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SBR TECHNOLOGY USED FOR ADVANCED COMBINED MUNICIPAL AND TANNERY WASTEWATER TREATMENT WITH HIGH RECEIVING WATER STANDARDS

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ABSTRACT

The wastewater treatment plant (WWTP) in Nowy Targ, Poland, is the largest in Europe based on classical sequencing batch reactor (SBR) technology. The plant was completed in April 1995 as one of the essential elements in a program for the protection of the water quality in the Czorsztyn Reservoir. The process technology was designed for application to a typical municipal wastewater with a separate unit to treat tannery wastewater containing chromium. Experience from plant operation showed that the municipal wastewater inflow to the WWTP included tannery wastewater with increasing chromium concentrations, caused by poor wastewater management in the city. The average value in the influent was around 3 mg Cr/l (1996-1997) and showed an increasing trend. Investigations were focused on identification of the factors affecting the process performance. In this paper, evaluation of the treatment efficiency and process performance during 2 years of plant operation is presented, including studies of nitrification, denitrification and biological phosphorus removal. A cycle analysis was performed to investigate the reduction of different parameters during different phases of a cycle. Results of a sludge activity study based on OUR, AUR and NUR tests are presented and discussed.

KEYWORDS

Chromium; nutrient removal; Sequencing Batch Reactor (SBR); sludge handling; tannery wastewater.

INTRODUCTION

The city of Nowy Targ (population of 34 000, 1997) is the administrative center of the Podhale region, located in the mountain area of southern Poland. The first mechanical wastewater treatment plant in Nowy Targ was built in 1955. Since this time, little has been done regarding environmental issues, even after the downstream construction of a large dam and water reservoir of 234.5 billion m^3 volume, begun in 1971, on the Dunajec River. The construction of a new, advanced wastewater treatment plant for Nowy Targ was found to be the most urgent task in this area. The construction was undertaken in cooperation with Swedish partners and with the financial support of the Swedish government. Of the three offers received during the bidding procedure, the SBR technology was chosen by the design companies. SBR technology is based upon an activated sludge process operating in a sequencing batch reactor. The choice of SRB technology was mainly due to the simplicity of the design, which, when compared with a continuous system with secondary clarifiers, allowed reduced construction time and an estimated 20% less total input to the construction. While SBR technology was chosen for biological treatment, the design did not include primary clarifiers in a primary treatment stage; the waste sludge was to be partially stabilized in a simultaneous aerobic process and dewatered in centrifuges. Separate chemical treatment for tannery wastewater delivered to the plant was also included in the design (Morling, 1996). The plant was designed in 1991-1992 and the technological start-up was conducted during the first six months of 1995. Over this period of time the Polish economic system had gone through a wide range of transformations. Big industry production was slowed down, affecting in Nowy Targ a shoe factory and a dairy plant, while an uncontrolled burst of small enterprises occurred, mostly in the fields of tanning and fur tailoring, which are traditional in the Podhale region. This shift in the profile of the local industry was accompanied by a significant drop in water consumption forced by raised water rates, which in turn resulted in major changes in quality and volume of influent wastewater to the Nowy Targ Wastewater Treatment Plant (WWTP).

RAW WASTEWATER CHARACTERISTICS

The hydraulic capacity of the Nowy Targ WWTP, expressed as the average daily flow, $Q_{av.d}$, is 21 000 m^3/d, where Q_{max} = 25 000 m^3/d. The wastewater volume was estimated based upon the growing water demand observed in the late 1980's. Furthermore, the existing sewer system was to be expanded to connect over ten small villages and settlements located in the vicinity of the plant. However, the economic transformation that had been taking place in Poland altered these assumptions. The average wastewater flow reaching the WWTP was $Q_{d50\%}$ = 12 720 m^3/d in the dry weather period of 1997. During wet weather periods the sewer system receives additional water volume due to the rain water infiltration; under these conditions the flow to the plant can reach $Q_{90\%}$ = 17 750 m^3/d. Characteristics of raw wastewater discharged to the plant are presented in Table 1. Values are given from the three different data: raw wastewater quality as assumed in the design, as well as average values for 1996 and 1997 at various probability levels.

