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EVALUATION OF PURIFICATION EFFICIENCY OF ACTIVATED SLUDGE TREATMENT PLANTS FOR PULP AND PAPER INDUSTRY WASTEWATERS IN FINLAND

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ABSTRACT

Since 1984, when the first activated sludge treatment plant (ASTP) was built to treat pulp and paper industry wastewaters in Finland, twenty more plants have been introduced by 1989. An evaluation was undertaken to find out the actual performance of the ASTPs in BOD_7, COD_{cr} and phosphorus removal. The evaluation included all the 12 ASTPs in operation in the pulp and paper industry at the beginning of 1987. The highest average BOD_7 removals were about 90 % at pulp mills as well as paper and board mills. COD_{cr} removal was generally higher at paper and board mills (about 40-70 %) than at pulp mills (about 25-55 %). Phosphorus was added to wastewater in most plants. In some ASTPs, phosphorus concentrations were lowered by 20-40 % compared with wastewater from the mill. In some plants phosphorus load on the recipient was higher than the load coming from the mill. In treated wastewater, correlations between suspended solids and BOD_7, COD_{cr}, phosphorus and nitrogen were significant in most plants. This indicated that low removal efficiencies resulted from poor suspended solids removal in the secondary clarification. Volumetric and sludge COD_{cr} loading rates could not explain removal efficiencies when all plants were included in the comparison. In plants treating chemical pulping effluents, higher removal efficiencies were normally achieved with lower loading rates. When the plants were studied separately, the influence of loading rate was generally significant.

KEYWORDS

Pulp and paper mill effluents; activated sludge treatment; BOD_7 removal; COD_{cr} removal; loading rates; phosphorus discharges; suspended solids

INTRODUCTION

Municipal wastewaters have been subjected to activated sludge treatment in almost all communities in Finland for over 15 years. Also, in some branches of industry, activated sludge process has long traditions, e.g. in food industry. In the pulp and paper industry, however, activated sludge process is a relatively new introduction in Finland. The first activated sludge plant in the pulp and paper industry was built at the beginning of 1984. Since then, we have had a boom of building and now there are twenty of them in the pulp and paper industry. The total number of pulp and paper mills in Finland is about forty. A few other biological methods, such as aerated lagoons, biofilters and anaerobic treatment have also been applied in the pulp and paper industry in Finland (Saunamäki 1989).

The first external treatment methods in the Finnish pulp and paper industry were mechanical clarifiers, which served to remove solids from the wastewaters. Activated sludge processes were introduced as more effective removal of organic material was required. That is why the present activated sludge processes were designed mainly to remove organic material from the wastewaters. In some plants, nutrients too, were considered as limits to nutrient discharge were set by the authorities.

Limits of wastewater discharge to recipients now apply mainly to suspended solids and BOD_7 loadings. In the operation control of the ASTPs, COD_{cr} measurement has lately become the common parameter to be analysed. It leads itself to quick analysis and normally correlates with BOD_7 and suspended solids. Finnish recipients are very sensitive to eutrophication. Phosphorus is the most common limiting nutrient in biomass production in inland waters at least. In the near future, more limits to phosphorus discharges are expected also for pulp and paper industry wastewaters.

A comprehensive survey was conducted to evaluate the actual performance of the ASTPs in the pulp and paper industry (Junna 1989, Rintala et al. 1989, Luonsi et al. 1988). The main purpose of the study was to provide an overall evaluation of the removal of organic load (BOD_7 and COD_{cr}) from the pulp and paper industry wastewaters in activated sludge treatment. Also, the behaviour of nutrients (phosphorus and nitrogen) in the purification processes was analysed. Factors affecting the removal efficiency were studied as well. This paper briefly reviews some of the results of the study.

