Wat. Sci. Tech. Vol. 22, No. 9, pp. 255–263, 1990.

0273–1223/90 $0·00 + ·50

PILOT AND FULL-SCALE TREATMENT EXPERIENCES ON PAPER MILL EFFLUENTS

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ABSTRACT

In this paper, biological treatability study results of a pilot-scale aerated lagoon treating white-waters from a mechanical groundwood-based pulp and paper mill, and long-term operating experiences on two full-scale aerated lagoon systems are presented. Biological treatability study was conducted in a 200 l semi-pilot aerated lagoon. The results have shown that five-day Biochemical Oxygen Demand (BOD_5) values are less than 50 mg/l for a hydraulic retention time of 5 days. BOD removal rate constant (K) was found as 1.01 per day for 20^{o}C. Bioassay tests were also conducted to evaluate the toxic impacts of white-waters on receiving waters and 96 hours median tolerance level T_L(96), was found as 84% for species Lapistes reticularis. Long-term operating results from two full-scale wastewater treatment plants for paper mill effluents are also presented.

KEYWORDS

Aerated lagoons; Bioassay tests; physico-chemical treatment; pulp and paper mill effluents; substrate removal kinetics; treatability studies; white-water.

INTRODUCTION

Pulp and paper industry is one of the major industries which are potential sources of pollution in the environment. Turkey can be listed among the first thirty countries of the World with respect to the production of pulp and paper. At the present time, there are about 40 paper and paperboard factories in Turkey. The government sector has a 55 percent share in the whole production and this is provided by eight factories of General Directorate for Turkish Pulp and Paper Association (SEKA), which is one of the largest state enterprises in the country. SEKA has given prime importance to the protection of the environment and four of its factories have their own full-scale wastewater treatment plants. General Directorate for Turkish Pulp and Paper Association gave the design and consultancy project of two pulp and paper factories to Istanbul Technical University with a special contract. This study was conducted in the scope of the related project.

The study was initiated with the determination of effluent characteristics and pollution profile for the pulp and paper industry. As a result of observations, by-product (fiber) recovery and waste reduction alternatives were investigated by in-plant control strategies. Physico-chemical and biological treatability studies were conducted to evaluate different treatment alternatives. In addition, results from full-scale treatment plants which are currently operated in the pulp and paper industry were analyzed to use these experiences in the determination of an appropriate treatment technology to local conditions.

MATERIAL AND METHODS

The investigated industry, SEKA Aksu pulp and paper factory,which was installed in Aksu village near the province of Giresun in the Eastern Blacksea region of Turkey,is a ground-wood-based pulp and paper mill. In this industry, an average of 65,000 t of newsprint paper is produced using 15,000 t of cellulose per year and 100 m^3 process water per tonne of paper. Production of newsprint paper includes three separate processes:barking, mechanical pulping and paper production (Fig.1). There is no cellulose production within the plant; cellulose which is required for production is supplied from the other factories of SEKA.

A comprehensive monitoring program was implemented in SEKA Aksu pulp and paper mill for one month. Hourly flowrate variations were monitored by means of three triangular weirs installed on the main discharge channels from the barking and the mechanical pulping, and the paper mill units (Fig.1). Composite samples were collected from the flow measurement points and major polluting parameters including pH, temperature, BOD_5, COD, TSS and total settleable matters (TSM) were determined. Physico-chemical analyses and treatability studies were carried out according to standard methods (1985).

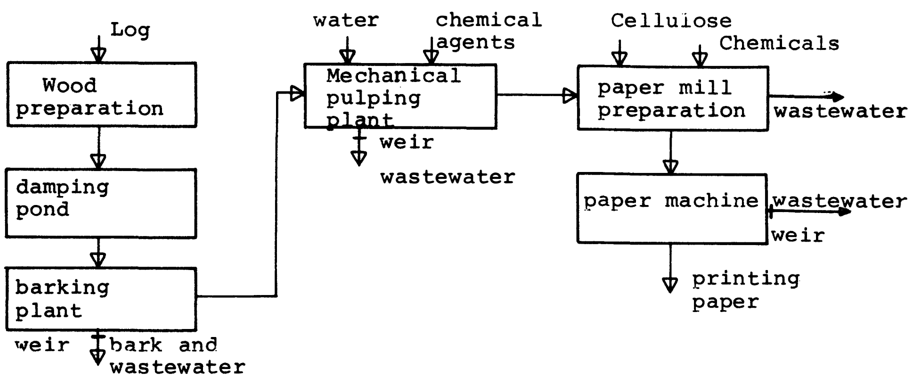

Fig.1. Process scheme of SEKA Aksu pulp and paper mill.