Table 1. Raw wastewater characteristics at the Nowy Targ WWTP

Parameter	Unit	Concentration, g/m^3					
		design values	1996	1997			
			50%	50%	60%	85%	90%
TSS	g/m^3	106	449	285.6	331.5	462.0	509.0
BOD_5	g O_2/m^3	332	262	216.1	241.5	315.0	344.5
COD	g O_2/m^3	526	746	550.0	630.0	823.5	903.8
Total nitrogen	g N/m^3	25.9	50.6	42.9	44.8	55.0	58.3
Total phosphorus	g P/m^3	12.4	7.3	5.4	5.8	7.3	8.6
Total Cr	g Cr/m^3	0.5	2.64	3.1	3.8	6.4	7.8

The most significant differences between the data assumed in the design and the average values measured at the plant can be seen in a four-fold increase in suspended solids concentration in 1996, a doubling of total nitrogen and an increase in chromium concentrations by more than a factor of six. The ratios between the characteristic parameters of the wastewater were in 1996: $COD/BOD_5 > 2.5$, $BOD_5/N \geq 5.0$, $BOD_5/P \geq 36$. The raw water quality is strongly influenced by the lack of respect for discharge requirements on the part of small tanneries, where wastewater with high chromium concentration is required to be sent to a separate pretreatment system located at the WWTP. A growing demand for leather products, combined with poor wastewater management in the small tanneries, resulted in a continuous increase in chromium concentration in municipal wastewater. The impact of this can also be seen in diurnal (Figure 1) and seasonal wastewater concentration fluctuations; a significant increase of chromium is observed in the fall season when production increases.

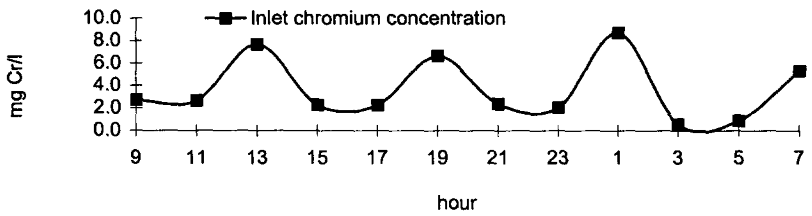

Figure 1. Inlet chromium concentration.

RECIPIENT CHARACTERISTICS

The effluent from the Nowy Targ WWTP is discharged to the Dunajec River, which has its source in the Tatra Mountains. The Czorsztyn Reservoir is located approximately 14.4 km downstream from the wastewater discharge. The purpose of the reservoir is to provide the necessary storage volume to reduce the risk of flooding and control the discharge flow. The characteristic parameters of the reservoir include: length, 10.5 km; maximum depth next to the dam, 48 m, and catchment area, 1147 km^2. Average low flows in the Dunajec River are 2.75 m^3/s at wastewater discharge cross-section and 4.75 m^3/s at the dam cross-section. Due to its unique location in the mountain region, the Czorsztyn Reservoir has considerably different characteristics to other Polish reservoirs, resembling more closely Alps reservoirs. The theoretical time for the water volume exchange within the reservoir is 463 days; according to the Polish Water Quality Standards such length of time qualifies the reservoir as a "still water body", to which more stringent quality standards apply. Sediments relocated by the movement of water will cumulate as deposits in the dead zone of the reservoir, where there is almost no water exchange and the ecosystem becomes closed (Banas and Styka, 1996). Table 2 compares the characteristic parameters of the effluent from the Nowy Targ WWTP and that required for plants with $Q > 2000\ m^3/d$ in Poland.

Table 2. Effluent quality standards

No.	Parameter	Unit	Polish standards for the treatment plants with $Q \geq 2000\ m^3/d$	Discharge permit for the Nowy Targ WWTP
1.	TSS	g/m^3	50	20
2.	BOD_5	$g\ O_2/m^3$	15	15
3.	COD	$g\ O_2/m^3$	150	75
4.	Total nitrogen	$g\ N/m^3$	30	20
5.	Total phosphorus	$g\ P/m^3$	1.0*	1.0
6.	Total Cr	$g\ Cr/m^3$	0*	0.5

* discharge to reservoirs

PLANT DESCRIPTION

The wastewater treatment plant in Nowy Targ has two separate treatment lines (Figure 2):

- the municipal wastewater treatment plant and sludge disposal system, and
- pretreatment of tannery wastewater hauled to the plant in septic tanks.

