Pergamon

Wat. Sci. Tech. Vol. 38, No. 4–5, pp. 69–77, 1998.
IAWQ

0273–1223/98 $19·00 + 0·00

PII: S0273-1223(98)00499-5

STRATEGIES FOR IMPROVEMENT OF SLUDGE QUALITY AND PROCESS PERFORMANCE OF SEQUENCING BATCH REACTOR PLANT TREATING MUNICIPAL AND TANNERY WASTEWATER

M. Kabacinski*, B. Hultman**, E. Plaza** and J. Trela**

* *Water and Sewage Works, ul. Polna 51, 34-400 Nowy Targ, Poland*
** *Division of Water Resources Engineering, Royal Institute of Technology, S-100 44 Stockholm, Sweden*

ABSTRACT

Advanced process technology has been implemented at newly built wastewater treatment plants in Central and Eastern Europe. The wastewater treatment plant (WWTP) in Nowy Targ, Poland, the largest in Europe based on sequencing batch reactor (SBR) technology, has shown that newly constructed plants must be integrated into the system of water, wastewater, and sludge management in the city and the region. A significant supply of tannery wastewater with increasing chromium concentrations in the influent to the WWTP has resulted in many operational problems related mainly to sludge treatment. Evaluation of the process performance and sludge handling for 2 years of plant operation is presented. Efficient biological phosphorus removal with concentrations lower than 1 mg/l in effluent is obtained. Nitrogen removal is characterised by a low nitrification rate and a high denitrification rate. Problems with sludge handling are related to high excess sludge production, insufficient sludge stabilisation, low sludge dewatering efficiency and high chromium content in the sludge. Different strategies for sludge handling improvement are discussed. Sludge should be treated as a resource, which is recirculating in an eco-cycle with recovery of nutrients and energy. Such a process is proposed for the WWTP in Nowy Targ. © 1998 Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Chromium; product recovery; Sequencing Batch Reactor (SBR); sludge handling; tannery wastewater.

INTRODUCTION

Implementation of advanced biological wastewater treatment in Poland

In many Central and Eastern European countries a rapid development has been observed over the last few years in the construction of advanced biological wastewater treatment plants (WWTP). In Poland, in the period 1990-1995, the volume of wastewater that required treatment decreased by 26% from 4.11 billion $m^3/$

year to 3.02 billion m^3/year. The fraction of biologically treated wastewater increased from 36.4% to 51.9%. Currently, 32% of the wastewater is discharged without any treatment into rivers, and as many as 273 cities out of 860 have no wastewater treatment (Kurbiel and Zeglin, 1997). Many old plants are insufficient, with only primary wastewater treatment, hydraulically overloaded, or in poor technical state. In the future, many of the existing plants must be upgraded. Because of the introduction of more stringent standards for nitrogen and phosphorus, highly effective technologies for both nitrogen and phosphorus removal will be implemented. The example of the sequencing batch reactor (SBR) wastewater treatment plant in Nowy Targ shows that it is prudent to take into consideration proper evaluations of water and wastewater management in the city and the region when designing and operating new plants. This includes perspective developments in the city and the resultant changes in wastewater characteristics.

Sequencing Batch Reactor technique used in Southern Poland

The City of Nowy Targ is located in the Podhale region, southern Poland, the same region as the newly constructed Czorsztyn reservoir around which many small wastewater treatment plants are planned to be built. Their purpose is to protect the water quality within the reservoir. Five small treatment plants have been completed and another ten are still under construction. About thirty small treatments plants are planned to be put into operation in the region with a flow capacity ranging from 200 m^3/d for 1000 person equivalents (pe) to 1500 m^3/d for 10,000 pe. Inhabitants in the region living in small villages are often not connected to wastewater collection systems. Many large and middle size industries operate without treating the wastewater.

