IDEAS FOR FUTURE SLUDGE MANAGEMENT AT THE NOWY TARG WWTP

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ABSTRACT

The wastewater treatment plant in Nowy Targ is based on sequencing batch reactor (SBR) technology. The plant operates with biological nitrogen and phosphorus removal and stabilisation of the sludge is performed in the reactors. The stabilisation is not efficient to produce a stable sludge and several odour problems are obtained. In addition, the sludge has a high chromium content and poor dewatering properties. A land deposit will be used for final disposal of the sludge. Different options are discussed to improve the sludge handling at Nowy Targ including better control of the tannery industries, methods to improve stabilisation and to control odour problems, volume reduction of the sludge and product recovery.

KEYWORDS

Chromium, Nowy Targ, odour, sludge handling, stabilisation, tannery wastes

INTRODUCTION

The disposal of sludge is a problem common to all methods of sewage treatment. Much of the substances in the influent will not be degraded and will be transferred to the sludge phase. Part of the sludge may be considered as a resource as the nutrients contents and organic materials used for instance as soil conditioner or for biogas production. Other substances may harm the environment such as heavy metals, organic micropollutants and pathogens. A main problem is that the valuable materials in the sludge is mixed with those that may harm the environment.

The economical value of sludge components is low and can only compensate for part of the sludge treatment costs. This has been recognised a long time as for instance stated by Babbitt (1953): "Values in sludge do not ordinarily return the cost of their recovery. The problem in most sewage-treatment plants is to get rid of the sludge as quickly as possible without causing a nuisance. This cannot always be accomplished without subjecting the sludge to some form of treatment. Where the sludge must be treated before disposal it is possible that some value may be recovered to repay in part the cost of treatment.

The principal values inherent in sludges from domestic sewage that can be recovered practically include fertilizer, grease, combustible gas, and heat units".

Due to the low economical value of sludge components main focus in Sweden has been to find a cheap and reliable method for final disposal of sludges. For treatment plants above 2000 person equivalents the sludge must be dewatered before final disposal. Each year the municipal wastewater treatment plants in Sweden produce approximately 1 million m^3 dewatered sludge with a corresponding dry solids content of 180,000 tonnes (VAV, 1991).

Sludge is stabilised by the following methods: Anaerobic digestion (70 %), lime stabilisation (15 %), aerobic digestion (3 %), composting (6 %), and no stabilisation (3 %) (Wittgren, 1996). Sludge disposal in Sweden in 1988 and in the European Union is shown in Table 1.

Table 1. Sludge disposal in Sweden (VAV, 1991) and in the European Union (Wilson and Jones, 1995).

Disposal route	Sweden (1988) %	European Union %
Agriculture	35	32
Incineration	0	13
Sea	0	5
Landfill		48
Deposition	40	
Land restoration	15	
Green belts	10	
Others		2

Main sludge disposal in Sweden is to agriculture or landfill similar to practice in the European Union, although incineration or disposal into the sea is not practiced. The authorities have encouraged the use of sludge to agricultural land if the sludge quality fulfils certain requirements concerning heavy metals and some key organic substances. However, the Federation of Swedish Farmers (LRF) recommended its members not to use sewage sludge after January 1, 1990. At the same time, the government has declared that the sludge should not be deposited on refuse tips, and incineration of sludge had not come into practice. Due to these reasons much attention has been given on methods to secure a sustainable sludge handling methodology.

Present situation of sludge handling in Sweden may be summarised as:

(1) Agricultural use of sludge is still encouraged by authorities although more stringent quality requirements are issued (Table 2).

Table 2. Maximum limits for metals (mg/kg dw) in Swedish sludges, 1973 & 1995 (Wilson and Jones, 1995).

Metal		1973	1995
Cadmium	(Cd)	15	2
Chromium	(Cr)	200	150
Copper	(Cu)	1500	600
Mercury	(Hg)	8	2.5
Nickel	(Ni)	100	100
Lead	(Pb)	300	100
Zink	(Zn)	3000	1500

Although the maximum limits for metals have become much more stringent, the use of sludge for agricultural land has not gained general acceptance from the public or the food industry. A national consultation group has recently been formed in Sweden in order to stimulate the use of sludge in agriculture and to agree on voluntary measures to satisfy the interests from the public and agricultural sector.

