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ADVANCED WASTEWATER TREATMENT

Report No 6.

SLUDGE HANDLING AT NOWY TARG WASTEWATER TREATMENT PLANT, POLAND

EVALUATION AND RECOMMENDATIONS FOR IMPROVEMENTS

**Bengt Hultman, Erik Levlin,
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PREFACE

A collaboration has existed since several years between the City of Nowy Targ, the Municipal Water and Sewage Works in Nowy Targ, Cracow University of Technology and the Royal Institute of Technology, KTH, in Stockholm. Results from this collaboration has been reported in five earlier reports with main support from the Swedish Institute (SI).

Report No 1. Phosphorus removal from wastewater. A literature review. Stanislaw Rybicki.
Report No 2. Proceedings of a Polish-Swedish seminar, KTH, May 30, 1997.
Report No 3. Proceedings of a Polish-Swedish seminar, Nowy Targ, October 1-2, 1998.
Report No 4. Factors influencing sludge settling parameters and solids flux in the activated sludge process. Anna Stypka.
Report No 5. Sustainable municipal sludge and solid waste handling, Proceedings of a Polish-Swedish Seminar KTH, August 24, 1999.

This report differs from the other reports as it is a direct investigation focused on the sludge handling problems at Nowy Targ. Financial support has been obtained from the Swedish International Development Agency (SIDA; Dnr Öst-1996-0767). The reason to include this SIDA financed report in the report series is the generality of the studied problem. Many municipalities are faced with the problem of having a metal content in the sludge far exceeding limiting values for use in agriculture and other beneficial uses. Although efficient source control is normally the best long range alternative, short term alternatives have to be developed. It is therefore the hope that this report should not only be useful for Nowy Targ but also for other municipalities facing similar problems.

Stockholm in August 1999

Bengt Hultman

SUMMARY

Different options for improved sludge handling have been studied for the Nowy Targ treatment plant. Information has been obtained from different reports and data has been collected from the plant in order to make different calculations and judgements. Supplementary information has been obtained from interviews and discussions with staff and from the Cracow University of Technology. In addition the evaluation has been compared with different information reported in literature.

Two main systems have been discussed and evaluated in order to comply with the many problems related to the sludge handling in Nowy Targ, including low stabilisation degree, odour problems and low dewatering properties. The first system has primary clarifiers, anaerobic digestion and a new landfill as main investments and the other system is based on incineration and deposit of the ashes in a constructed landfill at the plant.

The first system will solve many of the problems at Nowy Targ including a high degree of sludge stabilisation, much less odour problems and better dewatering properties of the sludge. The main drawback is that a new landfill area must be used. In many countries it will not be allowed to use landfills for deposition of sludges with an organic content above 5 %. In general, sludge disposal on landfill gets less and less acceptance.

Odour problems seem mostly to depend on disposal of sludges that are not sufficiently stabilised. Aerobic stabilisation, composting and anaerobic digestion seem to be cost-effective for stabilisation by biological methods. If the sludge is stored for a short period before further sludge handling increase of the pH-value or addition of substances (as nitrate) that inhibits septicity of the sludge seem to be useful.

The need to reduce the volume of the sludge makes heat drying and incineration two suitable treatment ways. Both methods have their advantages and disadvantages as discussed in the report. Heat drying will within about 10-15 years fill up the constructed landfill and complementary handling of the heat dried sludge must be considered. Incineration may be used either at a plant constructed later on near the treatment plant or at a central incinerator plant in the region. Chromium recovery from heat dried sludge is also a possibility for complementary handling of the sludge.

Heat drying involves certain fire risks that should be considered both during the drying process and later on if biological reactions causes a high temperature of the sludge. Biological reactions may also induce reactions that cause bad odour.

Use of incineration produces relative small volumes of ashes and the constructed landfill may at present sludge production last more than 50 years before it is filled-up. This solution may therefore be seen as a long-range solution especially if methods can be developed to recover chromium from the ashes. If incineration is used it is recommended to use only small additions of inorganic material as these will significantly increase the volumes of ashes and to avoid oxidation of chromium(III) to chromium(VI) that occurs at high redox potentials and at high pH-values. Two other problems at Nowy Targ in use of incineration is the poor dewatering properties of the sludge that makes incineration energy consuming and the relative small size of the plant to make incineration cost-effective.

CONTENTS

BACKGROUND AND OBJECTIVES

The City of Nowy Targ has built a new wastewater treatment plant (WWTP), which was partially financed by the Swedish Government (BITS) and designed by Swedish specialists. It has a design capacity of 120 000 person equivalents and is based on SBR technology which is one of the most efficient biological technologies for wastewater treatment. The plant is the largest classical SBR based plant in Europe and several smaller treatment plants have been built in Poland with the same technology. The plant was taken into operation in April 1995 and was officially opened in September 1995.

The town is located in the southern part of Poland on the feet of the Tatra mountains. Nowy Targ hosts about 35,000 inhabitants and including surrounding villages about 45,000 inhabitants are connected to the sewer net. The town is discharging its sewage into the Dunajec river.

The town hosts a number of industries linked to farming such as dairies and canning industries. The problematic industry type is, however, the tanning industry with about 300 industries which are all based on chromium tanning and sized from an artisan level to larger industrial plants (Kabacinski, 1997).

During the time of operation Poland has gone over a broad range of transformations of its economic system. Large industries had to slow down its production (in Nowy Targ a shoe factory and a dairy plant) while an uncontrolled burst of small enterprises occurred, mostly in traditional field in this area of tanning and fur tailoring. Such a shift within the local industry accompanied by a significant drop in water consumption caused high water rates. This resulted in major changes in quality and volume of the wastewater influent to the Nowy Targ wastewater treatment plant.

Problems related to the Nowy Targ wastewater treatment plant is much influenced by the tanning industry. Problematic substances in tannery wastes include chromium, sulphides and slowly biodegradable organic substances. Chromium compounds may have a toxic effect, sulphides are related to odour, labour safety and corrosion problems and may increase the sludge index (sludge bulking) and slowly biogradable organic compounds increase the sludge yield (as g volatile suspended solids/g removed COD or BOD) and increase the necessary time for sludge stabilisation.

Many studies have been performed to evaluate the wastewater treatment efficiency at Nowy Targ. Process technology and the efficiency of the wastewater treatment is controlled continuously. A good removal efficiency, BOD_5 (96.8 %), suspended solids (92.5 %), nitrogen (74.1 %), and phosphorus (89.5 %) has been obtained throughout the 3 year operation period. During the winter season the treatment efficiency has diminished due to low wastewater temperatures (during some periods even lower than 5 ^{o}C) and by increased pollution load to the wastewater treatment plant (increased pollution load from tanneries).

The problems at the wastewater treatment plant in Nowy Targ are, however, related to sludge treatment and disposal:

- The sludge age in the SBRs is not high enough to give an efficient sludge stabilization and the sludge gives therefore rise to very significant odour problems both for the plant staff and inhabitants in the surroundings of the plant.

- The sludge production is higher than the value used in the project design. The actual sludge production is about double that assumed in the plant design. The value of 0.6 kg/kg BOD_5 removed was assumed but in reality a value of 1.0-1.2 kg/kg BOD_5 removed was obtained.

- Sludge dewatering is insufficient and gives only about 15 % of dry solids after mechanical dewatering

- The combined effect of high sludge production and low dewatering efficiency gives rise to about 3 times larger volumes of sludge for disposal than design values

- The actual chromium concentration in the influent is about six times higher than the assumed value in the project. This results in high chromium concentrations in sludge. Values in a range between 5,000 - 20,000 mg Cr/kg dry solids are obtained.

- Due to the high chromium content in the sludge it can not be used in agriculture and it is difficult to find a disposal permit for land disposal. Since the beginning of the operation of the plant about 8000 tonnes dry solids of sludge has been stored directly at the area of the treatment plant and the surroundings. Some part of the produced sludge (1000 tonnes dry solids) has been transported to an incineration plant in Dabrowa Gornicza in the Silesia area (company Lobbe). At present sludge is disposed in a specially constructed landfill. However, the planned storage volumes can only store sludge for about three years until they are filled with the present sludge volume production.

The many problems related to present sludge handling practice have given rise to several studies to evaluate methods to improve the sludge handling. Many investigations have been performed to get better design data and laboratory works have been done for sludge characterisation and treatment evaluation. Full-scale studies at the treatment plant include better conditioning techniques and addition of lime for odour reduction. Polish external expertise was involved by the City of Nowy Targ to evaluate the situation at the WWTP and to give recommendations for solving the sludge handling problems.

A close co-operation has existed during the last four year between the City of Nowy Targ, the Water and Sewage Works in Nowy Targ, the Cracow University of Technology and the Royal Institute of Technology (KTH) in Stockholm. In general line with this co-operation the Royal Institute of Technology (KTH) received a grant from the Swedish International Development Agency (SIDA) to evaluate the present sludge handling and to recommend different actions to improve the sludge handling.

The objectives of the SIDA supported project were:

(1) Evaluation of present sludge handling results at WWTP in Nowy Targ.

(2) Evaluation of different suggestions for improving the sludge handling in Nowy Targ

(3) Evaluation of methods to decrease the odour problems from the sludge.

(4) Supplementary evaluation of the design of the landfill to facilitate future methods for odour control, diminish negative effects of leaching of pollutants into the groundwater and of runoff.

(5) Recommendations for future sludge handling at Nowy Targ and detailed planning for a second phase of the project.

The study is based on the following information sources:

- The listed documents and reports below written in Polish
- Data collected at the treatment plant
- Special investigations partly presented at a conference in Nowy Targ (Hultman and Kurbiel, 1998) and partly performed as master thesis works (Eklundh, 1999, Kamues, 1999)
- Relevant information published in literature
- Interviews and meetings with staff at Nowy Targ and at Cracow Technical University

At the conference at Nowy Targ October 1-2 1998 ideas were presented for future sludge management at the Nowy Targ treatment plan (Hultman et al. 1998) as a part of the SIDA project.

The following documents and reports written in Polish, were accessible and utilized during preparation of this report.

1. 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.

2. Banas J., Styka W. and Kurbiel J. (1997). *Opinia o zmianie warunkow pozwolenia wodno -prawnego dla oczyszczalni sciekow w Nowym Targu (Opinion on change of discharge conditions for the wastewater treatment plant in Nowy Targ),* Report, Cracow University of Technology, Institute of Water Supply and Environmental Protection, Poland.

3. Radzicki P. (1997). *Projekt budowlany i podstawowy skladowiska popiolow z utylizacji osadu nadmiernego oraz tymczasowego skladowiska osadu nadmiernego w oczyszczalni sciekow komunalnych w Nowym Targu (Construction of landfill for ashes disposal from excess sludge utilization and temporary excess sludge disposal at the Nowy Targ WWTP),* EKO-Konsulting-Projekt CONSEKO S.A., Krakow.

4. Kumiega E. (1997). *Ocena oddzialywania na srodowisko do rozwiazania projektowego skladowiska popiolow z utylizacji osadu nadmiernego oraz tymczasowego skladowiska osadu nadmiernego w oczyszczalni sciekow w Nowym Targu (Environmental Impact Assessment for construction of landfill for ashes disposal from excess sludge utilization and temporary excess sludge disposal at the Nowy Targ WWTP),* EKO-Konsulting-Projekt CONSEKO S.A., Krakow.

5. Montewski W. et al. (1997). *Koncepcja instalacji termicznej utylizacji osadu nadmiarowego oczyszczalni sciekow komunalnych w Nowym Targu (Concept of thermal utilization of wasted sludge at Nowy Targ WWTP),* BBM Design Sp. z O.O., Krakow.

6. Montewski W. et al. (1997). *Ocena oddzialywania na srodowisko instalacji termicznej utylizacji osadu nadmiarowego (Environmental Impact Assessment of thermal utilization of wasted sludge at Nowy Targ WWTP),* BBM Design Sp. z O.O., Krakow.

7. Gega J. (1997). *Opinia do opracowania pt. "Ocena oddzialywania na srodowisko instalacji termicznej utylizacji osadu nadmiarowego w oczyszczalni sciekow komunalnych w Nowym Targu" oraz "Koncepcji instalacji utylizacji termicznej odpadow" (Reevaluation of the reports "EIA of thermal utilization of wasted sludge at Nowy Targ WWTP" and "Concept of thermal utilization of wasted sludge"),* Krakow.

8. Banas J., Styka W., Kurbiel J. (1998). *Oczyszczalnia sciekow w Nowym Targu. Operat wodno-prawny do pozwolenia na eksploatacje (Wastewater treatment in Nowy Targ. Concession for operation permit),* Report, Cracow University of Technology, Institute of Water Supply and Environmental Protection, Poland.

PART A. BASIC DATA AND SPECIAL INVESTIGATIONS

I. WASTEWATER TREATMENT PLANT SCHEME

A detailed presentation of the plant design has been given by Kaciñski (1998) from which a summary is given with emphasis on sludge handling. The wastewater treatment plant in Nowy Targ is based on Sequence Batch Reactors (SBR). The plant is made up of mechanical stage (screens and sand traps with grease separators), biological stage (three SBR reactors) and a chemical stage based on dosing $Ca(OH)_2$ and $FeSO_4$. The plant was also equipped with a separate process line for neutralisation of chromic wastewater produced by tanneries and furriery workshop abundant in the area.

The design was made by a Swedish company from Stockholm ”SCANDIACONSULT” in co-operation with a Polish company ”HYDROEKOSAN” from Gliwice. The project was performed between 1992-1995. The operation started in April 1995 and the official start-up was in September 1995 thereupon the operation of the largest sewage treatment work in the Podhale region started.

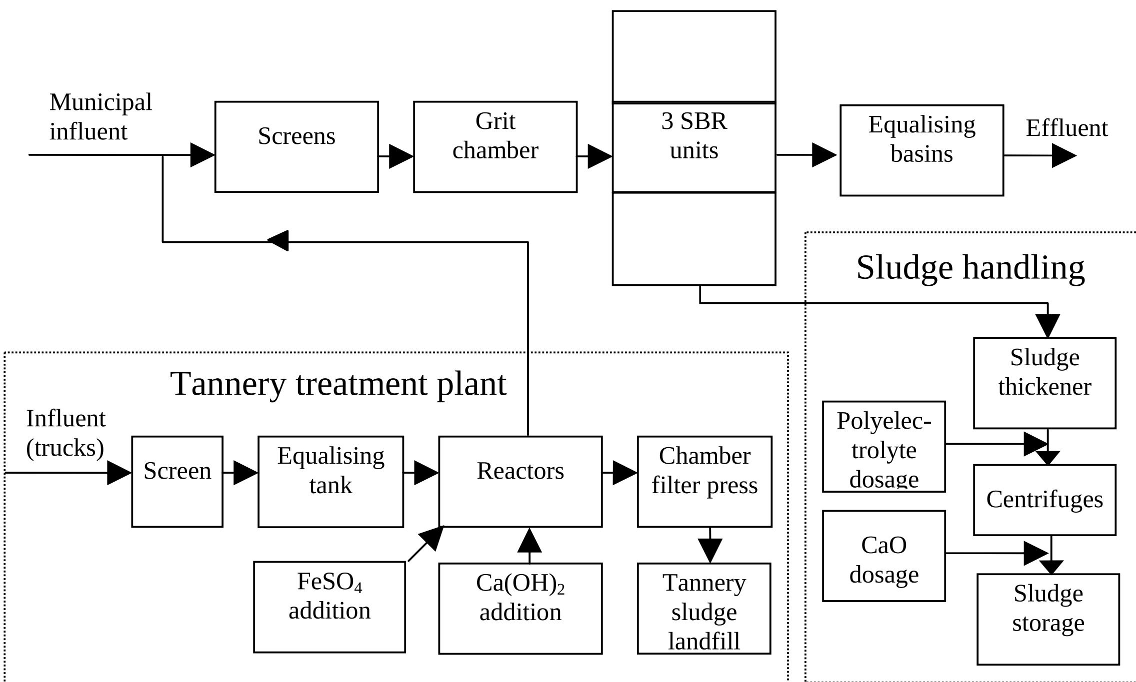


Figure 1. Flowsheet for the wastewater treatment plant in Nowy Targ .

The sludge processing at the Nowy Targ wastewater treatment plant consists of two parallel lines comprising (Kabacinski et al., 1998):

- Two gravity thickeners of the capacity 2 x 130 m^3 in continuous run.
- Two sludge pumps with a capacity of 2 x 15 m^3/h.
- Two decanting centrifuges with a capacity of 2 x 10 m^3/h.
- Polyelectrolyte dosage station with a capacity of 2.5 g electrolyte/kg of dry mass.
- Two polyelectrolyte feeding pumps.
- CaO lime dosing station with a lime dosing capacity from 4 to 40 kg/h.
- Excess sludge storage made up of seven tanks of aggregate volume about 24 000 m^3. The tanks´ dimensions are; 3 tanks 64 m x 20 m x 3 m, 2 tanks 64 m x 16 m x 3 m and 2 tanks 53 m x 20 m x 3 m. Walls of the tanks are constructed of ferroconcrete while their bottom is made of five layers; bentonite, 2 mm geomembrane, geotextile, a layer of slag in which drainage was placed and concrete plates. When the tanks are filled they will be covered with 1.5 mm geomembrane and a 300 mm layer of soil. At the moment two of the tanks have already been completed and another two are under construction. In case of an incineration plant in the future the sludge storage will be used for ash disposal.

The installation system for preparation and dosing of $FeSO_4$ and $Ca(OH)_2$ has been altered with respect to the original one and includes installation for the preparation of lime milk and of ferrous sulphate solution.

The chrome tannery waste neutralisation line has been modernised, which increases its capacity, improved the neutralisation process and allowed automation of some of the operations. Neutralisation equipment includes:

- Equalising, septic tank for tannery waste supplied by lorries, volume 28 m^3.
- Automatic sieve for preliminary separation of suspended solids in the supplied chromic waste.
- Two submersible pumps for pumping waste into the two reactors.
- Two reactors for neutralisation of chromic waste, volume 2 x 36 m^3. Each reactor is furnished with a decanting pump pumping pre-treated waste through screens, a mechanical mixer for mixing waste with lime and ferrous sulphate and a tanning sludge pump.
- A plate-and-frame filter press with a filtering surface of 36 m^2 and 38 frames.

II. CHARACTERISTICS OF SLUDGE FROM THE SBR STEP

II.1. Sludge separation, thickening and dewatering

Suspended solids separation proceeds efficiently at the WWTP in Nowy Targ. With three SBRs in operation the average total suspended solids concentration in the effluent was about 15 mg SS/l in 1997. Sludge sedimentation properties have been studied by Johansson and Sahlberg (1996). The sludge volume index (SVI) was 74 ± 17 ml/g during April - September 1995. Sharif (1998) analysed data from the period 1995 - 1997 and found good settling properties in all three SBRs (Table 1).

Table 1. Sludge volume (SV) and sludge volume index (SVI) in SBRs during 1995 - 1997 (average values).

Parameters	SBR1	SBR2	SBR3
SV cm^3/dm^3	346	385	399
SVI cm^3/g	70	93	91

Statistical analysis of data provided by the laboratory at the WWTP was performed and results are presented below. Sludge samples are taken from three points (Figure 2) and total suspended solids concentrations (TSS), density and water contents are measured.

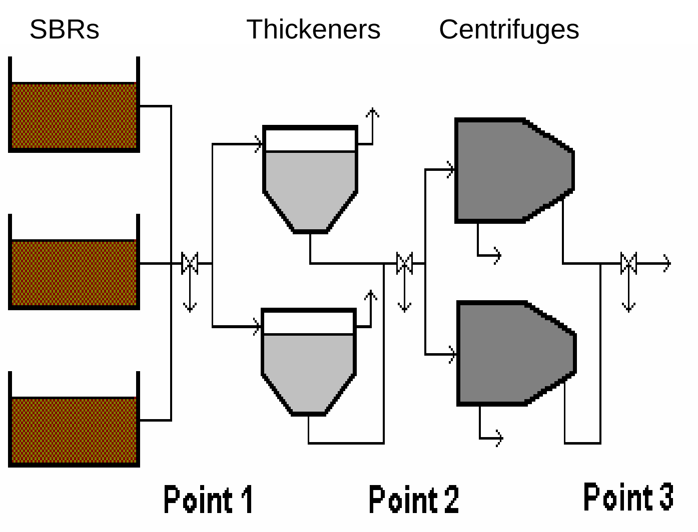
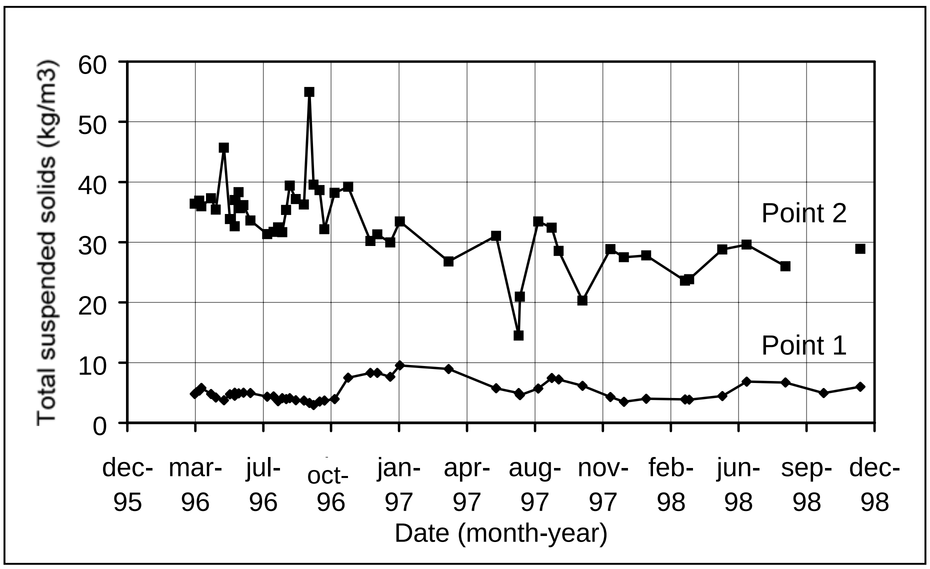


Figure 2. Sludge treatment - points of analyses.

