Studies in the Disposal of Pulp and Paper Mill Effluents in Eucalyptus Plantations

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ABSTRACT

Land disposal of untreated kraft pulp mill waste waters as irrigation water for industrial Eucalyptus Plantations has been investigated and discussed. Eight years irrigation studies have shown beneficial effect on tree growth. Effluent irrigation has induced nearly 50 percent rise in Mean Annual Increment values. Soil characteristics and productivity have not been adversely affected by effluent irrigation, though ionic c ncentration. as should be expected. has gone up sligrtly. Effluent irrigation has produced wood with higher bark contents and lower density over normally grown wood but the paper characteristics have given better overall values over unirrigated wood. Fibre dimensions of effluent grown wood are comparatively better than normal wood.

Introduction :

Rising costs of chemical and mechanical treatment of pulp and paper mill liquid effluents are proving to be a cognisable deterrent to speedy implementation of water pollution control measures in India. Huge capital outlays are required to set up even modest treatment plants and even the treated effluents do not usually meet the aesthetic standards, e.g. colour, expected in discharged effluents. Moreover high recurriug and maintenance costs of these plants can involve an appreciable percentage of the already low returns of an integrated pulp and paper mill. A case under study is that of Orient Paper Mills, Amlai, (M.P.), where an elaborate system of effluent treatment exists to treat approximately 20 MGD effluents produced during the production of 200 TPD paper. Of this quantity of effluent nearly 3.5 MGD are brown colour highly alkaline waste waters from the pulp mill area.

For the treatment of this brown effluent called grade-III effluent the Mills have installed an elaborate treatment plant at a capital cost of about 50 lacs in the Sixties and Seventies. The plant is working round the clock and in the process consumes nearly 2400 K.W. hrs power. Other regular recurring material, manpower and maintenance costs per year accumulate to approximately Rs. 3.4 lacs every year.

The treatment which involves both anaerobic and aerobic stages finally produces an effluent that is well within the standards specified under ISI Standard no. 3307-1965. The deep brown colour, however, remains. Though non-toxic to aquatic flora and fauna, this effluent becomes a source of aesthetic pollution of river into which it is finally discharge.

Land disposal of these effluents in treated or even untreated form as crop irrigation water has not only a great potential in reducing to a great extent the capital and recurring costs of conventional treatment technology but also eliminating the aesthetic pollution of riverine resources. Considerable work has been done in order to develop a technology for utilising pulp and paper mill waste waters to irrigate annual agricultural crops. Detailed bibliographical survey has been done in respect of pulp and paper mill effluents[1]. Annual agricultural crops have been studied more extensively because the results become available within a few month's time. Forest trees, because of their comparatively long rotation, have been less frequently studied. Nesterov et al have reported favourable response of several tree seedlings when irrigated with pulp and paper mill waste waters, Nesterov[2] has also reported response of several tree species to indus-

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trial effluents[1], Suitability of kraft pulp mill waste waters for slash pine plantation irrigation has been reported by Jargeman[4]. N E E R I have studied and reported the performance of *Sesbania grandiflora* (Agasti) and banana under kraft pulp mill effluent irrigation[1] (Page 103-107). Neelay and Dhondiyal have recently studied the effects of waste waters from a newsprint plant on the early growth of 13 woody forest species and reported favourable growth response in first three years study[5].

In addition to beneficial effect on plant growth the land disposal has been found effective in the removal of brown colour[6], Suspended solids and free ions from the effluent[1]. A large scale plantation irrigation system has, thus, potential of a continuously working natural filter.

To investigate in detail all the aspects of land disposal of effluents from pulp mill area an eight year project of continuous flood irrigation of eucalyptus plantation and evaluation of its effects on soil and growth and yield of wood was carried out by Orient Paper Mills, Amlai between 1977 and 1985. Results of these investigations are reported in this paper.