Aerobic biological treatability experiments were conducted in a pilot aerated lagoon (AL) plant. The pilot AL consisted of a cylindrical aeration tank with a volume of 200 l (Fig.2). Diffused air was used to supply the dissolved oxygen for microorganisms. The system was operated as batchwise and the reactor was fed with supernatant after 1 h sedimentation of combined effluent once a day. Domestic wastewater was used as the seed, and essential nutrients (N and P) were supplied to maintain BOD_5:N:P ratios of about 100:3:1. The pilot AL was operated for about 2 months at room temperature (~20 °C). Hydraulic retention times were varied in the range of 4.5 to 13.5 d.

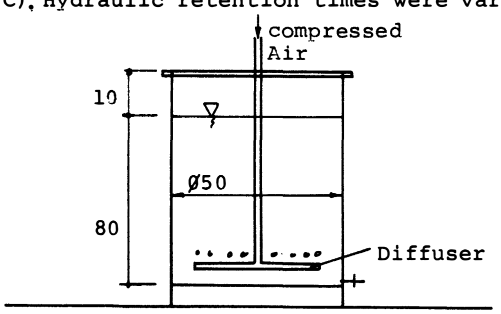

Fig.2. Pilot aerated lagoon system

Long-term performance data for two full-scale aerated lagoons were evaluated. The first AL(TP1) has been used to treat effluents from chemical treatment units of an integrated pulp and paper mill. In that plant, paper has been produced using sulphate and linters cellulose. Total design capacities for cellulose and paper are 226,500 t/year and 120,000 t/year, respectively. Specific wastewater flows have ranged from 260 to 320 m^3 per tonne of produced paper.

The second AL (TP2) has been used to treat effluents from chemical sedimentation and neutralization units of another pulp and paper mill. Specific wastewater flows have ranged from 365 to 540 m^3 per tonne of produced cellulose. Straw and reeds-based cellulose has been produced in this factory. Descriptions of the evaluated two lagoon systems are summarized in Table 1. Flow diagrams for each system are presented in Fig.3 and 4.

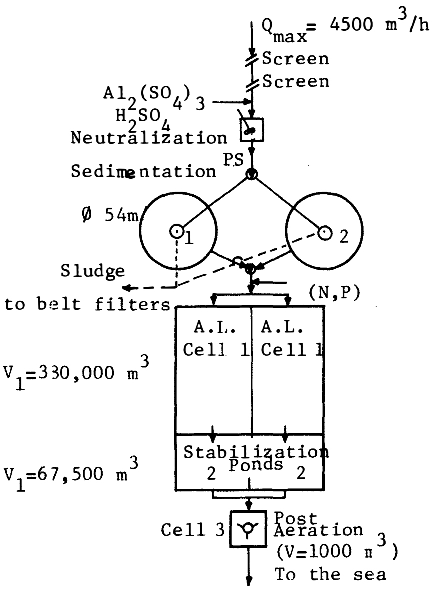

Fig. 3. Flow scheme of wastewater treatment system for the first plant(TP1).

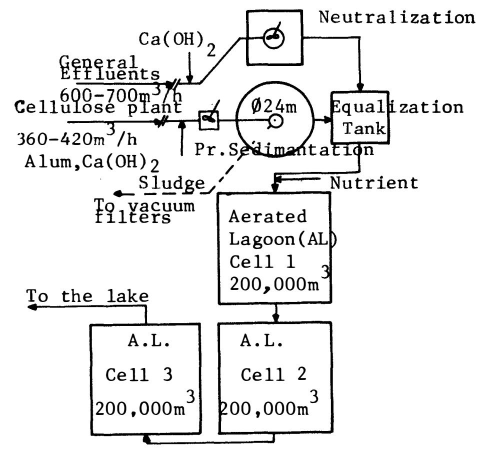

Fig. 4. Flow scheme of wastewater treatment system for the second plant (TP2).