The mean value of the concentration of excess sludge was 4.7, 6.3, and 5.1 kg SS/m^3 in 1996, 1997 and 1998, respectively, and with an average of 5.2 kg SS/m^3 between 1996 - 1998 (Table 2). The average concentration of thickened sludge was 36, 28 and 27 kg SS/m^3 in 1996, 1997 and 1998, respectively, and with an average of 33 kg SS/m^3 between 1996 - 1998 (Figure 4). The concentrations of excess sludge (point 1), thickened sludge (point 2) and dewatered sludge (point 3) as a function of time are shown in Figure 3 (Kamues, 1999). During some periods the excess sludge was pumped from SBRs at the end of reaction phase, not during the sedimentation phase, and this reflected in lower values of excess sludge concentrations. The mean values of the sludge density for 1996 - 1998 were 1.002 kg/m^3 and 1. 012 kg/m^3 of excess sludge and thickened excess sludge, respectively (Table 3 and Figure 5). Dry solids solids content used to measure the efficiency of the sludge treatment processe is presented in Table 4. Average value obtained in dewatered sludge (point 3) for the period 1996 - 1998 was only 15 % which was much lower than expected design value of 20 - 25 %. The values from Figure 6 also show that during 1997 and 1998 dry soilds content value has stabilised at the level of 14 % .

Histograms of TSS concentration, density and dry solids content in excess sludge, thickened sludge and dewatered sludge are presented in APPENDIX 1.



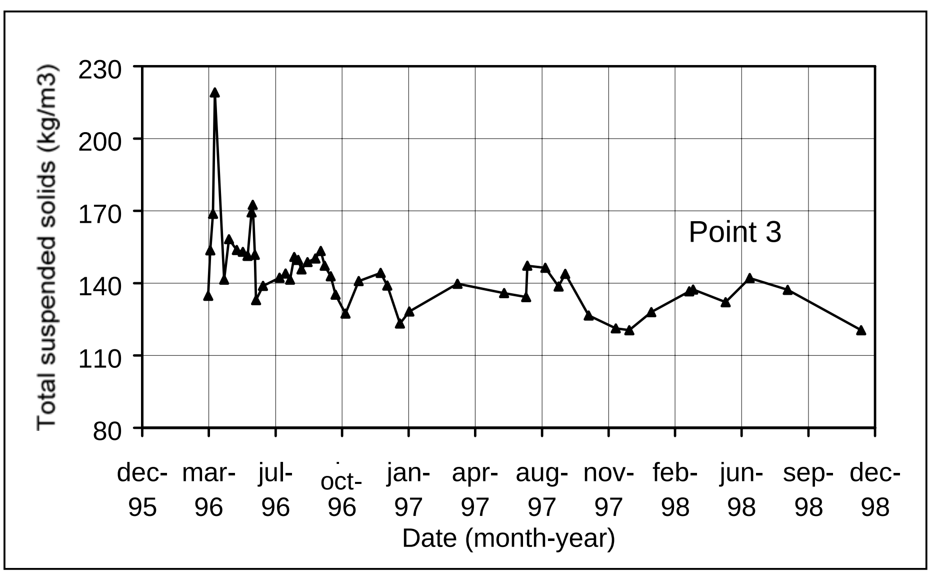


Figure 3. The concentration of excess sludge (point 1), thickened sludge (point 2) and dewatered sludge (point 3) as a function of time.

Table 2. Statistical evaluation of the TSS in the sludge treatment

	1996	1997	1998	1996 - 1998
Point 1. Excess sludge				
Mean value (kg/m^3)	4.71	6.32	5.09	5.18
Maximum (kg/m^3)	8.31	9.57	6.85	9.57
Minimum (kg/m^3)	2.95	3.48	3.85	2.95
Standard deviation	1.35	1.88	1.26	1.61
Coefficient of variation %	28.74	29.80	24.76	31.05
Number of samples	28	12	8	48
Point 2. Thickened sludge				
Mean value (kg/m^3)	36.34	28.48	26.94	32.63
Maximum (kg/m^3)	54.94	33.46	29.62	54.94
Minimum (kg/m^3)	30.18	20.3	23.61	14.49
Standard deviation	4.98	4.48	2.47	6.66
Coefficient of variation %	13.71	15.73	9.16	20.40
Number of samples	28	11	7	47
Point 3. Dewatered sludge				
Mean value (kg/m^3)	150.09	133.81	133.43	143.72
Maximum (kg/m^3)	219.10	147.20	142.10	219.10
Minimum (kg/m^3)	127.40	120.5	120.50	120.5
Standard deviation	16.67	9.70	7.24	16.17
Coefficient of variation %	11.11	7.25	5.43	11.25
Number of samples	30	12	7	49

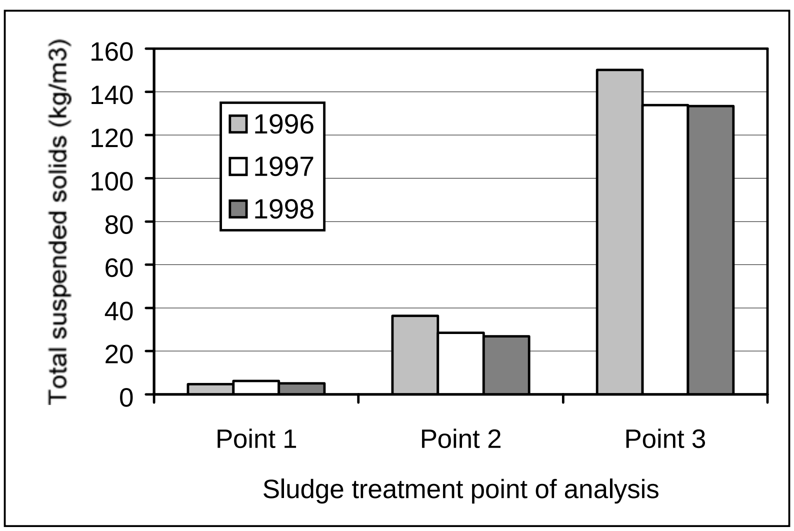


Figure 4. Comparison of TSS average values.

Table 3. Statistical evaluation of the density in the sludge treatment

	1996	1997	1998	1996-1998
Point 1. Excess sludge				
Mean value (kg/m^3)	1002	1003	1002	1002
Maximum (kg/m^3)	1005	1005	1003	1005
Minimum (kg/m^3)	999	1000	1001	999
Standard deviation	1.60	1.60	0.82	1.57
Coefficient of variation %	0.16	0.16	0.08	0.16
Number of samples	29	12	7	48
Point 2. Thickened sludge				
Mean value (kg/m^3)	1013	1010	1007	1012
Maximum (kg/m^3)	1025	1015	1013	1025
Minimum (kg/m^3)	1007	1006	1000	1000
Standard deviation	4.12	2.45	5.16	4.56
Coefficient of variation %	0.41	0.24	0.51	0.45
Number of samples	31	12	7	50
Point 3. Dewatered sludge				
Mean value (kg/m^3)	951	959	952	953
Maximum (kg/m^3)	1012	980	955	1012
Minimum (kg/m^3)	921	945	947	921
Standard deviation	24.23	8.64	3.27	16.91
Coefficient of variation %	2.55	0.90	0.34	2.09
Number of samples	30	12	7	49

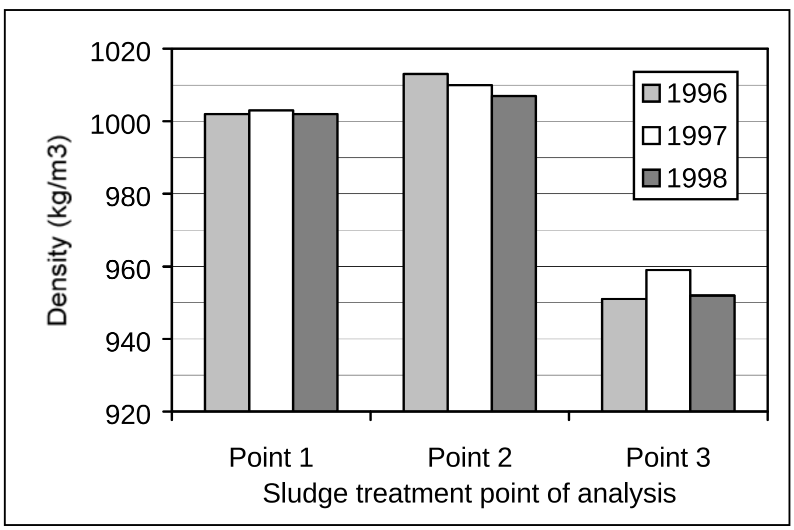


Figure 5. Comparison of density average values.

Table 4. Statistical evaluation of DS content in the sludge treatment

	1996	*1997*	*1998*	*1996 - 1998*
Point 1. Excess sludge				
Mean value (%)	*0.58*	*0.75*	*0.62*	*0.63*
Maximum (%)	*0.93*	*1.06*	*0.81*	*1.06*
Minimum (%)	*0.37*	*0.48*	*0.45*	*0.37*
Standard deviation	*0.13*	*0.19*	*0.16*	*0.17*
Coefficient of variation %	*22.73*	*25.73*	*25.77*	*26.55*
Number of samples	*28*	*12*	*6*	*46*
Point 2. Sludge thickened				
Mean value (%)	*3.89*	*2.79*	*2.47*	*3.39*
Maximum (%)	*5.90*	*3.30*	*2.90*	*5.90*
Minimum (%)	*3.10*	*1.90*	*2.20*	*1.30*
Standard deviation	*0.62*	*0.19*	*0.24*	*0.86*
Coefficient of variation %	*15.89*	*17.44*	*9.83*	*25.29*
Number of samples	*30*	*11*	*7*	*49*
Point 3. Sludge to dispose				
Mean value (%)	*15.77*	*13.96*	*14.01*	*15.07*
Maximum (%)	*22.00*	*15.30*	*14.90*	*22.00*
Minimum (%)	*13.60*	*12.30*	*12.70*	*12.30*
Standard deviation	*1.49*	*1.30*	*0.75*	*1.56*
Coefficient of variation %	*9.44*	*7.40*	*5.35*	*10.34*
Number of samples	*30*	*12*	*7*	*49*

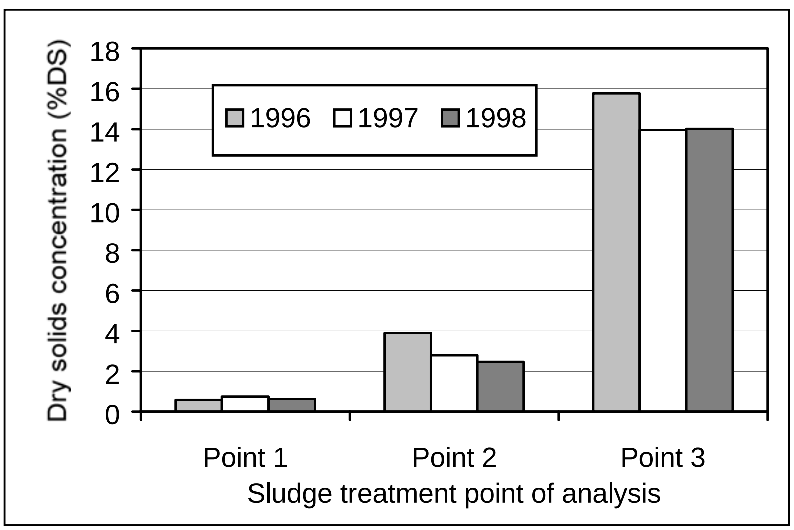


Figure 6. Comparison of dry solids average values.

II.2 Excess sludge production

There is no accurate measurements of the sludge amount produced at the Nowy Targ WWTP. Up to now there was not direct measurements of the excess sludge flow from SBRs. Therefore different methods can be used to come as near as possible to the right value. The amount of excess sludge can be calculated indirectly from the yield coefficient or the population load or directly from measurements of pumping time of excess sludge, stored volumes or amount of incinerated sludge.

Calculation from the yield coefficient

Excess sludge production may be indirectly calculated from the yield coefficient by the formula:

excess sludge production (kg SS/day) = removed BOD_5 (kg/m^3) * yield coefficient (kg SS/kg BOD_5) * flow (m^3/day)
or
excess sludge production (kg SS/day) = removed BOD_5 (kg/day) * yield coefficient (kg SS/kg BOD_5)

Similar formulae may be written for COD. Removed BOD_5 and COD for 1997 and 1998 are shown in Table 5.

Table 5. Average removal of BOD_5 and COD in 1997 and 1998 and quotient 1998/1997.

Time	Influent values		Effluent values		Removal	
period	BOD_5	COD	BOD_5	COD	BOD_5	COD
1997, kg/day	2 593	6 600	97.2	532.8	2 496 (96%)	6 067 (92%)
1998, kg/day	3 100	6 848	81.7	570.7	3 018 (97%)	6 277 (92%)
quotient 1998/1997	1.20	1.04	0.84	1.07	1.21	1.03

The yield coefficient is a function of type of organic materials, suspended solids in the influent, the sludge age, and the type of operation (for instance fraction of organic material degraded by nitrate or oxygen, respectively). The large portion of tannery wastes with a large fraction of slowly biodegradable or non-biodegradable organic materials gives rise to a higher sludge yield coefficient than for a domestic wastewater.

Table 6. The operational conditions for the Nowy Targ SBR - plant.

	1997 (Kabacinski, 1998)	1998 (Kamues, 1999)
Quotient SS/BOD_5 in influent	450/260 = 1.73	302/286 = 1.05
Sludge age		14 -30 days

For a sludge age of 25 days and a SS/BOD_5 ratio between 1 - 1.2 kg/kg a yield coefficient of about 1 - 1.2 kg SS/kg BOD_5 is typical. Based on a yield coefficient of 1.1 kg SS/kg BOD_5

and table 5 the sludge amounts for 1997 and 1998 may be calculated to 2750 and 3320 kg SS/day, respectively.

For the calculated sludge amounts the yield coefficient based on COD may be calculated to 0.45 g SS/g COD and 0.53 g SS/g COD for 1997 and 1998, respectively. These values are higher than would be expected for a municipal wastewater (about 0.3 g SS/g COD) and may be explained by the high influence of tannery wastes.

Calculations from typical sludge production for person equivalents

According to Imhoff (1982) a typical sludge production for an aerobically stabilized sludge is about 50 g SS/p. eq., day. For a connected population in Nowy Targ of 45 000 persons this would give a sludge production of about 2250 kg SS/day. The higher calculated sludge production (an additional amount of sludge of about 500 - 1000 kg SS/day) may be due to tannery wastes. Based on these assumptions about 75 % of the obtained excess sludge is due to municipal wastewater and 25 % due to tannery wastes.

Calculations from pumping time of excess sludge

A direct measurement of the excess sludge amount could be described by the formula:

excess sludge production (kg SS/day) = excess sludge concentration (kg SS/m^3) * excess sludge flow (m^3/day)

The excess sludge flow was, however not measured and could only be determined based on pumping capacity and pumping time. Based on this estimation an excess sludge production was calculated to 2570 kg SS/day during 1998. This value is less than the value calculated based on an assumed value of the yield coefficient (3320 kg SS/day).

Calculations from stored volumes

At three occasions the sludge was supplied to defined volumes. At the first occasion one chamber (volume 486 m^3) of landfill for the tannery wastes was filled with dewatered sludge from the SBRs during 3 weeks (21 days) in Feb 1996 and Jan 1998. The sludge volume can be calculated to 23 m^3/day. The sludge dry solids and sludge density during the period was about 13.4 % and 955 kg/m^3, respectively. The calculated sludge mass production may then be calculated to 2960 kg dry solids/day.

In May 1996 and November 1997 (totally during 50 days) sludge was stored in reservoirs for dairy wastes. The volume (length * width * sludge level) was 20 * 20 * 3.2 = 1280 m^3. The average sludge volume per day was 25.6 m^3/day. The sludge density was 962 kg/m^3 and the sludge mass can be calculated to 3600 kg/day.

At the third occasion dewatered sludge from the SBRs were deposited in the first sector of the constructed landfill. The deposited sludge volume was 3328 m^3 (64 * 20 * 2.6, where 2.6 is the sludge level) and the time to fill up the deposit was 139 days between May 26th and October 11th in 1998. The daily sludge volume production was in average 23.9 m^3/day.

During the period the dry solids concentration was about 14.0 % and the sludge density about 950 kg/m^3. The calculated sludge mass is thereby 3180 kg solids/day.

Calculations from the amount of incinerated sludge

The sludge mass of dewatered sludge was directly measured during the period February 1st to April 30th of 1998 (89 days) at which period 2100 tonnes of dewatered sludge were transported to Lobbe incineration plant in Dabrowa Gornicza in the Silesia region. The mass of dewatered sludge was 23.6 tonnes sludge/day. The sludge density was about 955 kg/m^3 and the dry solids concentration 14.0 %. The average daily volume and mass of sludge may then be calculated to 24.7 m^3/day and 3.300 kg dry solids/day.

Compilation of data

The sludge mass calculations are summarised in Table 7.

Table 7. Summary of sludge mass calculations from the SBRs of Nowy Targ

Calculation based on:	Period	Dry solids kg/day
Assumed yield coefficient, 1.1 kg SS/kg BOD_5	1997	2750
	1998	3320
Population load of 50 g SS/p. eq		2250
Pumping of excess sludge	1998	2570
Time to fill up a volume	Feb 1996/Jan 1998	2960
	May and Nov 1998	3600
	May 26th-Oct 11th 1998	3180
Mass determination of dewatered sludge	Feb 1st-April 30th 1998	3300

Direct methods with measuring of the time to fill up a volume or measurements of dewatered sludge mass are probably the most accurate to determine the sludge mass production. Measurements of pumping of excess sludge involve several uncertainties. The results, however, are in general agreement. An average value of the daily sludge mass production is about 3100 tonnes.

II.3 Chromium contents in biological sludge

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. Cr(III) phosphates have a very low solubility. Under oxidising conditions Cr(III) may be oxidised to Cr(VI).

The organic ligands in the organic complexes with chrome (III) are for instance 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).

A sludge production of about 3000 tonnes SS/day and a wastewater flow of 12 700 m^3/day correspond to a sludge production of 240 g SS/m^3. For an influent chromium concentration of 3 g Cr/m^3 the chromium content in the suspended solid can as a maximum be 1.25 %. Actual Cr content in the sludge 1996 - 97 was in average about 1.1 % (Kabacinski et al., 1998). For this content and an effluent concentration of 15 g SS/m^3 the effluent concentration of Cr in suspended form is 0.17 g Cr/m^3.

When all three SBRs were in operation an average chromium concentration of 0.39 g/m^3 was obtained (Banas et al., 1998). This value is slightly below the discharge limit of 0.5 g Cr/m^3.

The high chromium content in the sludge has several disadvantages:
- Difficulties to accomplish discharge limits
- Possible toxic effects on microorganisms (see section on biological stabilization of sludges)
- Possible risks for oxidation of Cr(III) to chromates, Cr(VI) (see section on incineration)
- Increased difficulties for sludge disposal

All these problems can be counteracted by a better source control of the tannery industries. Investments in pre-sedimentation or a filtration step for wastewater polishing should be effective for accomplishment of discharge limits.

III. WASTEWATER CHARACTERISTICS

The influent to the wastewater treatment plant contains in addition to municipal wastewater also a significant amount of tannery wastewater. Tanning of sheepskin is the primary industrial activity in Nowy Targ. The process includes sheepskin processing from the raw hide to the finished product. In Nowy Targ, domestic hides and hides imported from Germany, Italy, New Zealand, and Australia are the main raw materials used in the process. The form of chromium used in the tanning industries in Nowy Targ is chromium sulfate, $Cr_2(SO_4)_3$. Chromium is used primarily in the tanning of light skins such as sheep skin. The skins used in leather production are composed almost entirely of protein, 85%. The preliminary processes in tanning process are designed to prepare the hide protein so that undesirable impurities are removed, leaving the collagen receptive to adsorb the chromium used in tanning. Sheepskin processing from the raw hide to the finished product results in a wastewater high in chromium, sulfide, COD, BOD, and SS concentrations. Many processes may be used in skin processing including curing, fleshing, washing, unhairing, lime splitting, bating, pickling, degreasing and chrome tanning.

The uncontrolled burst of small enterprises in the field of tanning has led to a high increase of the influent chromium concentration from 1995 compared with 1996 and 1997 and with values today much higher than the design value (D.V.) (see figure 7). During 1996 and 1977 there has been an increasing trend of chromium concentration in the influent (see figure 8).