MATERIALS AND METHODS

Data

The evaluation was based on plant operation data obtained from mill representatives and on information given by local water authorities. The process control methods as regards sampling frequencies (once a day to once a month), sample types (composite or grab) and analysed parameters varied in the different plants. The data on BOD_7, COD_{cr} and SS measurements was considered sufficient, especially for the large plants. The BOD_7 and COD_{cr} values were for nonfiltered samples in all plants, with the exception of plant H, where nonfiltered samples were used only for effluent COD_{cr} analyses, and filtered samples both for influent and effluent. In plant J, TOD (total oxygen demand) was analysed instead of COD_{cr}. For plant J, the TOD of filtered samples is shown in the results. In nutrient measurements, in particular, the data was sometimes incomplete. The data was from the years 1985-1987. Since then improvements have been made in some plants.

Mills

The survey included wastewaters from paper and board mills, pulp mills and integrated pulp and paper mills (Table 1). The pulp mills included kraft and sulphite pulp mills and one thermomechanical pulp mill. In paper and board mills A, B, C, D and H pulp was manufactured mechanically or bought pulp was used. Many mills bleached at least a part of their pulp either with chlorchemicals (F, G, I, J and K), dithionite (A and H) or peroxide (B, D and L).

Activated sludge treatment plants

The survey included twelve plants. The types of the plants were the following: seven one stage plants, (plants A, B, C, D, H, I and L), three contact stabilization plants (plants F, G and K), one two-stage plant (plant J), and one two-stage plant with partial anaerobic pretreatment (plant E). Three of the kraft mills (plants F, G and I) had equalization basins and emergency basins. At the kraft and sulphite mills, pulping effluents were conducted direct in the aeration basin. All other streams at kraft and sulphite mills and all streams at other mills were first treated in primary clarification. All the results relating to organic material removals are presented for the ASTPs only, that is, primary clarification is excluded.

Statistics

To characterize the quality and quantity of wastewater averages, standard deviations as well as minimum and maximum values were calculated for different parameters from the data. Loading rates and other affecting factors were statistically characterized.

Correlation factors were calculated between the suspended solids and BOD_7, COD_{cr}, phosphorus and nitrogen in the ASTP effluents. Correlation factors were also calculated between COD_{cr} removal and loading parameters and some other factors, e.g. temperature, oxygen concentration, and sludge settling parameters.

RESULTS AND DISCUSSION

Wastewater quantity and quality

The maximum amount of wastewater coming to ASTP was about 105 000 m^3/d and the minimum about 5000 m^3/d (Table 1). The organic matter concentrations measured as BOD_7 and COD_{cr} had a wide variation in the different plants, as is shown in Table 1. The most concentrated wastewaters occurred in the NSSC mill (neutral sulphite semichemical) and in the CTMP mill (chemithermo-mechanical). The COD_{cr}/BOD_7 ratios were highest in the kraft mill effluents indicating low biological degradability.

The amounts of nutrients in pulp and paper wastewaters are usually low. In the ASTPs, nutrients were added to the purification process at least from time to time. Data on nutrients before such additions was scarce, and it was not possible to characterize the nutrient content of the incoming wastewater for all the mills over the total period.

TABLE 1. Main products of the mills, average flow rates, BOD_7 and COD_{cr} concentrations and COD_{cr}/BOD_7 ratios in the ASTPs.

Mill	Main production	Flow m^3/d	BOD_7 mgO_2/l	COD_{cr} mgO_2/l	COD_{cr}/BOD_7
A	paper	8900	560	1910	3.4
B	board, paper	10800	410	1390	3.4
C	paper	13500	230	490	2.1
D	board	6800	660	1710	2.6
E	board, NSSC pulp	4900	1830 1)	4580 1)	2.5
F	kraft pulp	52800	350 1)	1490 1)	4.3
G	kraft pulp	45800	450 1)	1740 1)	3.9
H	paper	14100	1340	2020 2)	
I	kraft pulp	104800	130 1)	690 1)	5.3
J	sulphite pulp	20800	1070	2990 3)	
K	sulphite pulp,paper	48400	350 1)	980 1)	2.8
L	CTMP	6000	1820	4230	2.3

1) after primary sedimentation, 2) filtered COD_{cr}, 3) filtered TOD

Organic matter removal

Figure 1 shows that an average BOD_7 removal of over 80-90 % was achievable both at pulp and paper mill ASTPs. COD_{cr} removal efficiencies at kraft and sulphite mill ASTPs were typically low compared to paper and board mills with mechanical pulping. This emphasizes the effects of pulping chemicals on the COD_{cr} composition of wastewater.

