# Economics of Wastewater Treatment in Small Paper Mills

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*Demand for establishing small paper mills with capacities ranging from 10–30 TPD, is increasing in the country. These mills will utilise agricultural residues as raw material. This necessitated study of the pollutional potentialities, treatment methods and the economics of wastewater treatment from these mills.*

*Data on nature and composition of the wastewaters from different sections of the mill and the estimated pollutional loads are enumerated and discussed.*

*Different treatment alternatives have been presented in the paper for disposal of the mill wastewater into inland surface waters and on land for irrigation. The economics of the waste water treatment for the mode disposal as indicated above have been worked out for 10, 15, 20 and 30 TPD plants making unbleached paper using 70 per cent straw pulp and 30 per cent gunny rag pulp.*

*Although it is possible to bring down the BOD and suspended solids to acceptable limtits by biological methods, COD and colour due to lignin can not be reduced to the acceptable level. For a total pollution control, the most economic solution is to use the wastewater on land, after primary treatment, for agricultural utilisation.*

*With the data presented in this paper, it will be possible for any small mill using different combinations of raw materials, to work out the cost of wastewater treatment facilities that have to be provided.*

## INTRODUCTION

In India, during 1970–71, the cost of installing a 100 tonne pulp and paper plant was approximately Rs. 1800 lakhs. Presently, for the same capacity the cost is estimated to be more than double. Further, the conventional raw material, *viz.* bambaoo, is getting rapidly depleted and practically all the existing mills employing bamboo are compelled to substitute 39–40% of the total requirement by hard woods. These mills, although to a very small degree, are also going in for the use of unconventional raw materials, such as bagasse, cereal straw, rags, jute sticks, etc., which form the residues of agriculture, as a substitute for conventional materials. The small mills, that are in operation in India, are using only the above mentioned agricultural residues. It is reported that large quantities of these agricultural residues are available in our country and can be procured with ease. So far these materials are being thrown out or burnt knowingly or unknowingly. It is recently estimated that for establishing new small paper mills, based on agricultural residues, with capacities ranging from 10 to 30 tonnes per day (TPD) of unbleached paper, it would cost 240 to 480 lakh rupees. In the light of this situation, the need for setting up a number of small paper mills (10–30 TPD) is recognised in recent years. Further, these mills do not normally go in for chemical recovery system since it is reported that chemical recovery even for a 30 TPD plant is not economically viable.

Today a large number of small paper mills are already existing and letters of intent for establishing many more new units have been issued, to various entrepreneurs, in different States. Although the water pollution problems associated with these mills have

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been recognised, no serious attempt seems to have been made to assess the economic viability of small mills, if they have to meet the standards laid down, for effluent discharge, by the newly formed Water Pollution Prevention and Control Boards at the State and Central level.

An attempt is made in this paper to work out the economics of wastewater treatment in small mills based on the know-how developed and information collected by National Environmental Engineering Research Institute (NEERI). Nagpur,

**COST OF ESTABLISHING SMALL PAPAR PLANTS**

The number of existing and proposed small paper mills, and their capacities are shown in Table 1.

**Table 1–Existing and Proposed Small Pulp & Paper Mills**

| Range TPD | Existing Mills No. of Mills | Existing Mills Capacity TPD | New Mills for which Letters of Intent Issued No. of Mills | New Mills for which Letters of Intent Issued Capacity TPD |
|---|---|---|---|---|
| 1–10 | 31 | 186.5 | 18 | 136.5 |
| 11–15 | 7 | 96.0 | 17 | 216,0 |
| 16–20 | 7 | 126.5 | 42 | 773.0 |
| 21–30 | 6 | 143.5 | 26 | 676.0 |
| Total | 51 | 552.5 | 103 | 1801.5 |

From the data glven in Table 1, it can be seen that there are 51 small paper mills with capacities ranging from 1 to 30 TPD with a total capacity of 553 TPD. Besides these, there are 35 units making exclusively straw and mill boards. Letters of intent for establishing 103 new units have been issued for producing a total quantity of 1800 TPD.

Permission for establishing mills with capacities greater than 30 TPD has been granted to only 29 parties. From this information, it is clear that the trend appears to be for going in for smaller units rather than big mills.

The capital cost for establishing the small mills for making unbleached packing and wrapping papers and the cost of production of a tonne of paper are given in Table 2.

TABLE 2–Capital and production Costs for Small Paper Mills Without Chemical Recovery

| Capacity TPD | With Indigenous Machinery Capital cost Lakh rupees | With Indigenous Machinery Cost of production per tonne paper, Rupees | With Imported Machinery Capital cost Lakh rupees | With Imported Machinery Cost of production per tonne paper, Rupees |
|---|---|---|---|---|
| 10 | 240 | 2660–2800 | 186 | 2685 |
| 15 | 280 | 2535–2700 | 226 | 2550 |
| 20 | 350 | 2900 | — | — |
| 30 | 450–490 | 3035–3100 | 476* | 2960* |

*With Chemical recovery

The Capital cost is estimated to go up by 20 to 50 lakh rupees if bleached paper is made.

**Mill Processes**

**Raw materials and Chemicals :–**

The raw materials used in small mills for pulping include rice and wheat straw, jute sticks, bagasse, grasses, waste cotton, gunny rags and ropes, waste paper and paper cuttings. It is recommended that mills with 20 to 30 TPD can also use bamboo and hard woods as well. Chemicals employed in pulping process include caustic soda, sodium carbonate and/or lime. With bamboo and hard woods, sodium sulphide and caustic are employed. Calcium hypochlorite in the form of bleaching powder is used for bleaching. Other chemicals used are alum, rosin, organic dyes and antifoaming agents.

**Water Requirements** :–A wide variation is observed in the values reported for water requirement in small paper mills. For a 10 TPD plant, the water requirement has been indicated to vary from 227 to 410$M^3$ per tonne of paper. For a 20 TPD plant, the requirements have been shown to be 227 to 300 $M^3$ per tonne. Normally, it is observed that the water requirements for making unbleached paper, will be of the order of 200–250 $M^3$ per tonne of paper. If one stage bleaching is employed, the requirements will go up by 5 to 10%. Normally 85 to 90% of the water used in the process for different operations comes out as wastewater.

**Manufacturing Processes and Sources of Wastewater**

**PREPARATION OF RAW MATERIALS**—The raw materials such as rice straw, rags and waste paper are first screened separately to remove sand and any other adhering foreign material, If necessary, they are cut to proper size and are used directly for pulping.

**Pulping**—All the raw materials used in small mills will be pulped separately. Rice straw or rags or ropes are digested separately, with caustic soda and/or lime in rotary digesters under pressure (4–5 Kg/cm$^2$) and heated with steam. The quantity of charge, chemicals, steam and digestion time depend upon the type of raw material used and the quality of pulp required. Normally, the digestion is carried out for 3 to 4 hours in case of s.raw. Digeston with caustic dissolves the lignin from straw so that cellulose fiberes are separated out.

After the required period of digestion, the pressure is released and the digester contents are emptied into a washing poucher. Black liquor (BL) can be segregated if the pulp is discharged on to floor with false bottom. In some mills it is reported that the black liquor will be reused after fortifying with required quantity of chemicals.