A new wastewater treatment plant has been built in the city of Nowy Targ. The plant has a capacity of 120,000 pe and is based on SBR technology. The plant is the largest in Europe and several smaller treatment plants have been built in Poland with the same technology (Banas and Styka, 1996). The SBR process has many advantages (Morling, 1996) and will probably be utilised in many other areas in the Eastern Europe.

SBR IN NOWY TARG – PLANT DESCRIPTION

The wastewater treatment plant in Nowy Targ began operation in April 1995 and was officially opened in September 1995. Two years of process data has been collected. The plant was designed for mechanical, biological and chemical treatment for municipal wastewater with a separate unit to treat tannery wastewater containing chromium. The plant was designed for treatment of 21,000 m^3/d. The daily flow is at present 12,000 m^3/d. The process technology was designed for application to a typical municipal wastewater but is actually working with municipal-industrial wastewater. The process configuration is presented in Fig. 1.

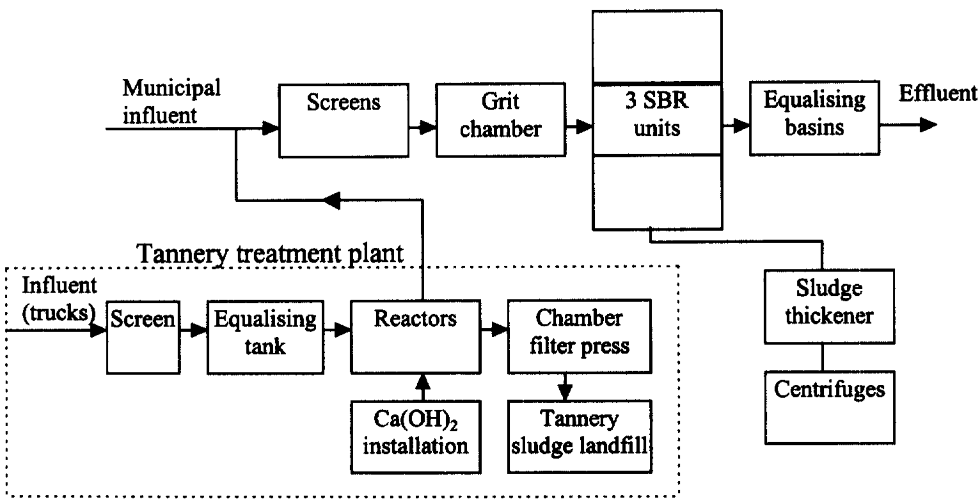

Figure 1. Wastewater and sludge handling at the Nowy Targ WWTP.

Only a small amount of wastewater, 20 m^3/d, was planned to be treated by the separate chromium tannery treatment plant. When the WWTP was designed (1991), there was a recession in tannery and furriery industries. It was assumed that the tannery treatment plant would treat the most toxic part of discharges from tanneries, that part containing chromium compounds. The remaining waste streams from these industries would be treated together with municipal wastewater. The two biggest tanneries in the city had also planned to construct their own pre-treatment plants.

Influent wastewater characterisation

An evaluation of the wastewater characteristics was performed in June 1991 before the design of the plant. Increased demand for leather products during the last 5 years resulted in an increase in production at the existing tanneries and furrieries and the development of many new ones. At present, about 300 tanneries operate in the city. This has caused a significant impact on wastewater characteristics. The actual values for the parameters characterising the influent wastewater are different from those initially determined as the design parameters. The influent wastewater changed in character from a municipal to municipal-industrial wastewater (Table 1) with higher values for COD, SS, N_{tot} and Cr. The ratio of COD/BOD_5 was predicted to be 1.6 and is at present 2.8.