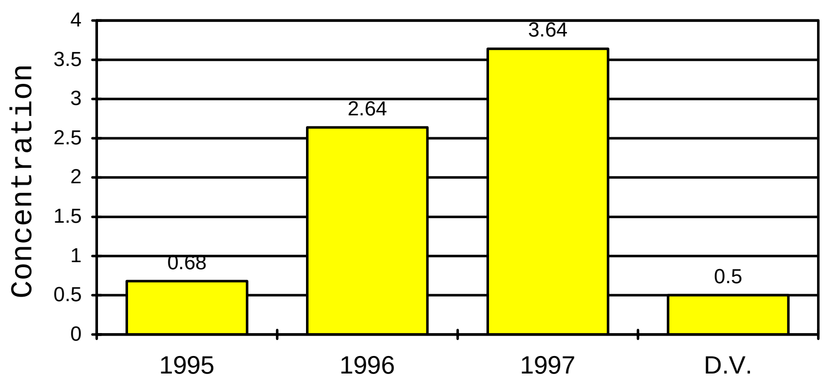


Figure 7. Influent average concentration for chromium during 1995 - 1997 compared with design value.

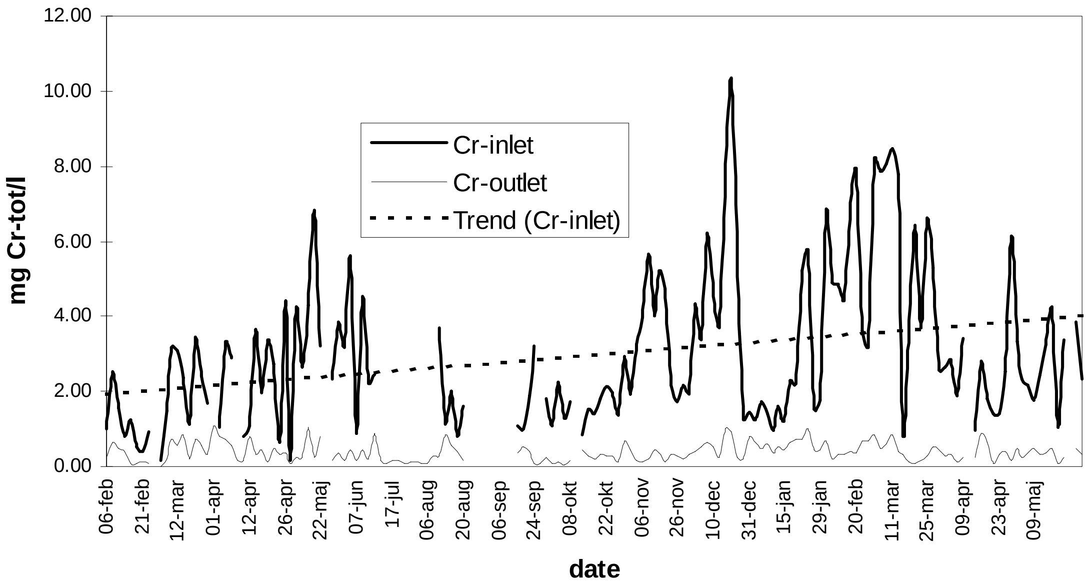


Figure 8. Concentration of chromium in the influent and effluent, 1996-1997

The raw water quality is strongly influenced by the small tanneries which do not respect the requirements to discharge their wastewater with high concentration of chromium to the separate pretreatment system located at the wastewater treatment plant. They also have a great impact on diurnal and seasonal wastewater concentrations; a significant increase of chromium is observed in the fall season when the production starts. The impact of small tanneries on the wastewater chromium concentration can be observed in Figure 9 where diurnal changes of chromium concentrations in the influent are presented (Finnell, 1998).

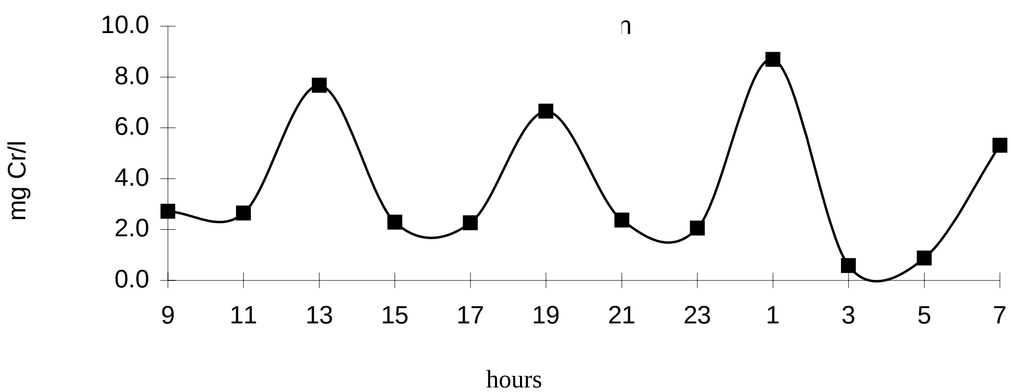


Figure 9. Inlet chromium concentration.

Characteristics of raw wastewater discharged to the plant is presented in Table 8. It complies the three different data: raw wastewater quality as assumed in the design as well as average values for 1996 and 1997 at different probability levels.

Table 8. 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 difference between the data assumed in the design and the actual average values found at the plant is seen in the concentration of suspended solids (almost four times increase in 1996), total nitrogen (two times increase) and chromium (over six times increase). The ratios between the characteristic parameters of the wastewater are shown in Table 9.

Table 9. The characteristic ratios in the raw wastewater (average values)

Ratio	1996	1997
COD / BOD_5	2.85	2.47
BOD_5 / COD	0.35	0.41
BOD_5 / N_{tot}	5.19	5.32
COD /N_{tot}	14.76	12.96
BOD_5 / P_{tot}	35.78	41.11

Characteristics of wastewater composition in the sewer net from different areas are shown in Table 6. During one week between September 4 and September 10, grab samples of 5 liters of discharges were collected from three sites of Nowy Targ sewage system: municipal (site l), industrial (site 2) and mixed (site 3). The samples were taken daily at the same time around 12.00 p.m.

Table 10 presents both the average values and the standard deviations for different parameters. As it is clear the standard deviations are high compared with the averages, mainly due to extreme peak values for the parameter concentration on some days. It is seen that samples from the industrial site has a much higher Cr concentration and a lower quotient of BOD_5/COD than samples from typical municipal wastewater.

Table 10. Wastewater composition in sewage system in Nowy Tag City compared with influent to WWTP during 97 09 04 - 97 09 1 0 (Sharif, 1998).

Parameter		Municipal	Industrial	Mixed	Influent
		Site 1	Site 2	Site 3	Site 4
SS	Average	711.26	575.14	596.91	393.71
	St.dev	50.31	85.22	471.38	99.11
Cr^{+3}	Average	0.13	4.98	10.07	5.42
	St.dev	0.04	7.97	12.39	0.97
Cl	Average	171.29	237.01	745.16	724.70
	St.dev	171.51	182.22	589.63	179.54
P tot	Average	9.19	7.62	5.41	5.24
	St.dev	4.49	6.71	3.89	2.23
N tot	Average	85.30	105.13	70.66	48.50
	St.dev	8.13	116.88	13.27	5.98
BOD_5/COD		0.48	0.39	0.38	0.38

The hydraulic design capacity of the Nowy Targ WWTP is: $Q_{av.d}$ = 21 000 m^3/d, Q_{max} = 25 000 m^3/d. The incoming wastewater volume has been assumed based on the growing water demand observed in late 80's. At that time the existing sewer system was also planned to be expanded to connect over ten small villages and settlements located within its vicinity. However, the economic transformation that has been taking place in Poland in the recent years has altered these assumptions. The average wastewater flow reaching the WWTP in the dry weather period of 1997 was only $Q_{d50\%}$ = 12 720 m^3/d. During wet weather periods a sewer system receives additional water volume due to the rain water infiltration; the flow to the plant reaches then $Q_{90\%}$ = 17 750 m^3/d. The flows occurring at the plant in 1997, together with their probability levels are presented in Figure 6.

The number of persons connected to the wastewater treatment plant is about 45 000 persons. Based on average concentrations and flow during 1997 the specific flow and pollutant load can be calculated (see Table 11). These data are compared with literature values,

Table 11. Specific flow and pollutant load at Nowy Targ in 1997 and typical values in literature

Parameter	Values at Nowy Targ 1997		Typical values Poland	Typical values Sweden
Flow	12 720 m^3/d	283 l/p,d	200 l/p,d	
TSS	285 g/m^3	81 g/p,d	65 g/p,d	70 - 90 g/p,d
BOD_5	216 g/m^3	61 g/p,d	60 - 70 g/p,d	70 - 90 g/p,d *
COD	550 g/m^3	155 g/p,d		
N	42.9 g/m^3	12.1 g/p,d	12 - 13 g/p,d	10 - 14 g/p,d
P	5.4 g/m^3	1.5 g/p,d	3 g/p,d	2.5 - 3.5 g/p,d

* BOD_7

Based on specific pollution loads the influent values for Nowy Targ are similar to those found in average. The specific load of phosphorus is however lower than expected.

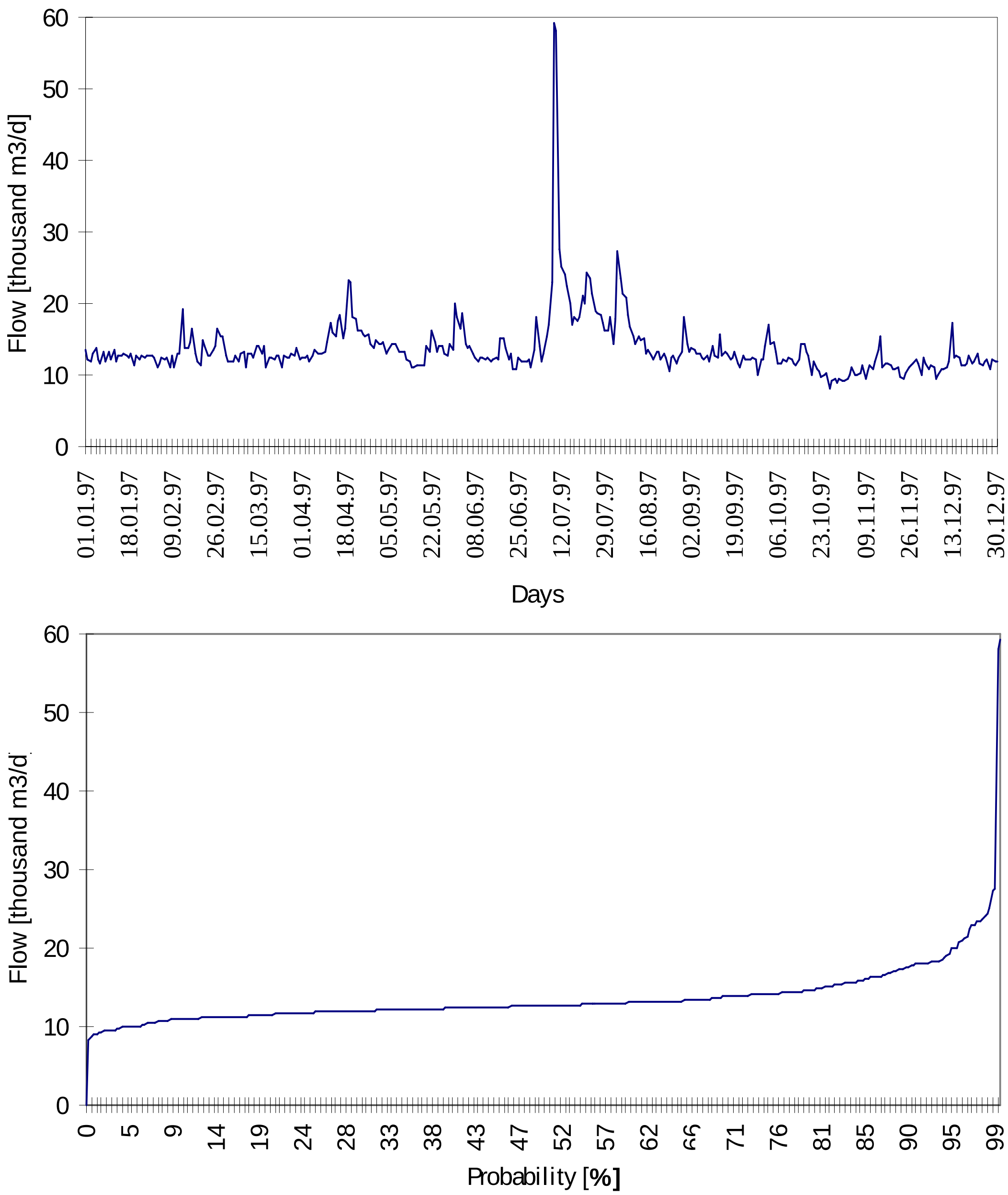


Figure 10. Flows and their probability levels at the Nowy Targ WWTP in 1997

IV. AEROBIC STABILISATION

IV.1. Measurements of sludge stability

Different stabilisation criteria for aerobic and anaerobic digestion are shown in Table 12. Some of the parameters are not suitable in case of anaerobic stabilisation. Other measurements may be based on for instance the quotient BOD_5/COD of the filtrated solution (Imhoff, 1996).

Table 12. Parameters of stabilisation criteria of sewage sludge (Bruce 1984).

Parameter	***Anaerobic digestion***	***Aerobic digestion***
Odour intensity	✓	✓
Gas chromatographic analysis (GCMS)	✓	✓
Volatile suspended solids fraction	✓	✓
BOD_5 of the filtrate	✗	✓
Rate of increase of COD of filtrate with storage	✓	✓
Specific oxygen uptake rate (SOUR)	✗	✓
Gas production during anaerobic incubation at 35°C	✓	✓
Volatile fatty acid	✓	✓
pH and pH change during storage	✓	✓
H_2S emission on storage	✗	✓
Nitrate concentration	✗	✓
ATP concentration	✗	✓

IV.2. Aerobic stabilisation in the SBRs

Sludge stabilisation has a major purpose to decrease odour problems. In addition sludge stabilisation improves hygienization of the sludge and decreases the sludge amount.

Data of importance for aerobic stabilisation as average values:
- sludge concentration in the reactor - 5.2 kg SS/m^3 (see previous section),
- sludge concentration after thickening - 33 kg SS/m^3 (see previous section),
- sludge age - 14 - 30 days (see previous section),
- volatile fraction of excess sludge, about 80 % (Styka et al., 1998),
- excess sludge - about 3000 kg SS/day (see previous section).

Tonkovic (1998 and 1999) 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 odorous, 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*h 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 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 characterised 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.

IV.3. Experimental studies of aerobic stabilisation

Aerobic stabilisation was studied during October and the beginning of November 1998 with excess sludge from SBRs (Kamues, 1999). The experiments were performed in a tank with a volume of about 200 l and equipped with an air injector (see Figure 11). About 130 l excess sludge was supplied to the tank and samples were taken every day. Only Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) and Oxygen Uptake Rate (OUR) were determined almost all the days, while other analyses as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), total N and chromium (Cr) were performed less frequently. The oxygen measurement system is shown in Figure 12.

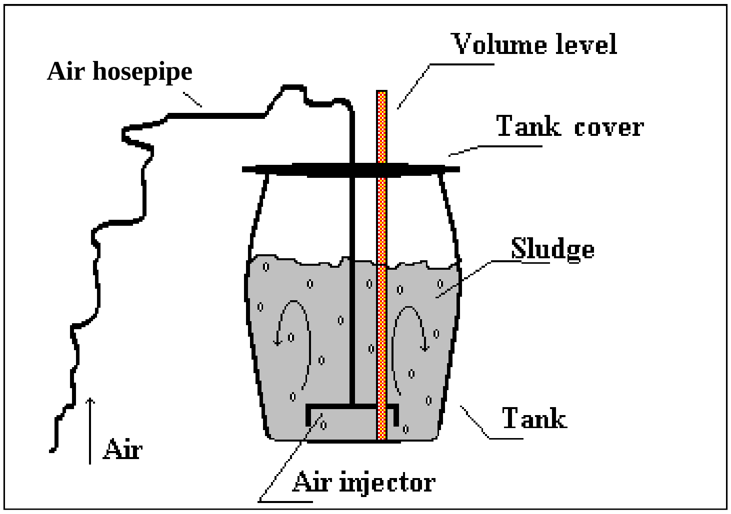


Figure 11. Apparatus of the aerobic sludge stabilisation experiment

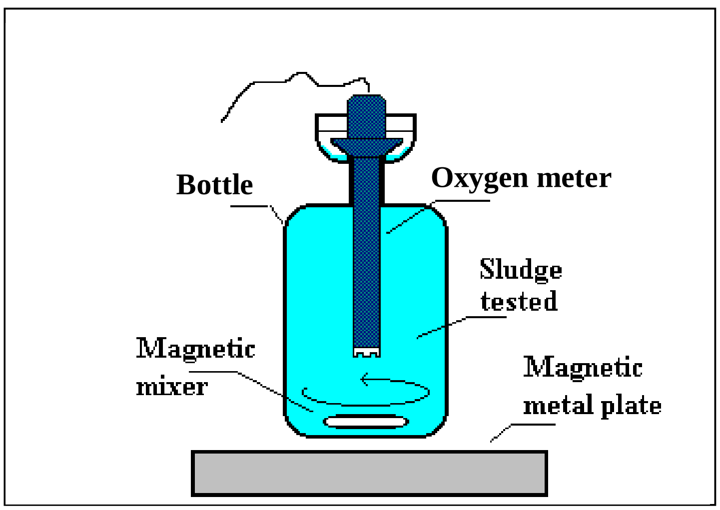


Figure 12. Oxygen measurement system

Two tests were carried out, one introductory for familiarisation with the equipment and secondary test during 20 days. Results from the last test will be summarised below based on results of Kamues (1999).

Measured values of TSS, VSS and evaporated volume (%) in the tank are shown in Table 13. Based on these values the difference of TSS-VSS, the volatile fraction, and values of TSS, VSS and TSS-VSS can be calculated compensated for evaporation losses.

Table 13. Changes of TSS and VSS with time

	Measured values					Compensated for evaporation			
Day	TSS	VSS	TSS - VSS	Evaporation	Comp.factor	TSS	VSS	TSS - VSS	VSS
	g/l	g/l	g/l	% (a)		g/l	g/l	g/l	%
0	3.76	3.01	0.75		1	3.76	3.01	0.75	80.05
1	3.84	3.02	0.82	4.73	0.9527	3.66	2.88	0.78	78.65
2	3.75	2.94	0.81	5.84	0.9416	3.53	2.77	0.76	78.40
3	3.74	2.93	0.81	8.96	0.9104	3.40	2.67	0.74	78.34
4	3.67	2.95	0.72	9.12	0.9088	3.34	2.68	0.65	80.38
6	3.51	2.71	0.8	9.29	0.9071	3.18	2.46	0.73	77.21
8	3.47	2.65	0.82	10.51	0.8949	3.11	2.37	0.73	76.37
10	3.42	2.61	0.81	10.67	0.8933	3.06	2.33	0.72	76.32
13	3.2	2.45	0.75	10.84	0.8916	2.85	2.18	0.67	76.56
15	3.13	2.38	0.75	14.27	0.8573	2.68	2.04	0.64	76.04
17	3.09	2.36	0.73	15.54	0.8446	2.61	1.99	0.62	76.38
20	2.97	2.26	0.71	20.64	0.7936	2.36	1.79	0.56	76.09

(a) - cumulative evaporated sludge volume in experimental apparatus

Percentage changes with time of TSS, VSS and TSS-VSS where the measured concentrations are compensated for evaporation losses are shown in Figure 13. The TSS and VSS values diminished with about 29 % and 32 % during 15 days stabilisation and with about 37 % and 40 % during 20 days stabilisation. The change of TSS-VSS was about 14 % and 25 % after 15 and 20 days stabilisation, respectively.

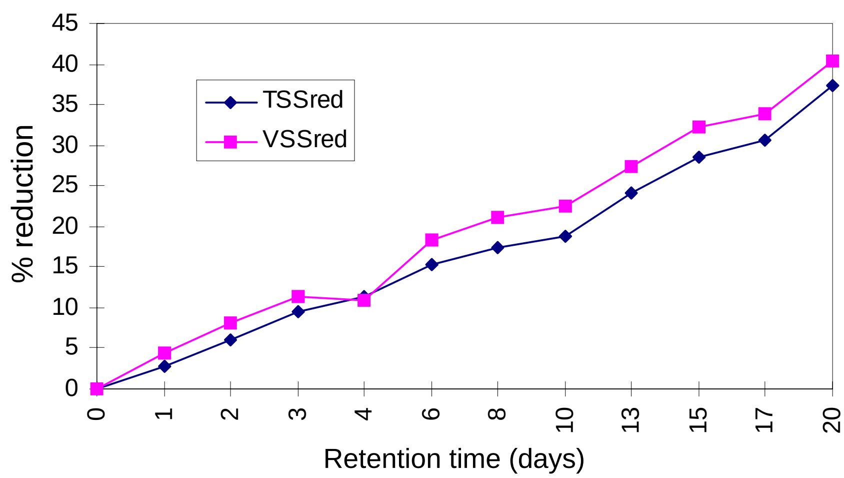


Figure 13. Percentage changes with time of TSS and VSS.

The volatile fraction of the sludge as a fraction of time is shown in Figure 14. Even after 20 days the volatile fraction had only diminished from about 80% to 76%.

