THE INFLUENCE OF SLUDGE CONDITIONERS ON THE SOIL CONDITIONING PROPERTIES OF SEWAGE SLUDGE

Report to the
WATER RESEARCH COMMISSION

by

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WRC Report No. 1540/1/10
ISBN 978-1-4312-0062-7

February 2011

EXECUTIVE SUMMARY

It was observed in previous studies that sewage sludge conditioned with polyelectrolytes was hard and difficult to crush. If this should be the case with all polyelectrolyte treated sludges, this change in the properties of the sludge may reduce the soil conditioning abilities of sewage sludge that are applied to agricultural land.

Sewage sludge is reported to be hydrophobic while it is claimed that other organic sludges produced by industry are hydrophilic. It was observed in the laboratory that dried sewage sludge is not easily wettable. This observation may indicate that dried sewage sludge exhibits hydrophobic properties. It is hypothesized that sludge dewatering agents may contribute to higher hydrophobisity of sewage sludge. Thus, the mechanical and microbial breakdown of the sewage sludge when applied to soil may be adversely affected by the restricted ability to wet the sludge. Sewage sludge that is added to soil contributes to the organic matter in the soil and it is expected that it would mineralize similar to soil organic matter. However, due to higher ambient temperatures in South Africa than in the European countries, the mineralization of soil organic matter is faster in South Africa than in the Northern hemisphere countries.

Most cationic polyelectrolytes are amine-based material. It is known that quaternary amines are good algalcides and therefore toxic. It is a requirement that polyelectrolytes used in potable water production should have a health certificate indicating the maximum concentrations allowable in potable applications. This is an indication that the material has toxic properties. If the sludge conditioner acts as an inhibitor of microbial activity in the treated soil, the mineralization of the sludge would be adversely affected. If the mineralization is adversely affected, the application rate of sludge to agricultural soil could be affected.

Alternatives to polyelectrolytes for sludge conditioning exist and the benefits and disadvantages of these alternatives should be quantified. Alternative sludge conditioners include: lime, aluminium compounds, ferri- and ferro compounds. The effect that metal salts would have on sludge quality could also be important and should be determined.

The objectives of this investigation were therefore:

a. To determine the effect of various conditioning agents (organic and inorganic) used in sludge treatment at different concentrations on the properties (dewatering, wettability, chemical composition, hardness, biodegradability, mineralization, etc.) of sewage sludge.

b. To develop an operating guideline for the use of dewatering agents for sewage sludge treatment.

The study was done by identifying the most common conditioning agents (organic and inorganic) that are normally used at sewage treatment plants for sludge conditioning. The effect of the different conditioning agents on the properties of the conditioned and unconditioned sludge were then determined. The specific resistance to filtration was used as a measure of sludge filterability. Sludge wettability was determined by determining the water uptake after sludge conditioning. The metal content of the inorganic conditioned sludge was measured with XRF analysis. The Shore hardness test was used to determine the hardness of the sludge. Sludge biodegradability was determined through BOD and COD analysis. Sludge mineralisation was studied by mixing the conditioned sludge with soil and determining the release of ammonia and nitrate nitrogen over time.

The following conclusions can be made as a result of the investigation:

- The polyelectrolyte sludge conditioners used for sludge conditioning prior to dewatering showed better sludge dewatering characteristics (filterability) than the inorganic sludge conditioners. Ferric chloride, however, showed good sludge dewatering characteristics. The disadvantage of the inorganic sludge conditioners is that they increase the heavy metal content of the soil.

- The water uptake of the conditioned and unconditioned polyelectrolyte treated sludges was about the same. Therefore, water uptake is not inhibited by the addition of polyelectrolytes to the sludge.

- The water uptake of the inorganic conditioned sludges was less than that of the unconditioned sludge. Therefore, the inorganic conditioned sludges appear to be more hydrophobic than the unconditioned sludge and could be more difficult to biodegrade in the soil.

- Little difference was observed in the hardness of the unconditioned and conditioned polyelectrolyte treated sludges. This may indicate that there is little difference in the hydrophobisity of the sludges if it is argued that a harder sludge is more hydrophobic than a softer sludge.

- The BOD/COD ratios of the conditioned and unconditioned polyelectrolyte treated sludge were about the same. Therefore, the sludge conditioners appear not to affect the biodegradability of the sludge adversely.

- The mineralization rate of the conditioned sludge was slightly higher than that of the unconditioned sludge. Therefore, sludge mineralization is not adversely affected by the addition of polyelectrolytes to the sludge.

- The conditioned and unconditioned sludge both add nutrients to the soil. The sludge should therefore be effective as a supplementary fertilizer for agricultural soil. However, the nutrients may also contribute towards groundwater pollution if the quantity applied to soil is not properly managed.

- The commonly used polyelectrolyte sludge conditioners should not cause any harm to the environment under conditions normally used for sludge conditioning prior to dewatering.

- The concentration of sludge conditioners (2 to 8 mg/g dry solids) used in this study appears not to have a negative effect on the soil conditioning properties of sewage sludge and could serve as a guideline for the concentration of sludge conditioners to soil.

The following recommendations can be made as a result of this study:

The polyelectrolyte sludge conditioners investigated are not adversely affecting the soil conditioning properties of sewage sludge. The inorganic sludge conditioners, on the other hand, have the potential to increase the heavy metal content of the sludge and consequently the soil on which the sludge is disposed. Therefore, the current practice of applying organic sludge conditioners to sewage sludge should be maintained. However, a watching brief should be kept on new sludge conditioning agents appearing in the market which could adversely affect the soil conditioning properties of sewage sludge.

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission entitled "*Influence of sludge conditioners on the soil conditioning properties of sewage sludge*". The financing of the project by the Water Research Commission is gratefully acknowledged.

The following people were involved in the project and their contributions are highly appreciated:

Mr HM Du Plessis	Water Research Commission
Mr J Harrison	eThekweni Water and Sanitation (Durban)
Mr K Fawcett	Cape Flats (Cape Town)
Ms M Loubser	University of Pretoria
Mr H Joubert	ERWAT
Mr W Rössle	ERWAT
Mr R Traut	Biwater

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1. INTRODUCTION

During previous research done at the University of Pretoria it was noted that polyelectrolyte treated sludge was inordinately hard and difficult to crush. If this should be the case with all polyelectrolyte treated sludges, this change in the mechanical properties of sludge may result in a reduction of the soil conditioning potential of sewage sludge when applied to agricultural land. Sewage sludge is reported to be hydrophobic (Mikkelsen and Keiding, 2002) while Daffonchio et al. (1995) has indicated that organic sludge is hydrophilic. Observations made in the laboratory have indicated that dried sewage sludge is not easily wettable. This observation may indicate that dried sewage sludge exhibits hydrophobic properties. It is further hypothesized that sludge dewatering conditioning agents may contribute to increased hydrophobisity of sewage sludge. Therefore, the mechanical breakdown of the sewage sludge particles in the soil may be adversely affected by the restricted ability to wet the sludge.

Sewage sludge added to soil contributes to the humus in the soil and is expected to mineralize similar to soil organic matter. Due to higher ambient temperatures in South Africa than in many European countries the mineralisation of soil organic matter is faster in South Africa than in the Northern hemisphere countries (Malherbe, 1952; Korentajer, 1991).

Most cationic polyelectrolytes are amine-based material. Quaternary amines are known to be good algalcides and as such are toxic material. It is a requirement that polyelectrolytes used in potable water production should have a health certificate stating the maximum concentration allowable in potable water applications. This is a further indication that the material has toxic properties. If the sludge conditioner (polyelectrolyte) acts as an inhibitor of microbial activity in the treated soil, the mineralisation of the treated sludge would be adversely affected. If mineralisation is affected adversely, the application rate of the sludge to agricultural soil could be affected.

Alternatives to polyelectrolytes for sludge conditioning exits and the benefits and disadvantages of such sludge conditioners should be quantified. Alternative sludge conditioners include: Lime, aluminium compounds, ferri- and ferro compounds. The effect that metal salts would have on sludge quality could also be important and should be determined.

The objectives of this investigation were therefore:

a. To determine the effect of various conditioning agents (organic and inorganic) at different concentrations on the properties (dewatering, wettability, chemical composition, hardness, mineralisation, etc.) of sewage sludge.

b. To develop an operating guideline for the use of dewatering agents for sewage sludge.

The approach for this study was firstly to identify the most common sludge conditioning agents normally used at sewage treatment plants. The effect of the different conditioning agents on the properties of the conditioned sludge was then determined and compared to the properties of the unconditioned sludge. The specific resistance to filtration was used as a measure of the filterability of the sludges. Sludge wettability was determined by determining the water uptake after sludge conditioning. The chemical composition of the sludge was determined by XRF analysis. The Shore hardness test was used to determine the hardness of the sludge. Sludge biodegradability was determined through BOD and COD tests. Sludge mineralisation studies were done by mixing the conditioned sludge with soil and measuring the release of ammonia and nitrate-nitrogen over time.

The materials and methods used for the study are outlined in Chapter 2 of the report. Results and discussions are presented in Chapter 3, followed by a general discussion (Chapter 4) and Conclusions and Recommendations (Chapter 5).

2. MATERIALS AND METHODS

2.1 SEWAGE SLUDGE SAMPLES

Sewage sludge samples made-up of a 1:1 mixture of flotated activated and digested sludge were obtained from ERWAT's Olifantsfontein water care works (OWCW). The total solids content of the samples were determined according to Standard Methods (1995) (Appendix A). The samples were kept in a refrigerator at 4°C for preservation prior to analysis. Different sludge samples were used for the study because the sludge samples could not be kept for too long under refrigeration prior to analysis.

2.2 SLUDGE TREATMENT

Zetag (Z7633, Z7220, Z7646) and Colloids (CZ7114) cationic polyelectrolytes and inorganic salts (alum, ferric chloride and lime) were used for sludge conditioning. The unconditioned and conditioned sludges were used for specific resistance to filtration (SRF) tests, water uptake, sludge hardness, heavy metal content, BOD:COD ratio determinations and mineralisation studies. Rheofloc 5356 and Zetag 8680 cationic polyelectrolytes used at the Northern Wastewater Treatment Works (NWWTW) (eThekwini, Durban) and Cape Flats Wastewater Treatment Plants (WWTP), respectively, were used for water uptake and mineralisation studies. Primary sludge from the Daspoort WWTW, treated with ammonia and phosphorous, was used for mineralisation studies.

2.2.1 Polyelectrolyte sludge conditioning

A 5 % solution of polyelectrolyte was prepared and diluted to a 1 % solution as per manufacturer's instructions. Different dosages (1; 2; 4; 6 and 8 mg/g dry solids) of polyelectrolyte were added to 500 g of sludge sample in a 1 litre beaker and the mixture was rapidly stirred at 100 revolutions per minute in a Leetex mixer for one minute (see Appendix A for calculation of volume of polyelectrolyte required). Thereafter the stirring speed was reduced to 30 revolutions per minute for 20 minutes for flocculation to occur.

2.2.2 Inorganic sludge conditioning

A 10 % solution of ferric chloride was prepared and dosages of 80, 120 and 200 mg/g dry solids were applied. Lime was prepared by mixing the powder with 50 ml water and applying dosages of 80, 120 and 200 mg/g. An alum stock solution of 25 % was made-up and alum dosages of 80, 120 and 200 mg/g dry solids were applied. The pH during ferric chloride conditioning was adjusted to between 5,5 and 7,0 and for alum to between 4,5 and 5,5 with lime. (Note: Dosages of 60, 80 and 120 mg/g were used to determine the effect of ferric chloride on water uptake).

2.3 SLUDGE CHARACTERISATION

2.3.1 Specific resistance to filtration

The apparatus to determine the specific resistance to filtration (SRF) consisted of a 90 mm Büchner funnel, a 500 ml graduated cylinder filtrate receiver, a stopwatch and a vacuum pump. Whatman no. 1 filter paper was used as the filter medium. The Büchner funnel was filled with either unconditioned or conditioned sludge and vacuum maintained at 50 kPa throughout the test. The time was recorded from when the vacuum was first applied until the vacuum was broken.