Materials and Methods :

Plantations—A thirty acre Eucalyptus plantation area, planted in 1970, was selected for carrying out the investigations. Soils of the plantation area are mostly sandy loam to loamy sand with slightly acidic reaction. Due to the consequent porosity the water retention capacity of the soils is low. Soil depth varies from 1 to 3 metres overlaying a continuous belt of hard rock. Initially planted at an espacement of 3m x 3m, the final plant population per acre stablished at 400 trees. Four random strips of 100 trees each were selected for recording Mean Annual Increment, plant height and diameter at breast height and total weight at the time of felling. Height and DBH measurements were recorded once a year before the commencement of spring growth. Fifteen years old and 8 years effluent irrigated trees in each strip were felled, cross cut and stacked as per the standard procedure for Eucalyptus trees. Whole felled material was also weighed. Randomly selected billets from each lot were analysed in the laboratory for bark percentage, physical and chemical characteristics of wood and pulping studies. Similar experimental procedures were followed for randomly laid strips in plantation area which was not irrigated with effluent. Otherwise, planting details and soil charecteristics were the same for both the blocks. Felling was also done at the same time.

Composite soil samples from various points spread over the demarcated area were collected at the end of felling operations in both irrigated and non-irrigated blocks. The augur depth at each collection point was maintained at one metre.

Effluent irrigation :

Effluent used for plantation irrigation is designated at the mills as grade-III effluent. Its constituents are digester house leakages, wash liquors from the pulp mill and caustic extraction effluent from the bleach plant. It is dark brown in colour with quite high alkalanity (average pH 8). Average BOD and COD values are, respectively, 206ppm and 1000ppm, characteristics in detail are given in table no. 1 as compared to IS Standard IS-3307-1965 indicating suitability of effluent for irrigation. This effluent normally goes through a series of treatment phases before final discharge into the river. For irrigation purposes, however only the pre-treatment or raw effluent was utilised.

Entire 30 acre plantation area was contour bunded with 18 inch high earth bunds. The effluent was pumped into the area at a high elevation point from which it was spread and flooded through a series of gravity

TABLE No 1

Characteristics of Untreated (raw) grade—III Effluent discharged into Eucalyptus plantation as compared to I.S. Standard.

S. No.	Parameters	Characteristics of Grade-III effluent	Tolerance limits specified bv I. S: 3307-1965.
1.	pH	8.0	5.5–9.0
2.	Total dissolved solids (mg/1)	1600	2100
3.	Sulphates (mg/1)	65	1000
4.	Chlorides (mg/1)	568	600
5.	Percent sodium	84	60
6.	BOD_5 at 20°C/mg/1	206	500

channels. In the 30 acre experimental block 20,000 gallons of raw effluent were pumped per hour continuously for about 250 dry days in each year. During the investigation period of 8 years, thus, the experimental area received nearly 120 million gallons of raw effluent every year and 960 million gallons during the entire period. In terms of volume of irrigant it comes to about 425 acre feet per year and 3400 acre feet for the whole period of experimentation.

Energy consumption in the pumping process has come to about 90,000K.W. hours each year.

Wood analysis and pulping studies.

Representative DBH logs in the size of 1.25 metres were selected from the stacks in the field from effluent irrigated and unirrigated lots and subjected to various laboratory evaluations. Bark contents and densities of wood were determined and values are given in table no. 3.

Fibre dimensions

Fibre length and diameter of wood and bark portions were determined with the help of Projectina Microscope. About 200 fibres of each were counted for length and diameter values and averages are given in table no. 4.

Chip classification

Debarked logs were chipped in the mill chipper and classified in the william chip classifier. The classification of chips is presented in table no. 5. The bark portion was separately chipped manually.

TABLE No. 2

Comparative growth performance of effluent irrigated and unirrigated Eucalyptus trees.

	Age (Yrs)	Mean tree height (m)	Mean tree DBH (m)	Per tree OB volume (m³)	MAI per acre m³
Effluent irrigated for 8 years	15	17	21	0.204	5.440
Unirrigated	15	14	19	0.136	3.620
Unirricated	18	18	21	0 264	5.866

TABLE No. 3

Physical Properties of wood samples

S. No.	Particulars	1	2
1.	Quality of wood	Eucalyptus (unirrigated)	Eucalyptus (effluent irrigated)
2.	Growing Region	Amlai Region	Amlai Region
3.	Age, year	15	15
4.	Bark content W/W	7.65	9.20
5.	Density	0 601	0 497

TABLE No. 4

Dimensions of wood and bark Fibre

Particulars	Eucalyptus (Unirrigated)		Eucalyptus (Effluent irrigated	
	Wood	Bark	Wood	Bark
Fibre Length mm				
Maximum	1.60	1.10	1.68	1 15
Minimum	0 70	0.40	0 85	0 45
Average	1.04	1.60	1.14	0.70
Fibre diameter Micron				
Maximum	17.50	17.70	17.48	17.80
Minimum	7 50	7 80	7 72	7.75
Average	10.70	10.10	10.80	10.15
Slenderness Ratio				
L/D	97 2:1	59.4:1	105.5:1	69.3:1

Table No. 5
Chips size Classification.