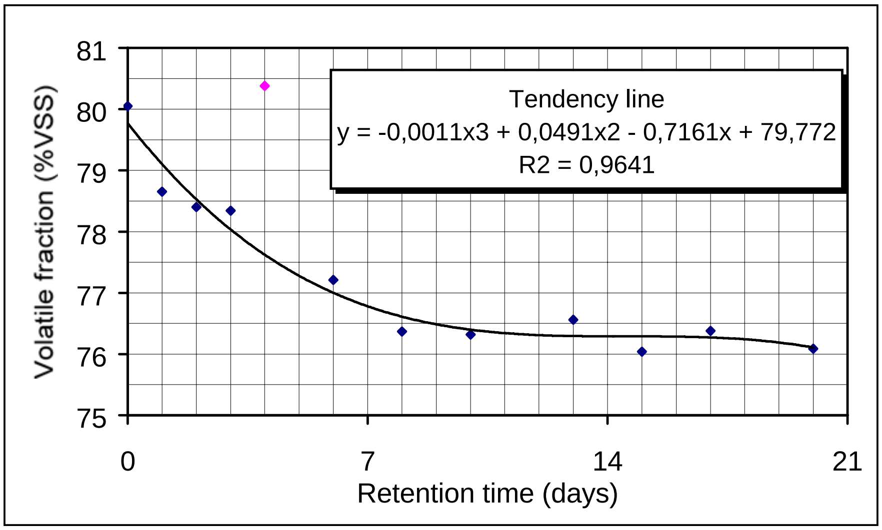


Figure 14. Volatile suspended solids fraction performance.

Values of temperature, oxygen concentration and pH in the experimental tank are shown in Table 14. The obtained values of specific oxygen uptake rate (SOUR) are shown in Table 15 and 16. Measurements were made of SOUR both with (12-18 mg/l) and without ATU addition. This substance inhibits nitrification and the difference between SOUR and SOUR without ATU addition is a measure of the nitrification activity.

Table 14. Experimental tank, operational condition

Day	Temperature, (^{0}C)	O_2 concentration, (mg/l)	pH - values
0	13.1	5.96	
1	12.5	8.39	
2	13.5	6.38	
3	14.2	7.30	
4	13.7	7.01	
6	13.1	8.87	
8	10.7	9.35	
10	11.5	8.54	
13	12.3	8.75	
15	10.0	11.10	6.84
17	12.4	9.06	6.75
20	10.7	10.24	6.25
Mean value	12.3	8.4	6.61

Table 15. Oxygen demand in relationship with the TSS concentration

Day	Temp. °C	SOUR (mg O_2/h g TSS)	Temp. °C	SOUR (+ATU) (mg O_2/h g TSS)	$SOUR_{netto-TSS}$ (mg O_2/h g TSS)
0	22.3	4.01	21.3	3.10	0.913
1	19.3	2.93	20.0	2.54	0.391
2	23.2	3.21	19.2	2.70	0.509
3	19.2	2.57	20.5	2.23	0.347
4	19.1	2.45	20.6	2.21	0.248
6	19.3	2.91	20.5	2.47	0.441
8	18.3	2.06	18.0	1.64	0.418
10	19.6	2.41	18.7	1.69	0.722
13	19.7	2.25	18.5	1.39	0.861
15	18.7	2.08	21.6	-----	----
17	19.7	1.79	19.6	1.31	0.483
20	18.8	1.52	19.4	1.20	0.321

Table 16. Oxygen demand in relationship with VSS concentration

Day	Temp. °C	SOUR (mg O_2/h g VSS)	Temp. °C	SOUR (+ATU) (mg O_2/h g VSS)	$SOUR_{netto-VSS}$ (mg O_2/h g VSS)
0	22.3	5.01	21.3	3.87	1.139
1	19.3	3.73	20.0	3.23	0.498
2	23.2	4.09	19.2	3.44	0.649
3	19.2	3.28	20.5	2.84	0.442
4	19.1	3.05	20.6	2.75	0.308
6	19.3	3.77	20.5	3.19	0.571
8	18.3	2.69	18.0	2.14	0.547
10	19.6	3.19	18.7	2.18	1.012
13	19.7	2.95	18.5	1.81	1.139
15	18.7	2.75	21.6	-----	----
17	19.7	2.35	19.6	1.72	0.625
20	18.8	2.00	19.4	1.60	0.403

The stabilisation process followed by SOUR is presented in Figure 15 and 16, respectively.

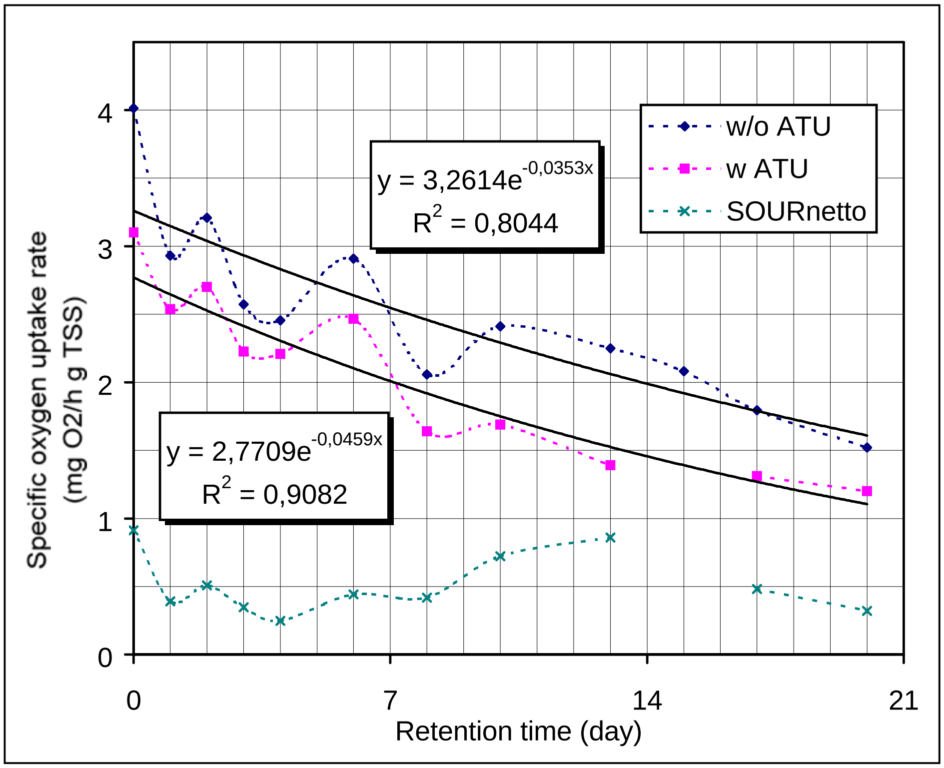


Figure 15. SOUR behaviour by time, related with TSS.

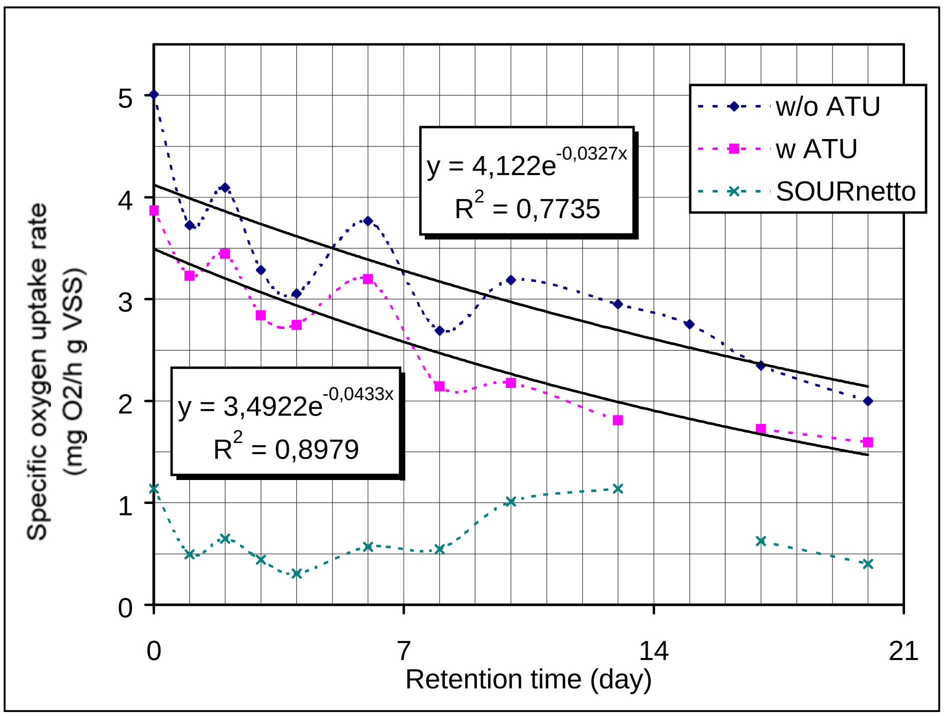


Figure 16. SOUR behaviour by time, related with VSS.

IV.4. Stabilisation criteria and sludge production

The volatile fraction (% VSS) has been used in several investigations as a stabilisation parameter (Bruce, 1984; Hartman and Vesilind, 1986; Kiely, 1997 and Lotto et al., 1991). Values of about 60% VSS indicate a stable sludge. In stabilisation of excess sludge from Nowy Targ the VSS was about 76 % after 20 days stabilisation at temperature of 12.3 ^oC (as average during the test period). This indicates that sludge differs much from a typical municipal wastewater sludge.

VSS in % is difficult to use as a stabilisation criteria. The specific oxygen uptake rate seems, however, to be a better measurement of the degree of stabilisation. Typical values for a stabilised sludge is a specific oxygen uptake rate below about 1.5 mg O_2/g VSS*h or 2.0 mg O_2/g TSS*h at 15 - 20 ^oC (Bruce, 1994 and Kiely, 1997). Values shown in Table 11 and 12 or in Fig. 11 and 12 indicate that the excess sludge from the SBRs must be aerated at least 2-3 weeks at about 12 ^oC in order to stabilise the sludge and to thereby reduce odour problems.

For an aerobic stabilisation of the excess sludge at 12 ^oC and for 2-3 weeks the following changes were obtained for the sludge (Table 17).

Table 17. Parameter changes in aerobic stabilisation of excess sludge.

Parameter	Initial values, %	Values after 2-3 weeks stabilisation, %
Volatile fraction	80.1	76.1
Inorganic fraction	19.9	33.9
Reduction of TSS		37.3
Reduction of VSS		40.4
Reduction of inorganic fraction		24.9

Aerobic stabilisation experiments have also been performed by Cracow University of Technology. These experiments were conducted in a plastic bottle of 100 l volume, equipped with a diffuser. The experiments were conducted for 2 weeks: June 17 to July 1, 1996.

Over that time the sludge was aerated. Oxygen content in the tank was high (over 5 g/m^3). VSS analysis of the sludge were conducted. The excess sludge used for the experiments had SS of 6 kg/m^3 and VSS fraction of 69.6% SS. After four days of aeration a small drop in the organic content was observed (down to 66.2% SS). After 2 weeks of aeration VSS decreased to 62.5% SS. The small drop in volatile fraction is in accordance with Figure 14.

For an excess sludge production of 3000 kg SS/day and a volatile fraction of 80%, Table 18 shows how aerobic sludge stabilisation for 2-3 weeks will affect sludge production:

Table 18. Changes in sludge produktion in aerobic stabilisation.

Sludge production	Excess sludge	Aerobic stabilised sludge
Total sludge, kg SS/day	3000	1880
Volatile sludge, kg VSS/day	2400	1430
Inorganic sludge, kg SS/day	600	451

V ODOUR EMISSIONS AND CONTROL

V.1 Odour emissions

The following factors are the key influences in development of odours (Rudolph, 1999):

- o Wastewater composition
- o Treatment procedures
- o Type of aeration
- o Sludge treatment methods
- o Dimensions
- o Water and air temperature
- o Weather conditions
- o Operating state and state of maintenance

With respect to wastewater composition the tannery wastes at Nowy Targ contains sulphurous compounds that may cause bad odour and the significant fraction of slowly biodegradable organic materials makes it difficult to stabilise the sludge. The process technology at Nowy Targ with biological and nitrogen removal requires a high sludge age (up to 40 days) to get a stabilised sludge (Tonkovic, 1998 and 1999).

The odour from the treatment plant seems mainly be connected with the disposal of sludge which is not sufficiently stabilised. In general odour problems are connected with the oxygen uptake rate of the sludge (Table 19).

Table 19. Potential for odour from sludges and sludge products (Meyers, 1998)

Sludge type	Oxygen demand mg O_2/kg/h	Stability	Potential for odour production
Secondary	3600	Least	Highest
Primary	1600	↓	↑
Nitrified	900		
Anaerobically digested	900		
Unstable compost	100-200		
Stable compost	20-40	Most	Lowest

The oxygen demand of the excess sludge was about 4000 mg O_2/kg/h at 20 ºC in the experiments with sludge stabilisation (cf Table 15) and has therefore a high potential for odour production.

The odourous emissions are caused by evaporating volatile substances from the sludge. Two gases are of special importance for causing odour problems. In an acid environment a smell of rotten eggs is obtained by hydrogen sulphide (H_2S) whereas an urine like smell is caused at alkaline conditions by ammonia (NH_3). The pH dependence of hydrogen sulphide and ammonia is shown in Figure 17.

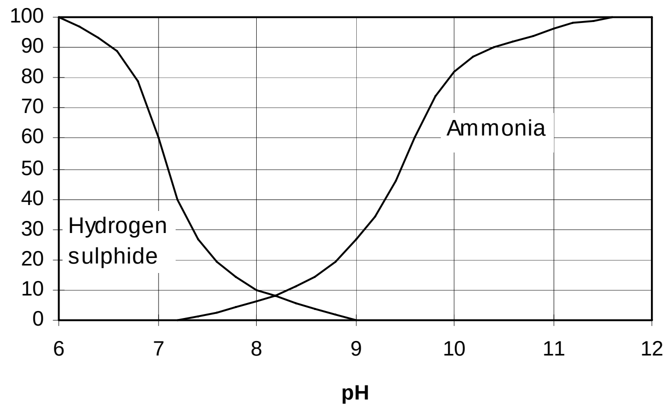
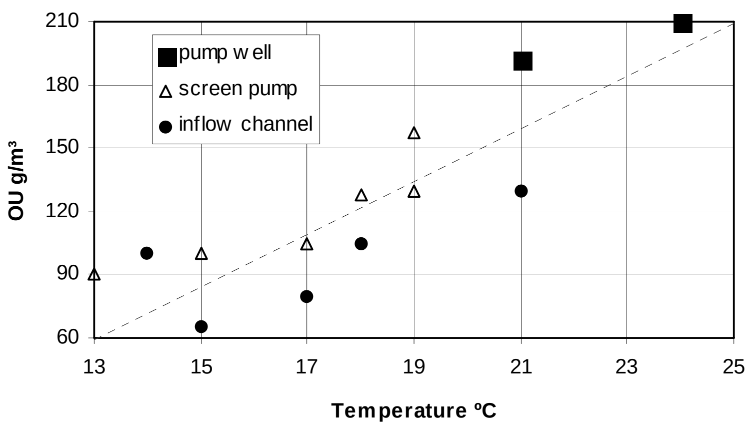
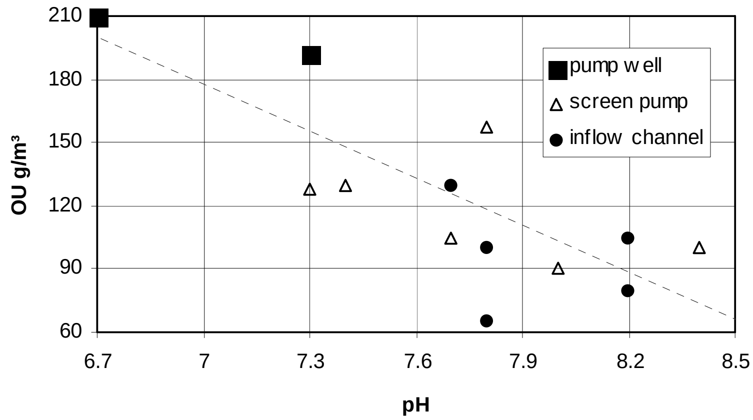


Figure 17. pH dependence of hydrogen sulphide H_2S as per cent of total sulphide and ammonia NH_3 as per cent of total content at 20 ºC (Rudolph 1999).

Development of hydrogen sulphide is accomponied by other volatile sulphide containing compounds as mercaptans and organic sulphides and different nitrogen compounds as amines. When sludge has reached septicity the different odourous compounds are produced. Therefore, odour problems normally increases with temperature (Figure 18). A decrease of odour problems can be expected for increasing pH-values to 8.5 due to a decreasing fraction of hydrogen sulphide (Figure 19; cf Figure 17).



Figur 18. Gaseous odour concentrations versus temperature (OU=Odour Units) (Rudolph 1999).



Figur 19. Gaseous odour concentrations versus pH-level temperature (OU=Odour Units) (Rudolph 1999).

Emissions from a drying process is much dependent on the type of drying (convection, contact etc) and the used temperature during the drying process. The condensates from sludge drying may contain high concentrations of organic and nitrogen compounds (Brautlecht and Gredigk, 1997, Steinle, 1997). Drying temperatures above 105 ºC evaporates not only water but also different volatile compounds. This evaporation may cause odour problems and may significantly decrease the heating value of the sludge. In incineration volatile organic compounds may also be evaporated from the sludge due to passage of the sludge through a drying and pre-heating zone before it enters the combustion zone.

V.2 Odour reduction

Odour reduction may be done by different methods to stop biological reactions causing production of odourous compounds. The main methods are:

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

The biological methods requires a special treatment unit with a residence time enough to degrade organic materials. The remaining organic material is degraded in such a low rate that the odour problems are small. Special studies on aerobic stabilisation is discussed in the next section in part A and other biological stabilisations in section B.

Addition of lime can either be used for sludge conditioning or as a post-treatment of dewatered sludge. Studies at Nowy Targ indicates a necessary dosage of about 0.45 kg CaO/kg dry solids of dewatered sludge (proposed by Cracow Technical University). The main problem related to odour in lime addition is the transfer of ammonium to ammonia which might be released to the atmosphere.

Thermal methods can produce a stable sludge that will not cause odour problems. However, odourous compounds may be produced during the thermal processes and the exhaust gases must therefore be treated.

Different compounds may be added with the purposes to (cf Lue-Hing et al., 1992, Meyers, 1998 and Rudolph, 1999:

- Stop biological reactions (as lime additions)
- Stop biological reactions causing septicity including hydrogen sulphide formation (by addition of hydrogen peroxide, nitrate, ferric ions and permanganate)
- Add special bacterial cultures for prevention of formation or removal of odourous compounds
- Oxidise by chemicals of already formed odourous compounds (by adition of hydrogen peroxide and permanganate)
- Bind odourous compounds (by addition of iron compounds to form ferrous sulphide or Fe_3S_4)
- Mask odour problems by different added agents
- Cover different odour producing areas by addition of adsorbing or biologically active materials (as compost filters)

Biological reactions that stops sulphate reduction to sulphide has a higher redox potential than for the sulphate reduction. Biological reactions involving oxidation of organic material and reduction of oxygen gas to oxygen(-II), nitrate to nitrogen gas, permanganate to mangan dioxide, mangan dioxide to manganous ions, and ferric ions to ferrous ions.

Claims have been made for the prevention and treatment of odours by bioaugmentation, where proprietary bacterial cultures are added to odour-producing units. This technology is, however, still uncertain with respect to results and general applicability. Chemical oxidation agents may oxidise sulphides to sulphur and destruct mercaptans and amines. An advantage is that the odour reduction is quick. By binding sulphides into an insoluble form hydrogen sulphide release is prevented. Different masking agents may reduce the odour problems related to human olfactory senses although the causing agents are not removed. This technology is not suitable if the odour is generated from large areas. Composting material may be produced from excess sludge and be used as compost filters to biologically remove odorous compounds.

V.3 Application for Nowy Targ

Present sludge production at Nowy Targ is about 3000 kg/days and the volatile fraction of the sludge is about 80 %. Based on experiments with aerobic stabilisation (see table 14) up to about 1000 kg VSS seems to be possible to remove per day with an efficient biological sludge stabilisation (for instance aerobic or anaerobic digestion).

Instead of using air as the oxygen source in aerobic stabilisation different chemicals can be used in oxidation of organic material. In order to reach a high degree of stabilisation (i.e. remove biologically 1000 kg VSS/day) the following alternative amounts of chemicals would be necessary in average per day (Hultman et al., 1998):

o Hydrogen peroxide, H_2O_2:	1,500 kg
o Calcium nitrate, $Ca(NO_3)_2$:	2,800 kg
o Ferric chloride, $FeCl_3$	28,000 kg

These high chemical dosages should probably solve the odour problems at the Nowy Targ treatment plant but would be very expensive. Additions of chemicals for odour prevention seems therefore only to be suitable as short term solution in sludge storage for instance before a following sludge treatment process as heat drying and incineration or to reduce already existing septicity of the sludge before a further sludge handling step. Addition of lime to keep the pH-value around pH 8.5 may also significantly reduce the odour problems (cf Figure 17 and 19).

Odour problems at Nowy Targ seem not to be severe as long as the sludge is aerated. Improved biological stabilisation in combination with the addition of small amounts of chemicals for short term odour control seem to be the most cost-effective way for odour control. Possibilities to use compost filters for better odour control from the constructed landfill is also an interesting method.