The specific procedure for conducting the tests was as follows: Three hundred milliliter of sludge was filtered in each case. The sludge sample was first allowed to filter through without the application of vacuum for the first approximately 5 minutes and the volume recorded as V_o. Vacuum was then applied (50 kPa) and the time recorded for every 5 ml filtrate collected. The test was conducted until the sludge was dewatered, i.e. when the vacuum was broken. The recorded filtrate volumes, V_0, V_1, V_2, V_3, etc. and the corresponding times T_0, T_1, T_2, T_3, etc. were used to plot a graph of Vx (abscissa) and Tx/Vx-Vo (ordinate). The slopes (coefficient b) of the graphs were determined and these values were used to calculate the specific resistance to filtration (Manual of Practice, 1988). An example of the calculation of the specific resistance to filtration is shown in Appendix B.

2.3.2 Water uptake rate

Samples of unconditioned and conditioned sludges obtained from the completed SRF tests were dried at both 30 and 105°C for 24 hours. Approximately 7 g of the sludge cake was weighed and put in a container (with filter paper intact) on a plastic grid. A fixed volume of water (500 ml) was added to the sample and the sample was left to soak in the water for fixed time periods (1 h; 24 h; 48 h; and 72 h). After the elapsed times, the cakes were removed from the container, allowed to drain for 5 minutes and weighed. The amount of water absorbed (water uptake) by the sludge cake was determined as follows:

$$\%\ \text{Water uptake} = \frac{\text{Mass of wet sample (g)} - \text{Mass of dry sample (g)}}{\text{Mass of wet sample (g)}} \times 100\%$$

The effect of the percentage solids content of the sludge on the wettability of the sludge was determined by drying the unconditioned and conditioned sludge at 30°C for 4; 8; 16; and 32 hours to attain different solids concentrations. Small portions of the sludge cakes were removed after the elapsed times and the percentage solids content determined. The rest of the sludge cake was used to determine water uptake rate as described above. Water uptake rate was also determined on sludge dried at 105°C. (Note: Zetag Z7633, Rheofloc 5356, Rheofloc 27680 and Ferric Chloride were used).

2.3.3 Sludge hardness

The hardness of the sludge cakes was determined with a Shore Scleroscope. The test consists of dropping a diamond tipped hammer under the force of its own weight from a fixed height onto the test specimen (sludge cake). The height of the rebound travel of the hammer is measured on a graduated scale. The scale consists of Shore units and is divided into 100 parts which represent the average rebound from pure hardened high-carbon steel.

2.3.4 BOD:COD ratios

The BOD:COD ratio of a sludge gives an indication of its biodegradability. The BODs and CODs of unconditioned and conditioned sludges were determined with standard procedures (Standard Methods, 1995).

2.3.5 Heavy metal content

The heavy metal content of the unconditioned and the inorganic salt conditioned sludge was determined with XRF analysis.

2.4 SLUDGE MINERALISATION

2.4.1 Pre-incubation

The characteristics of the soil obtained from ERWAT that was used in this investigation were determined by using Standard soil testing methods (1990) (Appendix C). The soil was dried at 40°C and passed through a 2 mm sieve prior to analysis.

The percentages carbon and nitrogen of the sludge used in the investigation were determined according to standard methods and are also shown in Appendix C.

The soil was pre-incubated in plastic containers to stabilise the environment and to allow the microbial communities to adapt to the conditions. The soil was first brought to field capacity. Three open-ended glass cylinders (40 cm long x 30 cm wide) were filled with soil. One end of the cylinder was covered with filter paper and filled with soil. The soil was compacted to resemble natural conditions until the cylinders were 75 % full. Water was added (25 ml) to each soil column and a rubber stopper was placed loosely on the top of the cylinder. The cylinders were left for 24 hours to allow the water to percolate down the soil profile. Samples were taken from the surface in the middle of the columns after the water front stopped moving to ensure equal wetness. The samples were weighed and dried overnight at 105°C and weighed again. The water content was calculated as follows:

$$\text{Water content (\%)} = \frac{\text{(Wet mass - Dry mass)} \times 100}{\text{Dry mass}}$$

The mean water content (23,7 %) from the three cylinders was considered to be the field capacity.

Soil samples (50 g) were pre-incubated for seven days in plastic containers and 11,8 ml of water was added to bring the soil to field capacity. The containers were left in an incubation room at 25°C. The containers were opened every second day to aerate the soil and water was added to maintain field capacity. This was done for a week and on the last day (day 7) duplicate samples were taken for NH_4^+-N and NO_3^--N analysis. These were used as the “Day 0” results.

2.4.2 Incubation

On day seven of the pre-incubation trial the sludge treatments were applied to the soil, the soil well mixed and brought to field capacity. The samples were left in the incubation room at constant temperature of 25°C. Duplicate samples were taken on days 1, 3, 7, 15, 28, 42 and 56 to determine the NH_4^+-N and NO_3^--N content of the soil. The procedure of aeration and adding water every second day was followed throughout the incubation period.

2.4.3 NH_4^+-N and NO_3^--N analysis

Soil analysis was carried out according to soil testing methods (Standard soil testing methods, 1990). One hundred millilitres of KCl solution was added to 50 g of soil and the sample shaken for one hour and then centrifuged to obtain a clear filtrate. A 50 ml aliquot was used for analysis of NH_4^+-N and NO_3^--N. The samples were analysed by a steam-distillation method in a Büchi Distillation apparatus. For the determination of the NH_4^+-N content, the steam volatilised from the distillation apparatus was bubbled through a boric acid indicator solution which was titrated with a sulphuric acid solution. Devarda’s alloy was added to the sample to determine the NH_4^+ N originating from the NO_3^--N and the solution was again titrated with the sulphuric acid solution. The samples were analysed in duplicate.

3. RESULTS AND DISCUSSION

3.1 DEWATERING

The specific resistance to filtration (SRF) of sewage sludge (1:1 activated sludge and digested sludge) obtained from the Olifantsfontein WWTP was determined using different organic and inorganic conditioners. The SRF of the unconditioned and conditioned sludges are shown in Tables 3.1, 3.2 and 3.3.

Table 3.1. Specific resistance to filtration of the unconditioned sludge samples.

Sample	% solids	SRF (m/kg)
Sample 1	1,73	$21,6 \times 10^{12}$
Sample 2	2,1	$61,3 \times 10^{12}$

Table 3.2. Specific resistance to filtration of the polyelectrolyte conditioned sludge (1,73% solids) at different dosages.

Polyelectrolyte	SRF (m/kg) 1 mg/g	SRF (m/kg) 2 mg/g	SRF (m/kg) 4 mg/g
Z 7633	$6,12 \times 10^{12}$	$1,34 \times 10^{12}$	$3,78 \times 10^{11}$
Z 7220	$7,74 \times 10^{12}$	$1,46 \times 10^{12}$	$2,58 \times 10^{11}$
Z 7646	$1,20 \times 10^{13}$	$2,50 \times 10^{12}$	$1,13 \times 10^{12}$
CZ 7114	$9,19 \times 10^{12}$	$3,75 \times 10^{12}$	$1,75 \times 10^{12}$

Table 3.3. Specific resistance to filtration of the inorganic salt conditioned sludge (2,1% solids) at different dosages.

Salt	SRF (mg/kg) 80 mg/g	SRF (mg/kg) 120 mg/g	SRF (m/kg) 200 mg/g
Alum	$4,42 \times 10^{12}$	$1,91 \times 10^{12}$	$1,50 \times 10^{12}$
Ferric chloride	$2,25 \times 10^{12}$	$1,06 \times 10^{12}$	$5,32 \times 10^{11}$
Lime	$5,15 \times 10^{12}$	$6,77 \times 10^{12}$	$7,94 \times 10^{12}$

The reduction in SRF as a function of dosage for the polyelectrolyte and inorganic salt conditioned sludges are shown in Figures 3.1 and 3.2 (Tables 3.2 and 3.3).

The percentage reduction in the SRF at different dosages for the polyelectrolyte and inorganic salt conditioned sludges are shown in Figures 3.3 and 3.4. Detailed results are shown in Appendix D (Tables D.1 and D.2).

Excellent reductions in the SRF were obtained with the polyelectrolyte conditioners (Table 3.2, Figure 3.1 and Figure 3.3). Percentage reductions in the SRF increase with increasing dosage (1 to 4 mg/g). Reductions in the SRF as high as 98,3 and 98,8 % were respectively obtained for the Z7633 and Z7220 conditioners. It further appears that the optimum dosage for the conditioners tested should be about 2 mg/g except for the CZ7114 polyelectrolyte (3 to 4 mg/g).

Reductions in the SRF's were also obtained with the inorganic conditioners. The best performance was obtained with ferric chloride followed by alum (Table 3.3, Figure 3.2 and Figure 3.4). Reductions in SRF of 99,1 and 97,6 % were respectively obtained using ferric chloride and alum as conditioners (200 mg/g). Ferric chloride compared reasonably well with the Z7633 and Z7220 conditioners. However, lime did not perform well as a sludge conditioner. The SRT increased slightly with an increasing lime dosage. All the organic conditioners performed significantly better than the inorganic salt conditioners.

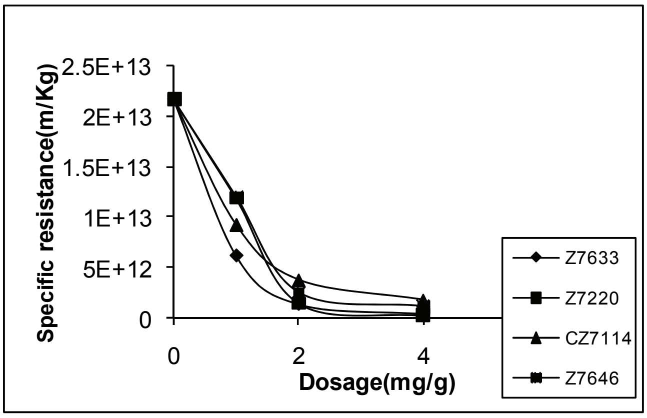


Figure 3.1. SRF as a function of dosage for different polyelectrolyte conditioners.

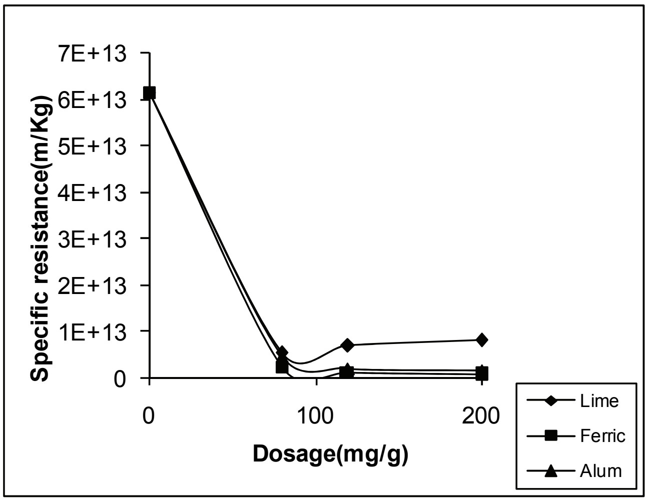


Figure 3.2. SRF as a function of dosage for different inorganic salt conditioners.

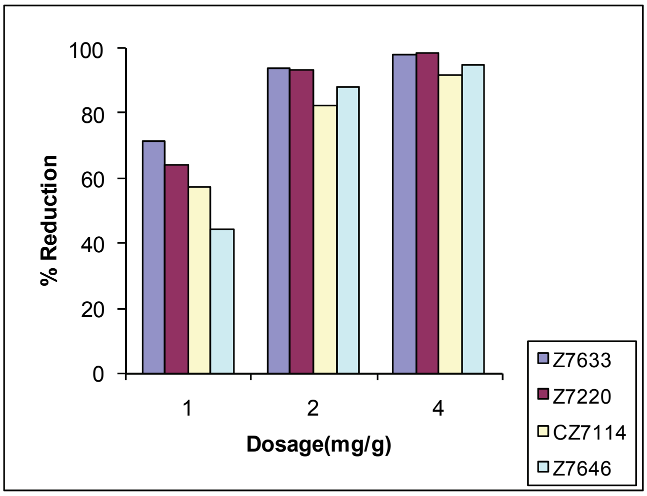


Figure 3.3. Percentage reduction in SRF of the polyelectrolyte conditioned sludge at different dosages (SRFo = 21,6 x 10^{12} m/kg).

