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MARINE OUTFALL ALTERNATIVE TO SOLVE THE COLOR PROBLEMS OF PULP AND PAPER INDUSTRY EFFLUENTS

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ABSTRACT

In this paper, elimination of color from the effluents of the secondary stage biological treatment plant of an integrated pulp and paper mill located at a tourism resort was investigated by using a marine outfall system. The investigated mill has a full-scale aerated lagoon system treating effluents from a chemical pre-treatment plant. The colored effluents from the treatment plant have been discharged to a river ending in the Mediterranean and this has resulted in deterioration of the natural appearance of the coastal waters used for recreational purposes. In this study, a marine outfall system with a diameter of 1200 mm and a multiport diffuser of 290 m were planned to eliminate the color problem from the lagoon effluents. The required initial dilution to reduce the color to unnoticeable levels in the marine environment was determined 70 by laboratory-scale dilution experiments. In addition to these investigations, long-term full scale treatment results of the related industry are presented. Oceanographic studies and water quality measurements were performed to evaluate the effects of effluents from the industry on the marine environment. Bioassay tests were also conducted to assess the toxic impacts of the secondary treatment effluents on the macro fauna using *Lapistes retucularis* as a test species. Considering these findings, a marine outfall system was designed. The designed marine outfall system is currently under construction.

KEYWORDS

Aerated lagoon; Bioassay tests; color elimination residual COD; marine outfall; oceanographic studies; physico-chemical treatment system; pulp and paper mill effluent; special construction for muddy sea bottoms.

INTRODUCTION

Pulp and paper industry is one of the major industries which are sources of environmental pollution. Despite continuing improvements in in-plant process control technologies, it is still necessary to treat pulp and paper mill effluents externally. Biological treatment systems such as aerated lagoons and activated sludge process are usually able to remove 85–95 % of the readily biodegradable fraction of biochemical oxygen demand (BOD) for these effluents. However conventional chemical and biological treatment systems are generally

less effective in removing some effluent constituents such as color, chemical oxygen demand (COD) and organochlorine compounds.

In the investigated industry, the Turkish Pulp and Paper Association's (SEKA) Dalaman Pulp and Paper Mill produces paper using sulphate and linters cellulose. Total design capacities for cellulose and paper are 225,000 t/year and 120,000 t/year respectively. The mill has a full-scale treatment plant with a capacity of 4500 m^3 per hour. The treatment plant has satisfied the effluent discharge standards which are currently applied for the pulp and paper industry but any significant color reduction cannot be achieved. The dark-brown colored effluents from the mill's treatment plant have been discharged to the Dalaman River via a 13 km long concrete collector and this has resulted in deterioration of the natural appearance of the coastal waters (Fig. 1). Considering the recreational importance of the Mediterranean coast of the region, SEKA decided to solve the color problem from the Dalaman Mill and the project was given to the Environmental Engineering Department of Istanbul Technical University (ITU). A marine outfall system was chosen as the most feasible and appropriate technology for color elimination from the investigated Dalaman Mill by ITU. This paper presents the results of the related project.

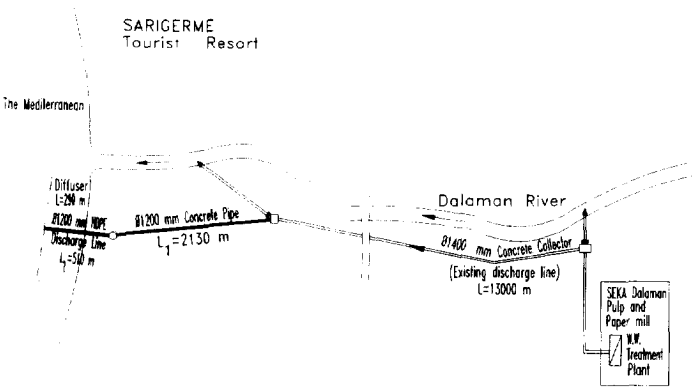

Figure 1. Schematic plan for SEKA Dalaman Pulp and Paper Mill effluent collector and marine outfall system.