Special attention should be directed towards addition of chemicals if incineration is used:

- Addition of inorganic materials (lime, ferric chloride etc) give rise to a higher production of ashes and limits therefore the residence time in the constructed landfill

- Addition of oxidising chemicals (as hydrogen peroxide and permanganate) may oxidise chromium(III) to chromium(VI) which is much more toxic and may more easily be transported from the landfill into the surroundings or recirculated back to the treatment plant.

- The oxidation of chromium(III) to chromium(VI) is facilitated by high pH-values for instance in addition of high dosages of lime

VI. SLUDGE VOLUME REDUCTION

VI.1 Moisture distribution in sludge

Water in sludge can be classified as free water, interstitial water, surface water and bound water (see Figure 20). Free water include void water that is not affected by capillary forces. This water may partly be removed by thickening processes.

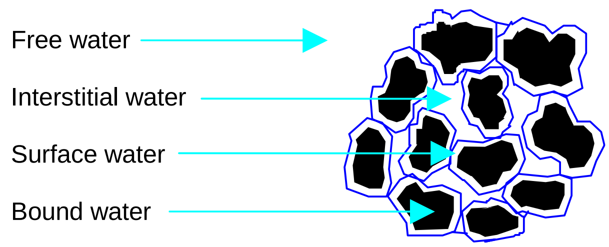


Figure 20. A visualisation of moisture distribution in sludge (Tsang and Vesilind 1990).

Interstitial water is inside the flocs when sludge is in suspension and is present in the capillaries when the cake is formed. This water may be partly removed by dewatering. Remaining capillary bound water and surface water may be removed by drying. Bound water is chemically bound to the solid particles and is not removed by drying but by the use of incineration.

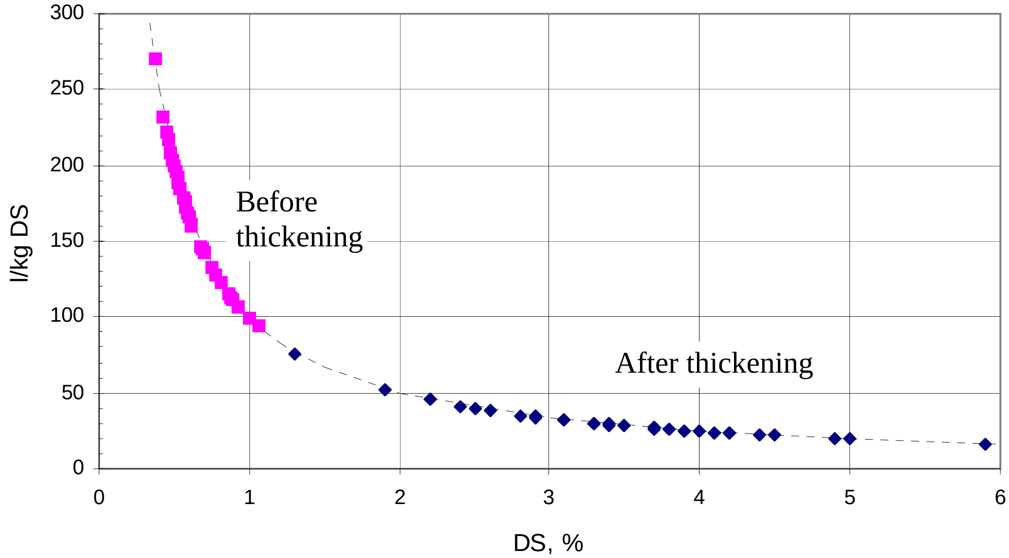
VI.2 Volume reduction in dewatering and thickening

During dewatering or thickening when the water is pressed out of the sludge, the volume reduction will mainly follow the formula for volume reduction of suspensions with voids filled with water. The specific gravity of sludge is a function of its volatile fraction and its fixed fraction. The volatile fraction has a specific gravity near the value of water. The specific gravity of the fixed fraction is often assumed to be 2.5.

The concentration and density of the excess sludge at Nowy Targ before and after thickening and after dewatering are shown in Table 20 as mean values for the years 1996, 1997 and 1998. Figure 21 shows sludge volume in l/kg dry solids versus percentage of dry solids before thickening, after thickening and after dewatering.

Table 20. Concentration and density of the excess sludge at Nowy Targ before and after thickening and after dewatering (Kamues, 1999).

Parameter	Concentration, %			Density, kg/ m^3		
Year	1996	1997	1998	1996	1997	1998
Before thickening	0.58	0.75	0.63	1002	1003	1002
After thickening	3.89	2.67	2.47	1013	1010	1007
After dewatering	15.77	14.00	14.00	951	959	952



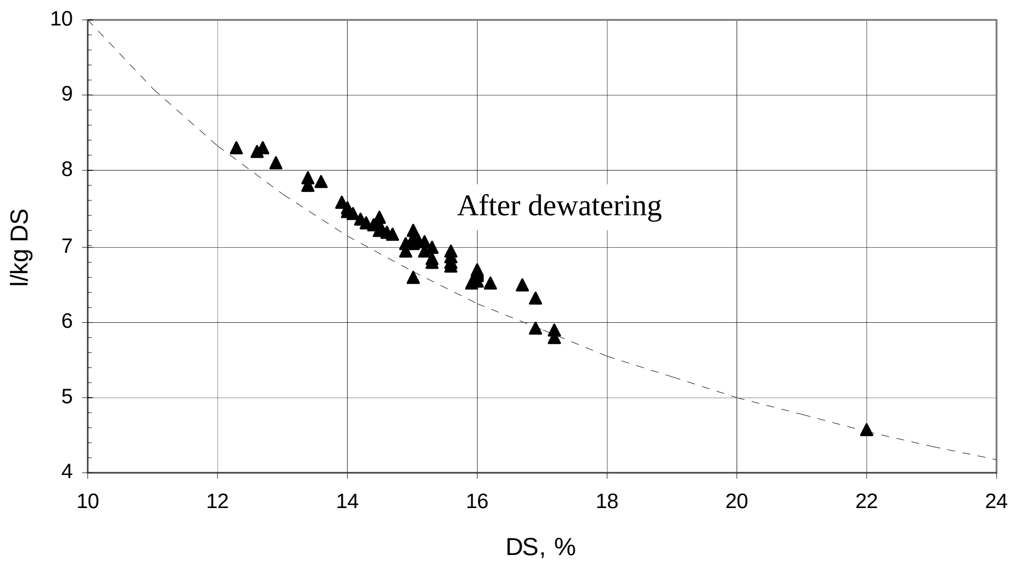


Figure 21. Volume in l/kg Dry Solids versus percentage of dry solids for sludge from Nowy Targ before thickening, after thickening and after dewatering. The volume reduction at a sludge density of 1 kg/ liter (100/% DS) is inserted as a dotted line.

The present sludge production of about 3000 kg SS/day and a sludge concentration of about 15 % and a specific gravity of 0.95 requires a volume need of about 24.3 m^3/day. A very efficient dewatering with formation of a sludge cake or a combination of dewatering and natural drying could reduce this volume need down to about 6 m^3/day. With the voids filled with air the sludge specific gravity is about 0.5.

Experiments at Nowy Targ have shown that a change from centrifugation to a filter press increased the sludge solids concentration from about 15 % to 19 % if polyelectrolytes were used as conditioning agents (Kabacinski et al., 1998). The use of 0.17 kg $FeCl_3$ and 0.83 kg $Ca(OH)_2$ gave after dewatering in the filter press a value of 30 % dry solids.

With the assumption that added $FeCl_3$ is precipitated as $Fe(OH)_3$ and added $Ca(OH)_2$ as $CaCO_3$ the added amount of sludge dry solids is about 1.2 kg per kg supplied sludge before conditioning.

The volatile fraction of the sludge without addition of inorganic conditioning agents was about 80 %. After conditioning with inorganic agents the volatile fraction may be calculated to 34 %. The VSS concentration after dewatering in the filter press may then be calculated to 15.2 % and 10.2 % with conditioning with polyelectrolytes and inorganic agents, respectively. The addition of inorganic conditioning agents will therefore not cause a volume reduction compared with the addition of polyelectrolytes.

Sludge from biological nutrient removal in the activated sludge process contain a high proportion of intercellular water, which can not be removed with ordinary dewatering methods (Kempton and Cusack, 1999). Processes which rupture intercellular water are required to remove this water. Waste activated sludge from biological nutrient removal can be dewatered to 12 to 15 % dry solids with ordinary dewatering methods. Undigested primary sludge can be dewatered to 30 % and digested primary and waste activated sludge can be dewatered to between 16 and 22 %.

VI.3. Volume reduction in heat drying

Special consideration have to be made on installation of sludge drying or incineration plants. A main requirement is that the plant has to be easy to maintain and operate and be handled by skilled personal.

Drying of sludge can be done by hot gases, either through convection drying or contact drying (Steinle, 1997) (Figure 22). At convection drying the sludge is heated directly by hot gases. The hot gas can be led above a bed of sludge or the sludge particles can be mixed with the hot gas in a fluidized bed. At contact drying the sludge is dried through a heated wall and is not in direct contact with the hot gases. The hot gas can be either combustion gases from a burner, hot air produced by the combustion gases in a heat exchanger or steam from a boiler. Use of steam requires that the gas temperature is higher than the condensation temperature.

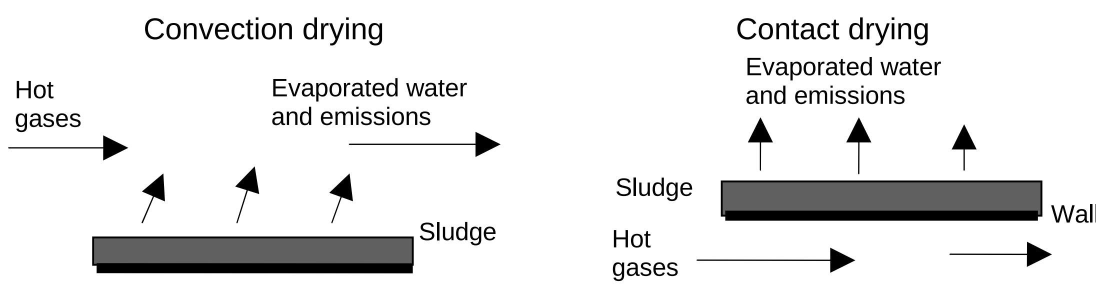


Figure 22. Convection drying of sludge there the sludge is heated directly by hot gases and contact drying there the sludge is dried indirect through a heated wall (Brautlecht 1997).

For incineration the sludge has to be dried to a water content that allows the sludge to burn. The energy from oxidation of the organic material must be higher than the energy consumed by evaporation of the water content of the sludge. The drying can be made either in the incineration plant or in a separate dryer. In both cases the energy required for evaporation of the water can be regained by condensation of the evaporated water.

The evaporation rate of different types of water is shown in Figure 23. After drying dry solids and bound water remain. Depending on the degree of heat drying some surface water may also remain.

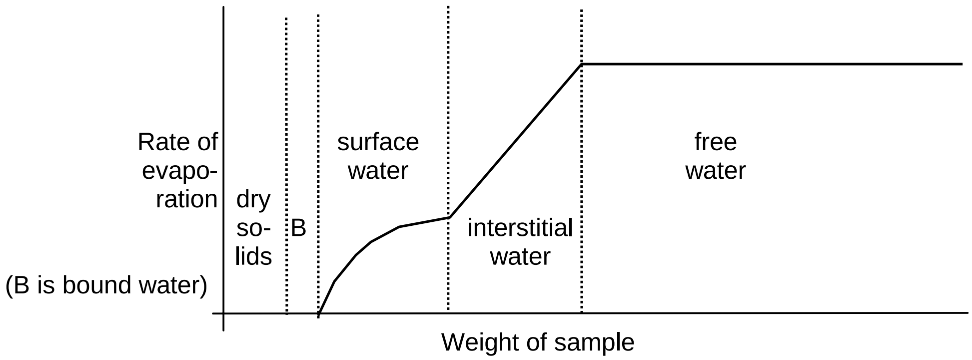


Figure 23. Drying curve for identifying different types of water in sludge (Lowe 1995).

During drying the sludge changes characteristics as illustrated in Figure 24 for a thin-film dryer. The sludge passes three zones (Lowe, 1995):

- The wet zone, where the sludge is free-flowing and can be spread easily onto the heated tube
- The sticky zone, where the sludge is pastry
- The granular zone, where the sludge is crumbly in nature and mixes much more freely

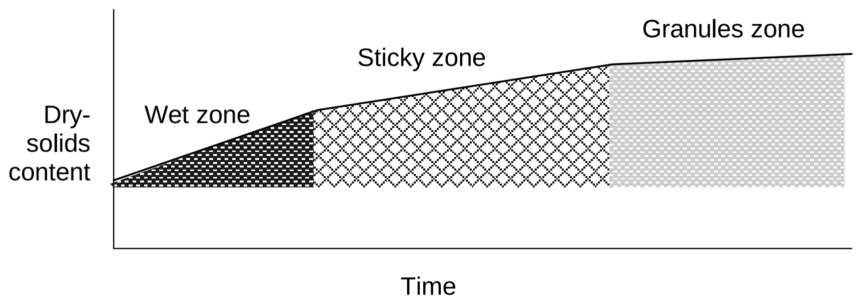


Figure 24. Changes in state through a thin-film dryer (Lowe 1995).

With respect to volume needs in storage it is important that the formed granules during the heat drying has as high density as possible. Vonplon (1997) recommends that the density of the formed granules should be at least 650 kg/m^3. Solmaz (1998) uses the value 700 kg/m^3 in a calculation example of the volume need in drying.

During drying a certain amount of volatile substances are removed. If this amount is neglected the total solids in the sludge is equal to the total sludge dry mass + the remaining water content. For Nowy Targ about 3000 kg dry solids are produced per day. If the dry solids is 90 % the total dried sludge mass will be 3300 kg/day. With a density of the granules of 700 kg/m^3 the volume need may be calculated to 4.7 m^3/day.

VI.4 Volume reduction in incineration

Ashes produced during incineration may either be handled wet or dry. Ash density is about 560 kg/m^3 dry and 880 kg/m^3 wet. Solmaz (1998) uses in a calculation example ash density of dry and wet ash 800 kg/m^3 and 1200 kg/m^3, respectively. The water content in wet ash was about 6 % in the calculation example for polymer conditioned sludge. For sludge in Nowy Targ the produced dry solids was about 3000 kg/day with a volatile fraction of 80 %. The produced amount of inorganic sludge is 600 kg/day. If the density of the ashes is 600 kg/m^3 the volume produced of ashes is about 1 m^3/day.

Stabilisation with lime will increase the inorganic content and thus decrease the volume reduction achieved through incineration. A higher daily volume of ashes is produced if the sludge is stabilised with lime. A typical dose of lime in stabilisation is 0.45 kg CaO/kg dry solids. For a sludge production of 3000 kg/day a lime dosage of 1350 kg is necessary and the total sludge production will be 4350 kg/day of which 1950 kg is inorganic sludge. With a density of ashes of 600 kg/m^3 the volume produced of ashes is 2.25 m^3/day.

Sludge is often burned at a temperature of about 800 to 850 ºC and the inorganic material is in a solid phase as a porous ash with a density of about 600 to 800 kg/m^3.

VI.5 Volume need for storage

Solmaz (1998) has examplified volume reduction of dewatered sludge conditioned either by polyelectrolytes or lime and given approximate data for the volume needs per kg dry solids (Table 21).

Table 21. Weight, volume and density for dewatered, dried and incinerated sludges, one conditioned with polyelectrolytes (PE) and the other conditioned with lime (Solmaz, 1998).

Process	Conditio-ning agent	Dry Solids, %	Weight	Volume	Density kg/l	Dry Solids	Volyme, l/kg DS
Dewater.	PE	25	1000	1000	1.0	250	4.00
Dried	PE	90	280	400	0.7	250	1.60
Incin.	PE	100	75	125	0.6	75	1.67
Dewater.	lime	35	1000	1000	1.0	350	2.86
Dried	lime	95	370	525	0.7	350	1.50
Incin.	lime	100	175	290	0.6	175	1.66

The volume need for sludge in Nowy Targ based on a sludge mass production of 3000 tonnes/day are illustrated in Table 22.

Table 22. Sludge volume needed at Nowy Targ based on a sludge production of 3000 kg dry solids/day of excess sludge with a volatile fraction of 80 %.

Type of sludge	Density kg/m^3	Mass kg DS/ day	Volume l/kg DS	Volume m^3/day
Dewatered excess sludge with polyelectrolytes (DS = 14 %)	960	3000	7.5	22.6
Dried dewatered sludge (conditioned with polyelectrolytes, 90 % DS)	700	3000	1.57	4.7
Incinerated sludge (conditioned with polyelectrolytes, 100 % DS)	600	600	1.67	1.0
Incinerated sludge (conditioned with lime 0.45 kg/kg DS)	600	1950	1.67	2.25

From the table it is seen that incineration is very advantageous as a method of sludge volume reduction especially when organic materials are used for sludge conditioning. Additions of inorganic chemicals, either for conditioning or for chemical precipitation, increases significantly the sludge volume produced per day in incineration.

The volume need for storage of the rest products depends on the reduction in volume in liter per kg dry solids reached by dewatering and drying and the reduction of dry solids solids reached through incineration or digestion. Figure 25 shows volume in liter per kg dry solids for the different examples of sludges from Imhoff (1996), Solmaz (1998) and Balmer and Frost (1990). Sludge from Nowy Targ are also included in the figure.

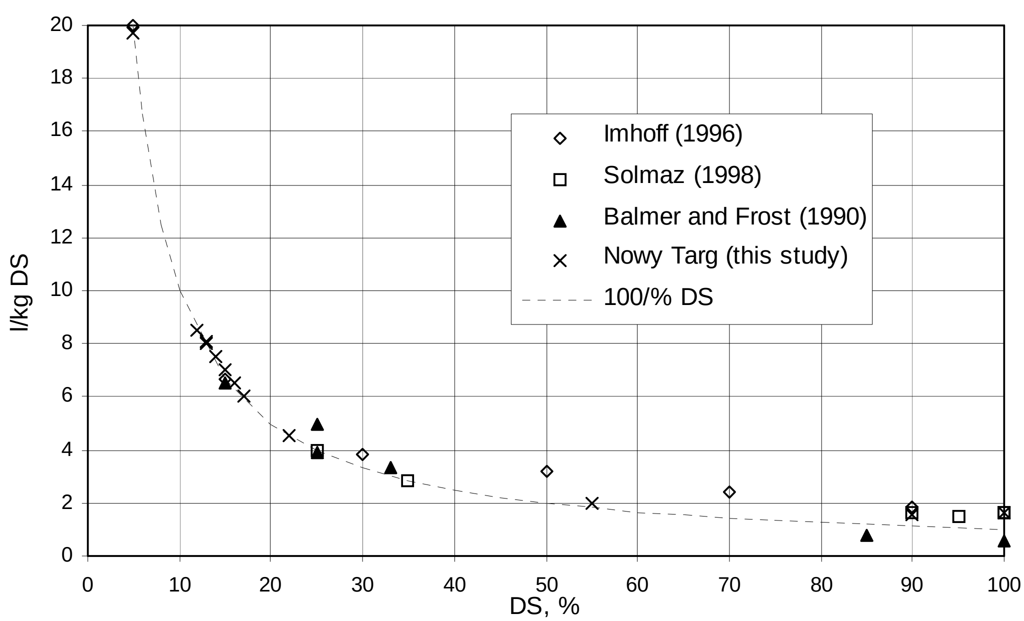


Figure 25. Volume in liter per kg dry solids versus percentage of dry solids for the different examples of sludges from Imhoff (1996), Solmaz (1998) and Balmer and Frost (1990) compared to sludge from Nowy Targ. The volume reduction at a density of 1 kg/ liter is inserted as a dotted line.

PART B: EVALUATION OF SLUDGE HANDLING OPTIONS AT NOWY TARG

I. IMPROVED WASTEWATER AND SLUDGE TREATMENT

I.1 Overview of suggested solutions

Suggestions for improvement of wastewater and sludge treatment at Nowy Targ treatment plant are:

Wastewater treatment

Use of pre-sedimentation and pre-precipitation (proposal by the Cracow University of Technology, CUT)

Sludge treatment

Additional aerobic sludge digestion (CUT proposal)

Anaerobic digestion (CUT proposal)

Sludge stabilisation with lime (CUT proposal)

Sludge incineration (with different pre-treatments) (proposal by the CUT and BBM Design Co)

The different suggestions will be discussed mainly based on

(1) Needs for new installations
(2) Possibilities to control odour problems
(3) Changes in mass and volume needs

I.2 Complementary wastewater treatment

Two primary clarifiers were proposed with a diameter of 21.8 m and a hydraulic loading of 1.0 m^3/m^2*h and located in the area of the temporary sludge storage. The primary clarifiers would be built 40 m from the grit chambers and be hydraulically linked to the existing treatment system.

Introductory studies were performed in a pilot scale to evaluate sedimentation of suspended solids in the influent after the screens. A solids removal of 65 % was expected in the primary clarifiers and a dry solids content after thickening of 5 %. If ferric sulphate (marketed as PIX) was added with a dosage of 13 g Fe/m^3 the removal of suspended solids was 65 - 79 %. The precipitated sludge had a volatile fraction of 44.8 %.

The use of primary clarifiers should improve the structure of the activated sludge, enhance the stabilisation degree and reduce the necessary air supply to the SBRs.