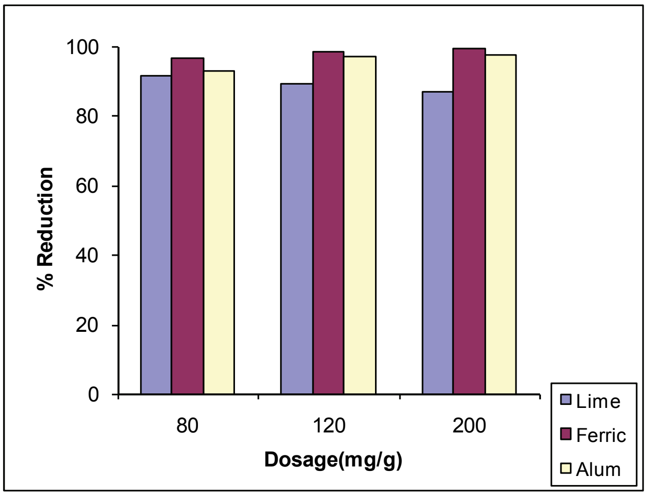


Figure 3.4. Percentage reduction in SRF of the inorganic salt conditioned sludge at different dosages (SRF_o = 61,3 x 10^{12} m/kg).

3.2 METAL CONTENT OF SLUDGE

The XRF analysis of the unconditioned and inorganic salt conditioned sludge are shown in Table 3.4.

A significant increase in the aluminium, iron and calcium content of the sludge was experienced after conditioning of the sludge with the inorganic conditioners. This and the fact that the inorganic conditioned sludge has a significantly higher specific resistance to filtration compared to the polyelectrolyte conditioned sludge, explains why that the polyelectrolyte conditioners are preferred for sludge conditioning.

Table 3.4. Percentage composition of unconditioned and inorganic conditioned sludge.

Composition	UCS	CS								
		Lime (mg/g)			Alum (mg/g)			Ferric chloride (mg/g)		
		80	120	200	80	120	200	80	120	200
S_iO_2	12,22	11,53	10,97	10,49	11,30	16,66	10,84	12	11,89	11,14
T_iO_2	0,20	0,21	0,20	0,18	0,21	0,29	0,20	0,21	0,22	0,17
Al_2O_3	4,32	3,79	3,63	3,37	6,70	-	9,58	4,02	4,47	3,79
Fe_2O_3	3,47	3,20	3,11	3,06	2,94	4,12	2,05	6,12	6,66	9,65
MnO	0,10	0,14	0,17	0,21	0,09	0,09	0,04	0,10	0,12	0,12
MgO	1,05	1,14	1,21	1,50	0,07	0,88	0,43	0,73	0,79	0,52
CaO	3,49	8,64	11,36	15,69	2,25	2,90	1,86	3,14	3,18	5,19
Na_2O	0,60	0,48	0,37	0,41	0,31	0,53	0,15	0,26	0,22	0,27
K_2O	0,97	0,70	0,33	0,12	0,85	1,29	0,74	0,76	0,83	0,66
P_2O_5	6,27	6,36	6,32	5,89	6,93	9,35	6,73	6,85	6,92	6,41
Cr_2O_3	0,01	0,02	0,01	0,01	0,02	0,03	0,01	0,02	0,02	0,02
NiO	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
V_2O_5	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
ZrO_2	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
LOI	67,14	63,56	61,79	58,40	67,53	52,37	67,21	65,65	64,50	61,89
Total	99,88	99,78	99,50	99,37	99,85	99,78	99,88	99,89	99,87	99,86

UCS: Unconditioned sludge; CS: Conditioned sludge: LOI: Loss on ignition.

3.3 SLUDGE HARDNESS

The hardness of the unconditioned and conditioned sludges is shown in Tables 3.5 and 3.6.

Table 3.5. Hardness of unconditioned and conditioned (polyelectrolyte treated) sludge (1,73% solids; dried at 105°C).

Polyelectrolyte	Hardness			
	UCS	CS		
	0 mg/g	1 mg/g	2 mg/g	4 mg/g
Z7633	30,2	22,9	29,1	49,8
Z7220		33,1	37,0	36,1
Z7646		40,2	32,2	26,2
CZ7114		27,2	33,6	35,4

UCS: Unconditioned sludge; CS: Conditioned sludge.

Table 3.6. Hardness of unconditioned and conditioned (inorganic salt treated) sludge (3,51% solids; dried at 105°C).

Inorganic salt	Hardness			
	UCS	CS		
	0 mg/g	120 mg/g	240 mg/g	480 mg/g
Alum	30,2	48,0	38,7	33,9
Ferric chloride		36,4	40,2	32,4

UCS: Unconditioned sludge; CS: Conditioned sludge.

It appears that sludge hardness increased with increasing polyelectrolyte dosage for the Z7633, Z7220 and CZ7114 polyelectrolytes (Table 3.5). This trend, however, was not observed for the Z 7646 polyelectrolyte treated sludge.

No significant increase in sludge hardness was observed for the sludge conditioned with the inorganic salts (Table 3.6).

3.4 SLUDGE WETTABILITY

3.4.1 Water uptake for polyelectrolyte conditioned sludges

The percentage water uptake for the polyelectrolyte conditioned sludges are shown in Figures 3.5 to 3.7. The detailed results are shown in Appendix E (Tables E.3 to E.8).

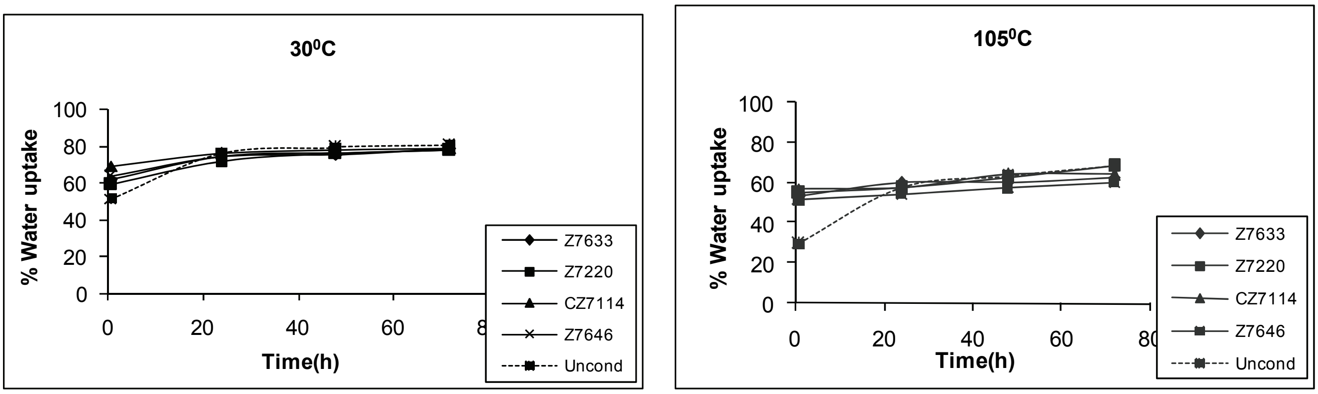


Figure 3.5. Percentage water uptake of the 2 mg/g polyelectrolyte conditioned sludge as a function of time and drying temperature (left 30°C, right 105°C).

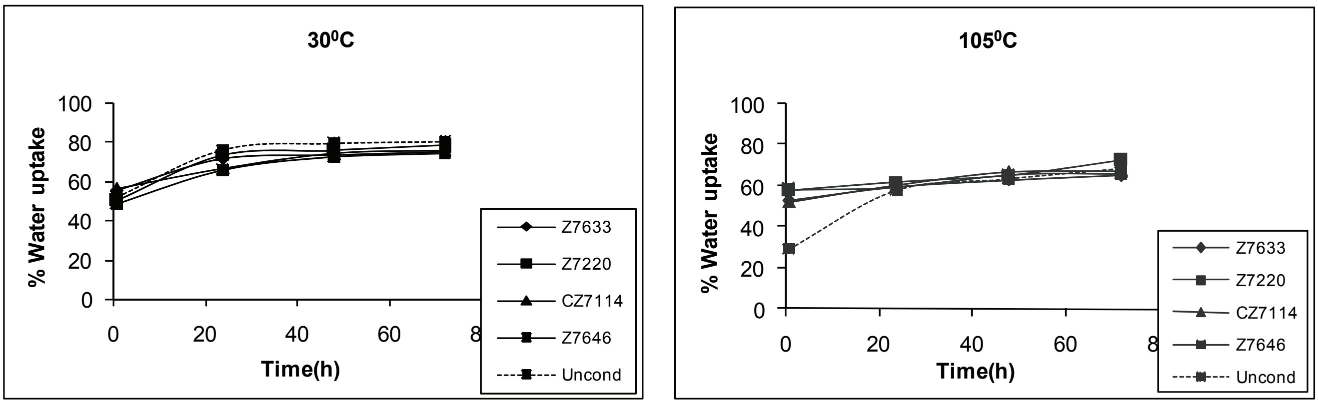


Figure 3.6. Percentage water uptake of the 4 mg/g polyelectrolyte conditioned sludge as a function of time and drying temperature (left 30°C, right 105°C)

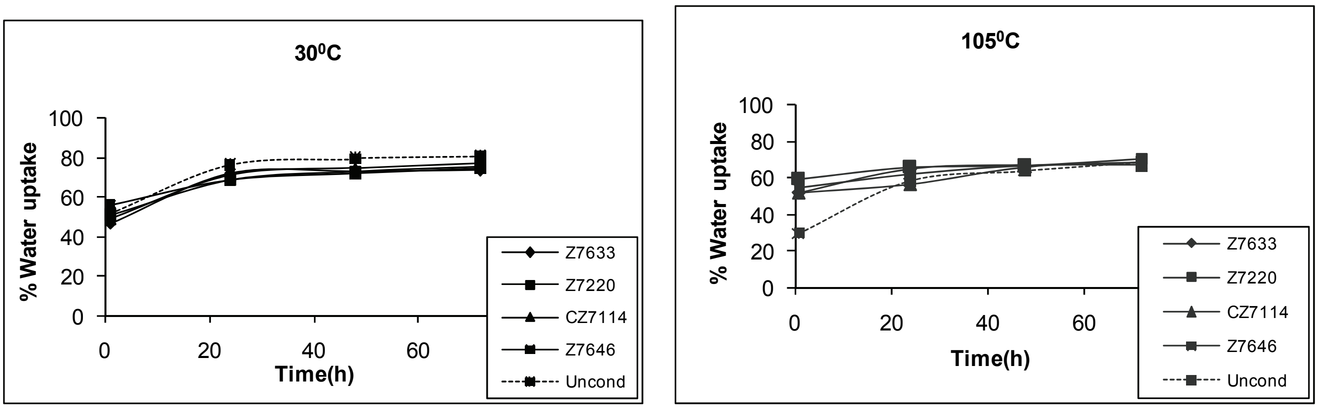


Figure 3.7. Percentage water uptake of the 8 mg/g polyelectrolyte conditioned sludge as a function of time and drying temperature (left 30°C, right 105°C).

The percentage water uptake was in most cases slightly higher for the unconditioned than for the conditioned sludges. This difference, however, was not significant. It is also interesting to note that significantly less water was taken up initially by the unconditioned

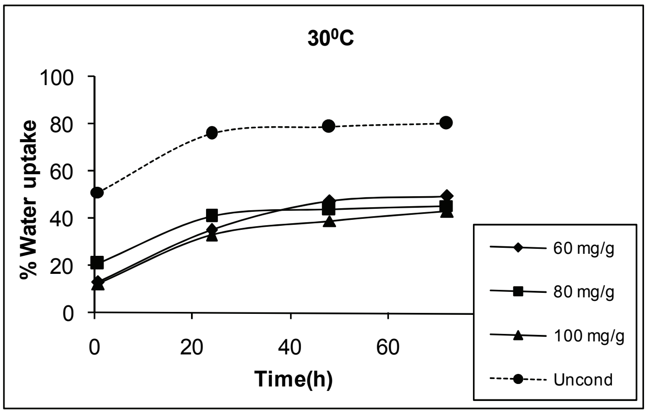
sludge dried at 105°C. This shows that the unconditioned sludge is initially more hydrophobic than the polyelectrolyte treated sludges. This apparent hydrophobicity disappears when the sludge is longer in contact with water.
The percentage water uptake increases with increasing drying time and appears to level off at the longer drying times. Some differences were experienced in the water uptake of the different polyelectrolytes. The differences, however, were not big. An increasing dosage of polyelectrolyte did not affect water uptake significantly. However, higher percentage water uptake was experienced at the lower drying temperature (Appendix E, Tables E.3 to E.8). This showed that the sludge dried at the lower temperature could be less hydrophobic.