TABLE 1. Descriptions of Full-Scale Aerated Lagoon Systems Operating in Pulp and Paper Industry in Turkey.

	TP1	TP2
Design capacity (m^3/h)	4500	1200
Influent COD of AL (mg/l)	700-1200(880)	385-1210(810)
AERATED LAGOONS		
Number of Cells in Series/or in parallel	2 parallel	3 series
HRT (days)	7	7
Liquid depth (m)	4	4.5
No of aerators	12 x 55 KW	6+4+4=16x75KW
STABILIZATION PONDS		-
No of Cells in parallel	2	
HRT (days)	1	
Liquid depth (m)	1.5	
POST AERATION TANK		-
Volume (m^3)	1000	
No of aerators	1 x 55 KW	

RESULTS AND DISCUSSION

Waste Characterization

Waste characterization includes flow rate measurements and determination of effluent parameters. Hourly flowrate variations were monitored for a month on the main discharge channels from the barking and the mechanical pulping plants, and the papermachine. Composite samples were collected from the flow measurement points and major pollution parameters were analyzed and results are summarized in Table 2. Flowrate measurements and discharge standards were also given in the same Table. As indicated in Table 2, wastewaters from the investigated industry are high in dissolved and suspended organic loadings. Investigations have shown that there are strong correlations between BOD_5 and TSS, BOD_5 and COD parameters. As a result, the most practical method of removing suspended solids was found to be physico-chemical treatment.

TABLE 2 Effluent Characteristics of SEKA Aksu Paper Mill

Location	Flowrate (m^3/h)	pH	T (^oC)	TSS (mg/l)	TSM (ml/l)	COD (mg/l)	BOD_5 (mg/l)
Barking plant effluent	112-300 (231)*	7.2-8.2 (7.6)	24-30 (27)	880-1000 (930)	80-100 (95)	1000	(350)
Mechanical pulping plant effluent	53-408 (258)	6.5-7.9 (7.4)	22-30 (26)	200-1200 (590)	30-350 (90)	2100-4000 (3050)	(900)
Paper machine effluent	249-395 (311)	6.5-7.9 (7.4)	24-30 (27)	480-1640 (950)	90-160 (130)	1550-2400 (1975)	(550)
Combined effluent	(960)	7.2-8.5 (7.6)	25-35 (27)	440-1040 (680)	70-100 (86)	(900)	(345)
Discharge Standards for Marine Outfall		6-9	35	350	-	400	250
Discharge Standards for Rivers		6-9	-	-	0.5	100	40

* Values in brackets show average values.

Reduction of Pollution Loads in SEKA Aksu Pulp and Paper Mill

It is possible to reduce the volume of the effluents by recirculating some parts of the process waters in pulp and paper factories. An extensive program, financed by United Nations Development Organization (UNIDO) for reduction of water use and fiber losses has been practiced since 1985 in SEKA Aksu plant. In the related project, a 50 % reduction in water demand and a 64 % decrease in fiber losses have been proposed by effective in-plant control strategies. At present time, process water requirement has been reduced from 140 to 100 m^3 per tonne of paper produced, and the target is 70. This corresponds to about 30 % reduction both in water use and fiber losses. Despite an extention of the plant capacity to about 100,000 tonnes paper per year, it has been expected that the specific water use would remain constant at about 70 m^3 per tonne of paper produced. This amount is quite satisfactory when it is compared with the varying water consumption in the range of 40-120 m^3/tonne paper for mechanical paper production (EPA, 1982). A 50 percent reduction in process water supply by recirculating the effluent from the chemical treatment unit has been proposed in the wastewater treatment plant that was designed by Environmental

Engineering Department of Istanbul Technical University. With such an application, besides reduction of raw water demand, a significant amount of heat recovery would also be possible.

Treatability Studies

Chemical and biological methods have been largely applied for treatment of wastes from pulp and paper industry. Waste treatment methods include chemical treatment followed by any of the systems such as marine outfalls, biological treatment and/or soil irrigation. The most common method of treatment for this industry is chemical treatment followed by aerated lagoons.