RESULTS AND DISCUSSION

Evaluation of existing wastewater treatment system

SEKA Dalaman Pulp and Paper Mill has a full-scale aerated lagoon system for wastewater treatment. Description of the treatment system is given in Table 1.

Most of the suspended solids (SS) and COD have been removed in the chemical pre-treatment units. Alum and PE have been used as coagulants for the chemical pre-treatment. This treatment plant was started up in 1971 and has been carefully operated since then. Figure 2 shows monthly average COD, BOD_5 and SS measurements of the lagoon effluents for the last 1.5 years (Eroglu *et al.*, 1991).

The treated effluents have always satisfied the discharge limits (COD = 1000 mg/l, BOD_5 = 350 mg/l, SS= 50 mg/l) but the dark brown color of the raw wastewaters have remained almost unchanged during the treatment operations. Excluding the color, the performance of the treatment plant is high and the total COD's in the lagoon effluent are around 300 mg/l which is nearly equivalent to the total residual inert COD of the effluent (Öztürk *et al.*, 1994).

Table 1. Description of Seka Dalaman Pulp and Paper Mill's full-scale wastewater treatment system

Design capacity (m^3/h)	4500
Influent COD (mg/l)	1400-2400 (1800 ave.)
CHEMICAL PRETREATMENT	
No of Sedimentation Tanks	2
Diameter (m)	54
AERATED LAGOONS (AL)	
Influent COD of AL (mg/l)	700-1200 (880 ave.)
No of cells in parallel	2
Effective volume (m^3)	2x330,000
Water depth (m)	4
No of surface aerators	12x55 kW
STABILIZATION PONDS	
No of cells in parallel	2
Effective volume (m^3)	2x67,500
Water depth (m)	1.5
POST AERATION TANK	
Effective volume (m^3)	1000
No of surface aerator	1x55 kW

Standard toxicity tests proposed by AWWA Standard Methods (1990) were applied using *Lepistes reticularis* as the test organisms to evaluate lethal or sublethal effects of the SEKA Dalaman Mill's effluents. Toxicity tests have demonstrated that the toxicity dilution factor (TDF) is the same both for the wastewater samples from the influent and the effluent of the aerated lagoon system. In other words, any fish death has not been observed for 96 hr exposure with undiluted wastewater samples. Considering an average dilution of 70 by the marine outfall system, no toxic effect from the Dalaman Mill's wastes in the marine environment is expected. Similar findings are also reported in the literature for pulp and paper mill effluents, Öztürk *et al.*, (1990) and Poole *et al.*, (1978).

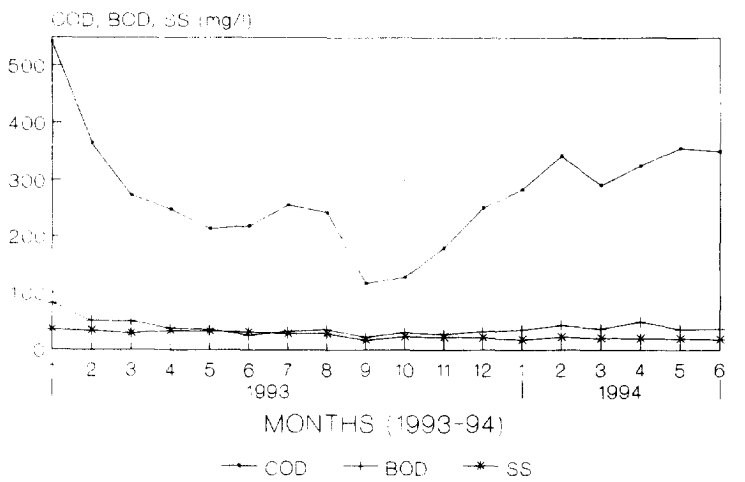

Figure 2. Monthly average concentrations of COD, BOD_5 and SS for the effluents from the SEKA Dalaman aerated lagoon system.

