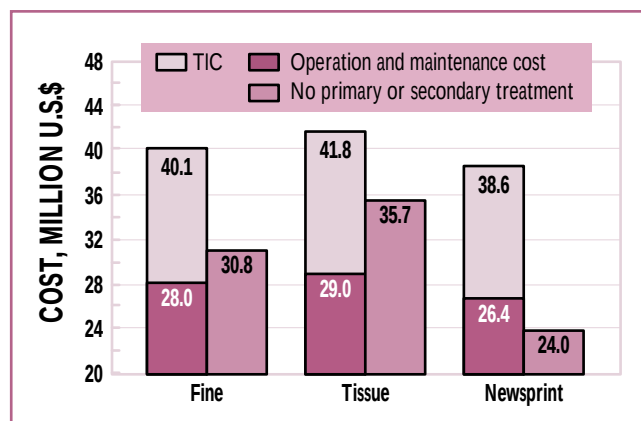
5. Estimated TIC for fine paper deinking mill



6. Estimated TIC for newsprint deinking mill



7. Estimated operation and maintenance costs for fine paper deinking mill



8. Cost estimates for 300 tons/day deinking mills

## COSTS

### Capital costs

The following assumptions are necessary for the capital cost estimates:

- Deinking facilities will produce 300 tons/day. The tissue and newsprint deinking systems include flotation and washing.
- The equipment list comes from the waste water treatment and closure diagrams.
- The location of the project is the northern portion of the Midwestern United States.
- Labor costs and indirect construction costs are 1992 merit-shop based.
- Piping and instrumentation was factored from equipment costs.

- Contingency is 10%.
- There is no allowance for land, owners' costs, spare parts, or startup costs.

Table II shows the estimated total installed cost (TIC) for each area of the waste water treatment system by deinking category. Primary and secondary treatments are necessary. The additional costs for closed cycle are US\$ 28, 29, and 26.4 million for fine paper, tissue, and newsprint, respectively. The TIC for a fine paper deinking facility typically ranges from US\$ 250,000–300,000 per daily ton. The TIC for a 300 ton/day deinking plant is therefore approximately US\$ 82.5 million. Making the facility closed cycle increases capital costs 34%.

Figures 5 and 6 show the relative effect of a deinking plant capacity on the estimated TIC for a fine paper and newsprint closed cycle facility. The estimate assumes 45% of the secondary effluent goes to filtration, reverse osmosis, evaporation, and crystallization.

### Operating and maintenance costs

Table III shows the additional operating and maintenance costs for closing a 300 tons/day deinking facility for a fine paper deinking. The costs are representative for all the deinking operations shown in Table II, however. This table uses the following assumptions:

## KEYWORDS

*Closed systems, costs, deinking mills, economic analysis, economics, effluent free mills, engineering, systems, systems engineering.*

- The cost of the 7.5 people required is an average loaded hourly rate of US\$16.78.
- Chemical cost for the polymer is US\$ 20/o.d. ton of sludge at a

dosage of 10 mg/L, for the phosphoric acid is US\$ 0.20/lb at a dosage of 1%, and for anhydrous ammonia is US\$ 0.07/lb at a dosage of 5%.

- Natural gas cost is US\$ 3.00/1000 std. ft<sup>3</sup>/min for startup only.
- Electrical cost is US\$ 0.06/kW·h with a requirement of 54,600 kW·h/day.
- Potable water cost is US\$ 1.00/1,000 gal with a requirement of 600 gal/day.
- Major maintenance costs/year are 3% of equipment costs.
- Replacement of the RO membrane is US\$ 100 for each g/meter per year.
- Cost of land filling solidified ash is US\$ 20/o.d. ton.

Figure 7 presents the effect of capacity on operating and maintenance costs for a fine paper system. Again 45% of the secondary effluent goes to advance treatment.

## CONCLUSION

Designing a closed cycle deinking facility is technically feasible. Such a facility will have no environmental effect on any receiving streams. There are environmentally safe ways of disposing the solid wastes. The cost of the facility, however, is high and not currently justifiable economically. Figure 8 summarizes both the TIC and operating and maintenance costs for closed cycle waste water treatment systems. TJ

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