Mesh size mm	Eucolyptus (Unirrigated)	Eucalyptus (Effluent irrigated)
1. +29	10.24	12.50
2 —29+22	13.19	15.20
3. —22+16	32.13	29.85
4. —16÷10	33.18	29.50
5. —10+5	10.24	10.60
6. —5	1.02	2 35
7. Accepted chips (%)	78.50	74 55
8. Rejected chips (%)	21.50	25.45
9. Bulk density kg/M³	234	239

Proximate chemical analysis

Wood and bark portions were powder.d separately in the Raymond Mini mill. The resultant powder was pased through 40 mesh sieves and later analysed for various parameters like ash contents, cold and hot water solubility, 1% NaOH and Alcohol-Benzene solubility, holocellulose lignin and pentosans. Tappi standared methods were used in various analysis. Results of proximate chemical analysis are given in table—6.

Pulping studies

2.5 kg chips were digested in 30 litre electrically heated autoclave with indirect forced circulation arrangement using 16 to 18 percent chemical having 22.4 and 24.4 percent Sulphidity keeping a bath ratio of 1:4 and cooking temperature of 165° C for 240 minutes. Yields were determined according to standard methods and are presented in table—7.

Fibre classification

Fibre characteristics of wood and bark unbleaehed pulps were determined with the help of Bauer Macnett classifier. 10 gm. of pulps were taken on O. D. basis with 15 minutes classification time. The chracteristics are given in table no. 8.

Pulp evaluation

The unbleached pulps of all the cooks (wood and bark) were beaten separately in PFI Mill for different revolutions to obtain pulps of 45°SR freeness. Standard hand sheets were prepared on the Critish sheet Making Machine and their strength properties were determined. Evaluation data are given in table–9.

Soil analysis

Composite soil samples from effluent irrigated and unirrigated soils were analysed for various parameters following methods of Jackson, Pipcr and the USDA Handbook no. 60 on saline and Alkali soils. Parameters like alkalanity, organic matter contents, electrical conductivity, Calcium, Magnesium, Sodium, Potassium, Chloride, Carbonate and Bicarbonate were determined. Values are presented in table–10.

TABLE No. 6
Proximate Chemical Analysis

S. No.	Particulars	Eucalyptus (Unirrigatde)		Eucalyptus (Effluent irrigated)	
		Wood	Bark	Wood	Bark
1.	Moisture in dust (%)	6.51	5.87	6 51	7.70
	Ash (%)	0.36	6.33	0.41	4 39
2.	Cold water solubility (%)	6.30	11.87	4.20	11.35
3.	Hot water solubility (%)	11.90	15.00	6.11	14.31
4.	1% NaOH solubility (%)	11.08	23.12	10.87	21.00
5.	Alcohol Benzene solubility (%)	1.53	3.10	1.50	2.24
6.	Hollocellulose (%)	72.78	73.40	74.55	67.90
7.	Lignin (%)	25.00	18.10	26.35	25.25
8.	Pentosans (%)	12.95	11.80	13.86	12.20

All the results are expressed on (O.D.) basis.