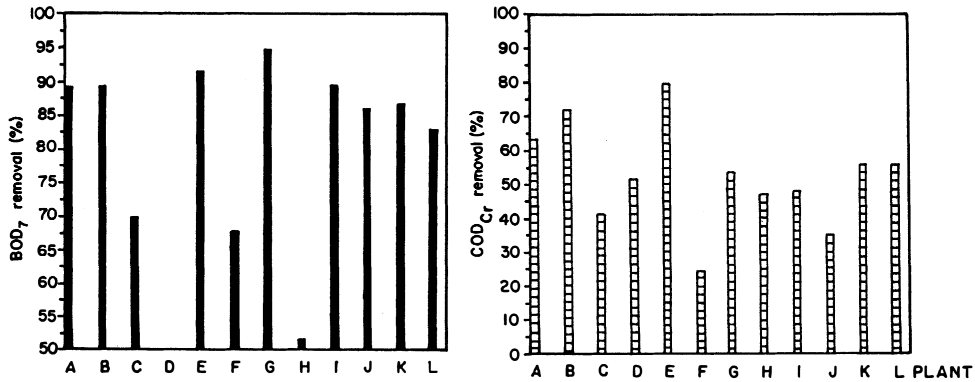

Fig. 1. Average removals of BOD_7 and COD_{cr}.
H filtered COD_{cr}, J filtered TOD

Phosphorus removal

Table 2 shows the average phosphorus residuals from pulp and paper mill ASTPs. These figures are still relatively high, when compared with municipal treatment plants. Municipal activated sludge plants with simultaneous precipitation (most common in Finland) can achieve residuals of about 0.2-0.6 mg/l.

The analysis of smaller selected data from ASTPs showed that 20-40 % of phosphorus was removed in some plants (data not shown). On the other hand, in some plants, higher amounts of nutrients were discharged to the recipient than came to the ASTP. This was caused by nutrients added in the process.

TABLE 2. Phosphorus Residuals in Treated Wastewaters

Plant		Number of observations	Mean mg/l	Standard deviation mg/l
A	T	109	0.90	0.47
	S	110	0.34	0.33
B	T	16	0.56	0.26
C	T	57	0.33	0.19
D	S	154	0.61	2.23
E		..	..	..
F	T	42	2.78	1.38
G		..	..	..
H	T	197	4.13	2.35
	S	195	1.26	1.53
I	T	151	1.43	0.66
J	S	212	1.22	2.14
K	T	29	1.52	0.40
L	T	33	1.52	0.81

T = total, S= soluble, .. = no data available

Effect of loading rates

Figure 2 shows volumetric and sludge COD_{cr} loading rates versus COD_{cr} removal efficiency. It can be seen that the applied average loading rates alone do not explain the differences in the average COD_{cr} removal efficiencies, in particular when the loading rates were given using COD_{cr}. The average loading rates were emphasized when the plants were grouped according to the production type, or, when an individual mill was studied in more detail. At the kraft and sulphite mills, higher loading rates resulted in lower COD_{cr} removal efficiencies. At the paper and board mills the applied average loading rates did not affect the treatment efficiency as much. To achieve the same COD_{cr} removal, the ASTP for paper and board mill wastewaters could have higher loadings than the ASTP for pulp mill wastewaters.