The pulp with black liquor, discharged into poucher is washed with water for a period of 2 to 3 hours. The washing from this section are called dilute black liquor. This wastewater is highly alkaline and coloured due to lignin. It will exert high BOD and COD. Washed pulp from poucher is pumped to knotters to remove the uncooked material and the pulp is further washed and thickened in a decker. The wastewater from this section, known as decker washes, is also coloured and will be dilute compared to poucher washings except that it will contain more suspended solids. The pulp is again given a further wash in Bellmer and the wastewater is known as Bellmer washings. The waste is usually light brown in colour. The number of washings will vary from mill to mill and depend on raw material used for pulping. If bleaching is employed, the pulp from Bellmer is treated with bleaching powder solution (8–10 Kg. bleaching powder per tonne of pulp) and the bleached pulp is washed in a second Bellmer. The washings are known as bleached Bellmer wastewater and are normally light coloured with low BOD and COD compared to the different pulp washing wastewaters.

Waste paper and paper cuttings are pulped in a hydrapulper. Beaters are used for this process and settled wastewater from paper machine is used for pulping to reduce the water requirements. Steam is also employed in hydrapulpers. Practically no wastewater is produced in this section.

Centricleaners are employed to separate out sand and other impurities from the pulp. The centricleaner rejects form a source of wastewater. This contains large concentration of coarse and fine suspended and settleable solids.

**Paper Machine**—Different proportions of bleached or unbleached pulps are diluted with water to the required consistency. If required, sizing chemicals such as alum, rosin and talc are added along with dyes during stock preparation for paper machine. The diluted pulp with added chemicals is run on paper machine. The sheet of wet paper is picked up by felt and dried between steam rollers. Finally the paper is collected on rollers.

Most of the water along with fine fibers gets drained out from the paper machine. The wastewater is often referred to as white water. The wastewater will have slightly acidic (pH 5–7) and contains considerable quantities of suspended solids with relatively low BOD. Settling of this wastewater results in the removal of suspended solids by over 80 per cent. In bigger mills, save–alls are used to recover fiber for recycling both the fiber and water into the mill processes. In smaller mills, only settling tanks or pits are used for recovery of fiber and water but these do not give efficient recovery.

**Characteristics of Wastewaters**

Since a variety of raw materials are used and different conditions of pulping are adopted, it is rather difficult to predict or generalise the characteristics of different wastewaters that are normally produced in small mills. However, data collected by NEERI from a few mills employing straw and gunny rag and rope digestion processes, are taken to work out the probable wastewater chracteristics from these mills. The pollution loads have been worked out on material balance. The conditions of digestion used in the mills from which the data are collected are also given below.

**Straw, Gunny rags and Rope pulping :**–To obtain one tonne of bone dry (BD) pulp, the quantities of raw materials, water, steam and chemicals used are as follows.

| | Straw pulping | Gunny rags or rope |
|---|---|---|
| Raw material (Tonne) | 2 | 1.33 |
| Caustic Soda (Kg) | 150 | 105 |
| Water ($M^3$) | 8 | 2.33 |
| Steam (Tonne) | 3.6 | 2.33 |
| Yield of unbleached pulp (%) | 50 | 75 |
| Quantity of black liquor produced ($M^3$) | 12 | 5 |

From material balance the quantity of black liquor in straw and gunny rag pulping will work out to 11.6 and 4.67$M^3$/tonne of pulp, respectively. However, the volume of black liquor is assumed to be 12$M^3$ for straw pulping and 5$M^3$ for gunny rag pulping per tonne of pulp in view of increased volume due to dissolution of chemicals and organics from raw materials.

Normally, 70% of straw pulp and 30% of rag pulp are mixed for making wrapping or packing paper. This proportion has been used in computing the characteristics of different wastewaters. The characteristics and loads of different pollution parameters present in the black liquors from straw and gunny rag and rope pulping are shown in Table 3.

**TABLE 3–Characteristics of Black Liquor from Digesters**

| Parameters | Straw | | Gunny Rags & Rope | | Mixed Straw & Rag* | |
|---|---|---|---|---|---|---|
| | Load | | Load | | Load | |
| | mg/l | kg/tonne pulp | mg/l | kg/tonne pulp | mg/l | kg/tonne pulp |
| Flow, $M^3$/tonne pulp | — | 12 | — | 5 | — | 9.9 |
| pH | 10.8–12.0 | — | 11.0–11.8 | — | 10.8–11.8 | — |
| Total solids | 44,400 | 533 | 37,600 | 188 | 43,384 | 429.5 |
| Suspended solids | 9,100 | 109.5 | 8,000 | 40 | 8,960 | 88.7 |
| COD | 38,800 | 466 | 32,240 | 160 | 37,800 | 374.2 |
| BOD | 12,250 | 147 | 4,890 | 25 | 11,150 | 110.4 |
| Sodium (Na) | 7,160 | 86 | 12,000 | 60 | 7,899 | 78.2 |

*Computed using 0.7 tonne of straw pulp and 0.3 tonne of rag pulp.

From the data given in Table 3, it can be seen that black liquor from straw pulping was only slightly stronger than that from rag pulping. Although there is no appreciable difference in the COD values, the BOD in the black liquor from straw pulping is about 2.5 times that of the black liquor from rag pulping. This is partly due to the fact that more organic matter from straw goes into solution and this material exerts BOD more readily than in the case of gunny rags and ropes. This could be seen from the COD to BOD ratios which are 3.2 and 6.6 in straw and rag black liquors, respectively. The BOD load per tonne of straw pulp is 5.88 times more than the BOD load in rag pulp. This can again be explained by the fact that about 50 per cent of the material in straw goes into solution while only 25 per cent of gunny rags and ropes gets dissolved during digestion.

The physico-chemical characteristics of individual washings during the manufacture of unbleached straw pulp are given in Table 4. The data presented in Table 4 is for a mill where no black liquor segregation is practised and only important pollution parameters are presented.

From the data given in Table 4 it can be seen that a total volume of 70 $M^3$ per tonne of pulp is discharged during washing of pulp for obtaining unbleached straw pulp. Although there was variation in the volume of wash water from poucher, decker and Bellmer, the average values from the three units were in the ratio of 3:2. 4:1. All the wash waters are alkaline with pH greater than 8.5. As could be expected, wash water from poucher is the strongest and that of Bellemer is the weakest. The concentration of suspended solids was highest in the decker wash water.

BOD, suspended solids and COD loads per tonne of unbleached pulp were 147, 110 and 466 kg, respectively. BOD load per tonne

**Table 4–Characteristics of Individual Straw Pulp Washings**

| | Poucher Wash | | Decker Wash | | Unbleached Bellmer Wash | | Combined Wastewater | |
|---|---|---|---|---|---|---|---|---|
| | mg/l | kg/tonne pulp | mg/l | kg/tonne pulp | mg/l | kg/tonne pulp | mg/l | kg/tonne pulp |
| Flow, M³/tonne pulp | 20–39 | — | 20–29 | — | 6.7–16.0 | — | 70 | — |
| pH | 9.6–10.1 | — | 8.8–9.6 | — | 8.5–8 8 | — | 8.8–9.8 | — |
| Total solids | 6,650–12,900 | 798–1,620 | 1,900–7,900 | 334–593 | 1,310–4,710 | 79–118 | 7,614 | 533 |
| Suspended solids | 990– 1,780 | 119– 159 | 1,260–2,100 | 151–205 | 290–1,060 | 17– 27 | 1,570 | 110 |
| C.O.D. | 6,460–11,060 | 623– 775 | 2,700–6,700 | 392–503 | 1,120–3,660 | 45– 92 | 6,657 | 466 |
| B.O.D. | 1,460– 3,400 | 197– 255 | 700–3,000 | 142–225 | 260–1,480 | 14– 37 | 2,100 | .147 |
| Sodium (Na) | — | | — | | — | | 1,228 | 86@ |

* Poucher. decker and unbleached Bellemer washes are in the ratio of 3 : 2.4 : 1.
@ Computed from material balance.

of bleached pulp in bigger kraft mills, with black liquor recovery, ranges from 35–75 kg. The high BOD load of 147 kg per tonne of unbleached pulp from straw is due to non-recovery of chemicals from black liquor. Sodium content in the wastewater was also high and this will increase the per cent sodium value of the total mill effluent. This reduces the usefulness of the combined wastewater on land for irrigation.

