# Ultra Filtration Aids Closing Water Loop In Paper Mill

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## ABSTRACT

An integrated paper mill adopting Kraft Sulphate process in Central India proposed water foot print reduction. The mill consumed freshwater from the nearby river to the tune of 180 - 225 cubic meters per ton of paper. Demand from other users such as agriculture, domestic consumption and lean flow resulted in the local regulatory body insisting on reduction of water use and wastewater discharge. Various wastewater streams from the mill were identified for recycling. Paper machine section effluent was selected for recycle and reuse. Complete pollutant reductions were achieved on COD and suspended solids and upto 99.3% on turbidity and other parameters meeting the desired mill water quality. Operational and capital cost was delineated for implementation and was found close to conventional chemical aided clarification due to large volume for wastewater treatment. Micro-ultrafiltration combination reduced freshwater consumption by about 30% which was available for reuse. The water loop in the paper machine section was closed increasing water use efficiency.


**Introduction**

Paper plays a significant role in the development of a nation. About 594 pulp and paper mills are operational now in India with an installed capacity of 8.42 million tonnes per annum (MTPA) as against 17 in the year 1950 with an installed capacity of 0.2 MTPA [1]. The paper mills vary in size depending on raw material, manufacturing process and product. Bamboo, eucalyptus, agricultural residues and waste paper are used generally in India. Fresh water requirement for the mills in India vary between 135-200 $m^3$ per tonne of paper produced ($m^3T^{-1}$) which is grossly high in comparison to US, where the consumption is reduced to 64 $m^3T^{-1}$ at end of year 1995[2,3]. With decreasing availability of fresh water from surface and ground waters and demand from other users, paper industries are forced naturally to look into alternative water sources for its sustainability. Waste water fills the gap for water production which ultimately leads to water reuse and increase water use efficiency.

**Literature Review**

Paper mills in India adopt physico-chemical coagulation route followed by biological oxidation [4]. Bio-oxidation route is widely employed for reduction of dissolved organic matter from the effluents for its relative low cost. The final treated effluent produced by the biological route is satisfactory to meet the discharge standards of Inland Surface Waters, as it is the case usually in India. However, since surface and ground water sources are dwindling in many parts of the country, existing practice of disposal into these sources do not augment well for the industry. Further treatment is necessary to make it usable. Chemical treatment results in addition of chemical and complicates waste management by increasing sludge. Specific purification technologies such as flotation, evaporation, and membrane filtration are used recently to concentrate and fractionate spent liquor, remove colour and treat bleach effluent [2, 5, 6 & 7]. Internationally, membrane filtration systems are used for water recovery. Membrane filtration such as micro-filtration (MF), ultra-filtration (UF), nano-filtration (NF), and reverse osmosis (RO) are being employed in the pulp and paper mills to reduce water foot print. In one such study, Extraction (E) stage bleach plant effluent was recovered through UF and NF combination [8].

The crux of the problem for recycle and reuse in India is that the treatment package must be easy to operate and recover resource thereby reducing costs. Increased water use efficiency by modern treatment techniques is one of the major challenges faced by the paper industries using obsolete technologies in India. A mill in Finland achieved upto 75% reduction in freshwater consumption by simply changing feedstock, recycling white water from paper machine, Decker & screens and cooling water condensates by adopting latest techniques in screening, clarification and evaporation [9]. Studies have indicated water recovery from combined effluents to be expensive and high grade water is possible, if streams are segregated. New developments in the area of wastewater treatment is development of liquid membranes which is relevant to the paper mill effluent treatment [10]. The present study aims to close water loop from a section in the mill. The mill under investigation is one of the oldest and largest in central India with an installed capacity of 0.08MTPA.