It is possible to dose the SBR reactors with $FeSO_4$ and $Ca(OH)_2$ solutions, but so far chemical precipitation has not been used. After precipitation of chromium in the tannery wastewater pretreatment process down to levels close to 0 mg/l, the wastewater is mixed with municipal wastewater and the waters are treated simultaneously in the biological reactor. To improve the removal of both COD and total suspended solids from the pretreated tannery wastewater, precipitation with $FeSO_4$ is also used.

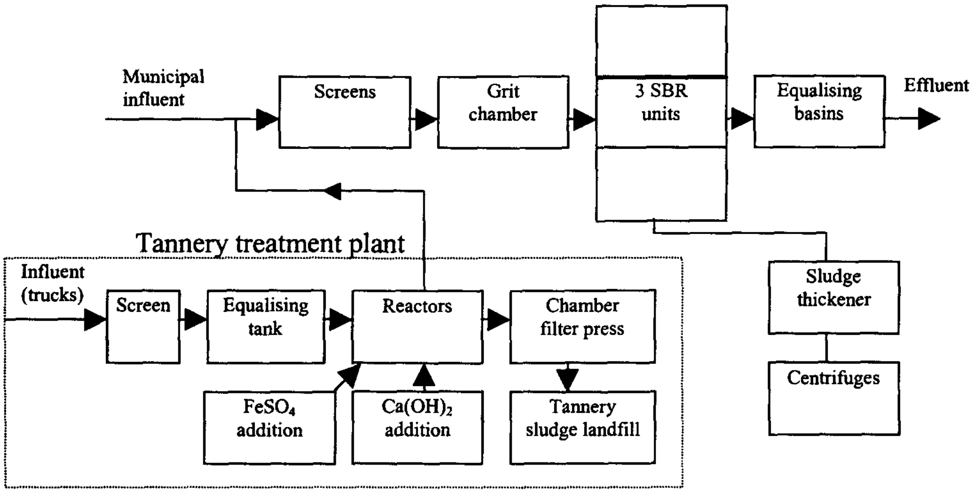

Figure 2. Wastewater and sludge handling at the Nowy Targ WWTP.

EVALUATION OF THE PROCESS PERFORMANCE

Process performance vs. number of reactors

The SBR reactors operate in a 6-h cycle (Figure 3). The time of a fill phase varies depending on the number of the reactors in operation; for 2 reactors the duration is 3 h, and for 3 reactors, 2 h.

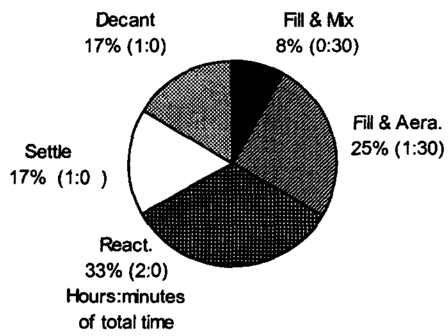

Figure 3. Operating strategy.

Actual process parameters and parameters assumed in the design are compared in Table 3.

Table 3. Process parameters

Parameter	Design value	Measured value (average over 2 years)
sludge age, days	26	14-30
sludge production, kg/kg BOD_5	0.6	1-1.2
sludge loading, kg BOD_5/kg SS*d	0.07	0.04-0.06
sludge dewatering, % dry solids	20-25	13-17%
amount of sludge at the actual flow	8 t/d	25 t/d