In small mills, only hypochlorite bleaching is practised. The minimum, maximum and average values of pollution characteristics of wastewater from bleaching of straw pulp is given in Table 5.

**Table 5– Characteristics of Wastewater From Bleaching Section**
(All values except pH & flow are in mg/1)

| | Minimum | Maximum | Average | Kg/tonne bleached pulp |
|---|---|---|---|---|
| Flow, M³/tonne paper | 5 | 13.33 | 8.33 | — |
| pH | 8.1 | 9.4 | 8.1–9.4 | — |
| Total Solids | 1690 | 2779 | 2387 | 19.9 |
| Suspended Solids | 450 | 960 | 713 | 5.9 |
| COD | 290 | 1259 | 763 | 6.4 |
| BOD | 140 | 750 | 330 | 2.75 |

The data presented in Table 5 indicate that about 8.3 M³ of wastewater was discharged per tonne of bleached pulp only from bleach section. This volume is about 12 per cent of the total wastewater produced during the three stages of pulp washing. The pH is on the alkaline range since bleaching powder is used in small mills. This wastewater was somewhat similar to domestic sewage with respect to COD and BOD values. The suspended solids concentration is somewhat higher compared to that from unbleached Bellmer wastewater.

BOD and COD loads contributed by bleaching section were less than 2 per cent of the pollution load present in the combined pulp section wastewater. However, the suspended solids load was as much as 5.4 per cent of the total suspended solids load from pulp section. Although BOD and COD loads were not appreciable, the bleaching section contributes significantly to the suspended solids load. Further, due to the use of bleaching powder, the calcium content in the waste will increase. This helps in reducing the per cent sodium value of the combined wastewater.

The physico-chemical characteristics of the combined wastewater from gunny, rag and rope pulp washing (with no black liquor recovery) is shown in Table 6. These values are computed from the actual composition of black liquor presented in Table 3 and assuming that same volume of wash water will be used in this case as well.

**Table 6–Characteristics of Wastewater From Gunny Rags and Ropes Pulping Section.**

| Characteristics | Total pulp washing wastewater with no black liquor segregation | |
|---|---|---|
| | Composition mg/l | Kg/Tonne unbleached pulp |
| Flow, $M^3$/tonne pulp | — | 70 |
| pH | 9.0–10.1 | — |
| Total Solids | 2690 | 188 |
| Suspended Solids | 570 | 40 |
| COD | 2286 | 160 |
| BOD | 357 | 25 |
| Sodium (Na) | 857 | 60 |

From the data presented in Table 6, it can be seen that BOD and COD values of the pulp washing section of rag digesters were lower compared to wastewater from straw digesters as explained already. This wastewater will not influence appreciably the composition of combined wastewater from the mill, since it forms only 30 per cent of the total wastewater from pulping operations.

The characteristics of wastewater from a Paper Machine employing straw pulp and waste paper pulp are shown in Table 7.

The volume of paper machine water averages to $130 M^3$ per tonne of paper. Normally, in bigger mills large volume of paper machine water, with or without fiber recovery, is recycled for wood washing, stock preparation, etc., and the volume of wastewater finally discharged will be in the range of 75 to 100 $M^3$ per tonne of paper. In smaller mills, recycling is not effectively practised and hence the volume will be higher compared to bigger mills.

Similarly, the concentration of different pollutants is also high.

**Table 7–Chemical Characteristics of Wastewater From Paper Machine**
(All values except pH & flow are in mg/l)

| | Minimum | Maximum | Average | Load Kg/tonne of paper |
|---|---|---|---|---|
| Flow, $M^3$/tonne paper | 109 | 146 | 130 | — |
| pH | 8.1 | 9.0 | — | — |
| Total solids | 1830 | 2419 | 2150 | 280 |
| Suspended solids | 1220 | 1740 | 1517 | 197 |
| COD | 1100 | 1400 | 1237 | 167 |
| BOD | 230 | 560 | 350 | 45.5 |
| Percent Sodium | 23 | 27 | 25 | — |

For example, white water in a well operated large mill will have a BOD, COD and suspended solids of 130, 770 and 780 mg/1, respectively. But the data presented in Table 7 for a small paper mill show that the values are almost double the values reported for bigger Mills. Since the volume is also high, the pollution loads contributed by the paper machine will be much higher in comparison to the bigger mills. Paper machine alone in a small mill contributes 46 Kg of BOD, and 197 Kg of suspended solids per tonne of paper. However, it should be possible to reduce these loads considerably if the mills employ effective system of fibre recovery and recycling.

The characteristics of combined wastewater for making unbleached paper have been computed from the composition of pulp washings of straw, gunny rag and rope digestion and the paper machine water as given in Tables 3, 6 and 7. Further, it is assumed in computing the data that for making one tonne of paper, 0.7 tonne of straw pulp and 0.3 tonne of rag pulp will be used. The chacacteristics and pollutional loads in the combined wastewater are shown in Table 8.

The data given in Table 8 indicate that the combined wastewater will have alkaline pH with high BOD and COD values. The BOD load contributed per tonne of unbleached paper will be 156 kg and this may go up to

**Table 8–Characteristics and Pollutional Loads in the Combined Wastewater**

| | mg/1@ | Load kg/tonne unbleached paper |
|---|---|---|
| Flow, $M^3$/tonne | 200 | — |
| pH* | 8.0–9.0 | — |
| Total solids | 3548 | 709.5 |
| Suspended solids | 1428 | 285.7 |
| COD | 2676 | 535.2 |
| BOD | 780 | 156 |
| Sodium | 423 | 84.6 |

*expected range.
@except for pH

160 kg if bleached paper is made. The BOD load from small mills will be 3 times the pollutional load discharged from bigger mills with chemical recovery system. Similarly, the suspended solids load which is 286 and 292 kg per tonne of unbleached and bleached paper, respectively, is about 2.4 times the load discharged from bigger mills. The combined wastewater will have sodium content of 423 mg/1, and high colour due to lignin.

The total dissolved solids concentration is 2120 mg/l of which 40% will be inorganic solids (848 mg/1). The combined wastewater will not be fit for irrigation in view of high sodium and BOD (780 mg/l). The wastewater requires treatment before it can be discharged into water course. Another objectional constituent will be lignin as it imparts colour and COD to the receiving body of water. Normally 90 to 95 precent of the lign present in the straw is removed during digestion with caustic and this quantity ends up in the pulp washing average Assuming that on an average 90% of the lignin present in straw ends up in the pulp washing, the quantity of lignin that will be present in the wastewater, from straw pulping alone will be of the order of 3090 mg/1. Gunney rags and ropes contain lower percentage of lignin as compared to straw. Therefore, the combined wastewater will have lignin concentration in the range of 750 to 850 mg/1. This quantity of lignin alone will exert a COD of 1350 to 1530 mg/1.

### Segregation of Wastewater

As mentioned earlier, black liquor is not segregated in small mills since no chemical recovery process is adopted due to economic reasons. This creates increased pollutional load in the wastewater. It further creates the problem of increased sodium content in the wastewater which makes it unfit for agricultural utilization. In addition to these two problems, the entire colour due to lignin and its derivatives will end up in the wastewater. Lignin *vis-a-vis* colour will not be removed during biological treatment. Although liginin does not exert BOD, it exerts 1.8 mg COD per mg and hence violates the COD tolerance limit for discharge into inland surface waters.