Water uptake at the lower drying temperature varied from 73,4 to 76,9 % for the different conditioners (8 mg/g) while water uptake varied from 66,4 to 70,2 for the same conditioners at the same dosage and higher drying temperature. Therefore, a significant amount of water could be taken up by the conditioned sludge which would enhance its biodegradability.

3.4.2 Water uptake for the inorganic conditioned sludge

The percentage water uptakes for the inorganic salt conditioned sludges are shown in Figures 3.8 to 3.10. The detailed results are shown in Appendix E (Tables E.9 to E.14).

The unconditioned sludge appears to take up water more readily than the salt conditioned sludges. Increasing dosage of the conditioner did not affect water uptake significantly. It also appears that little differences were experienced in water uptake at the lower and higher drying temperatures. The water uptake at the highest dosage (200 mg/g) varied from 31 to 47,2 % for lime, ferric and alum. This water uptake is less than for the organic polymer conditioned sludges.



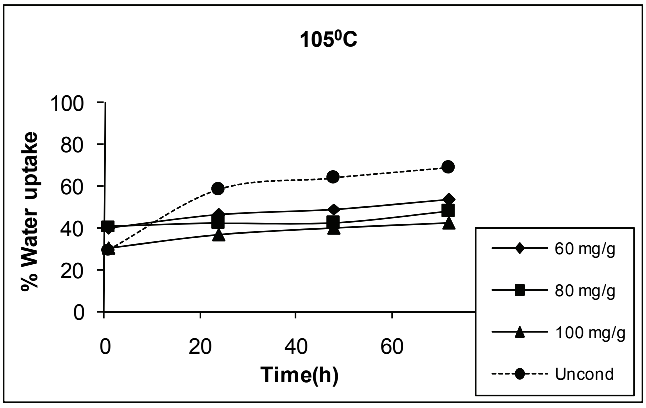


Figure 3.8. Percentage water uptake of ferric chloride conditioned sludge as a function of time, drying temperature and dosage (left 30°C, right 105°C).

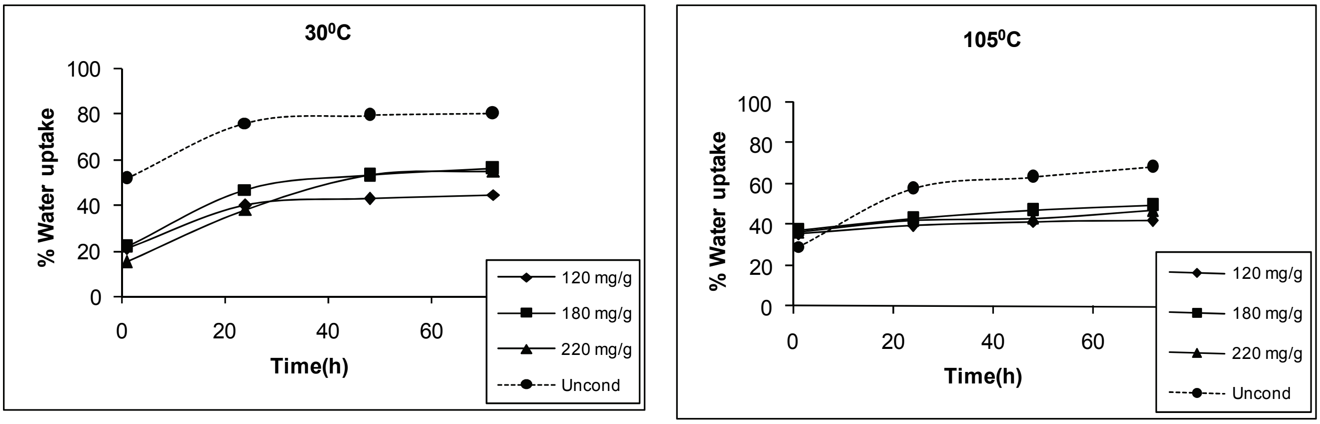


Figure 3.9. Percentage water uptake of alum conditioned sludge as a function of time, drying temperature and dosage (left 30°C, right 105°C).

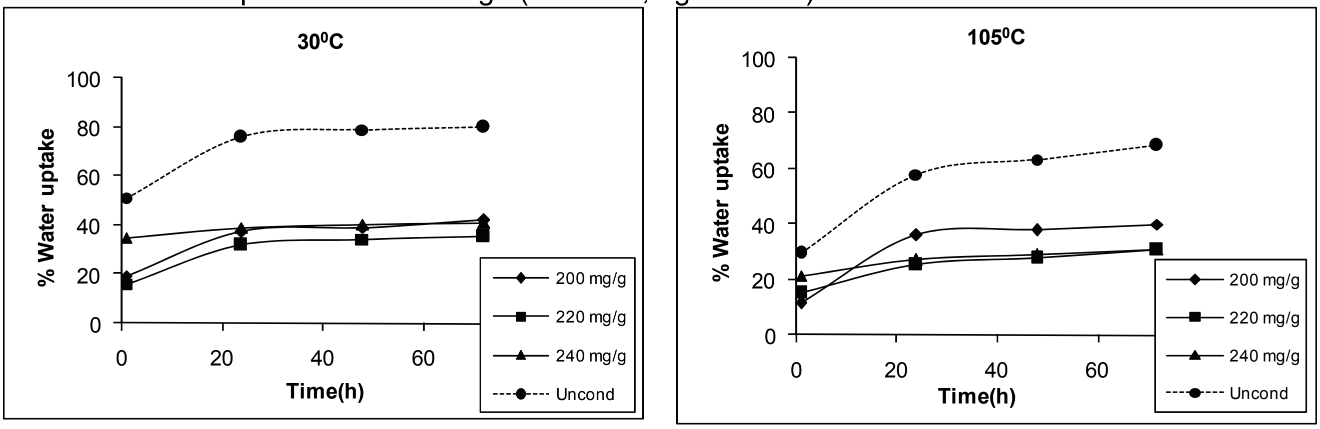


Figure 3.10. Percentage water uptake of lime conditioned sludge as a function of time, drying temperature and dosage (left 30°C, right 105°C).

3.4.3 <u>Water uptake as a function of the percentage solid concentration for polyelectrolyte and inorganic salt conditioned sludges</u>

The percentage water uptake for the unconditioned sludge is shown in Figure 3.11. The percentage water uptakes for the Z7633, Rheofloc 5356 and Z7680 polyelectrolyte conditioned sludges are shown in Figures 3.12 to 3.14, 3.15 to 3.17 and 3.18 to 3.20, respectively. Water uptake for the ferric chloride conditioned sludge is shown in Figures 3.21 to 3.23. The detailed results are shown in Appendix E (Tables E.15 to E.27).

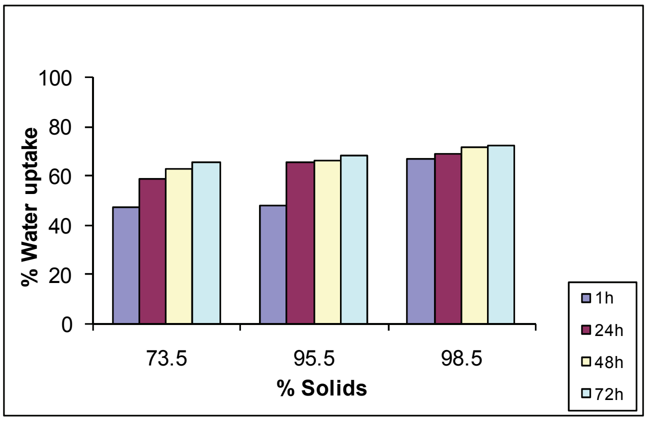


Figure 3.11. Percentage water uptake of the unconditioned sludge (Olifantsfontein) as a function of the percentage solids concentration at different wetting times.

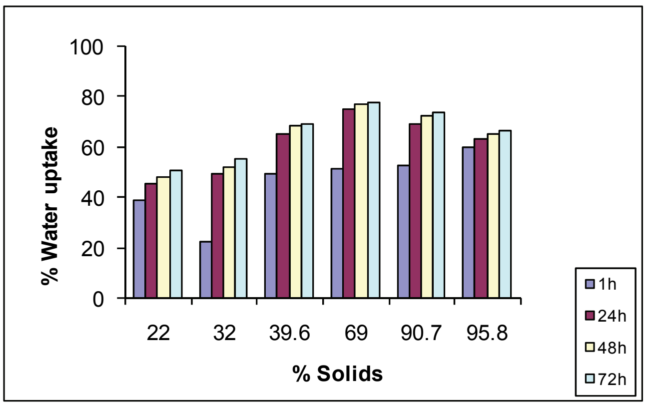


Figure 3.12. Percentage water uptake of the 2 mg/g Z7633 conditioned sludge as a function of the percentage solids concentration at different wetting times.

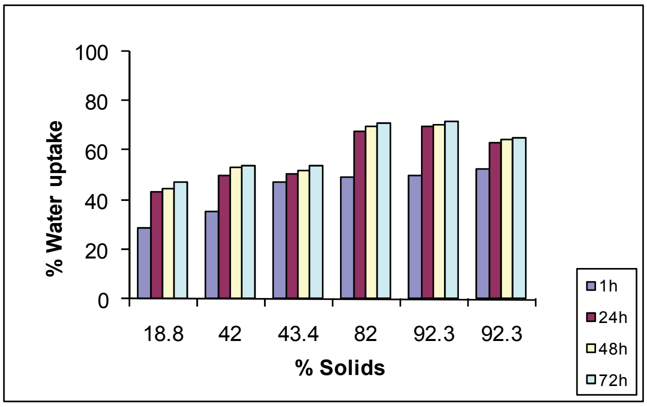


Figure 3.13. Percentage water uptake of the 4 mg/g Z7633 conditioned sludge as a function of the percentage solids concentration at different wetting times.

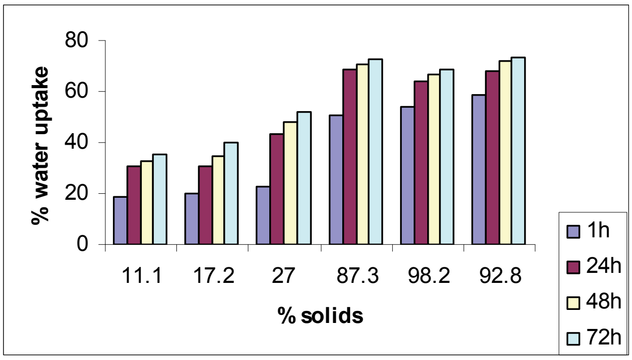


Figure 3.14. Percentage water uptake of the 8 mg/g Z7633 conditioned sludge as a function of the percentage solids concentration at different wetting times.

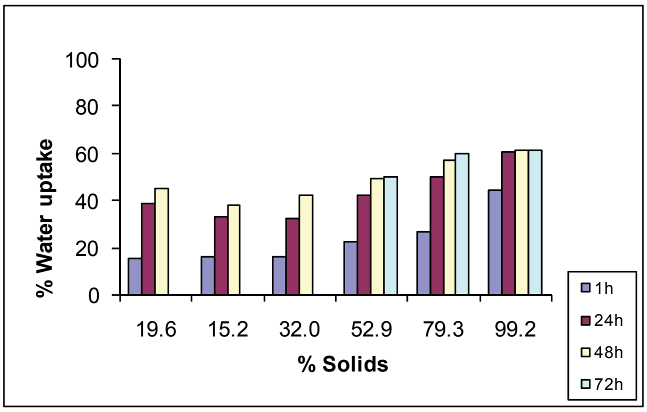


Figure 3.15. Percentage water uptake of the 2 mg/g Rheofloc 5356 conditioned sludge as a function of the percentage solids concentration at different wetting times.

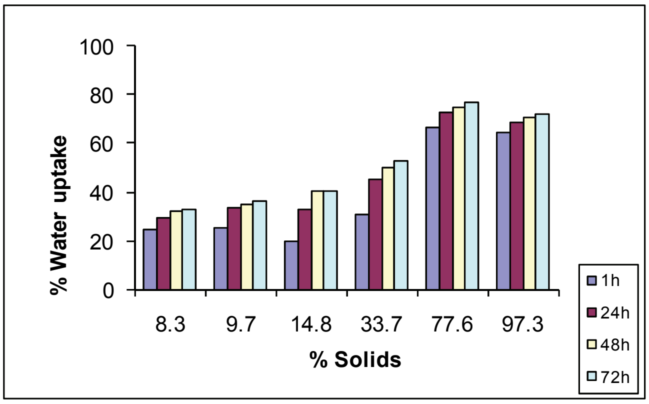


Figure 3.16. Percentage water uptake of the 4 mg/g Rheofloc 5356 conditioned sludge as a function of the percentage solids concentration at different wetting times.