**Material And Methods**

**Experimental design for water recovery**

The major areas for water consumption in the mill is from bamboo washing, chipper & digester house, pulp washing & bleaching, paper machine and chemical recovery. The freshwater consumption and wastewater generated from the process is presented in Table 1

The effluents were segregated into Grade I, II, and III based on the pollutant severity level and treated in separate effluent treatment plants. These details are not included here for brevity sake. Condensates from paper machine, turbine & evaporators and cooling water from spray pond is classified as Grade I wastewater. While effluents from stock preparation of the paper machine section, chlorination & hypo section of the bleaching plant, wash water from chipper house and supernatant from lime sludge ponds is classified as Grade II wastewater. The wastewater from washings and screening operations in the pulp section and caustic extraction stage in bleach

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**Table - 1**
**Water Requirement and wastewater generation of Pulp & Paper Mill**

| Details | Use area | Quantity, $m^3\ d^{-1}$ |
|---|---|---|
| Water consumption | Process | 27100-40700 |
| | Cooling | 1800-4300 |
| | Boiler | 1100-1900 |
| | Domestic | 2700-4500 |
| | Total | 32700-51400 |
| Wastewater generation | 26800-38500 | 28770-35737 |
| Installed Production, TPD | 250 | 179-192 |
| Wastewater generation, $m^3\ T^{-1}$ | 200 | 161-195 |

Source: Pulp & Paper mill under study

plant comprises the Grade III. This wastewater from pulp section is dark brown in colour due to the presence of lignin from the processing. Mill desired to augment production with the same freshwater input. Bench scale treatability study was conducted to implement recycling of paper mill effluent based on the pollutant level; specifically BOD, COD, SS, silica, chlorine and hardness causing compounds and meet the mill water quality. The order of preference of stream for reuse was based on the above criteria and presented in the Table 2 with least preference (caustic extraction stage and pulp mill effluents) at the end.

**Table 2**
**Physico-chemical characteristics of various streams in the mill**

| Parameter | PM | SRP | CT | HWD* | CE- PS | MWQ+ |
|---|---|---|---|---|---|---|
| Flow, $m^3/d$ | 12700 | 2000 | 3000 | 800 | 13,500 | - |
| Colour | 3.0 – 18 | 9.0 – 12 | 4.0-7.0 | 9.0 - 11 | 1800-2190 | NIL |
| pH | 5.5 - 7.0 | 10 – 12 | 2.5 | 7.0 - 11 | 7.3 – 8.1 | 6.8-8.5 |
| TSS | 447 -784 | 2802 - 2810 | 47 | 12 - 58 | 164 - 188 | < 400 |
| TDS | 450 - 524 | 2154 - 2706 | 4796 | 1256 - 1558 | 2386 - 2556 | < 400 |
| COD | 320 - 498 | 89 - 104 | 1440 | 68 - 136 | 640 - 754 | - |
| $BOD_{3d,\ 27^{\circ}C}$ | 75 – 130 | 11 – 14 | 273 | 12 - 19 | 185 - 225 | - |
| $Cl^-$ | 32 – 45 | 8.0 – 13 | 1852 | 155 - 363 | 738 – 788 | 25 – 100 |
| $SO^{4-}$ | 208 - 220 | 59 - 137 | 183 | 182 - 215 | 146 – 160 | - |
| $Ca^+$ | 75 – 107 | 29 – 32 | 249 | 175 - 184 | 162 – 198 | - |
| $Mg^+$ | 37 – 49 | 357 - 411 | 31 | 14 - 29 | 15.8 – 17.2 | < 20 |
| $Na^+$ | 33 – 43 | 218 - 219 | 18 | 175 - 184 | 238 – 250 | - |
| $K^+$ | 7.0 – 12 | 9 – 11 | 2.0 | 3.0 - 5.0 | 32 – 45.8 | - |

* Wastewaters from evaporators, sealing, cooling condensates.
Mill water quality after water treatment. Additionally turbidity (<5), hardness (70 450), alkalinity (50 150), silica (7.0 11.0) and total hardness (<185) are required for process use. All parameters are expressed in $mgl^{-1}$ except pH, colour (Hazen), turbidity (NTU) and Temperature (°C)

**Sampling and analysis of effluents**

Samples were collected from the raw paper machine, clarified white water, pilot and tissue plants, chlorine tower, chipper house, soda recovery plant, hot water drains and coal ash pond and samples composited. Analyses were carried out as per standard protocols for water and wastewater analysis [11].