In the light of this situation, it is desirable to segregate as much black liquor as possible from the digested pulp, before it is subjected to various stages of washing.

It has been reported that black liquor can be segregated by squeezing or by allowing it to drain out from a false bottom. From the information supplied by various mills, it is observed that 30 to 50 per cent of black liquor can be separated out from straw pulp and only 20% from gunny rag or rope pulp. The segregated BL cannot be discharged into stream or on land except during flood time in the river with prior approval from competent authority. Since its volume will be small it can be stored in lagoons for suitable period of time and discharged in a controlled manner into surface waters only during monsoon. This will help in reducing the colour, BOD and sodium in the remaining wastewater.

Based on the assumptions, indicated above, the pollutional loads in the final waste, after separation of BL have been worked out and presented in Table 9.

From the data given in Table 9, it can be seen that by segregating 50 per cent of black liquor from straw pulp and 20 per cent from rag pulp, it is possible to reduce the BOD load by 34 per cent and the sodium by 45 per cent. This would reduce the capital as well as running costs for the subsequent treatment of the combined waste-water. It also reduces the per cent sodium whereby the use of waste-water on land will be possible.

Another possible place for segregation is the rejects from centri-cleaners. These rejects will be small in volume but contain a very large percentage of suspended and settleable solids. If this waste-water is taken through a side hill screen, it should be possible to separate out 80-90 per cent of the suspended matter present in the centricleaner rejects. The sludge can be disposed off as solid waste. This method of segregation and treatment would considerably reduce the total load of suspended solids in the combined wastwater reaching the clarifier and lessens the problem of their handling in dilute form in the clarifier underflow.

Paper machine wastwater contains high amount of fibre which settles rapidly. This can also be recovered by employing suitable recovery system and both the recovered fibre and water can be recycled into the process. This would not only help in reducing the cost of waste treatment but also generate revenue in the form of extra paper and reduced water requirements.

**Standards For Discharge of Effluents Into Streams sewers and On Land**

The choice of method for treatment of wastewater depends on the quality requirements for final disposal. The treated effluent will have to be discharged either into sewers, if available, or surface waters. It can also be applied on land for agricultural utilization. Indian Standards Institution (ISI) has prescribed tolerance limits for industrial effluents for discharge into the three above mentioned media. These are shown in Table 10.

The tolerance limits given in Table 10 are only suggestive and these can be made more stringent or relaxed depending upon the local conditions. Further, the State and Central Water Pollution Control and Prevention Boards have been devoloping their own standards for different industrial effluents for discharge into surface waters. Therefore, the ISI Standards have to be viewed in this context and used only as guide lines.

Comparing the data given in Table 9 with ISI tolerance limits, it can be seen that the combined waste water cannot be accepted into any of the three media available for disposal and requires suitable treatment. The combined waste water after segregation of part of black liquor is also not fit for direct discharge into water course. However, combined wastewater resulting in segregations II and III can be made fit for discharge into sewers or on land for agricultural utilization by providing pretreat-

**Table 9–Characteristics of combined Wastewater with and without Black Liquor segregation**

| | With no BL segregation (I) | | With 30% straw BL and 20% rag BL segregation (II) | | | With 50% straw BL and 20% rag BL segregation (III) | | |
|---|---|---|---|---|---|---|---|---|
| | mg/l | kg/tonne paper | mg/l | kg/tonne paper | Percent decrease in pollution load | mg/l | kg/tonne | Percent decrease in pollution load |
| Flow, $M^3$/tonne | — 200 | — | — 200 | — | — | — 200 | — | — |
| Total solids | 3548 | 709.5 | 2930 | 586 | 17 | 2560 | 512 | 28 |
| Suspended solids | 1428 | 285.7 | 1300 | 260.5 | 10 | 1225 | 245 | 14 |
| COD | 2676 | 535.2 | 2138 | 427.5 | 20 | 1818 | 362.5 | 32 |
| BOD | 780 | 156 | 618 | 123.5 | 21 | 515 | 103 | 34 |
| Sodium | 423 | 84.6 | 314 | 62.8 | 26 | 255 | 51 | 40 |

**Table 10–I.S.I. Standards for Discharge of Industrial Effluents**

(All values except pH, temperature, and radioactive materials are in mg/l)

| Characteristics | Tolerance Limits for Industrial Effluent Discharged | | |
|---|---|---|---|
| | Into Inland Surface Waters (IS:2490–1974) | Into Public Sewers (IS:3306–1974) | On land for Irrigation (IS:3307–1965) |
| BOD, 5 days 20°C | 30 | 500[a] | 500 |
| COD | 250 | — | — |
| pH | 5.5–9.0 | 5.5–9.0 | 5.5–9.0 |
| Suspended solids | 100 | 600[b] | — |
| Total dissolved solids (Inorganic) | — | 2100* | 2100 |
| Temperature, °C | 40 | 45 | — |
| Oil and grease | 10 | 100 | 30 |
| Phenolic compounds | 1.0 | 5.0 | — |
| Cyanides | 0.2 | 2.0 | — |
| Sulphides | 2.0 | — | — |
| Fluorides | 2.0 | — | — |
| Total residual chlorine | 1.0 | — | — |
| Insecticides | Absent | — | — |
| Arsenic | 0.2 | — | — |
| Cadmium | 2.0 | — | — |
| Chromium (hexavalent) | 0.1 | 2.0 | — |
| Copper | 3.0 | 3.0 | — |
| Lead | 0.1 | 1.0 | — |
| Mercury | 0.01 | — | — |
| Nickel | 3.00 | 2 | — |
| Selenium | 0.05 | — | — |
| Zinc | 5.0 | 15 | — |
| Chlorides | — | 600* | 600 |
| Boron | — | 2* | 2 |
| Sulphates | — | 1000* | 1000 |
| Per cent sodium | — | 60 | 60 |
| Ammoniacal nitrogen (N) | 50 | 50 | — |
| Radioactive materials | | | |
| Alpha emitters, $\mu c$ | $10^{-7}$ | $10^{-7}$ | $10^{-9}$ |
| Beta emitters, $\mu c$ | $10^{-6}$ | $10^{-6}$ | $10^{-8}$ |

a Subject to relaxation or tightening by local anthority

b Relaxable to 750 by the local authority

* These requirements shall apply only when after treatment the sewage is disposed of on land for irrigation.

ment to bring down the suspended solids, BOD and correction for per cent sodium.

Takingthese into consideration the following methods of treatment have been suggested and discussed.

**Treatment Methods**

All the biological methods of treatment that are being used for sewage and industrial wastes can be adopted for treating pulp and paper mill wastewaters to bring down the BOD to any desired degree. Although, the BOD part of COD in the wastewater can be removed, the COD due to lignin cannot be reduced to any appreciable degree. This is due to non–degradability of lignin. Further, it gives rise to colour which persists in the effluent and in the water course, into which it is discharged, for a considerable distance.

Before the combined wastewater is treated biologically, it is necessary to remove the settleable or suspended solids to the maximum possible extent. Suspended solids in the waste can be removed by plain settling in a clarifier. The settled sludge can be thickened to about 2—4% solids concentration in a gravity thickner. The thickened sludge can be dewatered and dried on sand dying beds or in sludge lagoon. Centrifuges can also be used to concentrate the sludge such that the volume of dewatered sludge for handling will reduce appreciably. The dried or semi–dried sludge can be removed manually and disposed off as land fill.