Investments in primary clarifiers would have a general positive effect on the Nowy Targ treatment plant including:

- o Possibilities to remove much of the chromium before the biological step
- o Possibilities to increase the sludge age in the biological step and thereby increase sludge stabilisation and decrease odour problems from the biological sludge (see section on aerobic stabilisation)
- o Possibilities to handle an increased amount of wastewater at the treatment plant
- o Reduction of sludge volume due to better thickening properties of primary sludge compared to secondary sludge
- o Possibilities to have a better control of odour if ferric salts are added before the primary clarifiers due to precipitation of ferrous sulphides

The formed primary sludge must be further handled for stabilisation, volume reduction and odour control. Different stabilisation methods are aerobic stabilisation, anaerobic digestion, lime stabilisation and incineration (see these sections).

I.3 Aerobic stabilisation

Batch tests had been performed by CUT with excess sludge with an initial sludge concentration of 6 g SS and a volatile fraction of 69.6 %. After two weeks of aeration the volatile fraction had decreased slightly to 62.5 %.

If two of the SBRs were used for the wastewater treatment the third reactor could be used for aerobic stabilisation. Each reactor has the volume of 2400 m^3. Based on a sludge production of 3744 kg/day, a sludge density of 1.0 kg/l and an excess sludge concentration of 10 kg/m^3 and 20 kg/m^3 (after thickening) the additional stabilization time can be calculated to 6.4 and 12.8 days, respectively.

Results reported by CUT are in general agreement with experimental results reported in part A. In these studies the decrease of volatile suspended solids was 4 % during 2 weeks. The initial volatile fraction was however higher in the experiments (80 % compared with 70 %). Excess sludge before thickening was in average 5.8 - 7.5 1996 - 1998 (compared with assumed value of 10 kg/m^3) and after thickening 24.7 - 38.9 kg/m^3 compared with assumed value of 20 kg/m^3.

Experimental values from CUT and experimental studies and literature data indicate that a total sludge age in the SBRs and stabilisation unit must exceed about 35 - 40 days in order to get a stabilised sludge with little odour problems. Modification of the operation modes by use of one reactor for stabilisation may decrease odour problems significantly. However, use of only two reactors for wastewater treatment makes this treatment more sensitive to disturbances and may decrease possibilities to achieve treatment standards.

Four possibilities may be considered to obtain a biological sludge with a high stabilisation degree and with little odour problems.

(1) Investments in a new SBR reactor with a similar volume as the existing (2400 m^3). At the present sludge mass production of about 3000 kg/day, a density of 1.0 kg/l and a sludge

concentration after thickening of 24 kg/m^3 the solids retention time would be about 19 days. Possibilities to operate at certain periods two of the SBRs for stabilisation may also be considered. Based on experimental results in part A a reduction of sludge mass production of about 20 % may be expected for an increase of the stabilisation time with 20 %.

(2) Instead of investments in a new SBR reactor it may be possible to reconstruct the equilization basin for dairy wastewater. This basin is at present used for sludge storage and has a volume of 2500 m^3, i.e. about the same volume as one of the SBRs.

(3) Investments in new primary clarifiers. Changes related to the operation of the SBRs include:

- Less supply of organic material to the SBRs due to removal in the primary clarifiers, for instance 40 %
- Less sludge yield, for instance a decrease from 1.0-1.1 kg SS/kg BOD_5 to 0.8 kg SS/kg BOD_5. A somewhat higher decrease (0.6 kg SS/kg BOD_5) is assumed by CUT.
- A less sludge mass production, for instance a decrease of 20 %, due to a higher sludge age in the SBRs compared with operation without primary clarifiers.

With other factors assumed to be constant (as obtained sludge settling properties) primary clarifiers would increase the sludge age with a factor (1/0.6)*(1.05/0.8)* (1/0.8) = 2.7. This calculation shows that investments in primary clarifiers could probably solve stabilisation and odour problems of the sludge from the SBRs. However, the sludge from the primary clarifiers must be stabilised by different methods as aerobic stabilisation, anaerobic digestion, lime stabilisation, heat drying or incineration.

(4) If the sludge is aerobically stabilised it is possible to use a new-built basin or utilise the existing equalisation basin for dairy wastes. At present the following data are approximately valid:

- Flow, Q_{50}, about 13.000 m^3/day
- Total suspended solids, about 400 g TSS/m^3
- Estimated removal efficiency in primary clarifiers, about 60 %
- Estimated primary sludge concentration after thickening, about 5 % (50 kg/m^3)

With these data the produced mass and volume of primary sludge can be calculated to 3120 kg TSS/day and 62.4 m^3/day. The residence time for aerobic stabilisation of the primary sludge in a basin with the volume 2500 m^3 may be calculated to 40 days. This residence time is required for an efficient stabilisation and odour control.

I.4 Anaerobic digestion

In order to study sludge digestion abilities batch tests were run at sludge concentrations of 6 kg/m^3 and chromium concentrations of 6 g/kg dry solids (0.6 %). The limiting value of chromium content in anaerobic digesters according to WEF standards is 2.2 % Cr in dry solids (Banas et al., 1998).

Batch tests indicated inhibition in the production of methane gas (45 dm^3/kg VSS destroyed) and the sludge stabilisation measured as final organic matter was 61.4 %. For an anaerobic digestion time the required volume is 2100 m^3 (Banaš et al., 1998).

Different benefits with anaerobic digestion include energy savings in the SBRs, possibilities to use the produced methane gas for heating purposes, and better dewatering properties of the sludge compared with sludge from the SBRs.

The volume need for the digester depends on if only primary sludge is digested, i.e. if it is assumed that the excess sludge from the SBRs is sufficiently stabilised, or if both primary and secondary sludges are supplied to the digester. The special properties of tannery wastes may make it desirable to use somewhat longer residence times than for municipal sludges. The quite high volatile suspended solids fraction (61.4 %) after digestion indicates the need for longer residence times due to a high fraction of slowly biodegradable organics in tannery wastes.

The use of anaerobic digestion is expected to give at least as good biodegradation of organics as complementary aerobic stabilisation and will therefore be efficient for odour control. The obtained sludge could also be expected to have better dewatering properties than aerobically digested sludge. The anaerobic digestion has its main role for energy savings in SBRs and for methane production if primary clarifiers are used.

I.5 Lime stabilisation

In lime stabilisation burned lime (CaO) is added to the sludge in order to increase the sludge temperature and pH value. Studies at CUT indicate that a dosage of 0.45 kg CaO/kg SS is required.

Lime stabilisation is a simple process that requires minor investments but is costly due to the high costs for lime. The additions also increase the sludge mass of inorganic material which is important to consider in use of incineration. Addition of lime is efficient to control odour due to sulfide compounds. However, some odour problems may be obtained due to emissions of ammonia from the sludge due to high pH-values in the addition of lime.

I.6 Heat drying and incineration

I.6.1 Proposed solution of local incineration

Local incineration was proposed both by CUT and BBM Design Co. The general process configurations that were considered are:

- Sludge without being digested and with a dry solids content after thickening and dewatering of 30 % followed by incineration in a fluidised bed. The fluidised bed for the Nowy Targ treatment plant would have 1.0-1.2 m of diameter, and together with accompaning equipment it would cover the area of 12 * 18 m. The height of the furnace would be H = 13 m, including a chimney. A 2-stage emission gases cleaning system was assumed (Banaš et al., 1998).

- Two options from BBM Design Co (1997) with:

  - Option 1: Sludge dewatering by centrifuges (from 4% to 23% dry solids), followed by a filter-screw press (from 23% to 40%) and incineration with a fluidised bed

  - Option 2: Sludge dewatering by centrifuges (from 4 % to 23 % dry solids), followed by sludge drying to 80 % dry solids and incineration with a fluidised bed.

The BBM Design Co made laboratory studies of the dewatered sludge from the centrifuge and obtained the following results:

humidity	82-85 %
ashes	21 % of dry solids
volatile solids	73 % of dry solids
chlorine contents	0.1 % of dry solids
sulphur contents	0.24 % of dry solids
coloric value	13 280 kJ/kg dry solids
heavy metals	12 685 mg/kg dry solids

Different methods for heat drying and incineration were evaluated by the BBM Design Co:

Heat drying:

- direct and indirect systems for heat supply
- drying system with heated layers
- drying system with a mixer directly heated by gases
- drying system with a mixer and with indirect sludge heating
- fluidal drying system heated indirectly with steam

Incineration:

- fluidised bed
- multi hearth furnace where sludge heat is used for a direct drying of sludge with gases in a counter-current regime. Because of sludge treatment with high temperature gases a pyrolysis process and a final burning in a special furnace (T > 1000 ºC) is required

For a further evaluation of incineration technology a fluidized bed furnace was considered with the following features:

- sludge particles remain for a long time in 850^0C
- a complete incineration of organic matter occurs (gases are odourless).

I.6.2 EIA of sludge incineration

The proposed installation for waste sludge thermal utilization at the Nowy Targ WWTP, according to the ordinance of the Ministry of Environmental Protection, Natural Resources and Forestry (MEP NRF) issued may 13, 1995 (DZ.U. No.52, sec. 284), is an investment that may be considered as particularly hazardous for people's health and the environment since it utilizes the hazardous wastes. Therefore the BBM Design Co was required to present, as a supplement to their proposed solution, an evaluation of its impact on the surrounding area.

An environmental impact assesment (EIA) of sludge incineration considered:

- requirements in different regulations and ordiances
- identification of the present state of the environment in the neighbourhood area including own emission
- assessment of the environmental impact of the investment
- technological and technical solutions of the thermal utilization of wasted sludge
- possible ways of discharge and utilization of generated wastes

The purpose of the proposed BBM Design installation was to choose such method of sludge incineration, which assures that the European air pollution standards are not exceeded.

A two-stage cleaning process with calcium hydroxide and activated coke suspension followed by activated carbon adsorber is suggested to assure a high quality cleaning process for the removal of SO_2, HCl, heavy metals and dust. Vapor condensation from the sludge drying installation was also evaluated in the report with the condensed vapors directed back to the WWTP. Based on calculations it was concluded that noise generated by blowers, pumps, engines and a stack would not exceed the permissible noise level.

The wastes generated during the incineration process consist of ashes from the fluidized bed, wastes from the system of gas cleaning in absorption reactor and dusts. It was assumed that ashes and wastes generated during the process will be stored at the special site, fully protected from leakage and infiltration. The waste discharges are therefore seen as safe for the surface waters and the environment. The only source of soil contamination may be concerned with a dust emission from the chimney. However, a low level of emission (5 mg/Nm^3) should not create any hazard for the soil.

The BBM Design Co summed up their report with the following conclusions:

- The EIA shows that there is no hazardous impact of the installation on the surrounding area. However, due to a lack of an appropriate Polish standards for gas emission, some emission requirements should be imposed by the Committee of EIA.

- The installation output should not exceed 2650 tonnes dry solids/year (300 kg/h) due to the environmental constrains.

- Solid wastes, dust and ashes must be deposited at the appropriate waste site, that is properly secured against environment pollution.

- According to the EU regulations the installation can be put in to operation after an on-line carbon monoxide and oxygen analyzer is installed in emission gases. Measurements of emission gases volume, temperature and pressure at the stack outlet should also be conducted. The stack should be equipped with a special stand for measuring the concentration of other contaminants present in the emission gases.

I.6.3 Fire and explosion risk of dried sludge

Sludge that is dried to almost water free conditions may lead to risks for fire and explosion caused by spontaneous ignition (Melsa et al., 1997). An almost water free sludge has a fuel value equal to brown coal. For temperatures above the temperature for spontaneous ignition the sludge can start burning. There is also a risk for explosion if the concentration of sludge dust in the air above the sludge is between certain levels.

If the dry solids concentration of the sludge is below about 90 % biological reactions may start in the dried sludge so the temperature increases, similar to the temperature increase in composting. This temperature increase may also be a factor for burning risks of the sludge. If the biological reactions occur under anaerobic conditions there are risks for generation of bad odours.

Storage of an almost water free sludge requires measures to avoid fire and explosion. Installation of automatic fire detection and fire fighting equipment should be considered. To avoid explosion the ventilation should be such that dangerous dust concentrations are avoided. If the sludge is stored in a closed compartment the wall can be constructed to sustain the forces of an dust explosion. To avoid this problem the sludge can be dried to a water content, without these risks.

I.6.4 Incineration of lime conditioned sludge

Conditioning with lime will increase the inorganic content and thus decrease the volume reduction achieved by incineration. Another risk is that incineration of a lime conditioned sludge with a high chromium content will increase the risk for getting toxic carcinogenic hexavalent chromium species. Use of conditioning methods without lime should therefore be considered.

However, elimination of lime causes a decrease in ash softening and fusing temperatures which may necessitate lowering of the highest temperatures, thus increasing THC emissions. The elimination of lime may also cause larger emission of volatile organics and odourus component from the drying zone. To reduce the emissions a higher temperature may be required in the afterburner. Since lime addition makes the ash hygroscopic, the elimination of lime deteriorates the wet scrubber performance.

I.6.5 Application of heat drying and incineration at Nowy Targ

Heat drying and incineration of sludge are well established processes that have been reviewed in many articles, ATV (1997a and 1997b), Solmaz (1998), Vonplon (1997) and Wiebusch et al. (1997). For the EU as a whole sludge was disposed to landfill (40 %) and agriculture (37 %), was incinerated (11 %) or disposed of to the sea (6 %) based on data collected 1991/92. It is expected that more sludge will be recycled to land or incinerated with energy recovery and less will be disposed of in landfills (Davis and Hall, 1997). An overview is given by Wiesbusch et al. (1997) of technical data for different mono-incineration plants in Germany. Incineration is performed both with primary sludges and digested sludges and with and without preceeding drying.

Special factors that should be considered at Nowy Targ are:

- If only heat drying is used it is important to consider risks for fire. If the dry solids concentration is less than about 90 % biological reactions may start and increase the sludge temperature with possible risk for self-ignition. The biological reactions may also generate bad odour.

- If incineration is used it is advantageous to add as little inorganic material as possible in wastewater or sludge treatment in order to obtain as little ashes as possible and therefore increase the storage time for the ashes.

- If incineration is used oxidation of chromium(III) to chromium(VI) should be avoided due to the higher toxity of chromium(VI) and increased risks for transport to the environment or recycling back to the treatment plant. A high redox potential and pH-value favour the oxidation.

- The low dewaterability of the excess sludge from the SBRs makes it desirable to find methods to increase the dry solids concentration compared with that of dewatered sludge at present (about 14 % DS) before heat drying or incineration. This may be done with more efficient dewatering equipment (including preceeding conditioning) or by different natural dewatering and drying processes.

- Leachates from the heat drying or incineration installation increases the load or may disturb treatment processes if they are recycled back to the treatment plant.

- The relative small size of Nowy Targ for use of incineration may make the process costly both in installation and operation.

II. SYSTEMS CONSIDERATIONS

II:1 Overview of sludge handling options

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

A conceptual model of sludge handling options is illustrated in Figure 26. The different compartments in the figure are:

- o Pre-treatment outside the municipal wastewater treatment plant, i.e. mainly actions related to the tanning industry

- o Municipal wastewater treatment plant, i.e. changes in operation strategies to reduce excess sludge production, improve stabilisation and make investments in new treatment facilities that improve further sludge handling

- o Sludge treatment, i.e. methods to improve stabilisation, reduce odour problems, reduce sludge volume and product recovery.

- o Sludge disposal at landfill, i.e. on site treatment and improved storage facilities.

- o Sludge handling outside municipal wastewater treatment plant, i.e. finding a new deposit area and transport to incineration plant.

- o Systems considerations, i.e. the different options for improved sludge handling are interlinked and the most suitable solution for sludge handling at Nowy Targ is probably a combination of actions

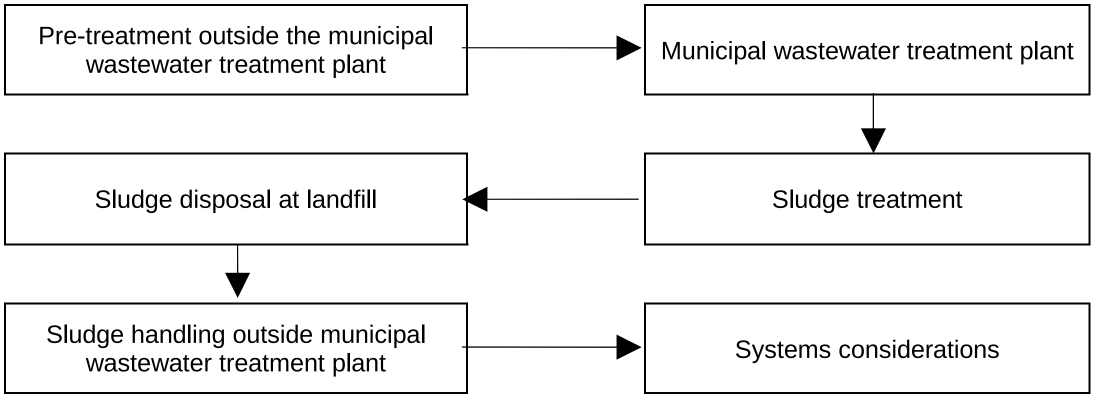


Figure 26. Conceptual model of sludge handling options.

II.2 Chromium recovery

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:

- o Changes in production technologies, i.e. substituting Cr(III) salts with vegetable and synthetic agents
- o Improved internal treatment of tannery wastes and recovery of Cr(III) for instance by use of ion exchange (Tiravanti et al., 1997) membranes (Cassano et al., 1997; Fabiani et al., 1997) or chemical precipitation (Wiegant et al., 1999)
- o Improved collection of tannery wastes to the special tannery treatment unit
- o 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.

A simple recovery system based on the fact that chrome tanning salts precipitate with magnesium almost completely at pH 8 to 9 is used at tannery plants in Kanpur India (Wiegant et al., 1999). After addition of magnesium oxide and three hours of stirring the precipitated sludge is separated from the wastewater. The sludge is dissolved in concentrated sulphuric acid and the obtained liquid is reused for tanning. Biological methods may also be used to treat tannery wastes at the plant (Roš and Gantar, 1998).

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 Cr(III) are for instance 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).

Several different ways are possible to dissolve chromium compounds from the sludge:

(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.

In figure 27 is shown the stability of pure metal hydroxide as a function of pH (Nilsson 1971). Chromium requires lower pH-level for solubilization than other metals. After the acid metal solution has been separated from the sludge, the acid is neutralised and the metals is precipitated as a metal hydroxide sludge.

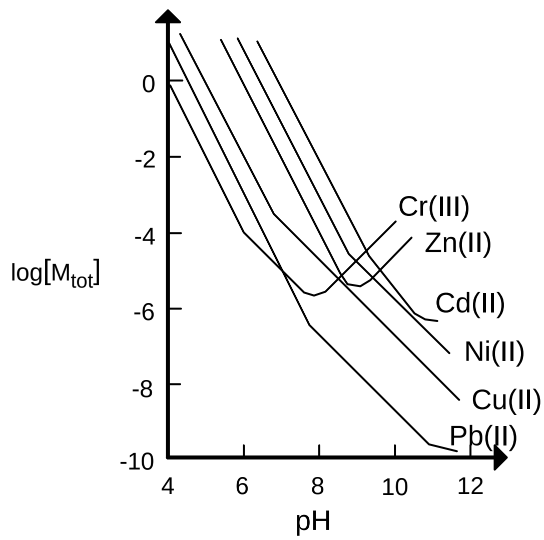


Figure 27. Solubility for pure metal hydroxide as a function of pH (Nilsson 1971).

The leaching can be done with with sulphuric acid at pH-level 1.5 or microbialy with addition of sulphur, which by the action of sulphide oxidising bacteria is transformed to sulphuric acid.

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). It has, however, been demonstrated that lime in sludge influences the conversion of non-carcinogenic and non-water-soluble chromium to a more toxic carcinogenic and water-soluble hexavalent form. Therefore, those installations that fail the health-risk criteria because of the hexavalent chromium emissions should consider changing their sludge conditioning practices if sludge is conditioned with lime (Lue-Hing et al., 1995). Under certain conditions, as use of sewage sludge for brick manufacturing, oxidation of Cr(III) to Cr(VI) may be significant due to the alkaline conditions during the heating process (Rump, 1998).

II.3 Evaluation of final sludge disposal

II.3.1 Constructed landfill at plant

The report ”Ashes disposal from excess sludge utilization and temporary excess sludge disposal at the Nowy Targ WWTP” has been prepared by the CONSEKO company in 1997. The report contains a detailed description of the planned investment, together with detailed drawings and cost analysis. The description of the investment includes an analysis of the location area, design assumptions and specifications, construction outlines and short EIA evaluation. As an Appendix all details of construction are included.

The proposed landfill volume by CONSEKO is 24 000 m^3. The landfill will consist of seven sectors: three of them of 3840 m^3 volume each (64 x 20 x 3m), two of 3072 m^3 volume each (64 * 16 * 3m) and the other two remaining sectors of 3180 m^3 volume each (53 x 20 x 3), the total volume - 6360 m^3.

Construction of the landfill was constrained by the area requirements and both investor and user agreed to build a landfill as a ”mixed construction”. It means that side-walls of the landfill would be erected from a reinforced concrete while bottom of the landfill would be just soil protected with geosynthetics as a tightening material. Each of the different sectors of the landfill is drained, and the leakage from the landfill together with rainfall are discharged to the main well. Estimated volume of the leakage from the one sector is 0.56 - 1.4 m^3/d.