Table No. 7

Kraft cooking of Eucalyptus

S.No.	Particulars	Unirrigated cooks					Effluent irrigated cooks		
		Wood			Bark		Wood		Bark
		a	b	c	d	e	f	g	h
1.	Chemical applied as Na_2O	16	17	18	18	16	17	18	18
?.	Sulphidity (%)	22.4	22.4	22.4	24.4	24.4	24.4	24.4	24.4
3.	Bath ratio	1:4	1 4	1:4	1:4	1:4	1:4	1:4	1:4
4.	Cooking schedule								
	i) Upto 135°C (mts)	120	120	120	120	120	120	120	120
	ii) From 135°C to 165°C (mts)	60	60	60	60	60	60	60	60
	iii) at 165°C	60	60	60	60	60	60	60	60
5.	Total cooking time (mts)	240	240	240	240	240	240	240	240
6.	Kappa No.	29.0	22.3	17.8	49.2	24.5	22.5	21.5	59.6
7.	Rejects free yield (%) (On O. D. raw material)	47.88	47.00	46.40	42.36	45.48	44.80	45.50	43.36
8.	Rejects (%) (On O.D. raw material basis)	5.08	1 49	0 51	—	2.14	1.59	0.84	—
9.	Total yield %	52.96	48.49	46.91	42.36	47.62	46.39	46.34	43.36
10.	Black liquor analysis.								
	i) °TW at 60°C	17.0	19.50	20.50	20.0	17.50	18.50	20.0	19.50
	ii) R.A.A as Na_2O (gpl)	17.05	19.37	22.47	16.27	12.40	13.95	16.27	15.50

Table No. 8

Fiber Classification of Pulp

S. No.	Mesh size	Retention % (wood)	Effluent irrigated Retention % (Bark)	Retention % (wood)	Unirrigated Retention% (Bark)
1.	+20	9.69	5.31	6.150	6.270
2.	—20+40	58.105	24.58	43.100	26.14
3.	—40—170	18.565	34.80	27.575	29.64
4.	—70+100	3.564	5.90	5.100	5.77
5.	—100+140	1.000	8.570	1.350	8.03
6.	—140	9.076	20.840	16.725	24 15

Table No. 9

Pulp Evaluation of unbleached pulp at 45° SR

S. No.	Particulars	Eucalyptus (unirrigated)				Eucalyptus (Effluent irrigated)			
		Wood		Bark		Wood		Bark	
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
1.	Revolutions	7000	5000	48000	2200	6250	5100	4975	2300
2.	Bulk (cc/g)	1.41	1.51	1.46	1.52	1.34	1.37	1.50	1.52
3.	Tensile Index (N.m/g)	58.72	61.76	67.84	16.12	74.74	75.72	68.11	32.24
4.	Burst Index (Kpa m²/g)	4 80	4.37	4.40	0.82	6.25	5.83	3.88	1.30
5.	Tear Index (m.N.m²/g)	9.13	7.61	7.59	2.60	10.00	5.81	5.88	2.20
6.	Double fold	340	310	464	2	624	788	306	4
7.	Brightness (% P.V)	32.0	24.0	26.0	17.7	28.0	28.0	29.0	17.9

Table No. 10

Chemical properties of effluent irrigated and unirrigated Eucalyptus plantation soils.

S. No.	Eucalyptus soil	pH 4.2:5	Organic matter	Exchangeable cations Ca^{++}	Mg^{++}	Na^{+}	K^{+}	EC. M.m has at 25°C	Saturation extract Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl	CO_3	HCO_3
				Meq/100 gm soil					Meq/L				Meq/L		
Plot 1	Effluent irrigated	7.6	2.05	0.027	0.013	4.34	0.42	0.42	10.0	4.0	3.391	0,30	12.0	Nil	8.0
Plot 2	Effluent irrigated	7.9	2.05	0 025	0.016	4.50	0.51	0.53	14.0	8.0	3.600	0.35	16.0	Nil	12.0
Plot 3	Unirrigated	6.2	1.31	0.046	0.006	3.17	0.28	0.12	8.0	4.0	0.739	0.22	8.0	Nil	6.0
Plot 4	Unirrigated	6.0	1.31	0.024	0.007	2.40	0.25	0.14	10.0	2.0	0.782	0.24	8.0	Nil	4.0

Results and Discussions :

Effect on tree growth—Comparative growth performance data for untreated effluent irrigated and unirrigated eucalyptus trees at 15. years age are given in table no. 2. Check data for various parameters at 18 years age from the same locality are also given in the table 10 bring out the rotation age advantage of effluent irrigated plantations.

Normally, the growth performance of eucalyptus plantations in the district has been considered poor and MAI's ranging between the minimum of 1.5m³per acre and maximum of 6.0m³ per acre have been recorded from various localities. Better maintenance of experimental blocks under normal growing conditions has given a MAI of 3.6m³ per acre at 15 years rotation. Continuous irrigation with raw effluent has, however, increased the MAI rate to 5.4m³, an increase of about 50 percent under the same geo-climatic conditions. Comparisions with 3 years older plantations in the same growing conditions (Table—2) suggest that wood yield level at 15 years under effluent irrigation become nearly at par with yield level at 18 years, an advantage that can greatly influence the economics of industrial plantation forestry and land returns.