The different methods that are normally employed for biological treatment of wastewater include anaerobic and aerated lagoons, trickling filters and the conventional or modified activated sludge process. Aerated lagoon and oxidation ditch are classified as modified activated sludge systems and popularly referred to as low cost waste treatment units for treating domestic and industrial wastewaters. All of the treatment methods can be used and the choice of one or the other depends on the locatian of the mill. For example, anaerobic lagoons will reduce the capital cost of treatment, provided the mill has the required land and natural lagoons. Further, this method will give 40—50% reduction in BOD and hence should be followed by aerobic treatment for rendering the final effluent fit for discharge into surface waters.

Activated sludge system is preferred in some places as it requires less area and gives better quality effluent. The secondary biological sludge, unlike domestic sewage activated sludge can be disposed off along with the primary sludge. Modified activated sludge processes can also be used but pulp and paper mill wastewater does not require extended aeration. Further, in this case, the extended aeration will be more expensive.

It is important to note that in the biological treatment units, the wastewater will cause excessive foaming problems due to the presence of black liquor. This problem also stresses the need for segregating as much black liquor as possible. However, foaming can be controlled by adding antifoaming agents and/or providing foam breakers by water jots.

Based on these considerations, 4 alternative flow sheets for wastewater treatments have been suggested. These will give an idea on the treatment requirements and Capital and running costs that have to be provided even at the planning stage of small mills.

Before discussing the suggested alternative treatment methods, it is worthwhile to consider the land utilization of the wastewater as a method of disposal. This would not only provide a valuable and continuous source of irrigation water but also reduce considerably the treatment requirements for the wastewater. Further this method of disposal helps in eliminating colour in the waste reaching the water bodies as the soil absorbs the lignin. This aspect was discussed earlier by one of the authors in an earlier paper. In 1974, the Government of India and the Indian Pulp and Paper Technical Association had set up a Committee to suggest the feasibility of chemical recovery and methods of effluent disposal in small mills. One of the objectives assigned to the Committee was to recommend treatment of effluent to make it suitable for agricultural purposes. The Committee submitted its report entitled 'Guide-lines for Chemical Recovery and Effluent Disposal in Small Paper Plants' in 1975. The treatment and disposal methods suggested in the Report include separation of suspended solids and discharge of the clarified effluent either on agricultural fields or into a dry nalla leading to a river. It was presumed that the effluent during its flow through dry nalla will be amply aerated and the BOD will be brought down to a satisfactory level. In making this recommendation, the following aspects should have been considered.

1. Since no black liquor will be segregated for chemical recovery, the combined effluent will be deleterious for crops since the per cent sodium will be higher than 60, and the total dissolved inorganic solids (TDS) will also be higher than permissible limit (2100 mg/l). Dilution of effluent will not bring down the per cent sodium value.
2. Nallas, whether flowing or dry are considered as inland surface waters by the Water Pollution Control and Prevention Authorities. Further, the expected BOD satisfaction, while flowing through nalla, will not take place. Hence the effluent finally joining the river or any water course will not meet the required standards.

**Suggested Treatment Alternatives**

**Treatment Alternative I** :–Alternative one envisages no segregation of black liquor and treatment of the combined wastewater after primary clarification in a conventional activated sludge system without sludge digestion facilities. However. the first washing, (i.e the concentrate pulp wash water) should be stored in an equalisation tank and mixed with other wastewaters at a uniform rate to minimise shock loads to the biological treatment unit, since pulp digestion and washing are batch operations in small mills.

The wastewater (200 $M^3$/tonne of paper) is proposed to be treated in a clarifier. The clarified effluent will be treated in an activated sludge system at an organic loading of 0.4 kg BOD/kg MLSS/day at a mixed liquor suspended solids (MLSS) concentration of 2000–3000 mg/1. The wastewater is normally deficient in nutrients (nitrogen and phosphorus) which are essential for biological treatment and hence should be fortified to get a BOD:N:P ratio of 100:5:1. Exact requirements of N and P depend on the concentration of these present in the wastewater and hence vary from waste to waste. The mixed liquor of activated sludge unit will be taken into a secondary clarifier. Required volume of secondary sludge will be returned to the aeration tank to maintain the MLSS concentration. Excess sludge is taken to primary clarifier.

The primary clarifier will have to be provided with a central thickening zone and a thickening pocket. The thickened sludge is proposed to be lagooned. The sludge lagoons are provided with a capacity to hold 200 days of sludge and divided into three cells so that they can be operated alternatively for filling, drying and cleaning. The supernatant from the sludge lagoons requires treatment and hence is taken back for treatment.

The final effluent leaving the system is expected to have a BOD around 30 mg/1 and suspended solids of about 50 mg/1 and hence satisfies IS:2490-1974 for discharge into inland surface waters. However, the effluent is likely to have COD value (around 1500 mg/1) and hence violates the standard for COD. Colour due to lignin in the effluent will also be high and this is responsible for the high COD value. If the COD has to be brought down to 250 mg/1 as prescribed in Standards, then practically all the colour due to lignin will have to be removed. With the present knowledge on the removal of colour from pulp mill wastes, the cost of treatment for colour removal will be exhorbitantly high. It is possible to reduce the colour to a major extent by black liquor segregation. No method for the removal of colour is, therefore, suggested in this paper. The treatment flow sheet is given in Figure 1.

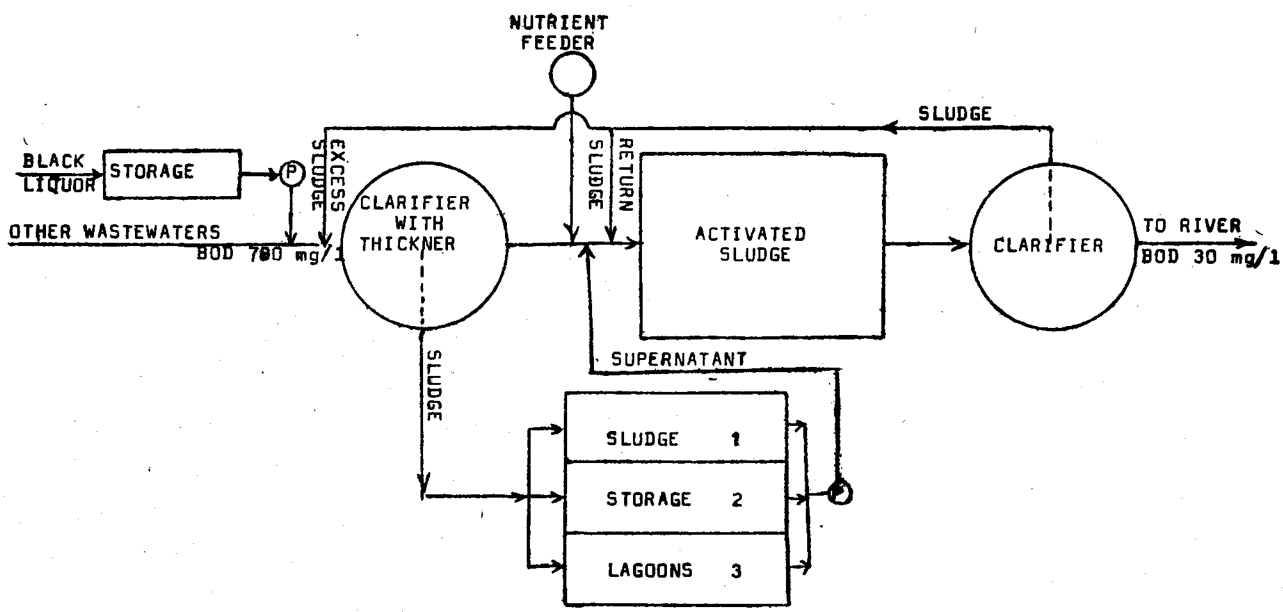


Fig. 1–Treatment Alternative I

**Treatment Alternative II** :

The suggested flow sheet for the treatment alternative II is shown in Figure 2. It is proposed to segregate about 30% of black liquor from straw digester and 20% from rag digester. The quantity of black liquor segregated is estimated to be about 2.82 $M^3$/tonne of paper and is proposed to be stored in lagoon having 200 days capacity. This lagoon will be able to handle a flow of 300 days due to evaporation that can be expected during storage. The liquor should be disposed off into the river during monsoon by controlled discharge.