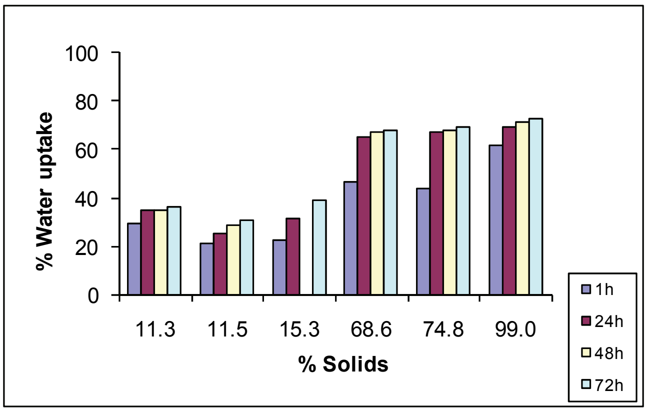


Figure 3.17. Percentage water uptake of the 8 mg/g Rheofloc 5356 conditioned sludge as a function of the percentage solids concentration at different wetting times.

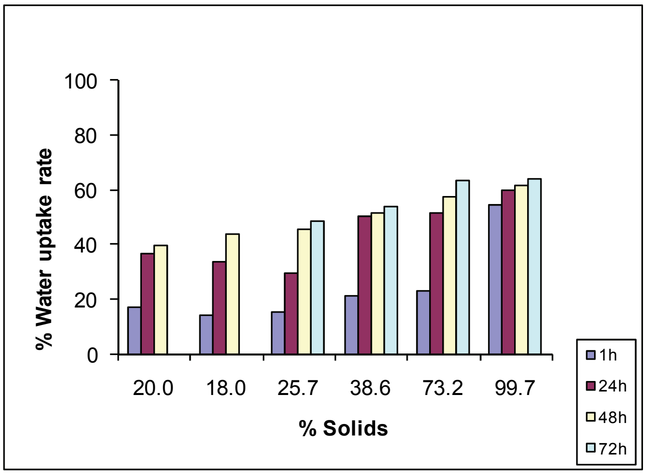


Figure 3.18. Percentage water uptake of the 2 mg/g Z7680 conditioned sludge as a function of the percentage solids concentration at different wetting times.

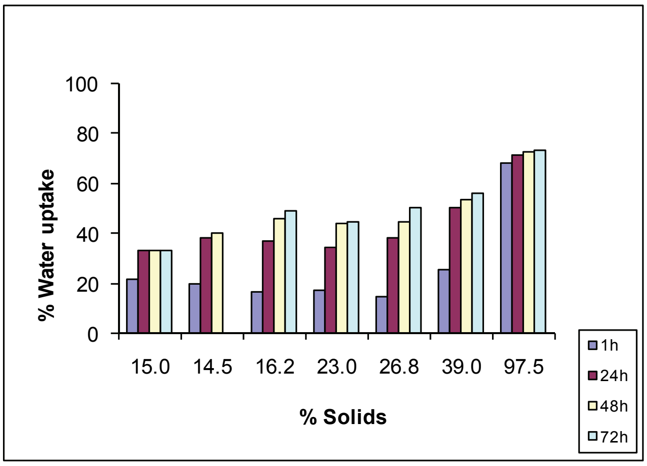


Figure 3.19. Percentage water uptake of the 4 mg/g Z7680 conditioned sludge as a function of the percentage solids concentration at different wetting times.

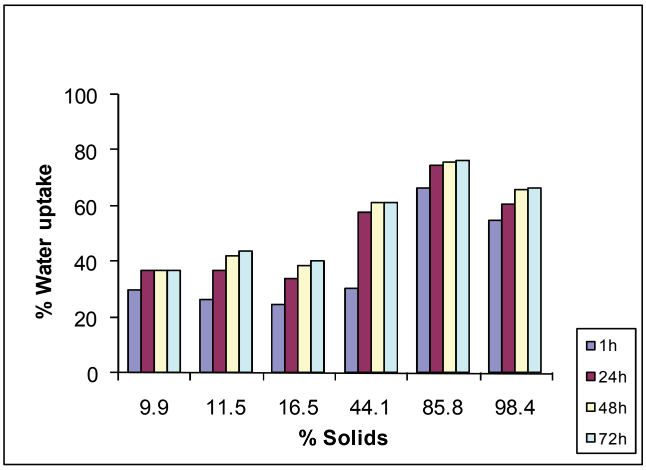


Figure 3.20. Percentage water uptake of the 8 mg/g Z7680 conditioned sludge as a function of the percentage solids concentration at different wetting times.

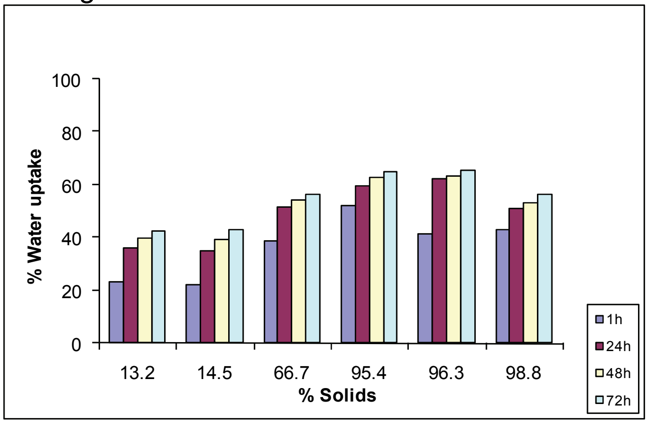


Figure 3.21. Percentage water uptake of the 60 mg/g Ferric chloride conditioned sludge as a function of the percentage solids concentration at different wetting times.

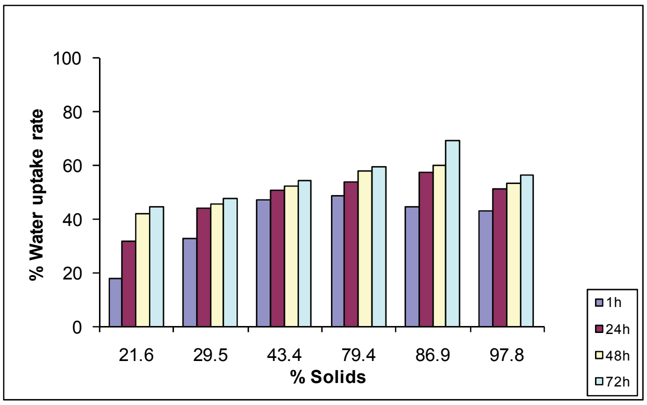


Figure 3.22. Percentage water uptake of the 80 mg/g Ferric chloride conditioned sludge as a function of the percentage solids concentration at different wetting times.

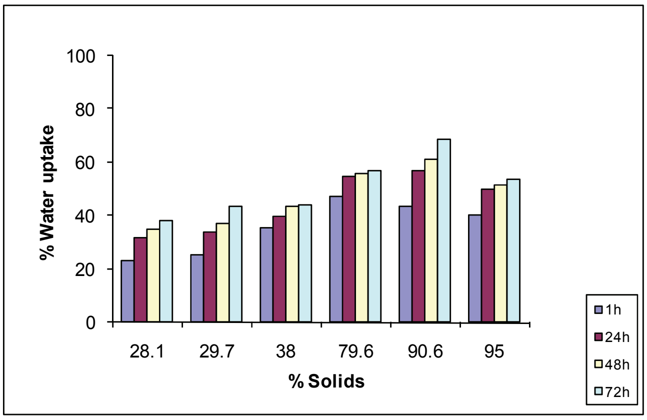


Figure 3.23. Percentage water uptake of the 120 mg/g Ferric chloride conditioned sludge as a function of the percentage solids concentration at different wetting times.

The percentage water uptake of the unconditioned sludge increased with increasing percentage solids content and increasing wetting time (Figure 3.11). Water uptake was 72 % at the highest solid content (98,5 %). Water uptake could not be determined at the lower percentage solid contents (< 73,5%) because the unconditioned sludge broke up.

The percentage water uptake increased with increasing percentage solids concentration and increasing wetting times for the Z7633 conditioned sludge (Figures 3.12 to 3.14). However, it appears that the percentage water uptake levels of at 70 to 90 % solids concentration. Percentage water uptake of approximately 65 to 78 % was obtained at the higher % solids concentration (Figures 3.12 to 3.14). An increasing polyelectrolyte dosage does not appear to have an effect on the water uptake.

The percentage water uptake for the Rheofloc 5356 conditioned sludge also increased with increasing percentage solids concentration and increasing wetting time. Water uptake of approximately 60 to 76 % was obtained at the higher solids concentrations (74 to 79%) (Figures 3.15 to 3.17). It also appears that less water were taken up at the lowest polyelectrolyte dosage (2 mg/g).

The percentage water uptake for the Z7680 conditioned sludge increased as a function of increasing percentage solids concentration and wetting time. The percentage water uptake was approximately 64 to 77 % at the higher percentage solids concentration (Figures 3.18 to 3.20).

The percentage water uptake for the ferric chloride conditioned sludge also increased with increasing solids concentration and increasing wetting time (Figures 3.21 to 3.23). The percentage water uptake was about 54 - 69 % at the highest percentage solids concentration. Therefore, it appears that a significant amount of water could be taken up by the dried conditioned sludge which would enhance the biodegradability of the sludge.

The initial water uptake of the sludges was done by drying the sludge at 30°C and 105°C for 24 hours, prior to water uptake being determined. Very similar water uptake percentages were obtained. This is probably due to the fact that the percentage solids after drying were approximately the same. Higher water uptake percentages are obtained at higher solids concentration because the sludges are drier and containing less water and in view of the fact that the uptake percentages are calculated on the wet mass.

3.5 BOD:COD RATIOS

The BOD:COD ratios of the sludges are shown in Table 3.7. The BOD/COD ratios of the unconditioned and conditioned sludges are about the same showing that the conditioning agents are not inhibiting the biodegradability of the sludges.

Table 3.7. BOD/COD ratios of unconditioned and polyelectrolyte conditioned sludges.

Sludge*	Polyelectrolyte	Dosage mg/gds	BOD mg/l	COD mg/l	BOD/COD
Olifantsfontein	Z7633	0	120 979	354 871	0,34
		2	93 964	353 748	0,27
		4	125 171	267 031	0,47
		8	97 579	287 600	0,34
Durban	Rheofloc	0	31 500	67 333	0,46
		7	55 000	122 000	0,45
Cape Flats	Z8680	0	37 500	77 000	0,38
		8	45 000	126 000	0,49

* Sludge dried at 105°C.

3.6 MINERALISATION

3.6.1 Ammonification

Ammonification of the unconditioned and conditioned (Z7633) Olifantsfontein sludge is shown in Figures 3.24 and 3.25. (Note: Sludge conditioned in laboratory). The detailed results are shown in Appendix F (Tables F.1 to F.2).

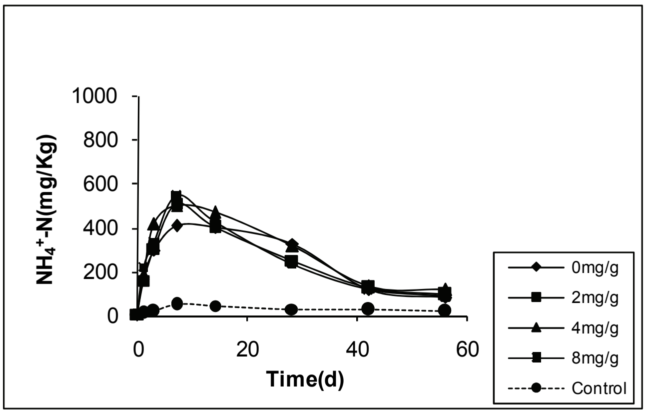


Figure 3.24. Extractable NH4+-N from soil treated with sludge dried at 30°C as a function of time.