Since sludge generates severe odour problems the designers decided to limit the nuisance by using bioactive materials and hygienization of sludge with lime. As a bioactive material Biolen Odour S was proposed. This substance removes H_2S and mercaptans from the sludge in the broad range of pH (4-9), even if their concentration in wastewater is below 1 mg/l. Biolen Odour S is recommended for sludge with 83% water content, for sludge with lower water content (75%) Biolen PRO may be used. This powdered product is based on selectively chosen yeast bacteria and enzymes, mixed with some mineral additives. The design assumes that after filling sectors of the landfill with sludge, they will be tightly closed to protect the environment from odour and gases emissions.

Over the time of a landfill operation (3 years) the sludge will release some water (15-18%) and its texture will be similar to humus or peat materials. Therefore special entrance gates would be built with platforms for sludge unloading. The platforms would be drained and the collected leakage should be discharged to the existing sewage system.

Landfill area is supplied with a drainage system for leakage water. Each sector of the landfill has a surface drainage system with 3 draining PVC pipes (160 mm diameter) discharging to a PVC well (400 mm diameter). The drainage system can be washed by a WUKO system. The whole drainage is protected from the surface vehicle traffic by concrete prefabricates.

Operation of the landfill, as proposed by the designer, requires that each sector after its filling up should be tightly closed to eliminate odour problems. As the landfill is being closed, a HDPE type geomembrane (thickness 1.5 mm) should be used to cover this sector area. The design considers such a covering as a temporary until sludge incineration facilities are completed. No additional sludge recultivation is planned.

II.3.2 Estimated time for fill-up of landfill

Different stabilisation and water removal methods give rise to different sludge mass and volume production (see Table 23)

Table 23. Calculated mass and volume production and residence time in deposit (24,000 m^3) at present conditions.

Process technology	Mass production, kg/day	Volume production, m^3/day	Residence time in deposit, years
Dewatered sludge, 14 % dry solids (a)	3000	22.6	2.9
Dewatered digested sludge, 25 % dry solids (b)	2400	10.7	6.2
Heat dried sludge, 90 % dry solids (c)	3000	4.7	14.0
Incinerated sludge, 100 % dry solids (d)	600	1.2	54.8
Incinerated lime stabilised sludge, 100 % dry solids (e)	1950	2.25	29.2

Notes:
(a) approximately present situation
(b) during sludge digestion 600 kg VSS/day is assumed to be removed, sludge density = 900 kg/m^3
(c) density of treated solids = 700 kg/m^3
(d) density of ashes = 600 kg/m^3
(e) stabilised with 0.45 kg CaO/kg DS; density of ashes = 600 kg/m^3

II.3.3. Environmental Impact Assessment of landfill

Evaluation by CONSEKO

The landfill is situated east from the WWTP at a reserve area, saved for a future upgrading of the plant. The landfill is located at a non-urban area, approximately 2.5 km from the city center and 150 m from Dunajec River. The nearest building is located at least 220 m from the landfill site. The valley of the Dunajec River plate is rather monotonic with a little slope on north-east side. This area is well protected against flooding with flood banks and river embankments.

To prognose the impact of the landfill on the surrounding area the Environmental Impact Assessment (EIA) was prepared by CONSEKO company before starting the construction.

Evaluation of design concluded in:
- Time of the exposion of landfill to atmospheric conditions and surface impact of sludge on air is limited to necessary minimum.
- Special means for limiting odour emissions by use of bacteriological methods.

- Hydrogeological investigations were done to estimate the background soil pollution and groundwater as well as piezometric holes were installed to enable groundwater monitoring in the surroundings of the landfill.
- The bottom and landfill walls are designed from suitable materials to protect soil and groundwater against pollution under the proper operation.
- Leakage drainage was designed to protect the sectors towards overfilling during there exposion to atmospheric conditions.

According to the EIA, the construction of the landfill will influence the atmosphere quality only. The impact will be limited to the area of the landfill. Since the landfill is located in the area reserved for the Nowy Targ wastewater treatment plant future upgrading, it is also confined within the limits of the plant's impact zone.

A protection zone around the WWTP and landfill sites is set up stretching out to 115 m from the plant. According to the authors of the report, beyond this zone an impact of the plant and a landfill on the air quality is negligible. Construction of the landfill even does not require any special land development. Land management of the protective zone for the wastewater treatment plant is described in the WWTP construction specifications.

EIA stated that design solutions meet all requirements for environmental protection, but stressed that activities towards elimination of heavy metals in the influent to the WWTP should be continued and that the following requirements should be fullfilled during the landfill operation:

1. It should always be used hygienization with lime and deodorant means in form of bioactive substances proposed by the project.
2. Drainage system should be spoiled temporary especially at the moment with surprising decrease of leakage water amount showing choked pipe.
3. After filling with sludge landfill should be covered tight according to project directives.

Discussion.

Complementary evaluation of the environmental impact of the landfill was made by Eklundh (1999). The general conclusion was that the landfill could be regarded as safe in agreement with the study of CONSEKO.

Four effects of the landfill might need further considerations:
- Due to biodegradation of organics methane gas is produced. The gas is a green house gas and is explosive at certain conditions.
- A large fraction (up to 40%) of the VSS seems to be biodegradable of the excess sludge based on tests with aerobic stabilisation. This means that a drainage water may be produced with high concentration of COD and ammonium. If this water is recycled back to the treatment plant the load to the plant is significantly increased. The drainage water may also have inhibiting effects on the treatment processes.
- The use of bioactive substances for odour control has in general shown varying results.
- Possible risks of fire should be consided if heat dried sludge is deposited in the landfill.

II.3.4. Groundwater quality monitoring

CONSEKO Co recommended that groundwater quality should be controlled by monitoring based on existing piezometers according to directives from hydrogeological documentation that means twice a year during first 2 years of landfill operations and thereafter once a year. Analyzes: sulphates, nitrates, chlorides, boron, chromium, zink, cadmium, copper, nickel, lead and mercury, morever measurement of water levels in the holes directly before sampling for analyzes and during periods between samplings once per quartal.

The present situation is as follows: Three piezometers are located at the site of the wastewater treatment plant for groundwater quality monitoring. Water level was found on the depth of 2 - 2.5 m. Results of the analyses of the water sampled from piezometers are presented in Table 24. The amount of drainage water discharged from the bottom of the sludge landfill is depending on weather conditions and varies between 4 and 25 m^3 per week. Results from the analysis of leakage water are also presented in the table.

Table 24. Results of the analysis of the groundwater and drainage water from landfill

Sampling place	Date	Cr^{+3} mg/l	COD mg O_2/l
piezometer P-I	96.06.19	0.6	-
piezometer P-II	96.06.19	0.4	-
piezometer P-I	99.03.08	0.07	34.2
piezometer P-II	99.03.08	0.13	64.7
piezometer P-III	99.03.08	not detectable	53.6
drainage from landfill	98.07.07	not detectable	1455.1
drainage from landfill	98.10.14	not detectable	3350.0
drainage from landfill	99.03.09	not detectable	14 117.4

From a morphological point of view the area is a valley of the Dunajec river, with slopes sloping gently towards and along the course of the river. Elevation above sea level is 579-578 m. Older and deeper layers of geological formations are from the Tertiary period and consist of sand and slate types, these formations are very eroded. The deepest layer is 5.7-5.8 m beneath ground level in south-west direction and 3.7-3.3 m in north-east direction of area. The layer above this is from Quartary period and mostly made up by river accumulated materials. The material consists of a mixture of gravel and pebble that is sometimes covered with clay, sediments and humus layers. The surface level is made of humus.

In the gravel and pebble level the surface water level is found. The free water level is located from 1.1-3.3 m below ground surface level. The stabilized groundwater level is found between 575.1-576.8 m above sea level. The groundwater level in subsurface is related strongly to the level of the Dunajec River and Czerwionce. The Dunajec River drains out water from the soil and flow from the groundwater goes towards the river. For the Czerwionce the case is the opposite (it feeds water to the soil). From time to time the level of the groundwater can rise to 579 m depending on the water level in the river. During the flood periods this area will be flooded. There are plans to build protective banks against the flood waves.

The soil consisting of gravel and pebble is unsorted and thus has very varied sizes of strata (materials), it also contains varying amounts of clay and has different values of permeability. The coefficient of filtration is over 100 m/day. The groundwater is slightly aggressive towards concrete.

II.3.5 Final disposal outside Nowy Targ treatment plant

Final disposal of sludge can be performed outside the Nowy Targ treatment plant. In this case the constructed landfill acts as an intermedient buffer deposit before final disposal. Different such options are illustrated in Figure 28.

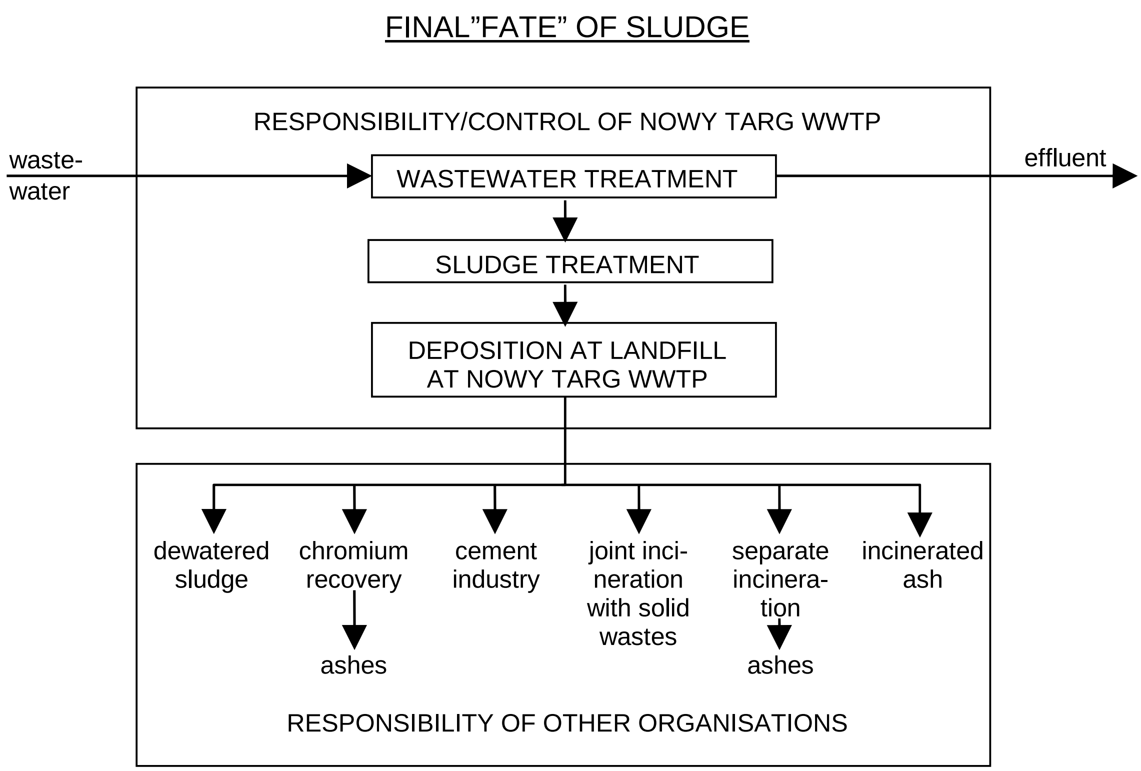


Figure 28. Final disposal outside Nowy Targ treatment plant

If incineration is used it is possible to use the constructed landfill for a long time period. At other sludge handling methods the landfill can only be used temporary before it is deposit at another deposit or is taken care of by other organisations. The different options will be briefly discussed:

The Cracow University of Technology suggests construction of a new landfill for both municipal wastes and wasted sludge. This would be the best solution from an economical point of view. The sludge must, however, be dewatered to much higher dry solids concentration than at present.

CUT calculated the required sludge deposit volume for ten years deposition for three different sludge handling processes (Table 25) and the corresponding deposition time in constructed landfill with the volume 12,600 m^3.

Table 25. Calculation by CUT of sludge deposit for three options for sludge handling processes.

Option I - sludge after aerobic stabilization, mechanically thickened, dewatered in centrifuges (up to 25% of dry solids) and chemically stabilized up to 40% of dry solids.

Option 2 - digested excess sludge, dewatered to 35% of dry solids

Option 3- digested + wasted sludge, 40% of dry solids

	Option 1	**Option 2**	**Option 3**
Sludge dry solids, D, kg/d	6269*	2434	2902
Sludge volume, V, m^3/d	D/10 x 40 = 15.7	D/10 x 35 = 7	D/10 x 40=7.25
Daily mass transported, G, t/d	1.4 x V = 22	1.4 x V = 10	1.4 x V = 10.2 t/d
Landfill volume for 10 years sludge deposition, V_{10}, m^3	V x 3650 = 57 300	V x 3650 = 25 500	V x 3650 = 26 500
Deposition time**	2 years 3 months	5 years	4 years 10 months

* 3432 kg/d (Sludge dry solids) +2837 kg/d (CaO) = 6269 kg/d

** Calculated volume of the local sludge deposit site is 12 600 m^3

A possibility might be to send heat dried sludge or ashes to a chromium recovery installation. Such an installation is situated near Cracow.

Incineration of sludge together with materials for the building industry is used for instance in Zürich. A special problem might be formation of chromates the if the sludge is incinerated during cement production.

Joint incineration with solid wastes is another possibility. Several such plants are in operation for instance in Germany. In this case it is of interest to find possibilities for a regional incineration plant for solid wastes and sludge. The high chromium content in the sludge can make ash disposal more difficult.

Separate incineration of the sludge at another incineration facility at Dabrowa Gornicza between February 1st and April 30th 1998 has been used in order to avoid acute problems with sludge disposal. It is then important to dewater the sludge efficiently in order to diminish transportation costs. The produced ash in incineration might be used for different purposes as for instance in the building industry.

II.4 Discussion of different system solutions

II.4.1 Proposed systems

Two main system solutions have been suggested for sludge handling at Nowy Targ. The first solution is illustrated in Figure 29.

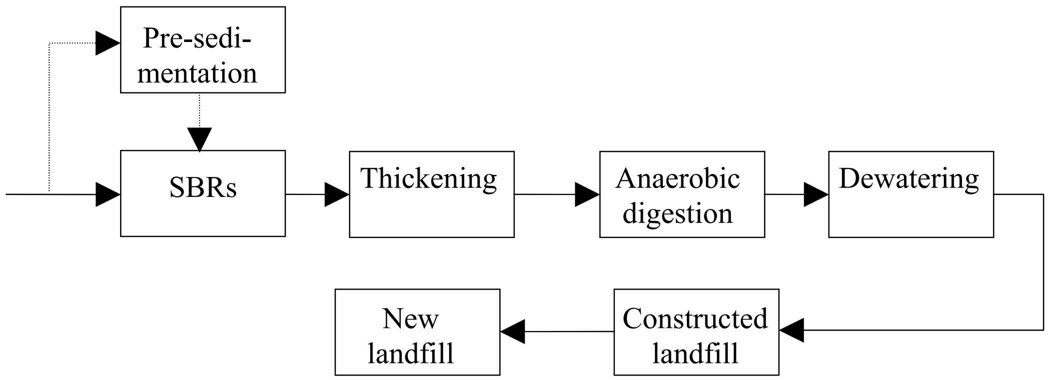


Figure 29. Proposed solution from Cracow University of Technology.

The proposed system uses the existing SBRs, thickeners, centrifuges and constructed landfill. New investments are:

- o Pre-sedimentation basins (a system without pre-sedimentation is also suggested)
- o Anaerobic digestion
- o New landfill area

Incineration is proposed by BBM Design Co and also by Cracow University of Technology. The proposed solution is illustrated in Figure 30.

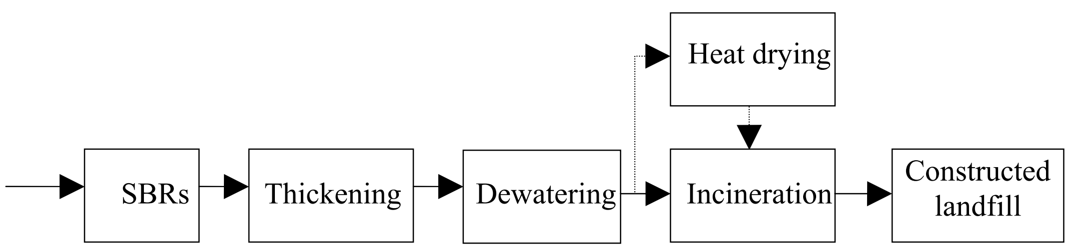


Figure 30. Proposed system solution with incineration from BBM Design Co and Cracow University of Technology.

The proposed system uses the existing SBRs, thickeners and constructed landfill. New investments are:

- o More efficient dewatering equipment
- o Incinerator with or without heat drying of dewatered sludge before the incinerator
- o Constructed landfill units in addition to the three tanks already constructed

The different process units have already been discussed both from a general standpoint as for application at Nowy Targ. The following discussion will be related to system function. In that respect the following effects will be discussed related to:

- o Wastewater treatment
- o Stabilisation

- o Odour
- o Volume needs
- o Chromium handling
- o Time aspects

II.4.2 Wastewater treatment

Installation of pre-sedimentation basins would have important beneficial effects on the wastewater treatment efficiency. The load to the SBRs will decrease significantly allowing better treatment results and a better stabilisation of the excess sludge. Possible negative effects of chromium on the biological treatment will be diminished due to removal of the main part of chromium in the primary clarifiers. This will also facilitate possibilities to secure effluent requirements of chromium.

The significant fraction of volatile suspended solids (VSS) that is not degraded in the SBRs may later cause a reject water (from digesters), leachate water from landfill or condensate water from heat drying and incineration. These waters must be treated. The most common way is to recycle these waters back to the influent of the wastewater treatment plant. Different solutions as anaerobic digestion, heat drying/incineration or disposal of excess sludge in the constructed landfill will therefore increase the load of especially COD and ammonium to the treatment plant. The recycled waters may also have some inhibitory effects on the biological processes.

II.4.3 Stabilisation

The different proposed solutions will produce a sludge that is stable enough to decrease biological reactions efficiently. This is of course especially valid in use of incineration. Some risks exist that chromium may have an inhibitory effect on the digestion process, especially methane production. If lime stabilisation is used it must be noted that biological reactions will start after some time then the pH-value has diminished due to neutralisation of lime with carbon dioxide in the air. If only heat drying is used for the stabilisation different biological reactions will start if the dry solids contents in the dried sludge is below about 90 %.

II.4.4 Odour problems

Odour problems at the treatment plant seems to be related to the low stabilisation degree of the sludge. When the sludge is deposited different biological reactions make the sludge septic and odourous compounds are emitted to the surroundings. The two systems produce a stabilised sludge (anaerobic digested) or ashes and the end product will not cause significant odour problems.

Some odour problems may be generated during heat drying or incineration. However, different methods are available to decrease these problems. The largest problem related to odour is probably storage of sludge before treatment by different stabilisation methods. If the sludge is stored for a short time different additions as lime or nitrate may significantly decrease the emission of odours.

II.4.5 Volume needs

With the present pollutant load to the treatment plant and with the constructed landfill completed with a total volume of 24,000 m^3, the time for fill up is about 6 years for the system with anaerobic digestion while it is about 55 years in incineration (Table 23). For an increased connection of sewers to the treatment plant and possible handling of sludge from other surrounding plants the time to fill up the landfill will be diminished proportionally to the increased load. Therefore, incineration is the only long range solution if the final destination of the sludge/ashes is in the constructed landfill.

For other sludge handling systems the constructed landfill can act as a tempory discharge of sludge before it is further handled for instance deposited on another landfill or thermally treated at another plant.

II.4.6 Chromium handling

The use of chromium in tannery industries is probably the main problem for the treatment plant. Many methods are available to recover and recirculate chromium in larger tannery industries and by use of information campaigns and improved collection of tannery wastes it may be possible in the future to significantly decrease the supply of chromium to the influent of the plant. However, it is likely that the chromium content for a long time is too high in the sludge for use in agriculture, landscaping etc. Therefore it seems better to deposit the chromium containing sludges or ashes in a controlled way (such as in the constructed landfill) and with a volume as small as possible. A long-range solution for deposit ashes can be to recover the chromium content and use the remaining ashes in for instance building materials.

II.4.7 Time aspects

The sludge handling system at Nowy Targ should be possible to use for a long time period. In many countries (Germany, Sweden etc) it will not be allowed to deposit sludges containing more than 5 % organic material. Even a significant increase of the pollutant load to the Nowy Targ treatment plant makes incineration followed by a deposition of the ashes a solution that can be used for at least 20-30 years. During this time another deposit place for the ashes may be found or methods to recover chromium and to use the rest of the ashes may be developed.

NEED FOR FURTHER INVESTIGATIONS

Main problems

The main problems in Nowy Targ in sludge handling are:

- o The sludge is not sufficiently stabilised
- o Odour problems are severe
- o Sludge dewatering is insufficient
- o The sludge contains a high concentration of chromium
- o The volume should be minimised before disposal

All these problems should benefit from research and development works.

Stabilisation of the sludge

Studies at Nowy Targ and supported by literature data have shown that a much higher sludge age is needed to secure a stabilised sludge. Possibilities of a separate stabilisation step should be further evaluated. One possibility is aerobic stabilisation with re-building of the existing equalisation basins for dairy wastes and which basins are at present used for sludge storage. Another possibility is investments in anaerobic digesters. Stabilisation will also decrease the sludge amount for further handling.

A special problem with the unstabilised sludge is that it will give rise to biological reactions that transfer different compounds (ammonium, COD etc.) into the leachate water. If this leachate is recycled back to the treatment plant it will increase the pollution load to the plant and may also contain certain inhibitory substances. The role of leachate on the plant function needs further investigations.