Physico-chemical treatability studies. Chemical treatment is a convenient method for reduction of suspended solids. It is a well known application that alum is an effective coagulant aid for wastes from pulp and paper industry. An extensive chemical treatability study was conducted to determine optimum concentration of chemicals. BOD_5 and COD removals were 51 % and 61 % for combined effluent, respectively. Concentrations of effluent suspended solids were less than 50 mg/l in all experiments. Optimum alum concentration was determined as 200 mg/l and addition of polyelectrolyte at 5 mg/l caused an extra increase in the floc formation. Results of treatability study with alum are given in Table 3.

TABLE 3 Physico-chemical Treatability Study Results with 200 mg/l Alum

Wastewater	pH	TSS (mg/l)	Removal Efficiencies(%) COD	BOD_5
Mechanical pulping and paper machine effluents	6.3	50	78	64
Combined effluents including barking wastes	6.1	50	61	51

Treatability studies with pilot AL. Since BOD_5 and COD values of effluents from the physico-chemical treatment unit did not meet discharge standards, the process wastewaters were further treated in a pilot AL system.

The flowrate of the feed was gradually increased from 6.7 l/d to 44.4 l/d and a COD removal of more than 70 % was achieved for all loading rates. Average values of the feed COD and BOD_5 were 600 mg/l and 270 mg/l, respectively. The steady-state treatment results of the pilot AL are given in Table 4.

TABLE 4 Steady-State Treatment Results of the Pilot AL.

Flowrate (l/d)	HRT (d)	Effluent COD (mg/l)	Effluent BOD_5 (mg/l)	Effluent TSS (mg/l)	Removal Efficiencies (%) COD	Removal Efficiencies (%) BOD_5
6.7	30	40	10	500	93	96
14.8	13.5	80	20	600	87	93
26.7	7.5	125	31	485	79	89
44.4	4.5	180	55	650	70	80
25	8.0	120	30	470	80	89

Kinetic Evaluation. The substrate removal in the completely mixing aerated lagoons can be estimated by the following equation:

$$S = S_o/(1+K.\bar{t}) \qquad (1)$$

where S_o is the influent substrate concentration (mg/l), S is the effluent (or the lagoon) substrate concentration (mg/l), $\bar{t}$ is hydraulic retention time (day) and K is substrate removal rate constant (l/d). Considering the treatability results given in Table 3, the substrate removal rate constants were found for about 20°C as 0.51 per day for the COD basis and as 1.01 per day for the BOD_5.

The substrate removal rate constants can be calculated for any temperature different from 20°C by using Arrhenius equation.

$$K_T = K_{20}.\theta^{T-20} \quad (2)$$

where θ is a constant which is generally equal to 1.035-1.10 for industrial wastes (Arceivala, 1986). Average BOD_5 removal rate constants for pulp and paper mill effluents have been reported as 0.81/day, which is reasonably close to the value predicted in this study (McKeown et al, 1974). Considering that the discharge standards of BOD_5 to the rivers are 40 mg/l, the required retention time in aerated lagoon is calculated by Eq.1 as 5.7 days.

Effects of Pulp and Paper Mill Effluents on Macrofauna

Lethal or sublethal effects of pulp and paper mill effluents or of their constituent chemicals are determined with bioassay techniques. This test requires a standard test organism to facilitate interlaboratory comparisons. Frequently used species include salmonides, such as Salmo and Oncorynchus, group of the genus Poecilia, and goldfish of the genus Carassius. In this study, species of Lepistes reticuloris were used as the test organism in bioassay tests, and 96-hr median tolerance level (96-hr LC_{50}), the volumetric lethal concentration at which 50 % of fish are dead after 96-hr exposure, was determined as 84 %. More information about bioassay test can be found elsewhere (Eroğlu et al, 1988). Bioassay lethal data with Lepistes species suggest that pulp and paper mill effluents are not particularly toxic. Despite the number of papers published (Poole et al, 1978), direct toxic effects, apart from accidental spills of process chemicals or fungicides, do not appear to pose serious problems, even though after minimal dilution, in most receiving waters. Considering a minimum initial dilution of 40 times by the marine outfall system, no toxic effect from pulp and paper industry wastes in the marine environment is expected.