(2) Deposit of sludge on landfill is recommended to be minimised and be less than 25 % from year 2000 and 10 % from year 2010. A special fee of land disposal will be introduced as a way to diminish sludge disposal.

(3) Possibilities of the use of incineration will be evaluated in certain metropolitan areas. In Stockholm, for instance, tests have been made on sludge incineration together with solid wastes or biofuels

(Mossakowska et al., 1998). If incineration will be used the intention is to recover phosphorus either from the ashes or from the sludge before incineration. Heat drying is also considered as a method to reduce the sludge volume and has been installed at Himmerfjärden treatment plant south of Stockholm (Dahlberg et al., 1995).

(4) Much interest has been devoted during the last years to the possibilities to split the sludge into different fractions that are used for product recovery. Two systems have been tested in full scale in the Nordic countries, namely the KREPRO and Cambi systems (Water Quality International, 1996a and 1996b).

SPECIAL PROBLEMS IN SLUDGE MANAGEMENT AT NOWY TARG WWTP

Kabacinski (1997) and Kabacinski et al. (1998) have described the treatment plant in Nowy Targ and problems related to sludge handling. The wastewater treatment plant in Nowy Targ is the largest plant in Europe based on sequencing batch reactors. A significant supply of tannery wastes with increasing chromium values in the influent has resulted in many operational problems related mainly to sludge treatment. At present, about 300 tanneries operate in the city. The real values for the parameters characterising the influent wastewater are different from those initially determined as the design parameters (Table 3).

Table 3. Comparison between parameters used for the designing of the plant and those obtained during operation of the plant (Kabacinski et al., 1998).

Parameter	Project value	Real value (average for two years)
BOD_5, mg/l	332	260
COD, mg/l	526	740
SS, mg/l	106	450
Cr, mg/l	0.5	3.0
Sludge age, days	26	14-30
Sludge production, kg/ kg BOD7	0.6	l-l.2
Sludge load, kg BOD_5/ kg SS*d	0.07	0.04-0.06
Sludge dewatering, % DS	20-25	13-17
Amount of dewatered sludge at actual flow, tonnes/day	8	25

The wastewater treatment plant is schematically shown in Figure 1. The plant has a special tannery treatment plant and another part intended for treatment of municipal wastewater. Many tanneries, however, discharge tannery wastes into the sewer net and the influent may therefore be described as a mixed municipal and industrial wastewater. The sludge from the SBR units are treated by use of thickeners followed by dewatering with centrifuges. The chromium concentration in sludge is in the range of 1,500-40,000 mg Cr/kg dry solids and makes agricultural use of sludge impossible. A sludge deposit is at present constructed with a sludge storage volume equivalent of 3 years.

Tanning leather with Cr(III) salts was first introduced in 1858 and today large quantities are consumed by the industry. For example, in 1985, leather tanning consumed 32 % of the total trade in chromium compounds (Walsh and O'Halloran, 1996b). The tanning procedure is a chain of several batch processes and produces wastewater that usually is characterised by high amounts of suspended solids, organic substances (COD, BOD) as well as high concentrations of inorganic salts like chloride, ammonia, sulphide, sulphate and chromium(III) salts.