Table 1. Comparison between parameters used for designing of the plant with those obtained during operation of the plant

Parameter	Project value, mg/l	Actual value (average for 2 years), mg/l	Parameter	Project value	Actual value (average for 2 years),
BOD_5	332	260	sludge age	26 days	14-30 days
COD	526	740	sludge production	0.6 kg/kg BOD_5	1-1.2 kg/kg BOD_5
SS	106	450	sludge load	0.07 kg BOD_5/kg SS*d	0.04-0.06 kg BOD_5/kg SS*d
N-tot	25.9	55	sludge dewatering	20 -25 % dry solids	13 -17 % dry solids
P-tot	12.4	7.5	amount of sludge at actual flow	8 t/day	25 t/day
Cr	0.5	3.0			

As a result of the change in the influent characteristics at the wastewater treatment plant, especially during the autumn-winter season, the pollution load has already reached the level determined for the design parameters while operating at 50% of the design hydraulic load.

Table 2. Efficiency of wastewater treatment during 2 years operation

Parameter	29.03.95-4.08.95 3 SBRs in operation			5.08.95-22.05.96 2 SBRs in operation			23.05.96-23.06.97 3 SBRs in operation		
	inlet mg/l	outlet mg/l	red %	inlet mg/l	outlet mg/l	red %	inlet mg/l	outlet mg/l	red %
BOD	180	21.4	73.4	267	8.5	96.8	252	8.1	96.8
COD	441	110	75.1	695	75	89.3	687	45	93.4
SS	190	24.0	87.4	393	21.5	94.5	446	18.7	95.8
N-tot	39.4	27.9	29.2	53.51	14.6	72.7	48.8	11.9	75.6
P-tot	4.95	2.22	55.2	7.44	0.94	87.4	6.18	0.49	92.1
Cr-tot	1.71	0.20	88.3	1.65	0.34	79.4	3.30	0.37	88.8

EVALUATION OF THE PROCESS PERFORMANCE

Operation strategy and wastewater treatment efficiency

The WWTP has operated with 3 reactors working with a cycle completion time of six hours: filling and mixing 0.5 h, filling and aeration 1.5 h, reaction 2.0 h, settling 1.0 h, and decanting 1.0 h. Evaluation of the results presented in Table 2 have shown that significantly better wastewater treatment efficiency is obtained with 3 reactors in operation. The first period presented in the Table 2 represents the start-up time of the plant.

It was also observed that during the winter season the treatment efficiency was diminished due to low wastewater temperatures (during some periods even lower than 5°C) and by an increased pollution load to the WWTP from the tanneries.

A significant supply of tannery wastewater in the influent to the WWTP is reflected by high concentrations of chromium in the raw wastewater. In Fig. 2, an increase in the influent chromium concentrations is observed as represented in the trend line. Average values for the years 1996-1997 show that high concentrations of chromium in the influent, 3.03 mg/l, are reduced by 87.1%, to 0.39 mg/l, in the treatment process.

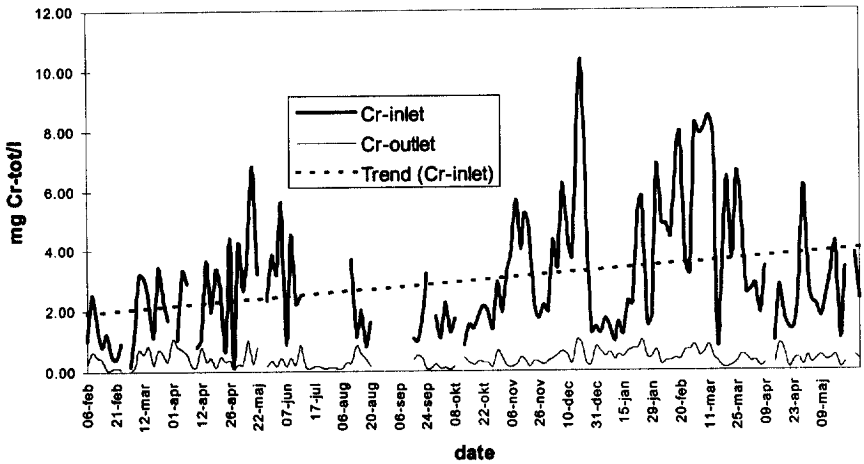

Figure 2. Concentrations of chromium in the influent and effluent, 1996-1997.