Design Considerations and Cost Analysis

Two alternatives were considered for treatment of SEKA Aksu pulp and paper mill. The first alternative was chemical treatment followed by high-rate aerated lagoon and marine outfall system; the second one was chemical treatment followed by standard-rate aerated lagoon. Final effluent from the aerated lagoon was planned to be discharged to the Aksu river which flows along the eastern boundary of SEKA Aksu pulp and paper mill.

From the findings of this study it can be concluded that the AL system with a 7 days HRT after chemical treatment with alum would produce a BOD_5 suitable to discharge into Aksu river. On the other hand, a high-rate aerated lagoon treatment of effluents from chemical treatment would be employed to satisfy discharge standards to the sea. Based on pilot-scale treatability studies, the full-scale wastewater treatment system was designed and parameters for the main treatment units of the two alternatives are given in Table 5.

The cost estimates cover the construction and operation costs of the complete treatment system including bar screens, rotary sieves, pumping stations, chemical treatment, aerated lagoons, sea discharge system, sludge dewatering, and chemical dosing units expenses. The cost data presented in Table 6 shows annual operation and investment costs for the two alternatives.

Evaluation of Full-Scale AL Performances

One of the principal objectives of this paper was to outline the treatment performances of existing aerated lagoons used for the treatment of the pulp and paper mill effluents in Turkey. Long-term operating results, covering 1987 and the first half of 1988, in two full-scale aerated lagoons are presented below.

Biochemical oxygen demand. In general, the monthly average effluent concentrations of the lagoons decrease to the minimum values, while BOD_5 removal efficiencies reach their maximum values during the summer months. The AL system performances significantly decrease during the winter season in TP2

TABLE 5 Summary of Design Parameters

Parameter	First Alternative	Second Alternative
Chemical Treatment Units:		
Sedimentation Tanks (2 units):		
Diameter (m)	35	35
Surface Hydraulic Load (m^3/m^2-h)	0.45	0.45
Side water depth (m)	3.6	3.6
Biological Treatment Units:		
Aerated Lagoons		
Liquid depth (m)	4.0	4.0
HRT (days)	1.0	7.0
No of cells in series	1	2
Surface area of each cell(m^2)	2470*	17300*
Total aerator power (KW)	25	120
Marine Outfall System:		
Pipe Diameter (mm)	600	-
Pipe Length (m)	1300	-
Pipe Material	GRP	-

* Design flowrate of biological treatment units was reduced about 50 percent by recirculating effluents from chemical treatment to the pulp and paper mill process.

TABLE 6 Summary of Construction and Operation Cost Estimated For 1989.

Parameter	1st Alternative	2nd Alternative
Energy cost	$ 53500.-	104000.-
Chemical cost	$ 119000.-	429000.-
Personal cost	$ 76000.-	90000.-
Construction cost*	$ 185000.-	150000.-
Total cost	$ 433500.-	773000.-

* Annual interest rate and the plant life were assumed 8% and 25 years respectively.

that is located in a cold region with a lagoon temperature of 4 to 8°C(Fig.6). The AL performance of TP1 during the winter seasons, however, does not differ so much from the annual averages, since TP1 is located in a quite temperate region with a lagoon temperature of 18 to 20°C for winter conditions(Fig.5). BOD_5 and COD removal rates for TP1 and TP2 in the winter and summer seasons are given in Table 7 together with substrate removal rate constants(K).

TABLE 7 The AL System Efficiencies and Rate Constants

Plant	Summer Months					Winter Months				
	Lagoon Temp.(°C)	Efficiency BOD_5(%)	Efficiency COD(%)	K(BOD) (1/d)	K(COD) (1/d)	Lagoon Temp(°C)	Efficiency BOD_5(%)	Efficiency COD(%)	K(BOD) (1/d)	K(COD) (1/d)
TP 1	28-35(30)	86	51	0.89	0.13	18-20(20)	83	44	0.63	0.09
TP 2	19-23(20)	76	49	0.08	0.032	4-8(5)	38	31	0.025	0.022

Considering the effluent standards for BOD_5 and SS are 270 mg/l and 130 mg/l, respectively, the effluent BOD_5 values in both lagoons have met these standards for almost all months.