Marine outfall as an alternative for color elimination

Why a marine outfall system? Pulp and paper industry effluents have generally a serious color problem like some other industries including textiles, fermentation and sugar. Conventional color removal technologies such as activated carbon, poly electrolytes and ozonization are currently not applicable economically for the pulp and paper industry. As a result of this reality, the color is mainly not considered as a standard polluting parameter in industrial effluent discharge standards. Dilution with the municipal wastes and joint treatment in the central city treatment plants are the most common ways of practice for these sort of colored industrial effluents so far. However, a marine outfall alternative can also be a feasible solution for the color problem if a proper recipient is available near the industry. The SEKA Dalaman Pulp and Paper Mill is an unique example for such an application. The colored effluents from the Dalaman Mill could easily be discharged to the Mediterranean bottom waters by gravity and the color problem could be eliminated by sufficient initial dilution with a multiport diffuser system. Considering these unique advantages, ITU and SEKA considered that the marine outfall system was the most practical and feasible technology for the ultimate disposal of the Dalaman Mill's colored effluents.

Color vs dilution experiments

Dilution experiments were carried out with the lagoon effluents and the Mediterranean water to assess the effect of the dilution on the color. For this purpose, the color measurements were performed by a spectra-photometer at 420 nm wave length and a colorimeter, and the results are given in Table 2. Considering the results given in this Table, the required initial dilution was estimated as about 70 to eliminate the color completely and the diffuser design was based on this value.

Table 2. Dilution vs color experiments results

Dilution Ratio	31.3.1991 Abs.	Transmit. (%)	19.6.1991 Abs.	Transmit. (%)	Color (Pt-Co units)
1.0	0.34	45	0.54	28	540
1.33	0.26	54.5	0.40	40	410
2	0.17	68	0.25	55	280
4	0.09	81	0.14	74	140
5	0.07	85	0.11	78	100
6.67	0.035	92	0.073	84	70
10	0.025	94	0.050	90	50
20	0.025	99	0.015	97	30
50	0	100	0	100	10
100	0	100	0	100	0
200	0	100	0	100	0

Site surveys

Topographic surveys. Topographic surveys were carried out to determine the final location of the discharge lines both on land and sea bottom and detailed topographic maps were prepared. The same total station was used both for the topographic measurements and oceanographic studies.

Oceanographic investigations. Oceanographic studies were carried out on 3 different dates to assess the seasonal variations in the marine environment. In this content, physical oceanographic parameters including temperature, conductivity, salinity, secchi disc depth and the current velocities and directions were sampled

at four different oceanographic stations. Beckman RS-5 model salinometer was used for temperature, conductivity and salinity measurements. Oceanographic densities were calculated by using the relations given by Riley and Skirrow (1975). A linear density gradient of about $5x10^{-5}$ g/cm^{3}m was found for the summer period. Secchi disc weather depths were in the range 9–20 m depending on the weather conditions. Based on the long term measurements at Dalaman Meteorological Station, the dominant winds are within the sector of ESE–S–W. On-site current measurements obtained by current meters show that the 95 percentile current velocities are 10 cm/s for the upper part and 5 cm/s for the bottom part. Current directions are quite variable depending on the wind directions.

Coastal water quality measurements. Coastal water quality parameters such as pH, concentration of dissolved oxygen (DO), BOD_5, total kjeldahl nitrogen (TKN), total phosphorus (tot. P) and total coliform were measured for the studied coastal waters at the same oceanographic sampling stations. All the measurements were performed according to AWWA Standard Methods (1990). The results measured in June 1991 are given in Table 3. Considering all the results for three different times, it can be concluded that all three (BOD_5, TKN and Total-P) parameters are less than 1.5, 0.85 and 1.5 mg/l, respectively. Concentration of DO is generally at the saturation value and concentration of the total coliforms are also very low, less than 15 per 100 ml.