The Other wastewaters (about) 200 $M^3$/tonne of paper) will be treated in the same way as in alternative I. The treated effluent is exqected to have a BOD of 30 mg/l and suspended solids of 50 mg/l and will be fit for discharge into inland surface waters except for COD and colour.

**Treatment Alternative III :**

The suggested flow-sheet for treatment alternative III, although similar to alternative II, differs from it in two ways. In this case, it is proposed to segregate about 50% of black liquor from straw and 20% from rag digesters. The segregated black liqnor (4.5 $M^3$ per tonne of paper) is proposed to be stored in a lagoon and discharged into river during monsoon.

Other wastewaters (about 200 $M^3$/tonne of paper) after primary clarification are proposed to be treated in an aerated lagoon instead of activated sludge. Nutrient addition is needed in this case also. Detention period in the lagoon will be 5 days. The aerated lagoon will be provided with a stilling chamber to prevent escape of solids in the effluent. Normally, no excess suldge is expected from aerated lagoon. Primary sludge will be disposed off into the sludge lagoons as discussed in alternatives I and II. Effluent of aerated lagoon is expected to have a BOD of 30 mg/l and suspended solids of 80 mg/l and is fit for discharge into inland surface waters except for COD and colour. The treatment flow sheet is shown in Figure 3.

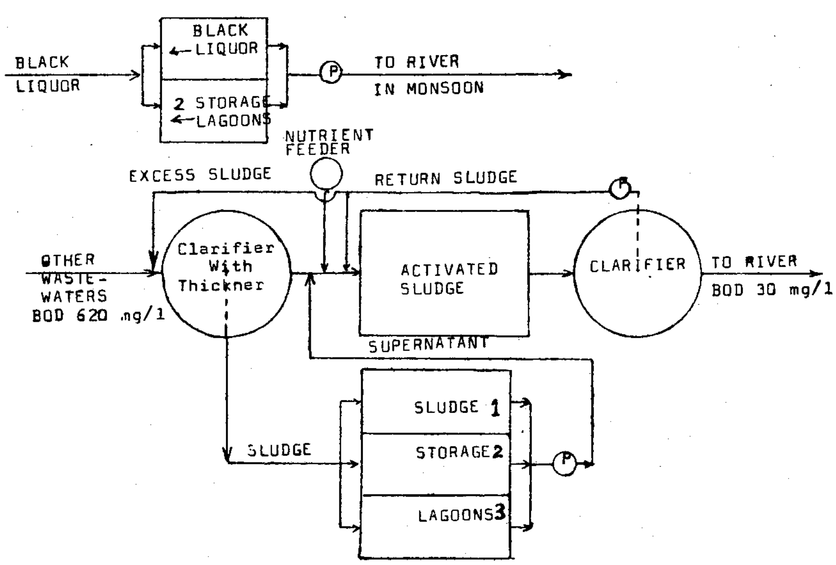


**Fig. 2–Treatment Alternative II**

**Treatment Alternative IV :**

In this alternative, it is proposed to use the combined waste, resulting after segregation of black liquor as suggested in alternatives II and III, on land for agricultural utilization. The treatment and disposal flow sheet is shown in Flgure 4.

The combined wastewater (about 200 $M^3$/tonne of paper) will be taken through a clarifier to remove the settleable solids. The clarified wastewater after mixing with calcium sulphate (gypsum), to bring down the per cent sodium below 60, will be used on land for irrigation. Depending on the type of soil, crops grown and the climatic conditions, a dose of 54 to 108 $M^3$ of wastewater can be applied on land per hectare per day.

It is of importance to mention that the studies carried out so far by NEERI, on agricultural utilization of pulp mill wastes, have indicated that several kharif and rabi crops (except 3 varieties

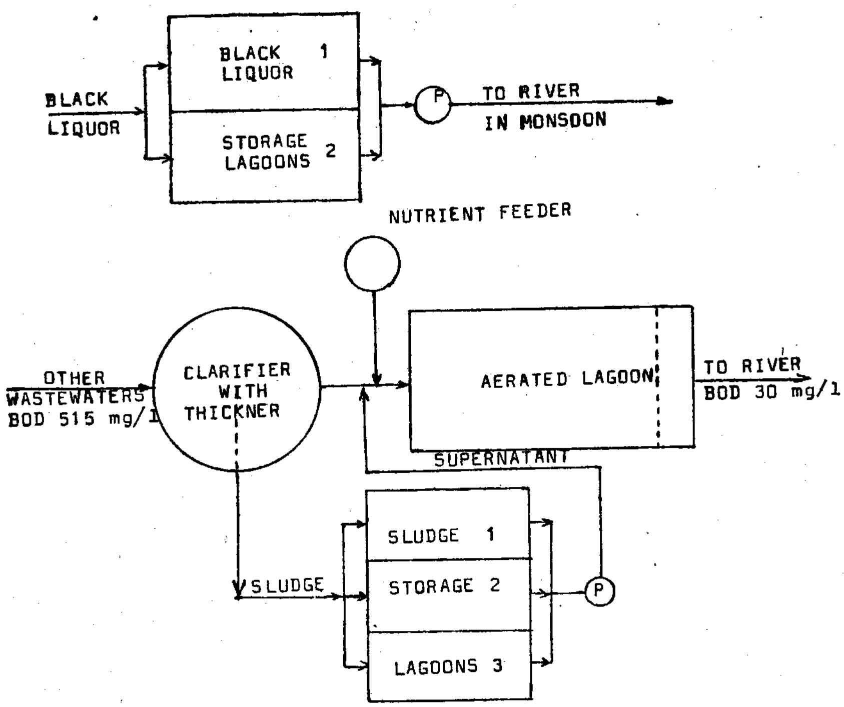


Fig. 3–Treatment Alternative III

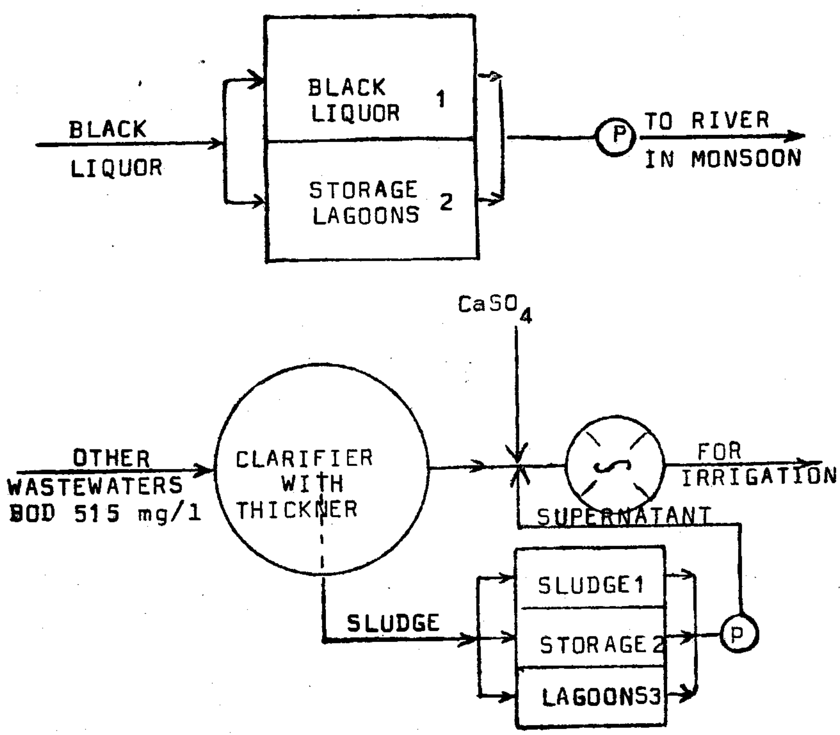


Fig. 4–Treatment Alternative IV

of grasses and groundnut) have responded favourably when irrigated with pulp mill effluent as such or diluted with plain water.