**Jar test for chemical aided clarification**

Phipps and Bird jar test apparatus was used to coagulation-flocculation experiments. Commercial grade lime of the concentration 100 – 600 $mgl^{-1}$ is used as coagulant. One liter of wastewater was taken separately in six glass jars and fixed coagulant dose was added in five jars with one serving as control for each set of the experiments. The solution was subjected to flash mixing at 100 RPM for one minute, followed by slow mixing for 15 minutes. The agitated solution was allowed to settle for 30 minutes and the supernatant was analyzed for the pollutant reduction.

**Membrane filtration**

The pre-treated effluent was passed through membrane filtration system comprising micro and ultra-filtration combination. The membrane system was from Genesys Membrane Spectra Pvt. India, Ltd. provided in a skid module. The system consists of cleaning in place (CIP) process, a Grundfos pump, feed, permeate and cleaning tanks. The filtration plant was initiated feeding with 5 minutes with tap water to remove the anti-scalants and membrane preservatives. The feed flow was maintained at 1 cubic meter per hour (1000 litres per hour @ 40°C). The operation was stopped and cleaning initiated when the trans-membrane pressure (TMP) reached 60 PSI or when the permeate flow was reduced by 10%. The membrane cleaning containing chlorine free fresh water is fed and both the reject and permeate ends discharge into the sewer system. Cleaning is carried out till the membrane regains the desired flow. The CIP process requires 10 micron filtered demineralised water for rinsing, chemical and preservative addition.

## Results and discussion

### Effluent characteristics and selection of effluent streams for reuse

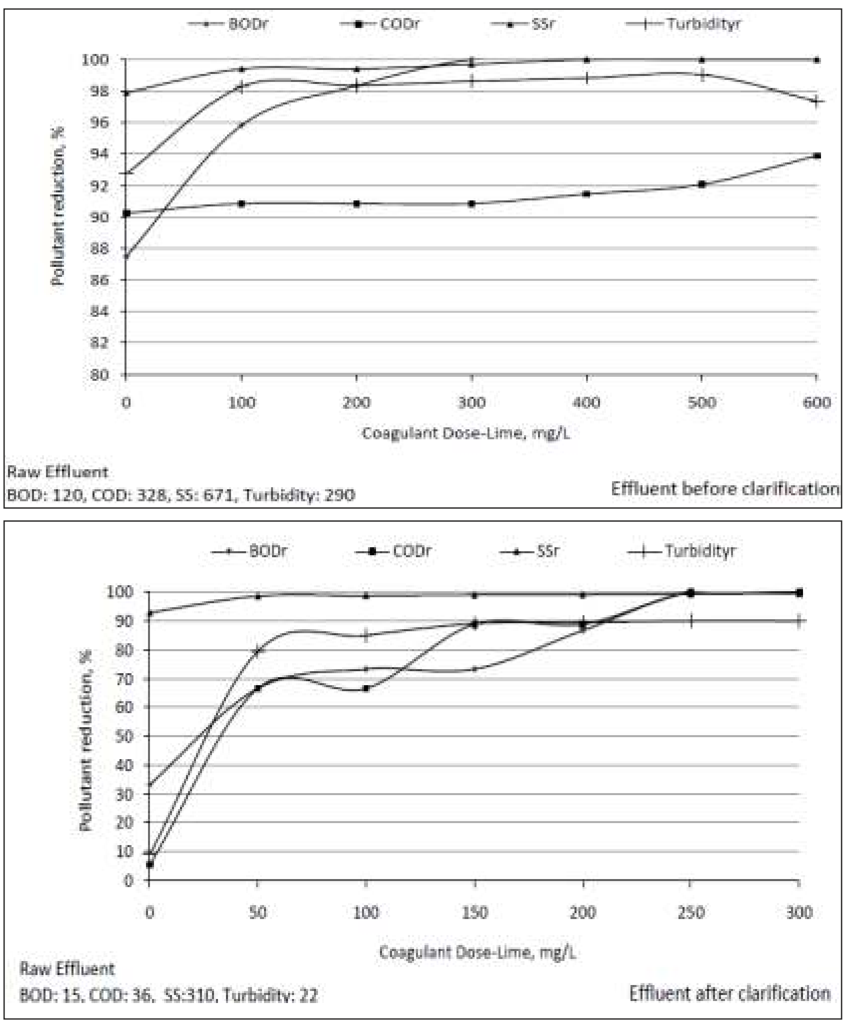
The mill produces about 12,700 $m^3$/d of effluent from the paper machine (PM). The wastewater balance aided selection of streams for recycling. Effluent analysis indicated that the wastewater from PM section appeared whitish in colour due to the presence of cellulosic fibrous materials, talc, whiteners & binders (Table 2). The effluent was notably low on total dissolved solids concentration (450-524 $mgl^{-1}$) and hence this stream was selected for recycle and reuse. Effluent streams from Chlorine tower (CT) section, caustic extraction and pulp section wash waters contained higher pollutant concentrations.