The wastewater treatment with only two reactors in operation was carried out for 10 months until May 96. However, poor sludge quality after aerobic processing and increasing chromium concentrations (Cr^{+3}) led to the start-up of the third reactor, as well as additional processing to increase the sludge age. Effluent characteristics achieved at various probability levels with two and three SBR reactors in operation are presented in Table 4. The plant showed a high BOD_5 removal regardless of the number of the reactors in operation. The required chromium concentration, that is, below 0.5 g/m^3, was maintained in approximately 70% of the samples. Chromium concentrations exceeding the required limits were observed when industrial wastewater was introduced to the plant, as well as increased COD and chromium concentrations in the raw sewage. Removal of total nitrogen depended greatly on the temperature. During summer when the treatment process temperature was above 10°C, total nitrogen concentration in the effluent was maintained below 15 g N/m^3. From May to November, complete nitrification was achieved, and the concentration of ammonia-nitrogen was almost zero. The average total nitrogen removal in years 1996 and 1997 was 75%. The removal of nutrients at the Nowy Targ WWTP has had a great impact on the protection of the water quality in the Czorsztyn Reservoir. With two reactors in operation the average concentration of total phosphorus in the effluent was 0.94 g P/m^3 and concentrations rarely exceeded the required limits. When all three SBR reactors were put into operation in 1997, the average effluent concentration of total phosphorus dropped down to 0.45 g P/m^3 and the probability of achieving the required concentration limit, $P_{total} \leq 1.0$ g P/m^3, was 95%.

Table.4. Effluent characteristics achieved at the certain probability levels with two and three SBR reactors in operation

Parameter	Concentration in the effluent at certain probability levels (g/m^3)				
	2 reactors	3 reactors (1997)			
	50%	50%	60%	85%	90%
BOD_5	8.5	8.9	9.8	13.5	14.7
COD	75.0	44.4	49.1	64.4	69.3
TSS	21.5	14.8	16.6	26.0	31.4
$N\text{-}NH_4$	-	5.7	9.6	14.1	15.5
Total nitrogen	14.6	10.7	13.0	17.3	19.0
Total phosphorus	0.94	0.45	0.52	0.71	0.87
Total Cr	0.34	0.39	0.45	0.66	0.7

Analysis of cycles

Nitrogen, phosphorus and chromium profiles observed in the SBR reactor during a single cycle in 1997 are presented in Figures 4-6. The SBR reactors have a longitudinal shape and mixers are mounted in three different sections of the reactors. During the experiment the samples were taken from three reactor zones: the inlet zone (point A), center zone (point B) and effluent zone (point C). The results confirmed the hypothesis that the SBR reactors in Nowy Targ do not work as continuously stirred tank reactors. The initial increase of both total nitrogen and ammonium nitrogen concentrations (Figure 4) in all reactor zones was caused by the filling of the reactor with raw sewage. During the aeration phase, intensive nitrification was observed, particularly in the inlet zone; nitrification rates decreased in the center and effluent zones. The experiments evaluating the SBR cycle were performed during the summer, suggesting that they may not reveal all problems that could emerge at the plant during winter. When the temperature dropped below 6°C, nitrification slowed down considerably and ammonia-nitrogen concentration in the effluent exceeded the required value, 6 g $N\text{-}NH_4/m^3$. The denitrification appeared 60 minutes after the diffusers were switched off. This indicated that there is a need to introduce an anoxic phase before the sedimentation and decant phase takes place. However, the denitrification efficiency seems to be sufficient even without such a phase in the SBR cycle. Release of phosphorus, typical for anaerobic conditions, was noticed only in the inlet zone (Figure 5). The release was accompanied by the uptake of organic carbon compounds from the incoming wastewater. The inlet zone also displayed the fastest uptake of phosphorus by biomass during the aerobic phase. The last phase of sedimentation and decanting induced a partial release of the phosphorus; however, the required effluent concentration was not exceeded. The fluctuation of chromium concentration within the reactor is presented in Figure 6. The chromium concentration in raw wastewater (filtered sample) was 4.84 g Cr/m^3. It can be seen that the Cr concentration increased in the inlet zone and then slowly decreased during the aeration phase. The concentration of chromium in both the center and effluent zones and in the final effluent remained at the same level, 0.5 g Cr/m^3. No influence of chromium on nutrient removal efficiency was found.