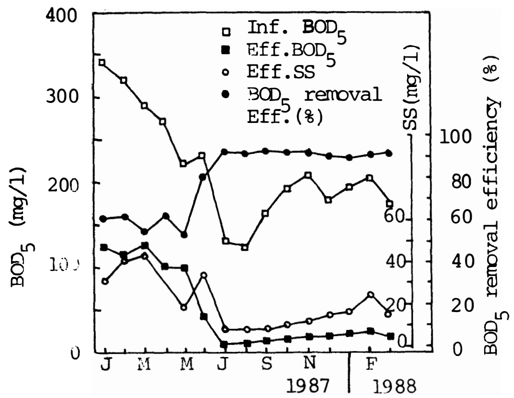

Fig.5. Monthly average concentrations of influent BOD_5, effluent BOD_5 and effluent SS, and BOD_5 removal efficiencies for TP1.

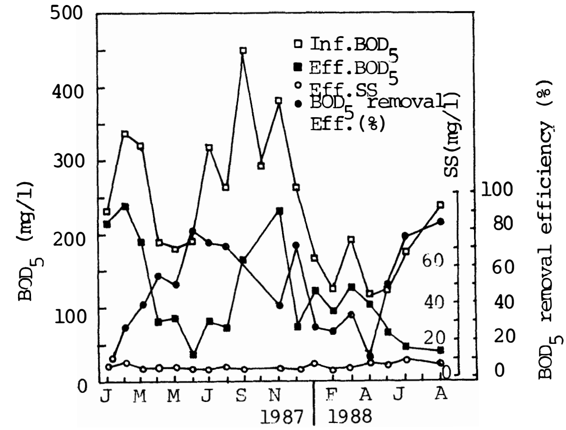

Fig.6. Monthly average concentrations of influent BOD_5, effluent BOD_5 and SS, and BOD_5 removal efficiencies for TP2.

Effluent suspended solids. Concentrations of effluent suspended solids in the TP1 have a significant correlation to the effluent BOD_5 values. In the TP2, however, suspended solids concentrations of the effluent are almost constant in the range of 5 to 10 mg/l. In both lagoons, the standard for suspended solids has been satisfied for all months (Figs.5 and 6).

Substrate removal rate constants. Substrate removal rate constants (K) defined in Equation 2 were calculated for TP1 and TP2 in summer and winter conditions (Table 7). Rate constants for TP1 are quite reasonable with the values reported by Mckeown et al (1974). On the other hand, rate constants for TP2 are lower than predicted values of operated lagoons treating pulp and paper mill effluents. The reason for such low rate constants was thought to be as the result of the cold climate and the nutrient deficiency. The average values of temperature correction factor (θ) in Eqs.2 were calculated as 1.05 for TP2 and as 1.035 for TP1, and it was concluded that a median value of 1.035 for θ could be used to estimate effluent BOD at various operating temperatures.

CONCLUSION

A 50 percent reduction in process water supply is possible by recirculating the effluent from the chemical treatment unit for the pulp and paper industry. Chemical treatability studies with alum resulted in BOD_5 and COD removals of 51% and 61%, respectively. Optimum alum concentration was determined as 200 mg/l for white-waters from the investigated industry and the addition of polyelectrolyte at 5 mg/l caused an extra increase in the floc formation. Considering the treatability results with the pilot aerated lagoon, the substrate removal rate constants were found for about 20°C as 0.51 d^{-1} for the COD basis and as 1.01 d^{-1} for the BOD_5.Bioassay tests suggest that pulp and paper mill effluents are not particularly toxic, and 96 hours median tolerance level, $T_L(96)$, is 84% for species *Lepistes reticularis*. Long-term operating results from two full-scale wastewater treatment plants treating pulp and paper mill effluents in Turkey clearly show that mechanically aerated lagoons are still reliable and appropriate systems to treat wastes from the pulp and paper industry.

ACKNOWLEDGEMENT

The authors appreciate Turkish Pulp and Paper Association (SEKA) for permission to publish the data used in this study.

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