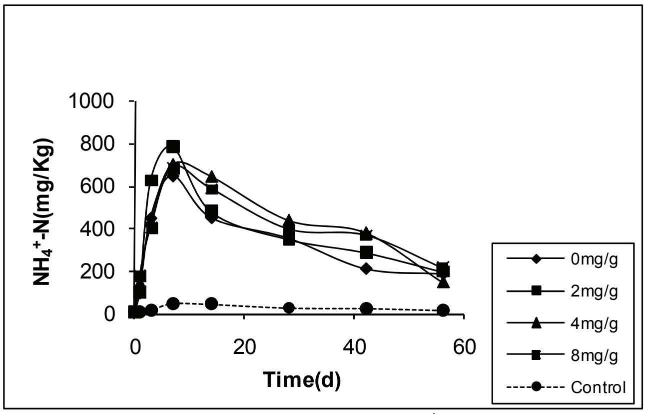


Figure 3.25. Extractable NH_4^+-N from soil treated with sludge dried at 105°C as a function of time.

The total amount of NH_4^+-N extracted from the soil is shown in Table 3.8.

Table 3.8. Total amount of NH_4^+-N extracted from the soil.

Polyelectrolyte dosage (mg/gds)	mg/kg NH_4^+-N.d (30°C)	mg/kg NH_4^+-N.d (105°C)
0	14 000.5	18 569.7
2	13 683.4	21 291.3
4	15 926.0	24 235.8
8	13 894.4	23 197.0

Note: Calculation of the total amount of NH_4^+-N extracted from the soil is shown in Appendix F1.

More ammonia-nitrogen was extracted from the soil when the sludge was pretreated at the higher temperature. This is due to the higher percentage solid content of the sludge. It also appears that the extractable ammonia-nitrogen increases with increasing polyelectrolyte dosage. However, this trend is not clear. More ammonia-nitrogen was also extracted from the polyelectrolyte treated sludge than from the unconditioned sludge. Therefore, the polyelectrolyte is not inhibiting the conversion of nitrogen into ammonia.

The ammonification of sludge obtained from sewage treatment plants at Olifantsfontein, Durban, Cape Flats and Daspoort is shown in Figures 3.26 to 3.29. The detailed results are shown in Appendix F (Tables F.3 to F.6).

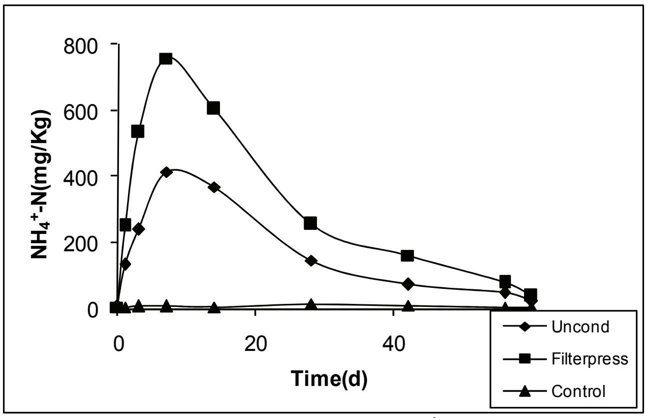


Figure 3.26. Extractable NH_4^+-N from soil treated with sludge dried at 105°C (Olifantsfontein).

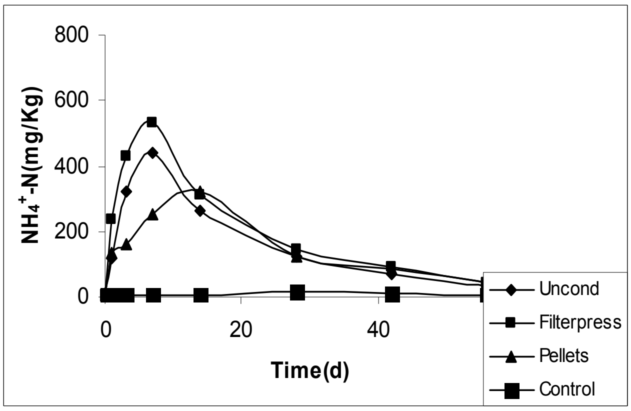


Figure 3.27. Extractable NH_4^+-N from soil treated with sludge dried at 105°C (Durban).

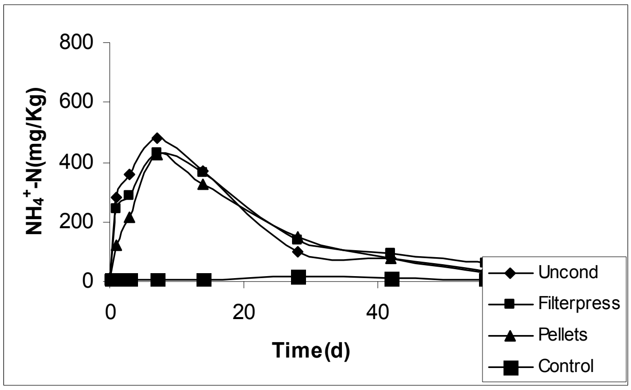


Figure 3.28. Extractable NH_4^+-N from soil treated with sludge dried at 105°C (Cape Flats).

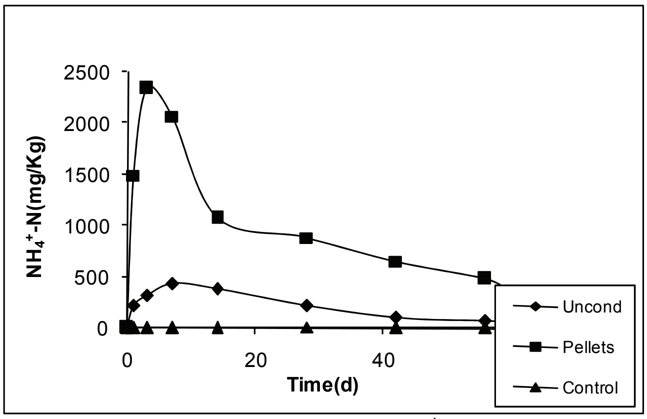


Figure 3.29. Extractable NH_4^+-N from soil treated with sludge dried at 105°C (Daspoort).

The total amount of ammonium-nitrogen extracted from the soil is shown in Table 3.9. More NH_4^+-N was extracted from the soil to which conditioned sludge was applied than from the soil to which unconditioned sludge was applied (Figures 3.26 to 3.29 and Table 3.9). This shows that mineralization is not affected by the polyelectrolyte conditioner. It is also interesting to note that significantly more NH_4^+-N was extracted from the pellets than from the unconditioned sludge in the case of the Daspoort sludge (Figure 3.29 and Table 3.9). This is due to the addition of ammonia to the sludge prior to pellitilisation of the sludge.

Table 3.9. Total amount of NH_4^+-N extracted from soil.

Place	Polyelectrolyte dosage (mg/gds)	mg/kg NH_4^+-N.d (105°C)
Olifantsfontein	0	10 123,0
	4	18 603,7
Durban	0	8 917,1
	7 (filter press)	11 109,4
	7 (pellets)	8 314,5
Cape Flats	0	10 369,4
	8 (filter press)	10 781,5
	8 (pellets)	9 566,4
Daspoort	Unconditioned	12 514,6
	Conditioned*	57 999,8

* Conditioned: Treated with ammonia and phosphoric acid.

3.6.2 Nitrification

Nitrification of the unconditioned and conditioned (Z7633) Olifantsfontein sludge is shown in Figures 3.30 and 3.31. The detailed results are shown in Appendix G (Tables G.1 to G.2). The total amount of NO_3-N extracted from the soil is shown in Table 3.10.

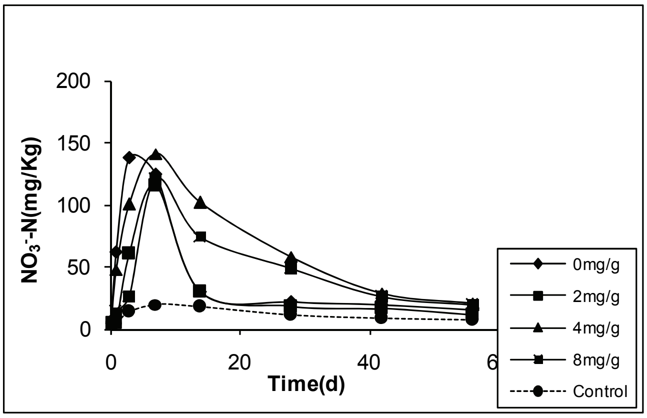


Figure 3.30. Extractable NO_3^--N from soil treated with sludge dried at 30°C as a function of time.

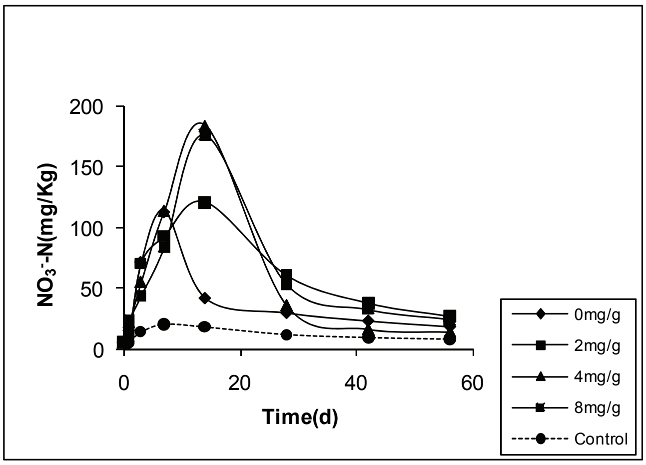


Figure 3.31. Extractable NO_3^--N from soil treated with sludge dried at 105°C as a function of time.

Table 3.10. Total amount of NO_3-N extracted from the soil.

Polyelectrolyte dosage	mg/kg NO_3^--N.d (30°C)	Mg/kg NO_3^--N.d (105°C)
0	1 527,6	1 472
2	1 029,9	2 879,2
4	2 918,5	2 886
8	2 050,6	3 170,8

Note: Calculation of the total amount of NO_3^--N extracted from the soil is shown in Appendix G1.

More nitrate-nitrogen was extracted from the soil that was dried at 105°C than the soil that was dried at 30°C (Figures 3.30 and 3.31 and Table 3.10). This is due to the higher percentage solid concentration of the sludge dried at 105°C. It further appears that somewhat more nitrate-nitrogen was extracted from the soil at higher polyelectrolyte dosages. It is also clear that nitrification is not inhibited at the higher polyelectrolyte dosages.

The nitrification of sludge obtained from sewage treatment plants at Olifantsfontein, Durban, Cape Town and Daspoort is shown in Figures 3.32 to 3.35. The detailed results are shown in Appendix G (Tables G.3 to G.6).

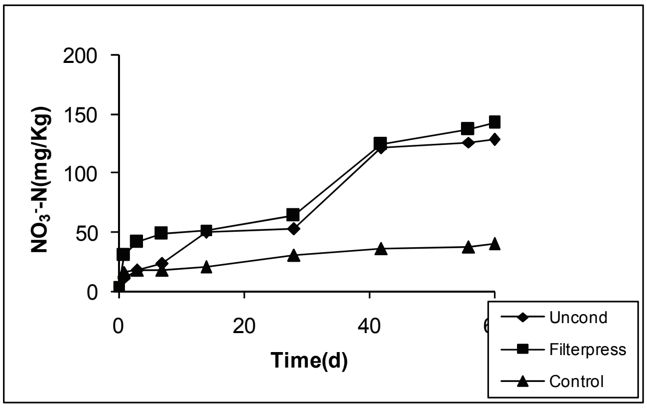


Figure 3.32. Extractable NO_3^--N from soil treated with sludge dried at 105°C (Olifantsfontein).

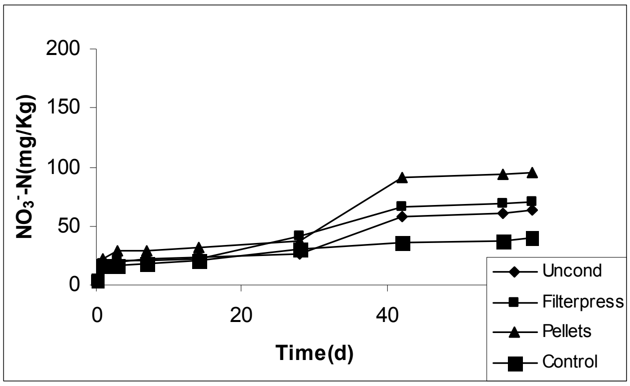


Figure 3. 33. Extractable NO_3^--N from soil treated with sludge dried at 105°C (Durban).