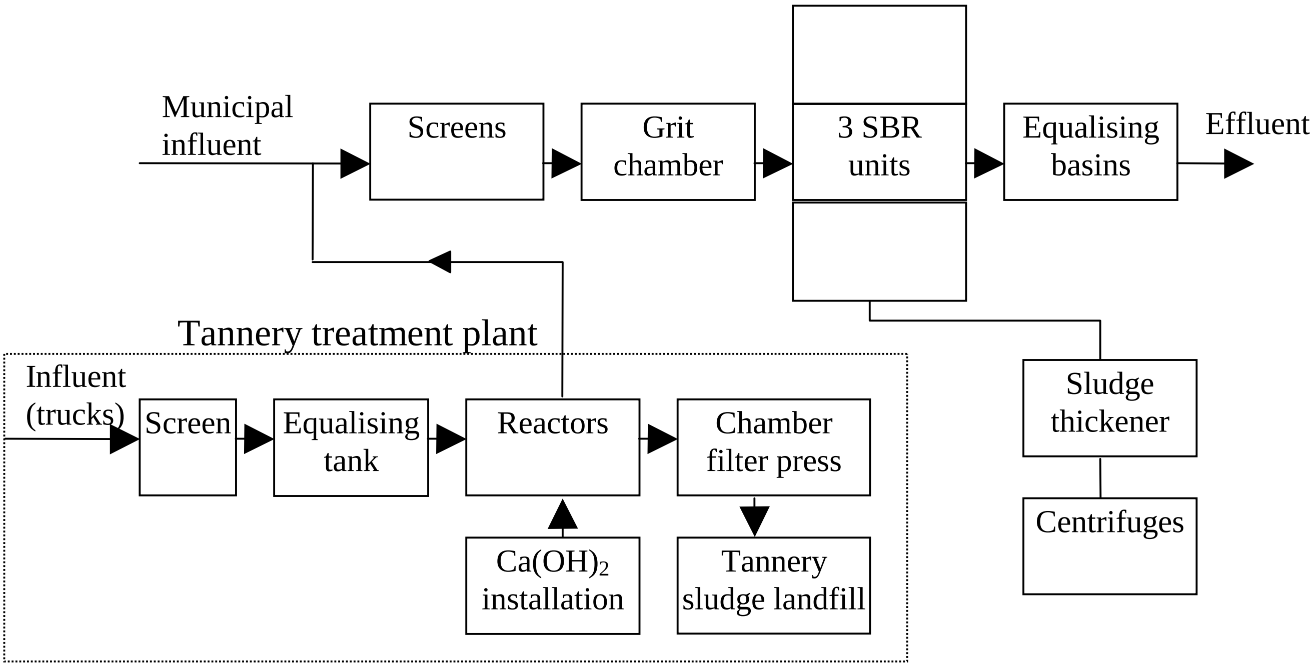

Figure 1. Wastewater and sludge handling at the Nowy Targ WWTP (Kabacinski et al., 1998).

Production of chrome leather involves an initial fleshing stage followed by soaking in a solution of lime and sodium sulphide (liming) which hydrolyses and dissolves globular proteins and hair. Hides are further prepared and treated with Cr(III), which forms crosslinks between collagen fibers which give leather its durable finish (Walsh and O'Halloran, 1996b).

Different approaches may be used to control environmental problems due to tannery wastes:

- Changes in production technologies, i.e. substituting Cr(III) salts with vegetable and synthetic agents
- Improved internal treatment of tannery wastes and recovery of Cr(III) for instance by use of ion exchange (Tiravanti et al., 1997) or membranes (Cassano et al., 1997; Fabiani et al., 1997)
- Improved collection of tannery wastes to the special tannery treatment unit
- Improved wastewater and sludge handling at the mixed municipal and industrial wastewater treatment part

It is probable that the most cost-effective way to handle the tannery wastewater problem is the first three approaches. However, only the last approach will be discussed in the following.

Three main problem may be identified in the sludge handling. The first problem is related to the high chromium content in the sludge, the second to difficulties to stabilise the sludge and the connected odour problems and the third to the large amount of produced sludge volumes.

PROBLEMS WITH CHROME IN THE SLUDGE AND POSSIBLE REMEDIES

In the tannery process part of the Cr(III) is soluble in ionic form and part as organic complexes. Cr(III) hydroxide has its minimum solubility around pH 8. Under oxidising conditions Cr(III) may be oxidised to Cr(VI).