The T_{90} value representing bacterial die off rate was determined as 0.9 hour for the summer in Dalaman coastal waters by using the PE bag technique. This value is in a good agreement with the value for a nearby Mediterranean coastal city, Bodrum, (0.7–1.0 hour) determined by ITU previously.

Table 3. Results of coastal water quality surveys (Dalaman, ITÜ-17.06.1991)

Station No	Depth (m)	pH	DO (mg/l)	BOD_5 (mg/l)	TKN (mg/l)	Total-P (mg/l)	Total Coliform (per 100 ml)
S_3	0.2	7.95	8.2	1.0			15
	4.0	8.15	8.5				
	10.0	8.20	8.5		0.77	0.5	
	16.0	8.20	8.5				
	20.0	8.20	8.5				
	25.0	8.20	8.5				
S_4	0.2	7.98	8.2	1.0			
	2.0	8.16	8.9				
	6.0	8.22	8.6				
	8.0	8.22	8.2				
	10.0	-	-		0.68	0.3	

Benthic and pelagic status of the sea. Samples from the sea bottom and the water column were taken at two stations to investigate the benthic and pelagic characteristics of the Dalaman coastal waters. Bottom sludge samples from the two stations were analyzed to yield the level of the organic pollutants. The results are given in Table 4.

The benthic area starts as sandy and graveled in structure of near the Dalaman River delta and continues to the deeper parts as muddy in character. Bivalves have been observed in the graveled and sandy shallow area. The main benthic groups in the muddy area are Polychaeta, Nematod and Decapoda. The organic matter of the bottom samples are significantly high in the muddy areas.

Table 4. Results of bottom sludge analyses (Dalaman, ITU, 19.06.1991)

Station No	Water depth (m)	BOD_5 (mg/kg)	TKN (mg/kg)	Total-P (mg/l)	Moisture content (%)
S_3	27	1780	630	280	43
S_4	10	50	96	140	18

Plankton and chlorophyll-*a* measurements were carried out to identify the pelagic structure of the aquatic medium. Plankton samples were taken by dragging the nets both as horizontally and vertically. Samples for chlorophyll-*a* were taken at 10 m water depth. The results are given in Table 5.

Table 5. Plankton and chlorophyll-*a* level are (Dalaman, ITU 19.06.1991 and (24.7.1991))

Sample location	Plankton	Horizontal dragging(ml/m^3)	Vertical dragging(ml/m^3)	Chlorophyll-a ($\mu g/m^3$)
from S_3 to S_4	Phyto	0.25 (0.20)*		230 (March 91)
	Zoo	0.04 (0.01)		1370 (June 91)
S_3	Phyto	-	0.24 (0.1)	1680 (July91)
	Zoo	-	0.14 (0.02)	Samples were taken from S_3 at 10 m water depth

* The values in parenthesis are for the date of 24.7.1991

Chlorophyll-*a* values are in accordance with TKN and P levels. The area shows the typical Mediterranean water character with low nutrient and primary productivity.

Geotechnical characteristics of the sea bottom. Soil structure and granulometry analyzed on the soil samples from the sea bottom. In addition to this, a detailed diver investigation with an underwater video camera was made to see the bottom topography of the sea. The findings of these investigations have shown that the sea bottom was covered with sand and gravel of variable granulometry up to 13 m water depth and then a muddy structure with a variable thickness was dominant. There was not any significant bottom flora on the investigated area.

Design and construction of the marine outfall system

Design criteria. The design criteria summarized in Table 6 have been considered for the Dalaman Pulp and Paper Mill's marine outfall system.

These criteria have been proposed in Water Pollution Control Regulation of the Ministry of Environment. Only the minimum initial dilution value has been taken as 70 due to the special case of this project.