The entire quantity of partially treated combined wastewater is being used by M/s Pudumjee Pulp and Paper Mills, Poona, on land for growing a variety of crops for the last several years with good success.

The sludge from the clarifier will be treated in lagoons, as in the other alternatives. Continued use of the wastewater on land is likely to create ground water pollution due to percolation of the absorbed colour. This is a drawback for this method of dispospal.

**Economics of Wastewater Treatment.**

The capital and running costs and land requirements for the 4 treatment alternatives have been worked out to highlight the comparative economics and are presented in Tables 11 to 14. These are for small mills making unbleached paper. If bleached paper is manufactured, the costs may increase by about 5 per cent. It may also be noted that the cost of treatment will vary with the raw materials and their proportion, the method of pulping and the final products made. Hence the data presented will give an idea on the costs but should not be viewed as absolute figures for all the different situations that will be prevailing in the small mills.

The capital costs reported do not include land cost and special site conditions such as water logging, rock cutting and special foundations. The estimates do not include initial and final pumping costs for the wastewater. Capital and running costs vary from place to place and from time to time. Estimates reported here are based on prevailing rates during early 1976.

Total annual expenditure is worked out by considering the annual running cost and repayment of loan on the capital cost. Repayment of loan on the capital cost is worked out on the basis of 10 per cent interest rate and 20 year repayment period for which the capital recovery factor works out to be 0.1174.

Running cost, total annual expenditure and paper production cost due to wastewater treatment have been presented for the two situations, *viz.*, with and without nutrients and/or chemical addition. For alternatives I, II and III, chemical cost is for nutrients, nitrogen and phosphorous, at the ratio of BOD:N:P of 100:5:1 and considering that nutrients are completely absent in the wastewater. Nutrient addition will be governed by the actual concentration present in the waste and hence actual cost of nutrients will be somewhat lower than those reported in Tables 11-14. For treatment alternative IV, chemical cost is for calcium sulphate required for per cent sodium correction.

**Table 11– Land Requirement, Capital and Running Costs For Treatment Alternative I**

| Capacity TPD | Capital cost: Lakh Rupees | Capital cost: Per cent of capital cost of the mill | Running cost (Lakh rupees/yr): Without chemicals | Running cost (Lakh rupees/yr): With chemicals | Total annual expenditure including repayment of loan (Lakh rupees/yr): Without chemicals | Total annual expenditure including repayment of loan (Lakh rupees/yr): With chemicals | Paper cost due to waste treatment (Rs per tonne of paper): Without chemicals | Paper cost due to waste treatment (Rs per tonne of paper): With chemicals | Land requirement (Hectares) |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 8.50 | 3.52 | 1.60 | 3.30 | 2.600 | 4.300 | 87 | 143 | 0.95 |
| 15 | 10.60 | 3.79 | 1.82 | 4.37 | 3.065 | 5.615 | 68 | 125 | 1.35 |
| 20 | 12.30 | 3.51 | 2.10 | 5.40 | 3.550 | 6.850 | 59 | 114 | 1.70 |
| 30 | 16.00 | 3.40 | 2.57 | 7.57 | 4.550 | 9.450 | 51 | 105 | 2.30 |

**Table 12–Land Requirement, Capital and Running Costs for Treatment Alternative II**

| Capacity TPD | Capital cost: Lakh rupees | Capital cost: Per cent of capital cost of the mill | Running cost (Lakh rupees/yr): Without chemicals | Running cost (Lakh rupees/yr): With chemicals | Total annual expenditure including repayment of loan (Lakh rupees/yr): Without chemicals | Total annual expenditure including repayment of loan (Lakh rupees/yr): With chemicals | Paper cost due to waste treatment (Rs. per tonne of paper): Without chemicals | Paper cost due to waste treatment (Rs. per tonne of paper): With chemicals | Land requirement (Hectares) |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 7.55 | 3.55 | 1.55 | 2.85 | 2.44 | 3.74 | 81.3 | 124.7 | 1.15 |
| 15 | 9.55 | 3.41 | 1.70 | 3.75 | 2.82 | 4.87 | 62.7 | 108.3 | 1.80 |
| 20 | 11.57 | 3.30 | 2.00 | 4.60 | 3.36 | 5.66 | 56.0 | 99.7 | 2.35 |
| 30 | 15.41 | 3.28 | 2.35 | 6.35 | 4.16 | 8.16 | 46.2 | 50.7 | 3.50 |

**Table 13–Land Requirement, Capital and Running Costs for Treatment Alternative III**

| Capacity TPD | Capital cost | | Running cost (Lakh rupees/yr) | | Total annual expenditure including repayment of loan (Lakh rupees/yr) | | Paper cost due to waste treatment (Rs. per tonne of paper) | | Land requirement (Hectares) |
|---|---|---|---|---|---|---|---|---|---|
| | Lakh rupees | Per cent of capital cost of the mill | Without chemicals | With chemicals | Without chemicals | With chemicals | Without chemicals | With chemicals | |
| 10 | 5.89 | 2.45 | 1.60 | 2.70 | 2.292 | 3.390 | 76.3 | 113.0 | 1.57 |
| 15 | 7.48 | 2.67 | 1.85 | 3.50 | 2.728 | 4.378 | 60.5 | 97.0 | 2.25 |
| 20 | 9.10 | 2.68 | 2.20 | 4.40 | 3.268 | 5.468 | 54.5 | 91.1 | 3.00 |
| 30 | 12.26 | 2.60 | 2.70 | 6.00 | 4.140 | 7.440 | 46.0 | 82.7 | 4.20 |

**Table 14–Land Requirement, Capital and Running Costs for Treatment Alternative IV**

| Capacity TPD | Capital cost | | Running cost (Lakh rupees/yr) | | Total annual expenditure including repayment of loan (Lakh rupees/yr) | | Paper cost due to waste treatment (Rs. per tonne of paper) | | Land requirement (Hectares) |
|---|---|---|---|---|---|---|---|---|---|
| | Lakh rupees | Per cent of capital cost of the mill | Without chemicals | With chemicals | Without chemicals | With chemicals | Without chemicals | With chemicals | |
| 10 | 3.88 | 1.60 | 0.810 | 1.170 | 1.266 | 1.626 | 42.2 | 54.2 | 27 |
| 15 | 4.[illegible]2 | 1.70 | 0.825 | 1.375 | 1.391 | 1.941 | 31.0 | 43.0 | 40 |
| 20 | 5.75 | 1.65 | 0.836 | 1.556 | 1.511 | 2.231 | 25.2 | 37.2 | 50 |
| 30 | 7.57 | 1.60 | 0.864 | 1.944 | 1.753 | 2.833 | 19.5 | 31.5 | 79 |

For working out increased paper cost due to waste-water treatment, annual paper production is taken as that of 300 days. The general specifications for the civil works are as per the PWD. The storage and aerated lagoons should be pitched inside and the bottom dressed and sealed with clay blanket or such cheap suitable method.