The organic ligands in the organic complexes with chrome(III) are i.e. proteins, amino acids and organic acids. While the solubility of the ionic form is dependent on the pH-value the solubility of the organic complexes may be independent of the pH-value. The type of complexes determines how easy they may be precipitated by for instance Fe(III) (Walsh and O'Halloran, 1996a).

The chromium speciation in tannery effluents undergo different changes in the wastewater treatment processes or recipients (Walsh and O'Halloran, 1996b). Bacteria may reduce Cr(VI) to Cr(III) (Wang and Shen, 1997). The removal efficiency of chromium in the activated sludge process varies considerably and is in average about 60 % based on studies at several plants (Rossin et al., 1982; Berg, 1986). At Nowy Targ WWTP the average value for the removal of chromium was 87.1 for the years 1996-1997 (Kabacinski et al., 1998).

Two main routes should be considered concerning handling of chromium containing sludges:

- Recovery of the chromium from the sludge
- Insolubilisation of chromium compounds in order to avoid spreading of chromium to the environment

The first approach was shortly discussed by Kabacinski et al. (1998). A process scheme was suggested in which sludge was fractionated into different products (see Figure 2).

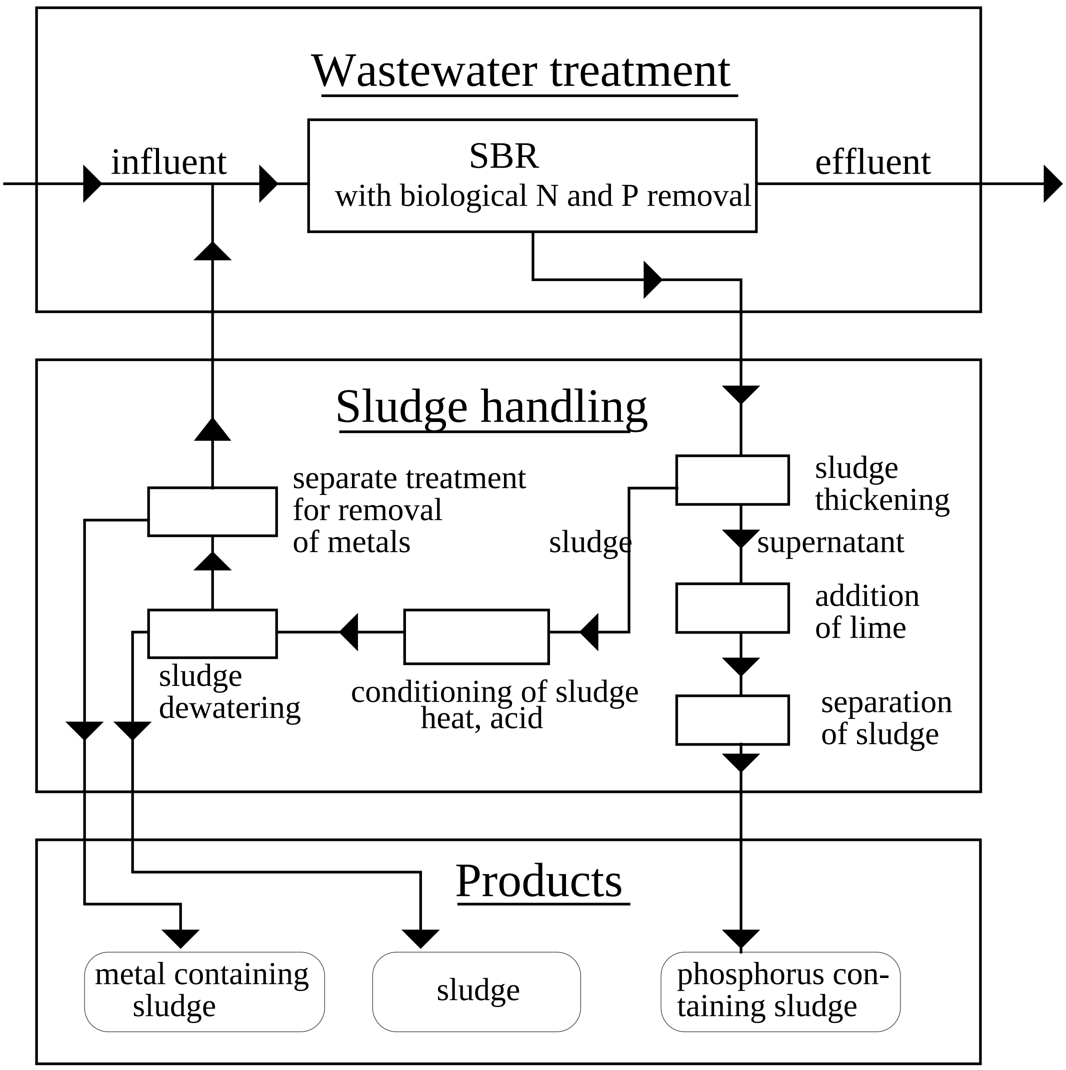

Figure 2. Process with recovery of phosphates and metals from sludge (Kabacinski et al., 1998).

The suggested process scheme may be seen as a possible long term solution for Nowy Targ. Phosphorus may be a limiting factor for the future and should be recovered. A major difficulty is to avoid co-precipitation of phosphorus with chromium compounds from the supernatant, i.e. for instance use a high separation efficiency in the sludge thickening process.

A next step in the sludge handling process is to dissolve chromium compounds from the sludge. Several different ways are possible:

(1) Conditioning of the sludge by use of heat and acids. The purpose is to break down chromium-organic complexes and to dissolve Cr(III) compounds.

(2) Use of bases as sodium hydroxide. In this case precipitated Cr(III) could be dissolved and a partial break down of chromium-organic compounds might occur.

(3) Oxidation of Cr(III) compounds to chromates, Cr(VI), that are soluble. Oxidation may be done by hydrogen peroxide under alkaline conditions (cf Tiravanti et al., 1997) or other strong oxidants.