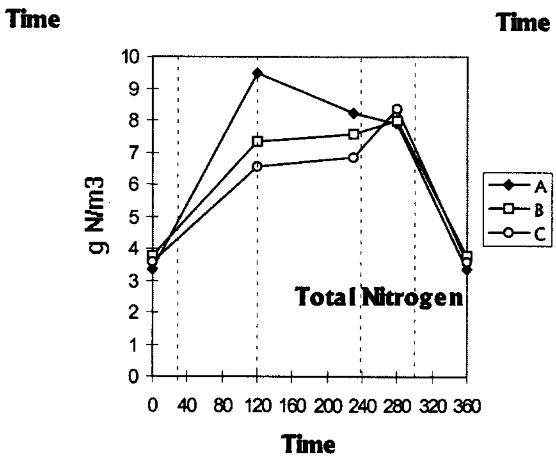

Figure 4. Nitrogen profiles

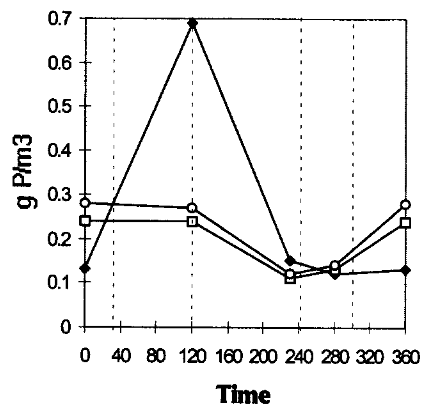

Figure 5. Phosphorus profile

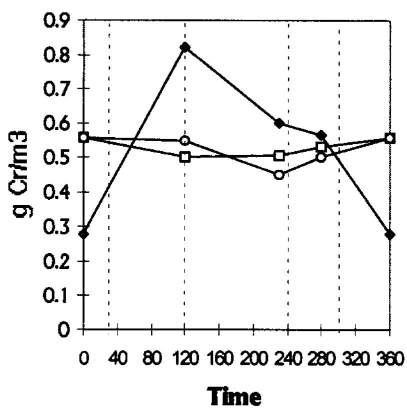

Figure 6. Chromium profile

SLUDGE ACTIVITY STUDY

In order to fully estimate the intensity of the biological processes, OUR, AUR and NUR tests were performed at the plant. The tests were conducted according to the method described by Kristensen *et al.* (1992). The results of the tests are presented in Table 5. Two series of OUR runs conducted in the reactor gave similar results. The values of OUR ranged from 29.2 - 44.9 mg O_2/g VSS*h in Run I, and from 30.1 - 46.9 mg O_2/g VSS*h in Run II. These values indicated good sludge conditions when the fraction of heterotrophic bacteria was approximately 25% of total biomass (Kristensen *et al.*, 1992). The OUR tests, a simpler test than AUR, were also used to calculate the nitrification rate (Run III, Table 5). In calculations the following relationships were used:

$$\text{Nitrification rate} = OUR_{Nit} / 4.33 \text{ g } O_2/\text{g N-}NH_4 \quad (1)$$

$$OUR_{Nit} = (N) - (H) \quad (2)$$

where: OUR_{Nit} - OUR value for autotrophs activity
N - total OUR value
H - OUR value for heterotrophs activity

The results of the OUR tests describing nitrification are presented in Table 5 (samples taken every 2 h).

Table 5. Results of the OUR (mg O_2/g VSS*h), AUR (mg N-NH_4/g VSS*h) and NUR (mg N-NO_3/g VSS*h) tests