### Physico-chemical treatment on paper machine effluents

The Jar Test experiment conducted on main paper machine effluent indicated much of the pollutant load was contributed by settleable fibre particles of cellulosic pulp origin. Thus experiments were carried out with paper machine effluents with and without settling and the results of the studies are presented in Figure 1.

Lime solution was dosed at the rate of 100 – 600 $mgl^{-1}$ to neutralize the acidic nature of the paper machine effluents. An optimum dosage was obtained where maximum pollutant removal of major parameters such as BOD, COD, SS and turbidity were achieved. The PM effluent was allowed to settle for ½ hour and the supernatant was used for treatability studies. The studies conducted on raw effluent before clarification indicated major pollutant reductions at lime dosages above 300 $mgl^{-1}$. The difference in the pollutant removals was observed after plain settling. Higher pollutant removals viz., COD, BOD and SS removals were obtained at lower lime dosage after clarification. Clarified effluent required lower doses of lime at the rate of 50-250 $mgl^{-1}$. The optimal lime dosage requirement was 200 $mgl^{-1}$. The optimal dose was selected based on maximum reduction of BOD, COD, SS and turbidity. The studies indicated plain settling improved significant pollutant removal from the paper section of this mill. However further treatment through is required to achieve mill water quality. While increasing the quantity of lime, higher pollutant reduction was observed which indicated correlation between pH and settling. The negative charge of the paper machine effluents generates a colloidal effluent, which was destabilized by increasing OH ions and the electric repulsion between cellulosic fibers reduced settling time [12, 13]. Requirement of exotic chemicals to enhance settling were not needed as lime fulfilled the pollutant reduction.

**Figure1**
**Percent pollutant removal of paper machine effluent with and without Clarification**




### Membrane filtration on the paper machine effluents

The use of micro-ultra filtration combination aided in complete removal of suspended solids. Micro-filtration pretreated the effluent to reduce suspended solids load on the ultra-filtration membrane which contained the colloidal and fine particles from the paper machine section wastewater. The effluents were analyzed for pH, turbidity, suspended solids and COD. The final treated effluent characteristics from the MF-UF process is presented in Table 3. While it was observed that partial COD, turbidity and solids were not completely removed with micro-filtration. Ultra-filtration eliminated solids entirely, COD maximum and turbidity upto 83.3% reduction. Research studies conducted elsewhere on E-stage effluent by UF system removed COD upto 87%, [14].