Experimental studies in a laboratory scale may be done to evaluate the efficiency and costs of these dissolution methods. The methods described have a conditioning effect on the sludge and part of the organic material is dissolved leading to a lower sludge production. In addition, the dewatering properties are normally improved compared to traditional methods with the addition of polyelectrolytes.

An important disadvantage of oxidising Cr(III) to chromates is the much higher toxicity of chromates compared with Cr(III). Chromates are suspected of causing cancers and contact dermatitis. If chromates are formed in a process step in a system for recovery of chromium much attention must be given to labour safety aspects.

The fate of chromium in combustion processes has been studied to some extent. Chromates are normally only a very small fraction (about 1 %) of the total chromium content in ashes (Tillman, 1994). However, under certain conditions, as use of sewage sludge for brick manufacturing, oxidation of Cr(III) to Cr(IV) may be significant due to the alkaline conditions during the heating process (Rump, 1998). Special methods are available for the immobilisation of chromium compounds (Hattori and Yaku, 1978).

PROBLEMS WITH THE STABILISATION OF THE SLUDGE AND POSSIBLE REMEDIES

Stabilisation of a sludge means that the sludge does not change significantly with time and that the biological reactions have stopped. The three main ways are:

- Biological methods (especially aerobic digestion, composting and anaerobic digestion)
- Chemical methods (especially the addition of lime)
- Thermal methods (especially heat drying and combustion)

Stabilisation may also be performed by use of nitrates or ferric salts. Reactions in sludge stabilisation with oxygen, nitrate, ferric irons and anaerobically are illustrated in Table 4. It is assumed that the VSS of the sludge has the composition $C_5H_7O_2N$.

The daily production of dewatered sludge at Nowy Targ WWTP was 25 tonnes with 15 % dry solids. For a volatile fraction of 80 % the daily sludge production would be 3 tonnes VSS. If 10 % of this VSS should be stabilised by the addition of chemicals as $FeCl_3$ or $Ca(NO_3)_2$, the daily need would be 8.6 tonnes $FeCl_3$ and

0.87 tonnes $Ca(NO_3)_2$, respectively. These additions would be to high and use of $FeCl_3$ and $Ca(NO_3)_2$ will instead be considered in next section as remedies for odour control.