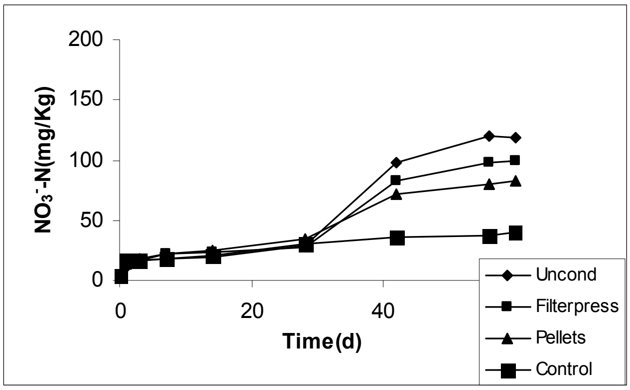


Figure 3.34. Extractable NO_3^--N from soil treated with sludge dried at 105°C (Cape Flats).

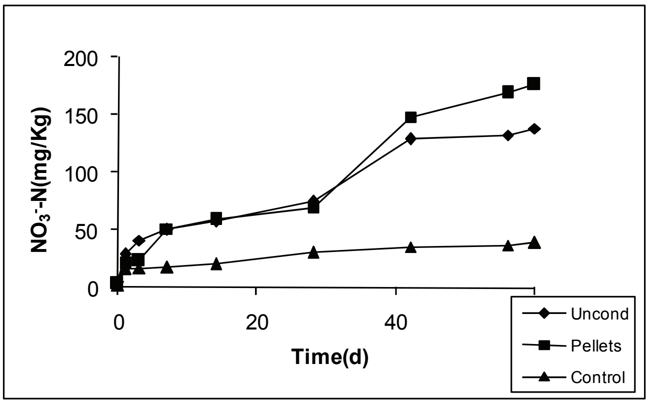


Figure 3.35. Extractable NO_3^--N from soil treated with sludge dried at 105°C (Daspoort).

The total amount of NO_3^--N extracted from the soil is shown in Table 3.11. More nitrate-nitrogen was produced from the conditioned than from the unconditioned sludge. The increase in nitrate-nitrogen, however, was not big at the low dosage of conditioner used. It is also interesting to note that nitrification is not inhibited by the addition of conditioner to the sludge.

The nitrate-nitrogen concentration in the soil is higher after sludge conditioning than before sludge conditioning. (not that significant) This higher nitrate-nitrogen concentration could be beneficial from an agricultural point of view. However, the higher nitrate-nitrogen concentration could also contribute to pollution of groundwater sources.

Table 3.11. Total amount of NO_3^--N extracted from the soil.

Place	**Polyelectrolyte dosage (mg/gds)**	**mg/kg NO_3^--N.d (105°C)**
Olifantsfontein	0 4	2 815 3 382
Durban	0 7 (filter press) 7 (pellets)	581 997 1 735
Cape Flats	0 8 (filter press) 8 (pellets)	1 773 7 651 1 110
Daspoort	Unconditioned Conditioned*	3 677 4 215

4. GENERAL DISCUSSION

It was observed during previous laboratory studies that sewage sludge conditioned with polyelectrolytes prior to dewatering was hard and difficult to crush after the sludge dried out. This change in the mechanical properties of the sludge might result in the reduction of the soil conditioning potential of sewage sludge when applied to agricultural land. Consequently, the effect of different commonly used polyelectrolytes as well as alternative inorganic salts were investigated for their sludge dewatering capabilities, water uptake, metal content, biodegradability, sludge hardness and their sludge mineralisation abilities. The effect of different conditioner concentrations as well as extreme sludge pre-drying temperatures (approximately 105°C) on sludge properties were investigated.

The sludge dewatering results showed that the polyelectrolyte sludge conditioners are superior to the inorganic sludge conditioners for sludge dewatering. The exception is ferric chloride which performed well for sludge dewatering. However, ferric chloride and the other inorganic sludge conditioners (alum and lime) contribute heavy metals to the soil which is not acceptable. Therefore, polyelectrolytes are preferred for sludge conditioning prior to dewatering.

Higher water uptakes were experienced with the polyelectrolyte treated sludge than with the inorganic salt treated sludges. The inorganic treated sludge appears to be more hydrophobic than the polyelectrolyte treated sludges. Therefore, it is likely that the polyelectrolyte treated sludge would be more biodegradable and therefore preferable as sludge conditioners.

The unconditioned and conditioned sludges (increasing dosage) showed about the same hardness. This is contrary with previous findings. Therefore, it appears that sludge hardness it not adversely affected by increasing dosages of polyelectrolyte. The same applies to the inorganic conditioners. Therefore, sludge hardness appears not to adversely affect the soil conditioning properties of sewage sludge.

The BOD/COD ratios of the unconditioned and conditioned polyelectrolyte treated sludges are low. Therefore, the sludge is not easy biodegradable. However, very little difference exist in the BOD/COD ratios of the unconditioned and conditioned sludges. Therefore, the polyelectrolytes are not inhibiting the biodegradability of the sludge and therefore the soil conditioning potential of the sludge.

Mineralisation of the polyelectrolyte treated sludge was not inhibited by high dosages of polyelectrolyte (8 mg/g). Therefore, the polyelectrolytes are not affecting the mineralisation of the sludge adversely. In fact, the polyelectrolytes contribute towards slightly higher nutrient concentrations in the soil. Therefore, agriculture should benefit when conditioned sewage sludge is used as a soil conditioner.

High concentrations of nitrate were produced during the mineralisation of Daspoort sludge pellets. These pellets originate from the active sludge pasteurisation process (ASP) where ammonia and phosphorous is added to primary sewage sludge prior to drying and pelletilisation. Therefore, the sludge should be an excellent soil conditioner.

The question will always arise whether mineralisation of sludge will cause pollution of the groundwater. This of course can happen. However, when sewage sludge is applied and used for agricultural purposes at agronomic rates, groundwater pollution should not be a problem.

5. CONCLUSIONS

- The polyelectrolyte conditioners showed better sludge dewatering characteristics than the inorganic sludge conditioners. Ferric chloride, however, showed good sludge dewatering characteristics. The disadvantage of the inorganic sludge conditioners is that they add heavy metals to the soil.
- The water uptakes of the conditioned and unconditioned polyelectrolyte treated sludges were about the same. Therefore, water uptake is not inhibited by the addition of polyelectrolytes to the sludge.
- The water uptakes of the inorganic conditioned sludges are less than that of the unconditioned sludge. Therefore, the inorganic conditioned sludges appear to be more hydrophobic than the unconditioned sludge and could be more difficult to biodegrade in the soil.
- Little difference was found between the hardness of the unconditioned and conditioned sludges. This showed that there is little difference in the hydrophobisity of the sludge.
- The BOD/COD ratios of the conditioned and unconditioned polyelectrolyte treated sludge were about the same. Therefore, the sludge conditioners are not affecting the biodegradability of the sludge.
- The mineralisation rates of the conditioned sludge was slightly higher than that of the unconditioned sludge. Therefore, sludge mineralisation is not adversely affected by the addition of polyelectrolytes to the sludge.
- The conditioned and unconditioned sludge add nutrients to the soil. The sludge should therefore be effective as a supplementary fertilizer for agricultural purposes. However, the nutrients may also contribute towards groundwater pollution if not correctly applied.
- The commonly used polyelectrolyte sludge conditioners should not cause any harm to the environment under the conditions normally used for sludge conditioning.

6. RECOMMENDATIONS

The polyelectrolytes investigated for sludge conditioning are not adversely affecting the soil conditioning properties of sewage sludge. However, inorganic sludge conditioners have the potential to increase the heavy metal content of the sludge. It is also more difficult to dewater sludges conditioned with inorganic chemicals than sludges conditioned with organic chemicals. Therefore, the current practice of applying organic sludge conditioners to sewage sludge should be maintained. However, a watching brief should be kept on new conditioning agents appearing on the market which could adversely affect the soil conditioning properties of sewage sludge.

7. LITERATURE

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APPENDIX A: CALCULATION OF TOTAL SOLIDS AND VOLUME OF POLYELECTROLYTE REQUIRED

Calculation of total solids:

% Solids = $\frac{W_3 - W_1}{W_2 - W_1} \times 100$

where W_3 = Tare Mass of dish after drying sludge in oven at 105°C

W_2 = Tare Mass of Dish with wet sludge

W_1 = Tare Mass of dish

Calculation of volume of polyelectrolyte:

2.5% solids = $\frac{2.5g\ dry\ solids}{100g\ wet\ sludge}$

In 500 g wet sludge is 2,5 x 500/100
= 12.5 % solids

For a 2 mg/g dosage = $\frac{12.5g\ dry\ solids \times 2mg\ solution}{1g\ dry\ solids}$

= 25 ml solution

APPENDIX B: CALCULATION OF SPECIFIC RESISTANCE TO FILTRATION

$$r = \frac{b2PA^2}{\mu C}$$

Where:
r = specific resistance (m/kg)
P = filtration pressure (N/m^2), P used for this work = 50 000
A = Filter area (m^2), a 90 mm filter paper was used, therefore A = 6.36×10^{-3} m^2
μ = filtrate viscosity ($N.s/m^2$)
C = Concentration of the sludge (Kg/m^3)
b = slope of filtrate discharge curve (s/m^6) from graph

For Unconditioned sludge 1,73% solids (See Table B1 and Figure B1)

C = 1.73 x 3/255
 = 0.02035 g/ml x 1000
 = 20.4 kg/m^3
b = 0.1199×10^{12} s/m^6
A = 6.36×10^{-3} m^2
μ = 1.1×10^{-3} $N.s/m^2$
r = $2 \times 0.1199 \times 10^{12} \times 50\,000 \times (6.36 \times 10^{-3})^2 / 20.4 \times 1.1 \times 10^{-3}$
 = 2.16×10^{13} m/kg

Z7633 at 2mg/g
C = 1.73x 3/255
 = 0.02035 g/ml x 1000
 = $20.4 kg/m^3$
b = 0.0092×10^{12} s/m^6
r = $2 \times 0.0092 \times 10^{12} \times 50\,000 \times (6.36 \times 10^{-3})^2 / 20.4 \times 1.1 \times 10^{-3}$
 = 1.66×10^{12} m/kg

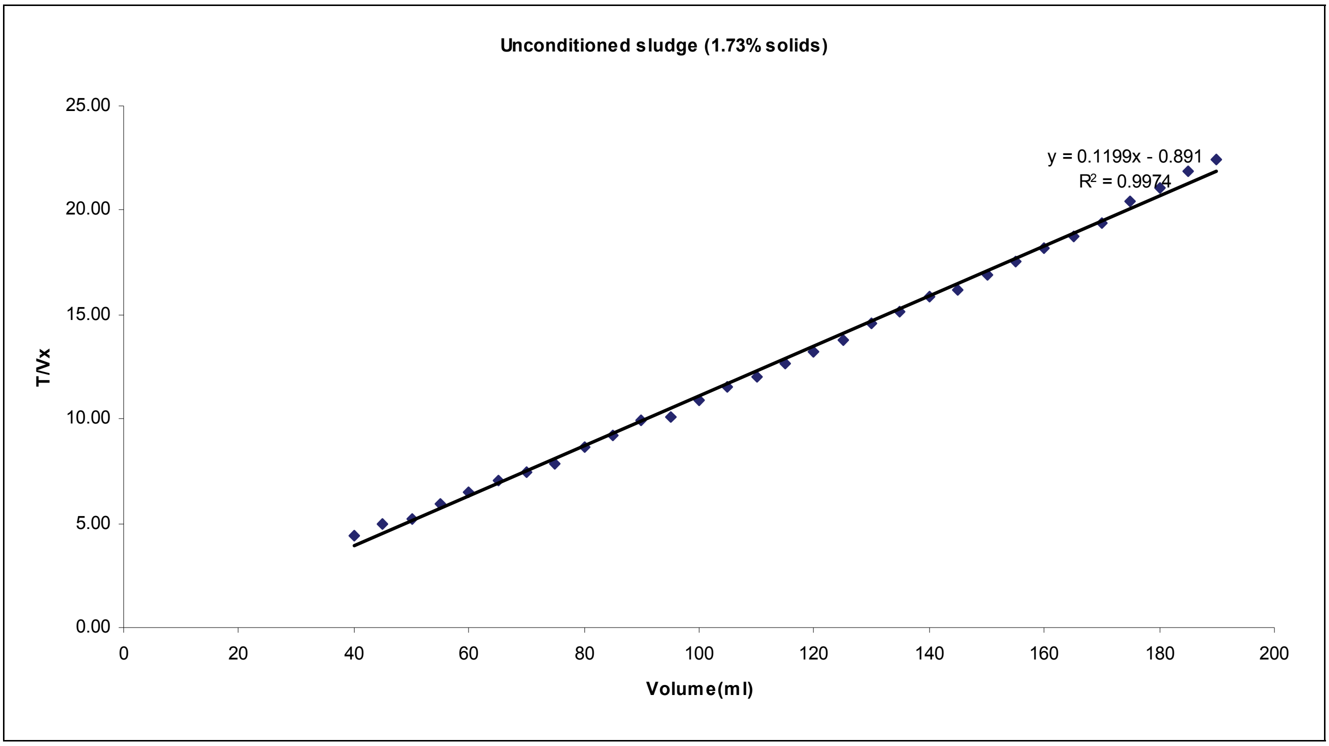

Figure B1. T/Vx versus volume.