A limiting factor in the current studies was the shallow soils of plantation area and underlyi g rock and coal formations. It limited the growth response of trees to a considerable extent. It can be expected that in more favourable geophysical conditions the growth response will be to the order of 100 percent instead of recorded 50 percent. In shallow soils another problem was encountered that of toppling down and uprooting of trees in high wind conditions. About 15 percent trees in irrigated area toppled down during the investigation period compared to 2 percent uprooting recorded in unirrigated areas.

Recent studies[5] and present observations also suggest that if effluent irrigation is begun right from the planting stage and continued through the entire rotation period till the felling, the MAI increases upto 200 percent can be achieved even in poor site index areas.

Effect on soil characteristics

Soil analysis data for both effluent irrigated and unirrigated plantation soils are given in table no. 10. Immediate effect of irrigation on continuing basis has been on the moisture contents of the soil at any given time during the dry period of the year. Greater availability of moisture has resulted in faster growth and hence taller trees in irrigated area. Addition of lignin compounds and dissolved solids to the soils from effluent has resulted in increased organic contents. In normal barren soils of the area organic contents average 0.59 percent. In raising organic matter in the soil the role of leaf litter must also be taken into account. This explains appreciably higher than normal percentage recorded for unirrigated areas.

Alkaline nature of the effluent has increased the pH of irrigated soil to a range of 7.5 to 8.0 in comparision to unirrigated areas (range 6.0 to 6.6) and virgin uncovered soils (average pH 6.5). The increase is, however, marginal considering the fact that nearly 120 million gallons of effluent have been discharged into the soil. This is also indicative of good porosity of soils of irrigated areas.

Ionic balance as might be expected, has undergone significant alteration specially in respect of Sodium, Chloride bicarbonate. All these are found in greater quantity in effluent irrigated soils. Sodium contents of irrigated soils have shown an increase of about 500 percent over unirrigated and virgin soils. Quite significant however, is the behaviour of Magnesium. In earlier studies[1] with annual agricultural Mg^{++} has shown a definite tendency towards total depletion under effluent irrigation. In eucalyptus plantation soils this trend has slowed down very significantly comparatively. Considering the data in table no. 10 for both irrigated and unirrigated soils it appears that regular leaf litter and complex chemical composition of decaying leaves has also contributed to the soil Ionic balance. Eucalyptus wood and leaves are rich in several minerals and essential oils which, on decomposition can be contributing several distinct chemicals to the soil. Eucalyptus woody matter is substantially rich In Calcium and Magnesium[7].

Low electrical conductivity of the plantation soils, both irrigated and unirrigated, is abnormal and can only be attributed to unexplored eucalyptus plants biochemistry-soil interaction. In experiments with annual agricultural crops there has been found an increased electrical conductivity in effluent irrigated soils. It has been reported that the soils of eucalyptus plantations greatly inhibit the growth of herbaceous plants[8]. More detailed studies are required to clarify this soil response.

Effect on wood characteristies and pulping behaviour

Study of table no. 3 points to higher bark contents in case of effluent irrigated trees, an increase of almost 20 percent over the unirrigated trees. Availability of greater moisture and more nutrients during the growth cycle under irrigation has brought about this increase. The wood density, however, is lower in case of irrigated trees. This is a normal expectation. Trees growing faster under favourable growing conditions produce less dense wood.

Fibre length of effluent irrigated wood has shown higher values at 1.14 m. m. compared to 1.04mm for naturally growing wood (table 4). In faster growing trees the fibres become extended and, therefore, the values obtained are as expected. The percentage of accepted chips, however, is slightly higher in case of naturally growing trees (table 5). Hollocellulose contents are slightly better in case of effluent irrigated trees. There is, however, highly significant lowering of hot water solubility of effluent irrigated wood.