Run I				Run II		Run III			
Date	OUR	AUR	NUR	Date	OUR	Time	OUR- N	OUR-H	OUR-Nitr
18.08.97	29.18	1.71	6.60	05.09.97	35.38	12 PM	40.24	36.47	3.77
19.08.97	31.94	3.63	4.05	06.09.97	40.37	2 PM	37.14	32.89	4.25
20.08.97	39.10	0.64	12.65	07.09.97	40.49	4 PM	41.52	41.18	0.34
21.08.97	44.86	0.51	6.28	08.09.97	35.79	6 PM	40.26	35.89	4.37
22.08.97	39.81	0.48	6.27	09.09.97	46.86	8 PM	43.04	29.76	13.28
25.08.97	30.77	2.57	3.08	10.09.97	30.13	10 PM	51.83	37.89	13.94
26.08.97	40.75	2.04	5.50			12 AM	39.56	35.62	3.94
27.08.97	39.28	2.03	4.23			2 AM	18.11	16.14	1.97
28.08.97	43.01	2.32	3.63			4 AM	28.50	26.27	2.23
29.08.97	29.46	1.98	2.24			6 AM	31.96	29.27	2.69
						8 AM	50.55	34.29	16.26
						10 AM	58.48	39.68	18.80
average	36.82	1.79	5.45		38.17		40.10	32.95	7.15

The average value of the OUR_{Nit} for that day was 7.1 mg O_2/g VSS*h, which is equivalent, according to equation (1), to a nitrification rate of 1.6 mg N-NH_4/g VSS*h. The average nitrification rate measured with the AUR test in August 1997 (Run I, Table 5) was 1.8 mg N-NH_4/g VSS*h. These values were higher than the nitrification rate of 1 mg N-NH_4/g VSS*h reported by Johansson and Salberg (1996) and the value of 1.4 mg N-NH_4/g VSS*h obtained during the experiments carried out in November 1997. The denitrification rates reported in Run I (Table 5) varied significantly. The measured average denitrification rate was 5.4 mg N-NO_3/g VSS*h and the fraction of denitrifiers in the total heterotrophic bacteria population was 48%. The average denitrification rates observed in the SBR reactors in Nowy Targ during other experiments conducted at the plant in 1995 and in November 1997 were 7.7 mg N-NO_3/g VSS*h and 8.7 mg N-NO_3/g VSS*h, respectively. Such high denitrification rates confirm the good denitrification potential of the sludge. The lower average denitrification rate and its high variability during Run I may have been caused by a shortage of easily degradable organic carbon source in the wastewater. The maximum denitrification rate observed at the plant was 12.6 mg N-NO_3/g VSS*h and was achieved at the maximum concentration of easily degradable COD = 121 g O_2/m^3.

SLUDGE HANDLING

Unexpected changes in the characteristics of the raw wastewater have created many problems in plant operation (Kurbiel *et al.*, 1996; Kabacinski *et al.*, 1998). Total solids concentration in raw wastewater is higher than assumed in the design and actual sludge yield at the plant is 1.0-1.1 kg SS/kg BOD_{5rem}. Centrifuge efficiency is lower (15-17% dry solids) than assumed in the design (25% dry solids), and sludge volume for further disposal is 50% greater than assumed. Additionally, the full stabilization of sludge is not achieved (67% of VSS) despite a greater sludge age (26 days) and chromium concentration in the waste sludge is 11 g Cr/kg dry solids, exceeding the limits for land application of sludge (0.5 g Cr/kg dry solids). As the existing municipal landfill is not designed to receive this type of sludge, the local authorities do not permit the disposal of the waste sludge, resulting in an accumulation of sludge at the plant site. Widespread educational campaigns carried out within the local communities have brought some results, namely that the volume of wastewater delivered in the septic tanks is increasing. However, the process of change is proceeding too slowly. The investor is looking for funds to finance and construct a sludge incinerator, or an efficient method for removing chromium from sludge.

CONCLUSIONS

Discharge of industrial wastewater with high concentrations of chromium to the municipal sewer system is not reasonable, from either an ecological or an economic point of view. With a constant growth in the number of small tanneries (now 300), there are still no real incentives to deliver the chromium wastewater to the pretreatment line at the plant.

Despite a high chromium content in the influent, a good efficiency of N and P removal has been obtained. Low nitrification rates are more likely to be associated with temperature effects than with process inhibition by Cr.

Apart from its primary goal of nutrient removal, the Nowy Targ WWTP also achieves additional removal of chromium from concentrations of 4-10 g Cr/m^3 to around 0.5 g Cr/m^3.

The plant faces a serious sludge problem; if the tannery wastewater discharge to the municipal sewerage system continues, the plant will have to build a sludge incinerator.

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