The comparative cost economics and land requirements for the 4 alternative treatment methods are given in Table 15.

**Table 15–Comparative Costs For the suggested Treatment Alternatives 10–30 TPD capacity mills. The higher values are for the 10 TPD and the lower for 30 TPD capacities.**

| Treatment alternatives | Capital cost (Rs/TPD capacity) | Annual running cost (Rs/TPD capacity) | Increase in paper cost due to waste treatment (Rs/tonne paper | Land requirement (Hectare/ TPD capacity |
|---|---|---|---|---|
| I | 53,000–85,000 | 25,200–33,000 | 105–143 | 0.077–0.195 |
| II | 51,400–75,000 | 21,170–28,500 | 91–125 | 0.115–0.117 |
| III | 41,000–59,000 | 20,000–27,000 | 83–113 | 0.140–0.157 |
| IV | 25,200–39,000 | 6,480–11,700 | 32–42 | 2.630–2.640 |

**Treatment Alternative I :**

Economics of treatment alternative I are presented in Table 11. Capital cost for wastewater treatment is about 3.4 to 3.8 percent of the capital cost of the pulp and paper mill. The capital cost for wastewater treatment works out to about Rs. 53,000–85,000 per tonne per day capacity of the mill. Paper production cost due to wastewater treatment is about 105–143 per tonne of paper. Land requirement is lowest for this treatment alternative while capital cost is highest.

**Treatment Alternative II :**

Capital cost for wastewater treatment in alternative II varies from 3.15 to 3.41 per cent of the capital cost of the mill (Table 12). The capital cost for wastewater treatment works out to about Rs. 51,400 to 75,500 per tonne per day capacity of the mill. Cost of paper production due to wastewater treatment is about Rs. 91 to 125 per tonne of paper (Table 15).

**Treatment Alternative III :**

From the data on economics presented in Tables 13 and 15, it can be seen that the capital cost for waste-water treatment is about 2.45 to 2.67 per cent of the capital cost of the mill. The capital cost for wastewater treatment works out to about Rs. 41,000–59,000 per tonne per day capacity of the mill. Cost of paper production due to wastewater treatment is about Rs. 83–113 per tonne of paper. Capital cost is lowest for this alternative among the three, as aerated lagoon is cheaper than activated sludge both in civil works and mechanical components. Land requirement for this alternative is only marginally higher than that for alternative I and II.

**Treatment Alternative IV :**

It can be seen from the data in Table 14 and 15 that the capital cost for wastewater treatment is about 1.6 to 1.7 per cent of the capital cost of the mill. The capital cost for wastewater treatment works out to about Rs. 25,200 to 39,000 per tonne per day capacity of the mill. Cost of paper production due to wastewater treatment is about Rs. 32–42 per tonne of paper.

Both capital and running costs are lowest for this alternative since no secondary biological treatment is involved. However, land requirement is highest as the wastewater is to be applied on land for utilization and hence capital cost may work out more than for other alternatives if land cost is also included. Moreover, disposal of wastewater on land requires additional water management which are not incorporated in the estimate. The returns from such utilisation is also not included in the estimates.

**Summary**

1. The trend in establishing small paper mills, 30 tonnes capacity and below, using agricultural residues is on the increase as these can be established with low capital.
2. Capital cost for 10 and 30 TPD plants for making unbleached paper with no chemical recovery is reported to be 240 and 470 lakh rupees, respectively.
3. Caustic soda and/or lime are used for pulping. Normally straw pulp is mixed in different proportions with rag and paper pulp for making unbleached packing and wrapping papers. For making bleached paper, calcium hypochlorite is used.
4. It is estimated that about 200 $M^3$ of wastewater will be discharged per tonne of paper. Data on pollutional characteristics of black liquors, pulp washing and paper machine water are presented and discussed.
5. The combined wastewater from a mill making paper, using 0.7 tonne of straw pulp and 0.3 tonne of gunny or rag pulp per tonne of paper, without black liquor recovery, will have BOD, COD and suspended solids concentration of 780, 2680 and 1430 mg/1, respectively.
6. The BOD and suspended solids loads from small mills will be 156 and 286 kg per tonne of paper respectively and are 3 and 2.4 times the corresponding loads discharged from bigger mills. The sodium concentration

*vis-a-vis.* the per cent sodium value will also be high in small mills.

7. Segregation of most concentrated wastewaters and their treatment and disposal is discussed. Segregation of 50 and 20 per cent black liquor respectively from straw and gunny rag digesters is possible and this would reduce the BOD and sodium loads in the combined wastewater by 34 and 40 per cent. This would not only render the combined waste fit for agriculture but also reduce capital and running costs of treatment.

8. Characteristics of combined waste with and without black liquor segregation, have been discussed in the light of ISI tolerance limits for industrial effluents discharged into (a) surface waters (b) sewers and (c) on land for irrigation. The importance of the choice in locating small mills to comply with the standards that are being developed by the water Pollution Boards has been highlighted.

9. Based on the know-how developed and information gathered by NEERI, 4 alternatives have been suggested for the treatment and disposal of wastewaters. Although, biological treatment brings down the BOD and suspended solids to the IS 2450-1974 limits, COD in the treated effluent will be much higher than the required limit of 250 mg/l. Colour is also not removed.

10. The combined wastewater remaining after black liquor segregation will be fit for agricultural use after correcting for per cent sodium by addition of gypsum. This method of disposal will solve the problem of colour due to lignin in the wastewater.

11. Comparative economics for the 4 alternative have been worked out and presented. For the alternatives I, II and III, the capital cost for waste treatment ranges from Rs. 41,000–85,000 per tonne per day capacity. The increased cost of paper due to waste treatment will range from Rs. 83–143 per tonne. Alternative III will be cheapest among the above 3.

12. The capital and running costs for treatment and disposal on land for irrigation (alternative IV) are lowest (1.6 to 1.7 per cent of the capital cost of the mill) and the consequent increase in cost of production of paper will be in the range of Rs. 32-42 per tonne.

**Recommendations**

1. Since chemical recovery is not economically viable upto 30 tonnes per day capacity mills using agricultural residues, black liquor segregation to the maximum possible extent by squeezing or draining and its storage in lagoon for final disposal into water course during monsoon is recommended.

2. Recovery of fibers from the wastewater, from where-ever possible, and recycling of the recovered fiber and paper machine water is suggested to reduce the pollution and to economise water requirements in the mills.

3. Removal of settleable solids by clarification is an essential primary step irrespective of the subsequent method used for waste treatment. The primary sludge is cellulosic and, along with the excess secondary biological sludges, should be dried on sand beds or lagoons. The dried sludge is fit for disposal as land fill.

4. Among the three biological methods of treatment, alternative III is recommended in view of its simplicity in operation and its low capital and running costs.

5. For a total and most economic solution, it is recommended to use the wastewater on land for agricultural utilization as indicated in treatment alternative IV.

6. In view of the pollution problems and the costs involved in the treatment and disposal, it is recommended to give a serious technical consideration in deciding the location of small paper mills. Further it is

hoped that these recommendations will form the basis for wastewater treatment and disposal for small mills.

**Acknowledgements**

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