Analysis of cycles

The Sequencing Batch Reactors in Nowy Targ operate with biological phosphorus and nitrogen removal. Several studies (Johansson and Salberg, 1996; Kabacinski, 1997) were performed which follow the reduction of different parameters during a cycle. As analysis were normally performed in the influent and effluent wastewater and there was no on-line instruments in the reactor, the evaluation of the cycles only provides information about the process performance.

The system had an excellent capacity to perform efficient biological phosphorus removal with concentrations lower than 1 mg/l in the effluent (Fig. 3). This is due to sufficient amount of organic carbon in the raw wastewater. The nitrogen removal process was characterised by low nitrification and high denitrification rates. Cycle analysis were performed both for the period with low (study 1) and with high (study 2) nitrogen removal efficiency as presented in Fig. 3. During study 1 a very low nitrification rate was observed.

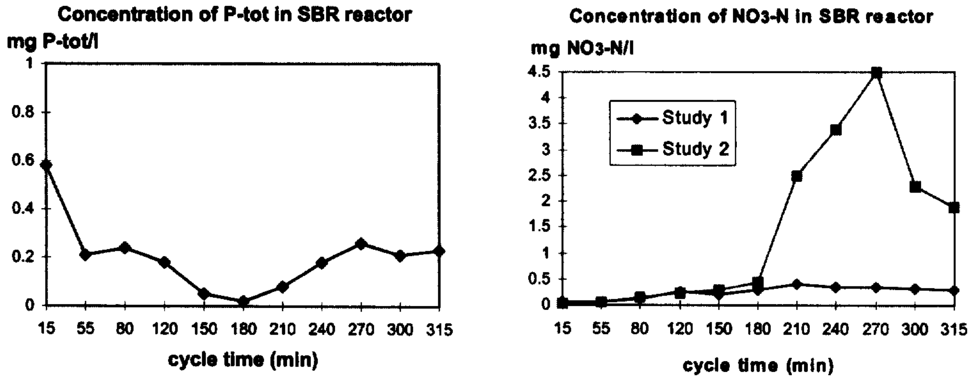

Figure 3. The variation in concentration of total phosphorus and nitrate nitrogen in the reactor during the cycle (filtrated samples).

REASONS FOR THE PROBLEMS WITH SLUDGE HANDLING

Excess sludge production and sludge characteristics

The problems which occur at the WWTP were mainly related to sludge treatment. The sludge production was higher than the value determined in the design of the WWTP. A design value of 0.6 kg/kg BOD_5 removed was assumed, but a value of 1.2 kg/kg BOD_5 removed was obtained. There were some problems associated with achieving the sludge age design value of 26 days and with achieving proper aerobic sludge stabilisation. It was difficult to produce a fully stabilised sludge even with a high value for the sludge age. This was caused by high concentrations of slowly biodegradable organic substances which influenced both aerobic stabilisation and the mechanical dewatering process. After mechanical dewatering using centrifuges, a value of 15% dry solids was obtained for the sludge. Experiments performed with the belt press gave the same results. Another study using a chamber filter press with addition of polyelectrolyte resulted in 19 % dry solids. With the addition of 10 kg/m^3 $FeCl_3$ and 50 kg/m^3 $Ca(OH)_2$ to a sludge with 6 % dry solids, dewatering on the filter press gave a value of 30 % dry solids. This technology was used for dewatering of the already deposited sludge. In this experiment the sludge was diluted from 15 % to 6 % dry solids before dewatering.