Appreciable differences in pulping behaviour have been noted for effluent irrigated wood. In its case, the rejects percentage was found (table 7) in the decreasing order from 2.14 to 0.84 percent comparing with 5 08 to 0.51 percent found for natural wood. Also, the kappa no. of effluent irrigated wood pulps decline from 24.5 to 21.5 as compared to 29.0 to 17.8 observed for natural wood pulp (Figure 1). These values are indicative of the better suitability of effluent irrigated wood over natural eucalyptus wood for pulping.

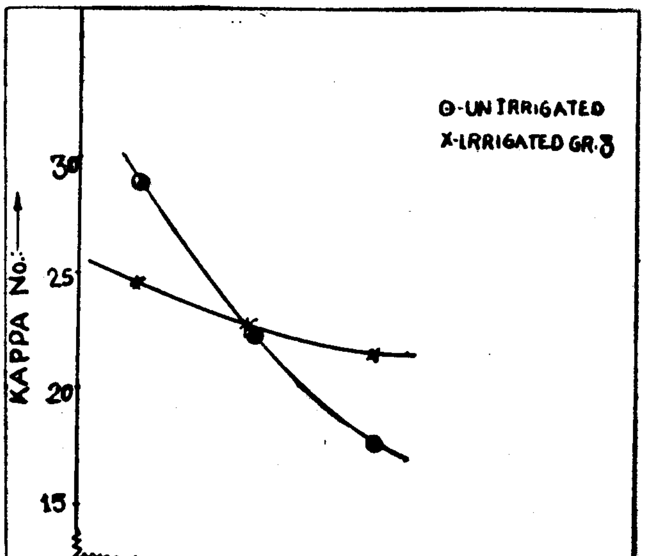

FIG. 1:— UN IRRIGATED AND IRRIGATED EUCALYPTUS DIGESTED WITH VARYING CHEMICAL PERCENTAGE VERSUS KAPPA NO.

Rejects free yields of unbleached pulps did not show significant variation. For effluent irrigated wood it was 45.48 to 45.50 percent as compared to 47.88 to 46.40 percent for naturally grown wood. Pattern of total yields as shown in Figure 2, however, shows some difference for both the type of woods due to variation in rejects percentage. Behaviour of pulps from bark portions has followed the behaviour of pulps from the wood, values of RAA are shown in figure no. 3.

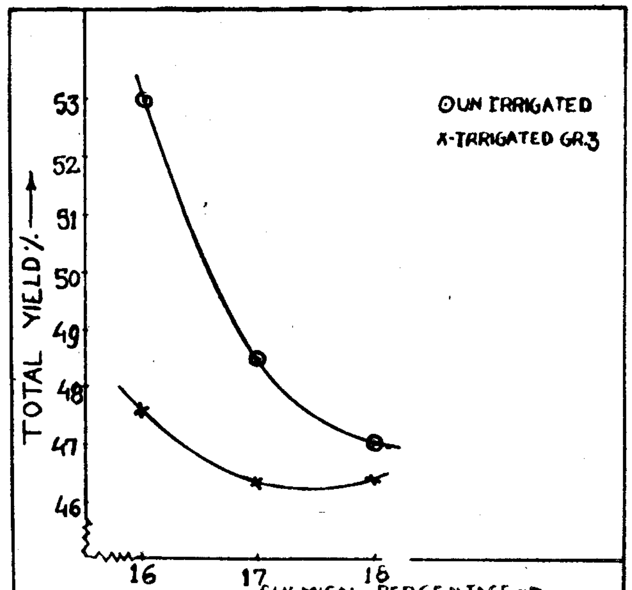

FIG. 2. UN IRRIGATED AND IRRIGATED EUCALYPTUS DIGESTED WITH VARYING CHEMICAL PERCENTAGE VERSUS TOTAL YIELD %.