Table 4. Examples of reactions in biological sludge stabilisation

HALF-REACTIONS (cf McCarty, 1971)	
$\frac{1}{20}C_5H_7O_2N + \frac{9}{20}H_20 \quad \frac{1}{5}CO_2 + \frac{1}{20}HCO_3^- + \frac{1}{20}NH_4^+ + H^+ + e^-$	(1)
$\frac{1}{2}H_2O \quad \frac{1}{4} O_2 + H^+ + e^-$	(2)
$\frac{1}{10}N_2 + \frac{3}{5}H_2O \quad \frac{1}{5}NO_3^- + \frac{6}{5}H^+ + e^-$	(3)
$Fe^{2+} \quad Fe^{3+} + e^-$	(4)
$\frac{1}{8}CH_4 + \frac{1}{4}H_2O \quad \frac{1}{8}CO_2 + H^+ + e^-$	(5)
BIOLOGICAL REACTIONS	
(1) and (2): $C_5H_7O_2N + 5O_2 \quad 4CO_2 + HCO_3^- + NH_4^+ + H_20$	(6)
(1) and (3): $C_5H_7O_2N + 4NO_3^- + 4H^+ \quad 4CO_2 + HCO_3^- + NH_4^+ + 2N_2 + 3H_2O$	(7)
(1) and (4): $C_5H_7O_2N + 20Fe^{3+} + 9H_2O \quad 4CO_2 + HCO_3^- + 20Fe^{3+} + NH_4^+ + 20H^+$	(8)
(1) and (5): $2C_2H_5O_2N + 8H_2O \quad 5CH_4 + 3CO_2 + 2HCO_3^- + 2NH_4^+$	(9)
NEED OF ELECTRON ACCEPTOR/PRODUCED METHANE IN DEGRADATION OF VSS	
Molar weight of VSS ($C_5H_7O_2N$): 113 g	
Oxygen need for degradation of VSS: $\frac{160}{113} = 1.42$ g O_2/g VSS	
Nitrate nitrogen need for degradation of VSS: $\frac{56}{113} = 0.496$ g N/g VSS	
Ferric iron need for degradation of VSS: $\frac{1120}{113} = 9.91$ g Fe/g VSS	
Methane production in degradation of VSS: $\frac{80}{226} = 0.354$ g CH_4/g VSS	

Tonkovic (1998) has reported from a research project with the purpose to establish the stability of waste activated sludge generated from different plants and to determine what further treatment that is required to produce a substantially stabilised (i.e. non-odorous) sludge.

In the study it was stated that "It has been previously thought that the waste activated sludge from BNR (biological nutrient removal) extended aeration plants (sludge age of approximately 25 days) was sufficiently stabilised to permit dewatering and stockpiling without odour generation. However, experiences at a number of BNR plants with large unaerated mass fractions for biological removal of nitrogen and phosphorus has demonstrated that these sludges are generally odourous, more so than with conventional extended aeration sludge. Experience in Australia and South Africa has shown that if extended aeration BNR sludge is dewatered and stockpiled extremely severe odour problems will occur particularly if the sludge cake stockpiles are disturbed".

In the biosolids guidelines in Australia, two parameters are used to determine the stabilisation grade: (1) reduction of volatile solids and (2) specific oxygen uptake rate (SOUR). For land disposal, the biosolids must achieve a SOUR criteria of less than 1.5 mg O_2/g TSS*hr for biosolids treated by an aerobic process. Even long stabilisation times with aerobic digestion might not give a sufficient reduction of VSS in the sludge (Tonkovic, 1998).