Odour problems

Odour problems seem mainly to occur if not sufficiently stabilised sludge is stored. Improved stabilisation is, thus, a method to reduce odour problems. If the sludge is handled by heat drying or incineration a long storage time should be avoided before these treatments. Short term actions for avoidance of odour problems should be studied. Methods that are available are additions of chemicals suppressing septic conditions in the sludge (as nitrate), binds sulphides (as iron salts) or inhibits biological reactions (as lime). Heat treatment may increase biodegradability of the sludge and biological reactions may therefore start in the sludge and cause odour problems.

Sludge dewatering

The type of wastewater treatment process gives often rise to an excess sludge with low dewatering properties. If heat drying or incineration is used these processes will need a higher concentration of the sludge in order to avoid excessive energy consumption and costs. Consequences of changing the dewatering equipment are of interest to evaluate. Possibilities should also be considered to use some natural or biological (such as use of reeds or composting) to increase the sludge dry solids concentration. The biological methods stabilise at the same time the sludge.

Chromium content in the sludge

The high chromium concentration in the wastewater has given rise to different problems in wastewater treatment and sludge handling. Different methods to reduce the chromium supply into the sewer net should therefore have a high priority and need to be further evaluated. Chrome(VI) is more toxic and easily movable than Cr(III). Different handling methods that oxidise Cr(III) to Cr(VI) should therefore be avoided. A special problem might be the use of oxidising substances for odour reduction and incineration of the sludge at alkaline conditions. These risks need further attention.

Minimisation of sludge volume

Heat drying and especially incineration reduce the sludge volume that is deposited. If incineration is used it is important to avoid the additions of inorganic materials during the sludge handling and if heat drying is used different methods should be evaluated to reduce the organic materials content before the heat drying process. Reduction of organic materials before the drying process will also diminish certain risks as fire and odour emissions.

Complementary investigation needs in use of heat drying

Two special investigations should be considered:

(1) Risks of fire or explosions during the heat treatment and methods to store the sludge for reduction of risks of fire and odour problems

(2) Methods for complementary treatment of the heat dried sludge (chromium recovery, incineration at a central plant etc.)

REFERENCES

Ates, E., Orhon, D. and Tünay, O. (1997). Characterisation of tannery wastewaters for pretreatment - Selected case studies. *Wat. Sci. Tech*., **36**, 2-3, 217-223.

ATV (1997a). Trocknung kommunaler Klärschlämme in Deutschland. *Korrespondenz Abwasser*, **44**, 10, 1869-1880.

ATV (1997b). Klärschlammverbrennung Beseitigung oder Verwertung. *Korrespondenz Abwasser*, **44**, 10, 1880-1884.

Balmér, P. and Frost, R.C. (1990) Managing change in an environmentally conscious society: a case study, Gothenburg (Sweden). *Wat. Sci. Tech.* **22**, 12, 45-46.

Banaš, J., Kurbiel, J. and Styka, W. (1998). Alternatives for modernization of sludge handling at the Nowy Targ WWTP. In: *Advanced Wastewater Treatment Report No. 3, Proceedings of a Polish-Swedish Seminar, Nowy Targ, October 1-2, 1998, Joint Polish - Swedish Reports,* Div. Water Resources Engineering, Royal Institute of Technology, ISRN KTH/AMI/REPORT 3048-SE, ISBN 91-7170-324-1, 55-60.

Banaš, J., Plaza, E., Styka, W. and Trela, J. (1998). SBR technology used for advanced combined municipal and tannery wastewater treatment at high receiving water standards. *Proceedings of the 2nd International Conference on "Advanced wastewater treatment, Recycling and reuse", Milan, Italy*, 649-656.

Berg, C. (1986). Metaller i kommunalt avloppsvatten. National Swedish Environmental Protection Board, SNV PM 1942 (in Swedish).

Brautlecht, P. (1997). Einfluß der Klärschlammtrocknung auf die Zusammensetzung der Brudenkondensate. *Korrespondenz Abwasser* 1997, **44**, 10, 1865-1884.

Brautlecht, P. and Gredigk, S. (1997) Gemeinsame Behandlung von Brüdenkondensaten aus der Klärschlammtrocknung und Deponiesickerwasser. *Korrespondenz Abwasser* **44**, 3, 493-498.

Bruce A. (1984). *Sewage sludge stabilisation and disinfection.* Water Research Centre. Ellis Horwood Limited.

Cassano, A., Drioli, E. and Molinari, R. (1997). Recovery and reuse of chemicals in unhairing, degreasing and chromium tanning processes by membranes. *Desalination*, **114**, 3, 251-261.

Davis, R.D. and Hall J.E. (1997). Production, treatment and disposal of wastewater sludge in Europe from a UK perspective. *European Water Pollution Control,* **7**, 2, 9-17.

Eklundh, A. K. (1999). Biological methods for sludge treatment and evaluation of landfill sludge disposal - Nowy Targ wastewater treatment plant, Poland. Master Thesis, Div. of Water Resources Engineering, Royal Institute of Technology, KTH.

Fabiani, C., Ruscio, F., Spadoni, M. and Pizzichini, M. (1997). Chromium(III) salts recovery process from tannery wastewaters. *Desalination*, **108**, 1-3, 183-191.

Faulstich, M. and Weibusch, B. (1998) Stand und Möglichkeiten der thermischen Klärschlammbehandlung und Reststoffverwertung in Deutschland. Paper 2 in Veröffentlichungen des Institutes für Siedlungswasserwirtschaft und Abfalltechnik der Universitet Hannover, Heft 107, ISBN 3-921 421-36-5.

Finnell J. (1998). *Impact of chromium on wastewater treatment efficiency in Nowy Targ, Poland - Proposal for technology development.* Master's Thesis Report, Royal Institute of Technology, Stockholm, Sweden.

Haglund, J.-E., Hultgren, J., Karlsson, B. and Årström, J. (1997). Förstudie angående slamförbränning vid Stockholm Vatten, Stockholm Vatten, R. Nr 10.

Hartman G. and Vesilind P. (1986). *Sludge management and disposal: for the practising engineer.* Lewis Publishers. Great Britain.

Hultman, B., Levlin, E., Plaza, E. and Trela J. (1998) Ideas for future sludge management at the Nowy Targ WWTP, In: *Advanced Wastewater Treatment Report No. 3, Proceedings of a Polish-Swedish Seminar, Nowy Targ, October 1-2, 1998, Joint Polish - Swedish Reports*, Div. of Water Resources Engineering, Royal Institute of Technology, ISRN KTH/AMI/REPORT 3048-SE, ISBN 91-7170-324-1, 83-94.

Imhoff K. K. (1996). *Kanalizacja miast i oczyszczanie sciekow. Poradnik*. Oficyna Wydawnicza Projprzem-EKP. Bydgoszcz.

Johansson Ĺ. 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). Experiences from the operation of sequencing batch reactor plant in Nowy Targ. *Advanced wastewater treatment, Report No 2*,I, Div. Water Resources Engineering, Royal Institute of Technology, ISRN KTH/AMI/REPORT 3045-SE, ISBN 91-7170-283-0.

Kabacinski, M. (1998). Description of process and evaluation of operation of the wastewater treatment plant in Nowy Targ. In: *Advanced Wastewater Treatment Report No. 3, Proceedings of a Polish-Swedish Seminar, Nowy Targ, October 1-2, 1998, Joint Polish - Swedish Reports*, Div. of Water Resources Engineering, Royal Institute of Technology, ISRN KTH/AMI/REPORT 3048-SE, ISBN 91-7170-324-1, 21-29.

Kabacinski, M., Hultman, B., Plaza, E. and Trela, J. (1998). Strategies for improvement of sludge quality and process performance of SBR plant treating municipal and tannery wastewater. *Wat. Sci. Tech.*, **38**, 4-5, 69-77.

Kamues T. (1999). *Evaluation of sludge handling with emphasis on stabilsation by aerobic digestion - Wastewater treatment plant in Nowy Targ, Poland.* Master's Thesis Report, Royal Institute of Technology, Stockholm, Sweden.

Kempton T. J. and Cusack E. (1999). Sustainable management of BNR biosolids. *Wat. Sci. Tech.* **39**, 6, 159-166.

Kiely G. (1997). *Environmental Engineering.* Mc Graw Hill. USA.

Lotto V., Spinosa L. and Santori M. (1991). Recent developments in sewage sludge processing: Influence of digestion on sludge characteristics. Elsevier Applied Science. Great Britain. 32-40.

Lowe, P. (1995). Developments in thermal drying of sewage sludge. J. CIWEM, **9**, 6, 306-316.

Lue-Hing, C., Zenz, D.R. and Kuchenrither, R. (1992). Municipal sewage sludge management processing, utilization and disposal. Water Quality Management Library, Vol 4, Technomic Publishers, London.

Melsa, Bäckler, Hanssen, Husmann, Wessel and Witte (1997). Trocknung kommunaler Klärschlämme in Deutschland. Korrespondenz ABWASSER, **44**, 10, 1869-1884.

Meyers (1998). Encyclopedia of environmental analysis and remediation. Vol 2, John Wiley & Sons Inc.

Nilsson, R. (1971) Removal of metals by chemical treatment of municipal waste water. *Wat. Res.*, **5**, 51-60.

Roš, M. and Gantar, A. (1998). Possibilities of reduction of recipient loading of tannery wastewater in Slovenia. *Wat. Sci. Tech.*, **37**, 8, 145-152.

Rossin, A.C., Sterritt, R.M. and Lester, J.N. (1982). The influence of process parameters on the removal of heavy metals in activated sludge. *Water, Air and Soil Pollut.*, **17**, 185-198.

Rudolph, K.-U. (1999). A low-cost approach to tackling odours. *WQI*, 1/2, 28-31.

Rump, H. (1998) 7. Klärschlamm als Hauptbestandtail von Baustoffen. Veröffentlichungen des Institutes für Siedlungswasserwirtschaft und Abfalltechnik der Universitet Hannover, Heft 107, BMBF-Statusseminar Stoffliche Verwertung von Klärschlammen und Aschen aus der Klärschlammverbrennung als Baustoff. ISBN 3-921 421-36-5.

Sharif A. (1998). *Efficiency and process performance of sequencing batch reactor with respect to wastewater characteristics - Wastewater treatment plant in Nowy Targ, Poland.* Master's Thesis Report, Royal Institute of Technology, Stockholm, Sweden.

Solmaz, S. (1998). Thermische Entsorgung von Klärschlämmen. *Korrespondenz Abwasser* **45**, 10, 1886-1899.

Steinle, E. (1997). Emissionen bei Trocknungsanlagen. *Korrespondenz Abwasser*, **44**, 3, 498-510.

Styka, W., Plaza, E. and Kabacinski, M. (1998) Biochemical processes in the SBR reactors and the process efficiency at the Nowy Targ WWTP. In: *Advanced Wastewater Treatment Report No. 3, Proceedings of a Polish-Swedish Seminar, Nowy Targ, October 1-2, 1998, Joint Polish - Swedish Reports*, Div. of Water Resources Engineering, Royal Institute of Technology, ISRN KTH/AMI/REPORT 3048-SE, ISBN 91-7170-324-1, 31-43.

Tillman, D.A. (1994). Trace metals in combustion systems. Academic Press, Inc. 221-222, ISBN 0-12-691265-3.

Tiravanti, G., Petruzzelli, D. and Passino, R. (1997). Pretreatment of tannery wastewater by an ion exchange process for Cr(III) removal and recovery. *Wat. Sci. Tech*., **36**, 2-3, 197-207.

Tonkovic, Z. (1998). Aerobic stabilisation criteria for BNR biosolids. IAWQ 19th Biennal International Conference, 21-26 June 1998, Vancouver, Canada, Book 3, 344-352.

Tonkovic Z. (1999). Aerobic stabilisation criteria for BRN biosolids. *Wat. Sci. Tech*. **39**, 6, 167 - 174.

Tsang, K.R. and Vesilind, P.A. (1990). Moisture distribution in sludges. *Wat. Sci. Tech*. **22**, 12, 135-142.

Vonplon, A. (1997). Stand der Technik und Verfahrensvarianten der Schlammtrockung. *Umwelt*, **27**, 1/2, 32-36.

Vesilind, P.A. and Ramsey, T.B. (1996) Effect of drying temperature on the fuel value of wastewater sludge. *Wat. Management & Research,* **14**, 189-196.

Walsh, A.R. and O'Halloran, J. (1996a). Chromium speciation in tannery effluent - I. An assessment of techniques and the role of organic Cr(III) complexes. *Wat. Res*., **30**, 10, 2393-2400.

Walsh, A.R. and O'Halloran, J. (1996b). Chromium speciation in tannery effluent - II. Speciation in the effluent and in the receiving estuary. *Wat. Res*., **30**, 10, 2401-2412.

Wang, Y.-T. and Shen, H. (1997). Modelling Cr(VI) reduction by pure bacterial cultures. *Wat. Res*., **31**, 4, 727-732.

Wiegant, W.M., Kalker, T.J.J., Sontakke, V.N. and Zwaag, R.R. (1999). Full scale experience with tannery water management: An integrated approach. *Wat. Sci. Tech.*, **39**, 5, 169-176.

Wiebusch, B., Seyfried, C.F., Johnke, B., and Credo, S. (1997). Stand der Mono-Klärschlamm-verbrennung in Deutschland. *Korrespondenz Abwasser*, **44**, 3, 473-492.

APPENDIX 1A - Total suspended solids

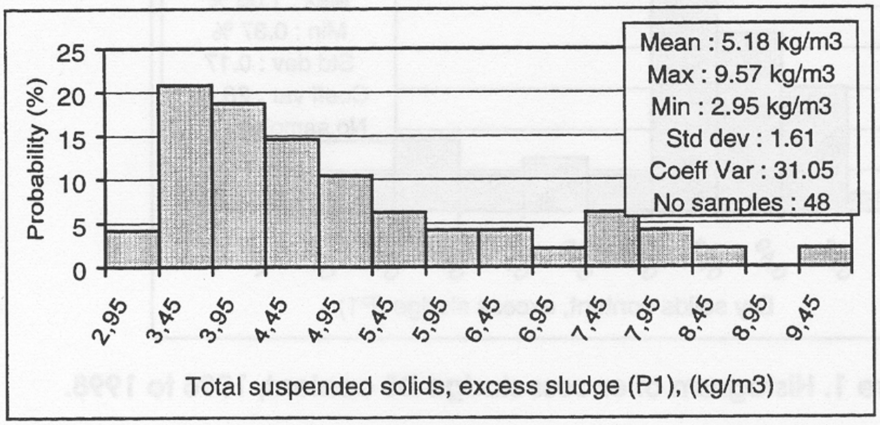


Figure 1. Histogram of excess sludge TSS concentration, 1996 to 1998.

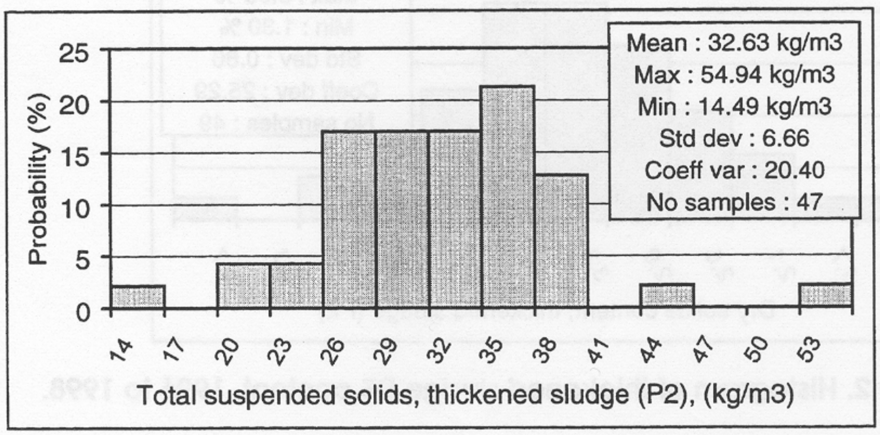


Figure 2. Histogram of thickened sludge TSS concentration, 1996 to 1998.

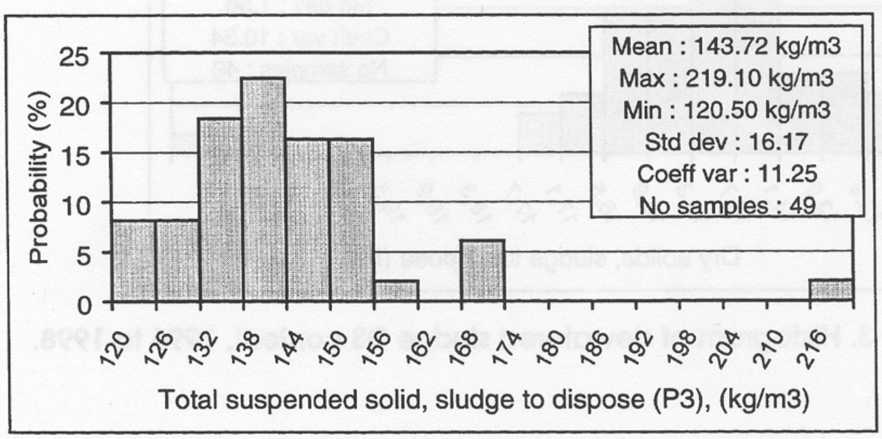


Figure 3. Histogram of dewatered sludge TSS concentration, 1996 to 1998.

APPENDIX 1B - Dry solids content

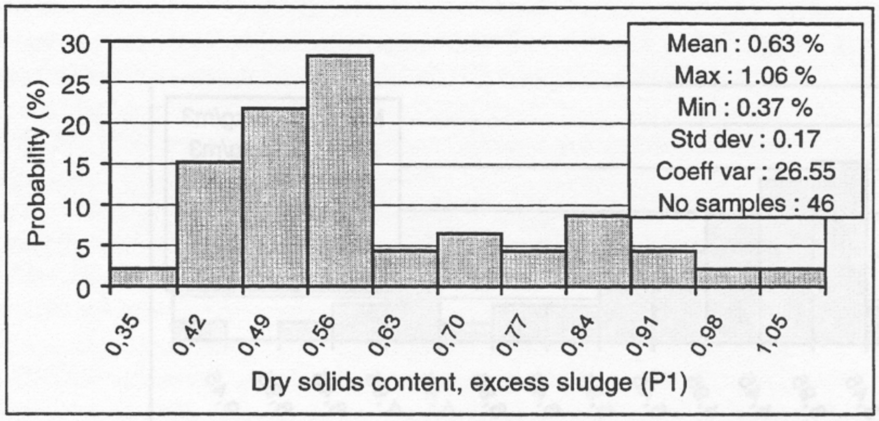


Figure 1. Histogram of excess sludge DS content, 1996 to 1998.

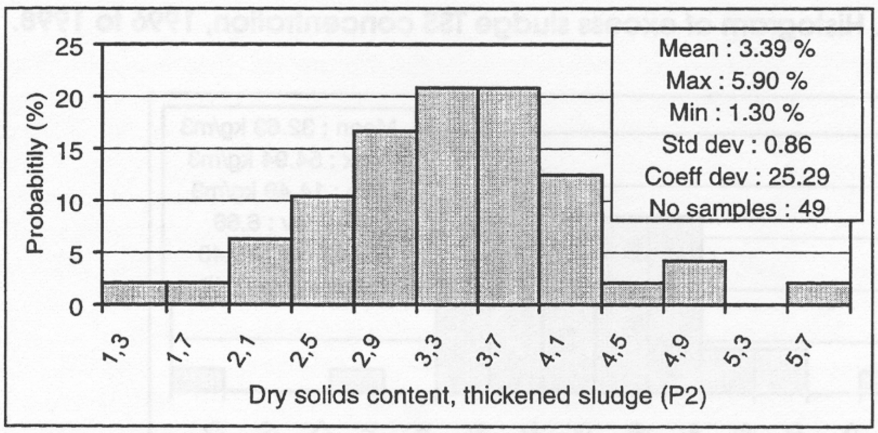


Figure 2. Histogram of thickened sludge DS content, 1996 to 1998.

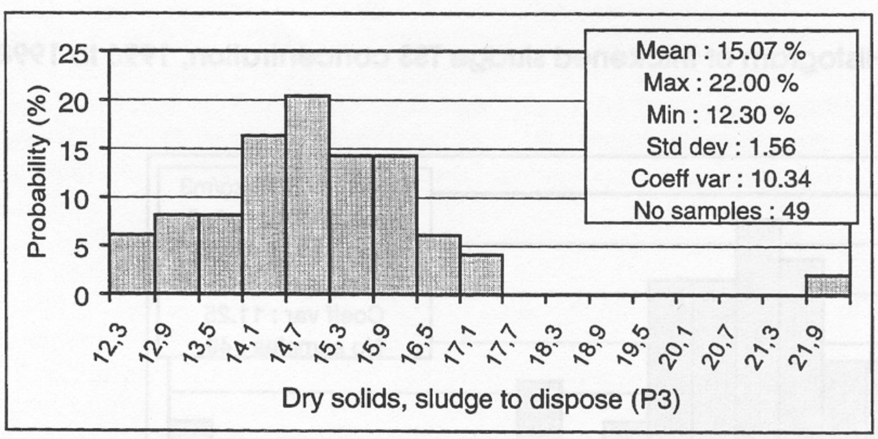


Figure 3. Histogram of dewatered sludge DS content, 1996 to 1998.