The differences in COD_{cr} removal efficiency and in the effect of loading rates between chemical pulping and paper making (combined with mechanical pulping) demonstrate the role of wastewater characteristics, especially the COD_{cr} content, on the process performance. In the chemical pulping process, more COD_{cr} is normally released in the wastewater than in mechanical pulping combined with paper making. This surplus COD_{cr} is mainly lignin compounds, which have reacted with the chemicals used in the pulping and bleaching process. The compounds thus formed are considered slowly biodegradable, which means that a longer treatment time is required.

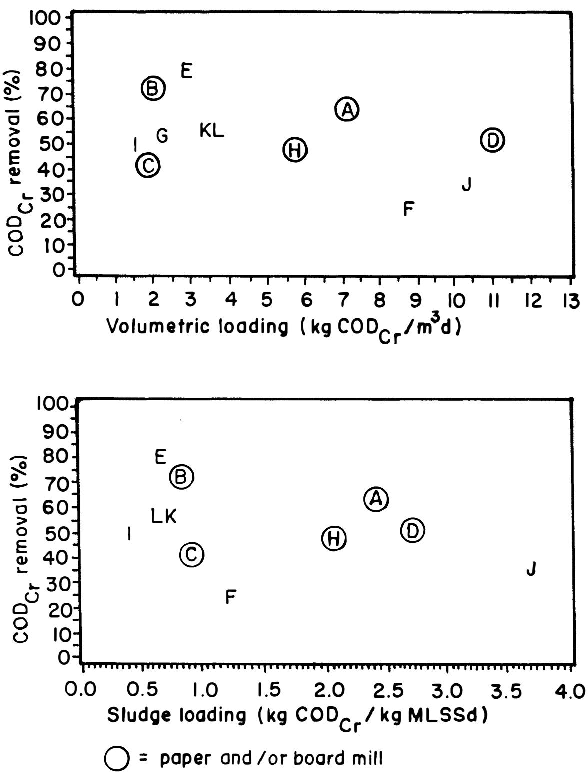

Fig. 2. Average volumetric and sludge loading rate versus COD_{cr} removal efficiency. H filtered COD_{cr}, J filtered TOD

Other factors affecting purification efficiency

In addition to loading rates, the effects of other factors were also studied: oxygen concentration in the aeration unit, sludge volume index, amount of biomass in the aeration unit, treatment temperature, etc. The influence of individual factors was eliminated by wide variation and insufficiency of data. Nevertheless, temperature and sludge settling properties were found to affect the removal efficiency in some plants.

Temperature. Earlier, when the suitability of activated sludge treatment as an external purification method for pulp and paper wastewaters was under consideration, there were some doubts about the treatment temperature being too low in winter conditions. Since then, manufacturing processes have changed to the extent that sometimes wastewater temperatures tend to be too high. Table 3 shows that treatment temperatures vary a lot. The lowest temperatures are measured in wintertime. Interruptions in the manufacturing process diminish wastewater production, and in winter this may result in a low treatment temperature (below 5°C). Problems are normally faced in restarting the ASTP after a production break, if no special measures have been taken. In normal production, the operation temperature was not found to affect removal efficiencies.

TABLE 3. Treatment Temperatures in the ASTPs

Plant	Number of observations	Mean °C	Standard deviation °C	Min °C	Max °C
A	100	29.8	6.1	18	42
B	..	..	..	..	..
C	410	21.3	4.3	2	31
D	..	..	..	..	..
E	..	..	..	..	..
F	252	28.2	3.4	12	35
G	..	..	..	..	..
H	107	35.7	2.5	29	42
I	150	23.6	4.3	15	32
J[1)]	159	14.5	5.0	4	27
K	93	23.7	4.3	16	32
L[2)]	90	29.4	4.7	14	38

1) first aeration basin 2) incoming wastewater
.. no data available

Role of suspended solids

Correlation coefficients between suspended solids and BOD_7, COD_{cr}, total phosphorus and total nitrogen in the treated wastewaters were often statistically significant (Table 4). Figure 3 shows an example of ASTP treated wastewater suspended solids versus COD_{cr} concentrations at paper mill H. The results indicated that poor operation of a plant in respect to organic material or nutrient removal was usually related to an overflow of suspended solids from the secondary sedimentation basin. The highest removal efficiencies were reached when sludge settleability was good. Sludge settleability is affected by factors such as loading rate, which was discussed earlier.