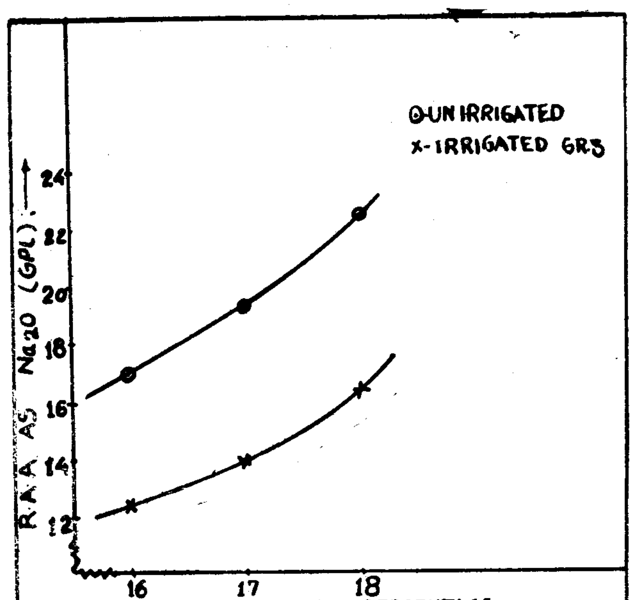

FIG. 3.— UN IRRIGATED AND IRRIGATED EUCALYPTUS DIGESTED WITH VARYING CHEMICAL PERCENTAGE VERSUS RESIDUAL BLACK LIQUOR R.A.A.

Effluent irrigated eucalyptus wood fibres have also shown better retention values (Table 8) than normal wood. Strength properties of unbleached pulps from effluent irrigated wood have shown much better values over normal wood (Table 9), Tensile index of irrigated wood pulps was as high as 75.72 compared to 61.76 of the normal wood pulps. Burst index, tear index and double fold value are also better in case of effluent irrigated wood pulps.

The above studies indicate the superiority of wood from effluent irrigated eucalyptus for pulp and paper manufacture over the wood from naturally grown eucalyptus.

Economics considerations

From the studies reported in this paper some valuable conclusions and guidelines can be drawn. Brown alkaline waste waters emanating from kraft pulp mills can be used to irrigate Eucalyptus plantations and increase per acre wood yields thus helping in raising forest land productivity and reducing the economic rotation cycle. A daily discharge of 3.5 million gallons can irrigate a minimum area of about 240 acres of plantations without any detrimental effect on plant growth and soil physico-chemical properties. In a model irrigation scheme, however, where the soils are to be kept at optimum moisture level by fortnightly irrigation, this amount of daily effluent discharge can benefit a plantation area of about 3600 acres on sustained basis. This can eliminate entirely the necessity of discharging the effluent in good water resouaces like rivers and lakes.

Wood yields per acre can be increased by a minimum of 50 percent in effluent irrigated plantations. An additional 20 percent pulp from the same plantation area means lessening of pressure on forest resources to meet the cellulosic raw material demand by ever expanding pulp and paper industry in the country.

The above benefits can be linked to cost considerations of a land disposal scheme. In the present experiments covering 30 acres of irrigated eucalyptus plantations energy consumption has been estimated at 90,000 kilo watt. hours to dispose 0.48 million gallons of raw effluent. At 50 paise per kilo watt. schedule it comes to Bs. 45,000 per year on energy costs. For discharging the whole of 3.5 MGD effluent as irrigation water, therefore the annual energy costs will come to approximately 3 3 lacs, little less than the costs involved in conventional treatment system currently operating. The block expenditure will be much less if the entire effluent quantity is discharged as irrigation water because the costly structures like clariflocculator, various lagoons, aeration ponds fitted with several aerators, will not be required, Instead 4-6 pumping sets (number depending on the topography and lay of the plantation blocks) will be required. The effluent can be spread over the area through gravity channels. Under this system the total annual recurring costs of conventional treatment can be reduced by half as the total manpower burden will be less, equipment maintenance load will be lessened by 60 to 80 percent and material costs like those of fertilisers (used in anaerobic treatment), which currently amounts to Rs 2-3 lacs every year, will be reduced to a negligible level.

The land disposal of the pulp mill waste waters as irrigation water for pulp wood plantation can, therefore, be considered as simple but vastly superior alternative to the existing treatment procedures. Three important aspects of this will be(1) Decreased operational costs, (2) Increased forest productivity and (3) Complete control of water pollution of riverine resources.

Acknowledgement :

The authors are indebted to Sri I. M. Bhandari, Executive Vice-President, Orient Paper Mills, for his constant encouragement and interest in the above studies and for permission to publish the results. Thanks are also due to Sri N. R. Agrawal, Works Manager, for his active interest in the above investigations. Some aspects of disposal and treatment of grade–3 effluent were elaborated by Sri N.N. Nayak of Water Resources Department of the Mills, for which the authors express their appreciations.

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