The WWTP in Nowy Targ handles a wastewater where much of the organic material is slowly biodegradable as indicated by a low quotient between BOD_5 and COD (about 0.35 g BOD_5/g COD) (Kabacinski et al., 1998). Ates et al. (1997) have characterized the soluble fraction of chemically precipitated tannery wastewater. The experimental results indicate that around 20 % of the total COD is expected to be resistant to biological degradation; of the remaining portion 35 % is determined as readily biodegradable COD, leaving 45 % as slowly biodegradable COD. In addition to the high fraction of slowly biodegradable organic material that may indicate the need for long stabilisation times to diminish odour problems, the wastewater contains sulphur containing substances that may worsen the problems with odours. Aerobic digestion, composting, anaerobic digestion, and thermal treatment seem to be the major alternatives for stabilisation of the excess sludge.

ODOUR PROBLEMS AND POSSIBLE REMEDIES

Odour problems are normally related to hydrogen sulphide. Sulphides may exist in wastewater handling systems due to:

- Direct discharges into the sewer net by industries as tanneries, oil industry etc. In a few cases sulphides may also be supplied from groundwater.
- Hydrolysis and degradation of organic sulphur compounds as certain proteins
- Microbial reduction of sulphate to sulphide in anaerobic oxidation of organic material

Direct discharges of sulphides are uncommon in Sweden. However, odour problems due to hydrogen sulphide formation have been recognised since a long time. In a survey to municipalities it appeared that 46 % (162 answers out of a possible of 288) municipalities had problems induced by hydrogen sulphide formation (Holmström et al., 1978). At present most municipalities use some method to reduce hydrogen sulphide formation. Supply of air or calcium nitrate are the most common methods. Compost filters are often used to treat odourous air.

Odour is normally obtained under anaerobic conditions for instance in primary sedimentation basins and during sludge treatment, while the sludge is thickened, dewatered, or stored without previous efficient stabilisation. Many alternatives are available for diminishing problems related to sludge odours (Huang et al., 1978).

Methods that should be considered for odour control at the Nowy Targ WWTP include:

- Addition of ferric salts (for instance during the conditioning of sludge) for increasing the redox potential and binding of sulphurus compounds
- Addition of lime and/or calcium nitrate on the surface of deposited sludge
- Covering of deposited sludge by for instance compost, that acts as a biological step for removal of odorous gases
- Supply of air to the deposited sludge in order to keep a high redox potential in the sludge

SLUDGE DEPOSIT VOLUME NEEDS AND POSSIBLE REMEDIES

The daily production of dewatered sludge at the Nowy Targ plant was about 25 tonnes with a 15 % dry solids (Kabacinski et al., 1998). A sludge deposit will be constructed with a sludge storage volume equivalent of 3 years. An important issue is therefore to find methods to decrease the sludge volume and thereby increase the time before the sludge deposit area is occupied.

Many technical solutions are available to decrease the sludge volume, including:

- Improved sludge dewatering by use of better conditioning methods or dewatering equipment
- Heat drying and incineration of the sludge
- Improved sludge stabilisation that decreases the organic contents in the sludge
- Special methods with product recovery (cf figure 2)

The planned and partly built sludge deposit area has a potential for different natural and biological dewatering and stabilisation methods. These methods should be seen as a complementary sludge treatment before final disposal. Several methods are available and should be considered:

- Use of composting as a method of sludge stabilisation, odour reduction and volume reduction. Composting increases the stability of Cr complexes (Qiao and Ho, 1998).
- Dewatering of wastewater sludge by natural air drying by use of drying beds (Marklund, 1997). Possibilities should be evaluated of possible use of conditioning of sludge by freezing/thawing in combination with the natural dewatering (Hellström, 1996 and Kvarnström, 1997).
- Use of plants on the sludge plants in order to evaporate water and supply oxygen through the root system

DISCUSSION

Experiences with wastewater handling in Nowy Targ have shown that significant operational problems can occur if industrial developments are not considered during the design of the WWTP. The sludge handling at Nowy Targ does not function properly, mainly due to an increase in discharges of tannery wastes. The amount of sludge at actual flow had the projected value of 8 tonnes per day, which may be compared with the actual value of 25 tonnes per day.