The daily production of dewatered sludge at WWTP in Nowy Targ was 25 tonnes (15% dry solids). No suitable method of sludge disposal has been secured. Currently, all unstabilised sludge has been stored directly on the WWTP grounds and in surrounding areas. Since the beginning of the WWTP operation, about 15 000 tonnes of sludge has been stored. Odour problems made this method of disposal unacceptable for the city and its inhabitants. Improperly deposited sludge creates a hazardous impact on the environment: soil pollution, ground and river water pollution. The run-off water from illegal sludge deposits flows directly to the receiving waters resulting in secondary contamination of the environment. According to the investigations, chromium does not leach considerably from the sludge. The content of chromium in sludge was 25 400 mg/kg dry solids while 0.97 mg Cr/kg hydrated sludge was found in the leachable water. Higher concentrations of chromium were only found in the surface layer of soil (about 2 cm). The concentration of chromium in the deeper layers was within the standard limits.

Chromium in sludge

The chromium concentration in sludge was in the range of 1 500-40 000 mg Cr/kg dry solids. Unstabilised sludge and high chromium concentrations in the sludge made the agriculture use of the sludge impossible. Many different strategies have been considered to improve the sludge quality. A sludge with good quality could be used for agriculture. In this case the sludge must meet requirements with respect to metal concentrations. In many countries sludge usage in agriculture is commonly applied and accepted. To guarantee the proper sludge quality suitable for agriculture use, a quality control standard must be applied to the dewatered sludge.

Measurements of the concentration of different metals in the sludge from Nowy Targ are presented in Table 3. These were compared with limiting values for sludge application to agricultural lands, with respect to metal concentration, as set by Polish standards and EU directives. Some countries in the EU have more stringent limiting values as exemplified by Sweden (SEPA, 1995). Different measures must be enacted to decrease the chromium concentration in the sludge. These should include more stringent control of discharges of industrial wastewater and actions to increase the ecological knowledge of the society and the owners of tanneries.

Table 3. Average values of metal concentration in sludge in Nowy Targ and limiting values from Polish, Swedish and EU directives

Metal	Metal concentration in sludge in Nowy Targ, mg/kg dry solids	Limiting values in Poland, mg/kg dry solids	EU directives, mg/kg dry solids	Limiting values in Sweden, mg/kg dry solids
Cd	0.81	10	20 - 40	2
Cu	56.4	800	1000 - 1750	600
Ni	6.4	100	300 - 400	50
Pb	42.7	500	750 - 1200	100
Zn	707	2000	2500 - 4000	800
Hg	-	-	16 - 25	2.5
Cr	10 950	500	-	100

STRATEGIES FOR SLUDGE HANDLING IMPROVEMENT IN NOWY TARG

Based on different expert reports containing recommendations for solving the problems and for improving the situation at the WWTP in Nowy Targ (Kurbiel *et al.*, 1996), it was decided to implement the following long-term solutions:

1. Construction of the sludge deposit with a sludge storage volume equivalent of 3 years.
2. During the 3 year period, the construction of an incineration plant for sewage sludge is planned. In this case the ash will be deposited at the existing sludge deposit area.

The concept of liming of sludge, using burnt lime, was accepted and will be realised. Suitable technological units, located after the centrifuges, will be constructed in 1997. According to experiments made by Cracow University of Technology (Kurbiel *et al.*, 1996), mixing sludge after centrifuges with burnt lime provides additional chemical stabilisation and dewatering.

To lessen the present impact of the unstabilised sludge, the following prevention measures connected with sludge dewatering and incineration were enacted:

- 1500 t sludge stored at the WWTP in 1996 was dewatered to 30% dry solids. For this purpose, a mobile chamber-filter press was used. A portion of this sludge was also incinerated. In 1997, it is planned that 3000 tonnes of sludge will be dewatered.
- 1000 t of the dewatered sludge was incinerated in 1996 at the combustion plant in Dabrowa Gornicza located in the Silesia area. In 1997, it is planned that 2700 t of dewatered sludge will be incinerated.

DISCUSSION

Experience with wastewater handling in Nowy Targ has shown that significant operational problems can occur if industrial developments are not considered during design of the WWTP. Such oversight can cause large differences between actual concentrations in the influent and the design values. Therefore, designing and construction of new advanced treatment plants should be combined with effective control of industrial discharges.