Design methods used in the project. The marine outfall system has been designed for a maximum flow rate of 4,500 m^3 per hour. Manning's formula for n = 0.012 was used for the hydraulic calculations. The hydraulic design of the diffuser was made using the method developed by Rawn *et al.*, (1961). The method given by Brooks (1973) was used for dilution calculations. The critical velocity of the design currents were taken as 5 cm/s and 10 cm/s for the bottom and surface currents respectively. Hydrodynamic design of the marine pipe line was made according to the methods given by Grace (1978) and Janson (1989). Significant

wave characteristics predicted by the SMB method for the project area were as follows: H_s = 7 m, T_s = 10 sec, L_o = 156 m. The design results of the pipe line are summarized in Table 7 and the schematic plan of the whole system is given in Fig. 1.

Table 6. Design criteria for Dalaman Mill's marine outfall system

Parameter	Design Values
Initial Dilution (D_1)	$\geq$ 70
Length of shore protection zone (m)	300
T_{90} (h)	1.5
Total Coliforms in the shore protection zone (no/100 ml)	$\leq$ 1000
Minimum discharge depth (m)	20
Total Coliforms in the lagoon effluent (no/100 ml)	1000

Table 7. Description of the SEKA Dalaman Pulp and Paper Mill's marine outfall system

Design capacity (m^3/h)	4500
Discharge Line:	
On the land : Material	Concrete
Length and diameter	2130 m, ϕ 1200 mm
In the sea : Material	High Density Poly Ethylene (HDPE)
Length and diameter	510 m, ϕ 1200 mm
Diffuser : Material	HDPE, PN= 4 atm.
Length,diameter-no of ports and diameters of horizontal ports	40 m, ϕ655 - 8 ϕ70 120 m, ϕ581 - 13 ϕ90, 12 ϕ90 130 m, ϕ517 - 15 ϕ100, 12 ϕ125
Water depth	35 m
Distance between two ports	5 m
Total hydraulic head for the discharge	6 m
Total investment cost	~ 1,000,000 US Dollars

Construction of marine outfall system

The marine pipe line from the special manhole on the coast was designed as HDPE pipe. The main discharge line with a diameter of 1200 mm was prepared as 60 m length modules by butt welding on the coast and then each module was placed into the trench on the sea bottom. Concrete sinker blocks were used to sink the pipe and the modules on the sea bottom were fixed with flanges by the divers. In the surf, up to 10 m water depth zone, the pipe line was buried into the trench and then the trench was filled with sand, gravel and stones of special granulometry. Between 10 and 35 m water depths, the main discharge pipe was laid on the sea bottom and stabilized by granular material. The required weight of the pipe against the hydrodynamic forces was provided by concrete weights on the pipe. In the area of the diffuser, a different laying method was used due to the unexpected irregularities of the sea bottom topography and the weak muddy structure of the soil.

In this problematic location, the diffuser was fixed on the supports constructed between two steel piles. The minimum distance between the sea bottom and the pipe was 50 cm and intervals of the supports were 6 m. The piles of the supports were inserted into the muddy bottom soil a minimum of 6 m by air lift piling

technique. The horizontal axis of the diffuser was kept at 32 m water depth by diver assisted air lift piling technique. This technique was used for the first time in Turkey for piling in such a high water depth. The laying of the 290 m length diffuser section has been almost completed and the marine outfall system will be started up by early spring of 1995. It is expected that this marine outfall system will improve the environmental quality of the Dalaman coast.

CONCLUSION

Pulp and paper industry effluents have generally a serious color problem like some other industries including textiles, fermentation and sugar. Conventional color removal technologies such as activated carbon, chemical treatment with polyelectrolytes and ozonization are currently not applicable economically for the pulp and paper industry. However, marine outfall alternative may be a feasible solution for the color problem if a proper recipient is available near the industry. The SEKA Dalaman Pulp and Paper Mill is an unique example for such an application. The colored effluents from the Dalaman Mill could easily be discharged to the Mediterranean bottom waters by gravity and the color problem could be eliminated by sufficient initial dilution with a multiport diffuser system. It is expected that this marine outfall system will improve the environmental quality of the Dalaman coast.

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