An evaluation of suitable sludge handling is much dependent on future development in tannery industries. This evaluation should include expected future production, possible changes in production technology, possibilities of improved internal treatment methods, and improved collection of tannery wastes for separate treatment.

At the wastewater treatment plant several possibilities are available:

- Changes in operational strategies
- Investments in new technical process steps
- Complementary treatment of sludge at the sludge deposit
- Transport of the sludge to other sludge handling plants (for instance for incineration)

Operational strategies may be changed by operating only two reactors for wastewater treatment and use of the third for sludge stabilisation. A common way to treat wastewater in Sweden is the use of pre-sedimentation followed by the activated sludge process and anaerobic digestion of the sludge. Investments of pre-sedimentation tanks (one of the reactors of the SBRs could possibly be used) and anaerobic digestion would probably solve most of the acute problems at Nowy Targ (odour reduction and some volume reduction). Pre-sedimentation, especially in combination with coagulation is an efficient method for pollutant removal from tannery wastewater (Roš and Gantar, 1998) and the efficiency of the digestion may be increased by thermal pretreatment (Pinnekamp, 1998 and Water Quality International, 1996b). Final deposition of sludge would, however, still be a problem both related to chromium and limited space for deposition.

Heat drying of sludge is an interesting method to substantially reduce the sludge volumes. Even less sludge is produced in incineration. This process is, however, expensive and much consideration must be laid on treatment of the flue gases and safe handling of ashes.

Natural conditioning, dewatering and stabilisation of sludges should be of interest to evaluate at Nowy Targ due to the available area of the land deposit which is not yet occupied by sludge. These methods may prolong the time until decisions must be taken for the future sludge handling at Nowy Targ.

The sludge from Nowy Targ WWTP has some similarities with contaminated soils or sediments. Different methods for remediation of soils and sediments may therefore be of interest to evaluate. Landfarming is a method where waste residues are applied to the surface layers of a soil and the soil is cultivated regularly to ensure adequate mixing and aeration. Aerobic microbial activity in the soil then ensures the degradation of the waste. Soil is laid out to a depth that can be cultivated using conventional agricultural equipment (usually < 0.75 m) and the soil bed is usually constructed above an impermeable base, incorporating a leachate collection system (OECD, 1994, and Ferdinandy-van Vlerken, 1998).

SUMMARY AND RECOMMENDATIONS

(1) The sludge handling at Nowy Targ must consider possible developments of the whole wastewater handling system, including source control, changes in production technologies, better collection of tannery wastes for separate treatment, changes in operational strategies, investments in new treatment facilities, sludge treatment at the land deposit, possibilities to transport sludges to other sludge handling facilities and final disposal.

(2) Much attention should be given to source control, changes in production technologies, and better collection of tannery wastes.

(3) Some possible changes of operational strategies may be studied as the use of one of the reactors in the SBR system for separate sludge stabilisation or changes of sludge treatment technologies for instance use of lime and iron salts instead of polymers in conditioning for improved odour control.

(4) Different new investments should be considered such as the use of pre-sedimentation and anaerobic digestion of the sludge or better dewatering equipment followed by heat drying. By this method the land deposit can be used a much longer time, during which time different sludge strategies can be tested and evaluated. Transport of heat dried sludge to an existing incineration plant in the neighbourhood may also be an interesting possibility.

(5) The use of natural methods for sludge handling at the land deposit should be evaluated in order to improve sludge stabilisation, diminish odour problems and decrease the sludge volume. Such methods include natural dewatering by freezing/thawing, use of plants to increase evaporation, composting and use of landfarming. Produced compost could be used as a cover of sludge deposits to decrease odour problems.

(6) Environmental effects of the sludge deposit and methods to decrease pollution loads should be evaluated. Possibilities to restore the landfill in the future is also of interest to study.

(7) As a long term strategy, different methods should be evaluated to use the produced sludge as a resource with product recovery of different sludge components.

(8) Due to the many possibilities for sludge management at Nowy Targ, methods as Life Cycle Assessment (LCA) should be considered in addition to other evaluation methods as costs, process performance, relability and risk assessment.

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