The sludge handling at Nowy Targ WWTP does not function properly, mainly due to an increase in discharges of tannery wastewater. The aerobic stabilisation of the sludge is not sufficient which causes odour problems, and the high chromium concentrations in the sludge make agricultural use impossible. Other alternatives for sludge handling must therefore be evaluated. The possible solutions considered are improved dewatering through use of a mobile chamber-filter press and the incineration of the dewatered sludge. Pyrolysis of sludge has been tested, and the removal of as much as 65% dry solids may be obtained at temperatures around 500°C.

Sludge handling methods utilising heat treatment in combination with pressure or the addition of acids, or both, has recently gained an increasing interest due its ability to diminish the sludge mass, improve the sludge dewatering properties and recover valuable products in the sludge such as phosphates. Full-scale experiments with such systems have been done in Sweden with the KREPRO-process (Water Quality International, 1996a) and in Norway with the Cambi-process (Water Quality International, 1996b). A similar system is illustrated in Figure 4, modified from Levlin *et al.* (1996) with respect to process configuration in Nowy Targ.

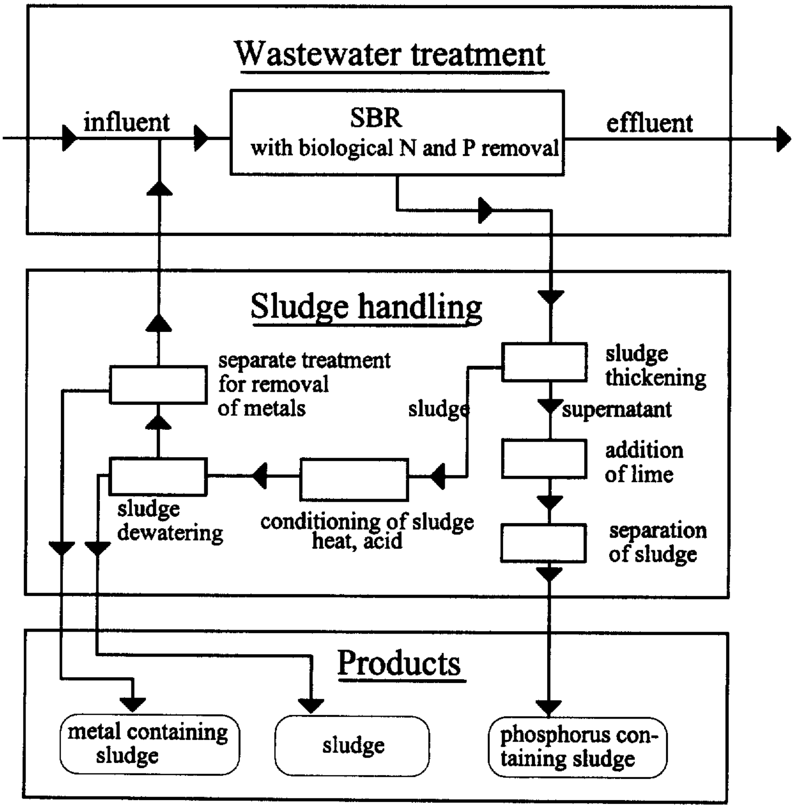

Figure 4. Process with recovery of phosphates and metals from sludge.

The purpose of the system is to separate phosphates from the sludge after the biological phosphorus removal step by use of anaerobic conditions during gravity thickening. The supernatant from the thickening step is treated with lime for production of calcium phosphates. Sludge from the thickening step is treated by heat and acids in order to release metals from the sludge. In this way a sludge produced has low metal concentrations. The liquid phase must also be handled to remove metals.

CONCLUSIONS

The studies performed at Nowy Targ SBR treatment plant included evaluation of the process performance and discussion of different strategies for sludge handling improvement. They showed that:

Due to a rapid increase in number of tanneries in the city chromium concentration in the influent had an increasing trend. During 1996-97 average concentration in the influent was 3 mg Cr/l which resulted in a chromium content in the sludge of 10 950 mg Cr/kg dry solids.