### Collation of the treatability studies for selection of treatment scheme for water recovery

Based on the study, the water recovery has been derived based on the difference in the input fresh water consumption and reduction in wastewater generation. A number of small scale paper manufacturers in India avoid aerobic biological treatment as it is power and foot print intensive [15]. In this case it was proposed to use the paper machine section effluent treated through chemical enhanced settling followed by MF-UF membrane filtration. The

**Table 3**
**Effluent quality at different stages of the study from paper machine section**

| Parameters | Raw effluent | Without clarification* | With clarification$^{+}$ | MF-UF combination |
|---|---|---|---|---|
| pH | 4.9 | 6.9-7.1 | **6.0-6.1** | **7.2** |
| Turbidity | 326 | 3.0-4.0 | 9-12 | 2-4 |
| TSS | 532 | 11-15 | 35-37 | Nil |
| TDS | 460 | 505-510 | 500-505 | 300-310 |
| BOD | 116 | 15-22 | 2 | - |
| COD | 432 | 54-58 | 9.0-10.0 | NIL |

* Addition of lime @ 400 mg/l and $^{+}$ addition of lime @ 200 mg/l for neutralization and settling

operational (OM) cost of effluent treatment was calculated based on the chemicals requirement and electrical cost incurred. It was estimated to range between ` 3.62 – 4.2 per cubic meter of wastewater treated with a recovery of about 70-75% water for reuse.

A process developed for water conservation in Germany, through a combination of advanced oxidation through ozonation followed by biooxidation generates water fit for use in most types of paper production. The cost of treatment varied between ` equivalent 3.4 13.6 per cubic meter of wastewater [16] saving about 20% of freshwater.

However a capital investment of ` 12.2 crore was estimated for implementation of the scheme. A combination using ozone and electron beam irradiation combination costs about 13.8 crores for treatment [17]. However, the effluent could achieve toxic free, organic and recalcitrant compounds degradation and nothing significant could be achieved towards water reuse or recovery. The OM cost is comparable to conventional physico-chemical treatment for this case. A study conducted in the last decade on recovery of water from a paper mill had indicated operational costs at ` 4.39 per cubic meter of wastewater treated through physicochemical route using alum and polyelectrolyte followed by filtration and activated carbon adsorption [18]. Additionally, freshwater water consumption was reduced upto 30% with an annual saving of Rs. 11.50 lakhs towards water cess (@ 35 paise per cubic metre )[19]. UF treatment processes require fewer chemicals and add very little as sludge as compared to chemical treatments. If this water is reused, the low TDS level contributes to a lower water recovery cost also due to less sludge handling costs.

Additional foot print of the effluent treatment plant was increased by about 20% for installation of membrane filtration systems. Based on this treatment scheme, the mill reduces water footprint from the existing unit wastewater generation from 115 to 80 $m^3 t^{-1}$.

However, closing the water loop in a section could achieve unit wastewater reduction upto 80$m^3 t^{-1}$. Additional treatment in the form of advanced oxidation and reverse osmosis/nanofiltration is required to reduce water foot print to achieve the proposed guidelines for the large scale wood based integrated pulp and paper mills in India [20], which fixes the unit water consumption and wastewater discharge standard at the rate of

Bench mark (63 /50 $m^3$/t) ,
Best achievable (67/53) and
Relaxed standards (80/63).

## Conclusion

Paper production is water intensive and many countries in Asia and Europe face severe water shortage resulting in production cutting. Water recycle/reuse have gained momentum recently in the Indian paper industry due to water scarcity and increasing regulatory pressures. Reduction in water foot print through conservation and reuse is not possible without the use of advanced treatment processes. Experiments were conducted to obtain a quick and fast viable treatment scheme for closing water loop in a section of paper mill using ultra filtration membrane system. The mill reduced water footprint by about 30%. The idea was use of less complicated membrane filtration systems such as UF than nano and reverse osmosis membranes for its simplicity and ease of use. The intangible benefits achieved by the mill are many such as conservation of fresh water, less fresh water cess, reduced freshwater desalination cost and assured source of water aiding running production line.

## Acknowledgement

Authors thank Director, National Environmental Engineering Research Institute, Nagpur for providing necessary infrastructure and guidance on the study.

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