TABLE 4. Correlation Coefficients between Suspended Solids and other Variables in Outcoming Wastewaters.

Plant	COD_{cr}	BOD_7	P	N
A	0.76*** 104	0.45*** 104	0.27** 104	0.34** 104
B	0.66*** 80	0.50** 37	0.88*** 19	0.97*** 18
C	0.70*** 414	0.68*** 124	0.64*** 57	..
D	0.53*** 191	0.32 14	-0.06 1) 210	..
E	..	..	..	..
F	0.43*** 98	0.43*** 75	0.86*** 40	-0.21 3
G	..	..	..	..
H	0.22* 2) 122	0.77*** 356	0.51*** 243	0.37*** 90
I	0.23** 152	0.69*** 152	0.69*** 151	0.77*** 150
J	0.20*** 3) 293	0.50*** 273	0.03 1) 290	-0.10 1) 185
K	0.72*** 66	0.77*** 35	0.59*** 29	0.93*** 25
L	0.72** 12	0.67*** 43	0.50** 32	0.68*** 32

1) soluble P and N, 2) filtered COD_{cr}, 3) filtered TOD; Significant at the *=95%, **=99% and ***=99,9% confidence level. Number of observations below the corresponding correlation coefficient. (..= no observations).

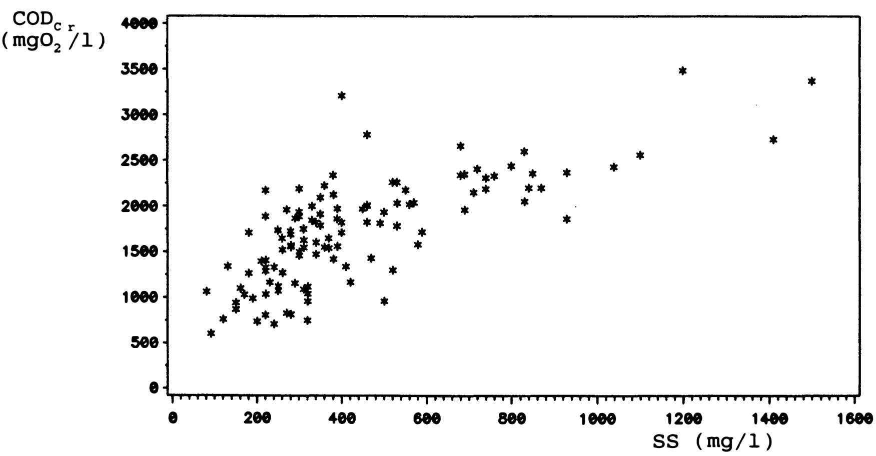

Fig. 3. Suspended solids versus COD_{cr} concentration (nonfiltered) in outcoming wastewater at paper mill ASTP (plant H).

CONCLUSIONS

A purification efficiency exceeding 90 % of BOD_7 removal could be achieved in activated sludge treatment at best for paper and board mill wastewaters as well as sulphite and kraft mill wastewaters. Overall, COD_{cr} removal was better at paper and board mill ASTPs than at chemical pulp mill ASTPs. This was most likely attributed to the slowly biodegradable compounds present in chemical pulping effluents.

Suspended solids concentrations correlated in most plants with BOD_7, COD_{cr}, nitrogen and phosphorus concentrations in ASTP treated wastewater. This means that poor organic material or nutrient removal efficiency followed from solids escaping from the secondary clarification.

A phosphorus removal of about 20-40 % was achieved is some ASTPs, while in some plants, nutrients added to the treatment process resulted in higher loadings to the recipient than were present in the wastewater coming from the mill.

Temperatures in the treatment units were high enough for biological operation in normal wastewater production. In winter the temperature can be very low during production breaks, which can severely affect the operation of the plant.

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