Despite the increased chromium concentration in influent high removal efficiencies (excluding start-up time) for BOD (96.8%), suspended solids (95.2%), phosphorus (89.5%), and nitrogen (74.1%) were obtained.

High chromium concentration in the sludge together with increased sludge production, poor sludge dewatering properties and odours made sludge handling a crucial problem for the plant.

Short-term solutions include construction of a special land deposit for the sludge, reduction of the sludge volume and elimination of odours. Alternative methods of sludge handling with use of special conditioning technologies should be considered.

Long-term solutions should be sustainable with emphasis put on source control of chromium discharges by use of legal enforcement, economic incentives, information campaigns, and the development of technical methods for on-site treatment of tannery waste.

ACKNOWLEDGEMENTS

This work has been realised as a part of Swedish-Polish co-operation within a consortium established between the Royal Institute of Technology, Stockholm, Sweden, and Cracow University of Technology, Cracow, Poland, the City of Nowy Targ, Poland, and the Water and Sewage Works in Nowy Targ. The co-operation is supported by the Swedish Institute and the Royal Institute of Technology.

REFERENCES

Banas, J. and Styka, W. (1996). Zastosowanie oczyszczalni scieków SBR do ochrony zbiornikow wodnych na przykladzie zbiornika Czorsztynskiego (Usage of SBR wastewater treatment plants for the protection of water reservoirs using the example of the Czorsztyn reservoir). *VII Ogolnopolskie Seminarium Naukowo-Techniczne "Ochrona Jakosci i Zasobow Wod"*, 199-212, (in Polish).

Johansson, Å. and Salberg, H. (1996). *Full scale study of sequencing batch reactor in Nowy Targ, Poland,* Master's Thesis Report, Royal Institute of Technology, Stockholm, Sweden.

Kabacinski, M. (1997). Zarys procesu technologicznego z uwzglednieniem usuwania azotu i fosforu oczyszczalni sciekow w Nowym Targu (Outlines of process technology with regard to nitrogen and phosphorus removal at the wastewater treatment plant in Nowy Targ). *Konferencja "Wysokosprawne oczyszczalnie sciekow w aspekcie zaostrzonych wymogow usuwania azotu i fosforu"*, Gdanska Fundacja Wody, (in Polish).

Kurbiel, J., Styka, W., Banas, J. and Mucha, Z. (1996). *Oczyszczalnia sciekow w Nowym Targu - koncepcja modernizacji urzadzen do przerobki i usuwania osadu (Wastewater treatment plant in Nowy Targ - recommendations for the modernisation of sludge treatment and disposal)*, Report, Cracow University of Technology, Institute of Water Supply and Environmental Protection, Poland, (in Polish).

Kurbiel, J. and Zeglin, K. (1997). High-effective technologies of biological nitrogen and phosphorus removal implemented in Poland. *Proceedings of Swedish-Polish seminar on "Advanced wastewater treatment", 30 June 1997,* Royal Institute of Technology, Stockholm, Sweden.

Levlin, E., Westlund, L. and Hultman, B. (1996). *Rening av avloppsslam från tungmetaller och organiska miljöfarliga ämnen*, (Removal of heavy metals and toxic organic compounds from sewage sludge), Report 1996-08, VA-FORSK, (in Swedish).

Morling, S. (1996). Modern SBR technology in Europe - a 10 year perspective. *VATTEN* **52**, 25-30, (in Swedish).

SEPA (1995). *Användning av avloppsslam i jordbruket (Usage of wastewater sludge in agriculture)*, Report 4418, Naturvårdsverket (SEPA) Förlag. (in Swedish).

Water Quality International (1996a). Hot prospects, *WQI*, July/August, 23.

Water Quality International (1996b). Thermal test, *WQI*, July/August, 24-25.