Table B.1. Experimental data for the determination of the specific resistance to filtration (unconditioned sludge, 1.73% solids)

	Unconditioned sludge 1.73%		
Time(s)	Volume(ml)	Vx	T/Vx
	45		
8	50	5	1.60
25	55	10	2.50
46	60	15	3.07
59	65	20	2.95
76	70	25	3.04
102	75	30	3.40
126	80	35	3.60
177	85	40	4.43
223	90	45	4.96
262	95	50	5.24
326	100	55	5.93
391	105	60	6.52
457	110	65	7.03
521	115	70	7.44
588	120	75	7.84
691	125	80	8.64
783	130	85	9.21
897	135	90	9.97
962	140	95	10.13
1087	145	100	10.87
1211	150	105	11.53
1326	155	110	12.05
1457	160	115	12.67
1590	165	120	13.25
1722	170	125	13.78
1899	175	130	14.61
2047	180	135	15.16
2218	185	140	15.84
2345	190	145	16.17
2533	195	150	16.89
2720	200	155	17.55
2914	205	160	18.21
3097	210	165	18.77
3302	215	170	19.42
3575	220	175	20.43
3793	225	180	21.07
4049	230	185	21.89
4266	235	190	22.45
4460	240	195	22.87
4713	245	200	23.57
5019	250	205	24.48
5407	255	210	25.75

For conditioned sludge see Table B2 and Figure B2.

$$r = \frac{2bPA^2}{\mu C}$$

90 mm diameter, filter paper

$$A = \pi r^2 = \pi (D/2)^2$$
$$= \pi (90/2)^2$$
$$= \pi (0{,}045)^2$$
$$= 6{,}36 \times 10^{-3}\ m^2$$

$$b\ (\text{unconditioned}) = \text{slope}$$
$$= 0{,}1199\ \frac{s}{cm^6} \times \frac{(100\ cm)^6}{1\ m^6}$$

$$= 0{,}1199\ \frac{s}{cm^6} \times \frac{(10^2\ cm)^6}{1\ m^6}$$

$$= 0{,}1199 \times 10^{12}\ s.m^{-6}$$

$$C = \frac{1{,}73 \times 3}{255} \times 1000$$

$$= 20{,}4\ kg/m^3$$

μ = $1{,}1 \times 10^{-3}\ N.s.m^{-2}$; $P = 50\ 000\ N.m^{-2}$

$$r = \frac{2 \times 0{,}1199 \times 10^{12}\ s.m^{-6} \times 50\ 000\ N.m^{-2} \times (6{,}36 \times 10^{-3}\ m^2)^2}{1{,}1 \times 10^{-3}\ N.s.m^{-2} \times 20{,}4\ kg.m^{-3}}$$

$$= \frac{2 \times 0{,}1199 \times 10^{12}\ m^{-6} \times 50\ 000 \times 4{,}04 \times 10^{-5}\ m^4}{1{,}1 \times 10^{-3} \times 20{,}4\ kg.m^{-3}}$$

$$= 2{,}16 \times 10^{13}\ m^{-2} \times \frac{m^3}{kg}$$

$$= 2{,}16 \times 10^{13}\ m/kg$$

Z7633 1 mg/g

$$r = \frac{2 \times 0{,}0326 \times 10^{12}\ s/m^6 \times 50\ 000\ N.m^{-2} \times (6{,}36 \times 10^{-5}\ m^2)^2}{1{,}1 \times 10^{-3}\ N.s.m^{-2} \times 19{,}6\ kg.m^{-3}}$$

$$= 6{,}12 \times 10^{12}\ m/kg$$

Table B.2. Experimental data for the determination of the specific resistance to filtration (z7633, 2 mg/gds, 1,73% solids)

	Z7633(2mg/g)1.73 %		
time(s)	volume	Vx	T/Vx
	50		
8	55	5	1.60
12	60	10	1.20
21	65	15	1.40
36	70	20	1.80
51	75	25	2.04
62	80	30	2.07
81	85	35	2.31
100	90	40	2.50
115	95	45	2.56
123	100	50	2.46
157	105	55	2.85
179	110	60	2.98
206	115	65	3.17
234	120	70	3.34
266	125	75	3.55
301	130	80	3.76
338	135	85	3.98
364	140	90	4.04
398	145	95	4.19
431	150	100	4.31
469	155	105	4.47
500	160	110	4.55
553	165	115	4.81
604	170	120	5.03
642	175	125	5.14
690	180	130	5.31
738	185	135	5.47
789	190	140	5.64
840	195	145	5.79
892	200	150	5.95
952	205	155	6.14
1000	210	160	6.25
1077	215	165	6.53
1140	220	170	6.71
1217	225	175	6.95
1319	230	180	7.33
1402	235	185	7.58
1504	240	190	7.92
1692	245	195	8.68
1857	250	200	9.29
2041	255	205	9.96
2375	260	210	11.31
2696	265	215	12.54

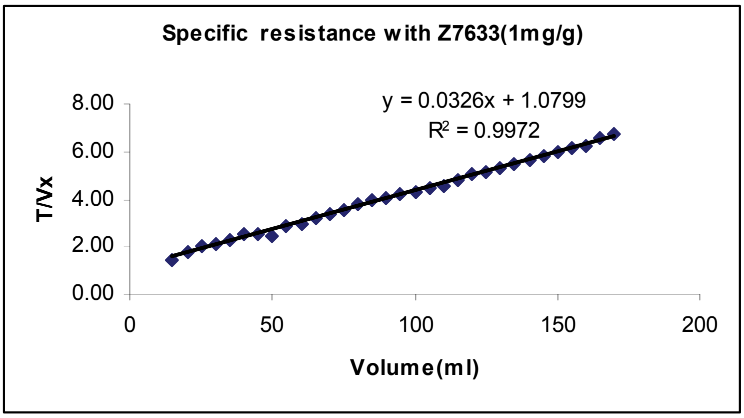

Figure B2. T/V_x versus volume.

Calculation of reduction in specific resistance to filtration:

$$\text{SR reduction (\%)} = \frac{SR_{untreated} - SR_{treated}}{SR_{untreated}} \times 100\ \%$$

Where,
$SR_{untreated}$ = specific resistance to filtration of unconditioned sludge and
$SR_{treated}$ = the specific resistance of conditioned sludge.
e.g. For Z7633 1 =mg/g 1.73% solids (see Table 3.1 and 3.3 for SRF values):
$SR_{untreated} = 2.16 \times 10^{13}$
$SR_{treated} = 6.12 \times 10^{12}$
% Reduction $= 2.16 \times 10^{13} - 6.12 \times 10^{12} / 2.16 \times 10^{12} \times 100$
$= 71.7$

APPENDIX C: PHYSICAL AND CHEMICAL PROPERTIES OF SOIL

Table C.1. Physical and chemical properties of the soil.

Texture Class			Inorganic N (mg/Kg)		$pH(H_2O)$	% C
% Clay	% Sand	% Silt	NH_4^+ - N	NO_3^- - N		
20.6	61.6	14.4	4.26	20.5	6.4	0.49

Table C.2. C and N contents of the various sludge treatments.

Sludge source	% C	% N	C:N ratio
Olifants Uncond 1	38.96	2.98	13.1
Olifants Uncond 2	77.05	4.48	17.2
Olifants Filter P	76.05	5.78	13.2
Cape Uncond	73.53	4.91	15
Cape Filter P	75.32	4.19	17
Cape Pellets	75.54	4.62	16.4
Durban Uncond	71.9	4.43	16.2
Durban Filter P	71.19	4.53	15.7
Durban Pellets	61.5	3.69	16.7
Daspoort Uncond	76.28	3.88	19.7
Daspoort Pellets	53.12	5.62	9.5

APPENDIX D: PERCENTAGE REDUCTION IN THE SRF OF THE CONDITIONERS AT DIFFERENT DOSAGES

Table D.1: Percentage reduction in SRF of the polyelectrolyte conditioned sludges at different dosages ($SRF_o = 21,6 \times 10^{12}$ m/kg)

Dosage(mg/g)	Z7633	Z7220	CZ7114	Z7646
1	71.7	64.2	57.5	44.4
2	93.8	93.2	82.7	88.4
4	98.3	98.8	91.9	94.8

Table D.2: Percentage reduction in SRF of the inorganic salt conditioned sludges at different dosages ($SRF_o = 61,3 \times 10^{12}$ m/kg)

Dosage(mg/g)	Lime	Ferric	Alum
80	91.6	96.3	92.8
120	89	98.3	96.9
200	87	99.1	97.6

APPENDIX E: WATER UPTAKE FOR POLYELECTROLYTE AND INORGANIC CONDITIONED SLUDGES

$$\% \text{ Water uptake} = \frac{\text{Mass of wet sample(g)} - \text{Mass dry sample}}{\text{Mass of wet sample(g)}} \times 100\%$$

Table E.1: Percentage water uptake of the 2 mg/g polyelectrolyte conditioned sludge at 30°C.

	1h	24h	48h	72h
Z7633	61.7	73.7	75.1	78.1
Z7220	58.6	71.4	75.3	77.4
CZ7114	68.9	75.4	77.6	78.5
Z7646	62.9	74.3	76	77.4
Unconditioned	51.3	75.9	78.9	80

Table E.2: Percentage water uptake of the 4 mg/g polyelectrolyte conditioned sludge at 30°C.

	1h	24h	48h	72h
Z7633	55	71	73.1	74.8
Z7220	49.8	73.3	75.6	78.1
CZ7114	56	66.6	74	75.3
Z7646	48.2	65.5	72	74.1
Unconditioned	51.3	75.9	78.9	80

Table E.3: Percentage water uptake of the 8 mg/g polyelectrolyte conditioned sludge at 30°C.

	1h	24h	48h	72h
Z7633	46.6	71.7	72.8	73.4
Z7220	50.4	68.3	72.7	75
CZ7114	48.8	70.6	74.3	76.9
Z7646	55.9	68.1	71.3	74.4
Unconditioned	51.3	75.9	78.9	80

Table E.4: Percentage water uptake of the 2 mg/g polyelectrolyte conditioned sludge at 105°C.

	1h	24h	48h	72h
Z7633	53.6	60.1	60.2	63
Z7220	55.1	57.7	62.5	68.1
CZ7114	56.9	57.6	63.9	64.1
Z7646	51.3	54.5	57.6	60.4
Unconditioned	29.5	57.9	63.3	68.4

Table E.5: Percentage water uptake of the 4 mg/g polyelectrolyte conditioned sludge at 105°C.

	1h	24h	48h	72h
Z7633	52.8	59.8	63.1	65.3
Z7220	57.7	62.1	65.4	72.4
CZ7114	52.3	60.6	66.6	67.1
Z7646	58.2	59.2	65.3	65.8
Unconditioned	29.5	57.9	63.3	68.4

Table E.6: Percentage water uptake of the 8 mg/g polyelectrolyte conditioned sludge at 105°C.

	1h	24h	48h	72h
Z7633	51.3	64.3	66.4	67.6
Z7220	58.8	65.1	66.2	70.2
CZ7114	51	56	65.7	67.6
Z7646	54.6	61.3	65.9	66.4
Unconditioned	29.5	57.9	63.3	68.4

Table E.7: Percentage water uptake of the 80 mg/g inorganic salt conditioned sludge at 30°C.

	1h	24h	48h	72h
Lime	19.5	37.6	39.1	42
Ferric	13.1	35.1	47.5	49.7
Alum	20.8	39.7	42.6	44.5
Unconditioned	51.3	75.9	78.9	80

Table E.8: Percentage water uptake of the 120 mg/g inorganic salt conditioned sludge at 30°C.

	1h	24h	48h	72h
Lime	16	32	34.3	35.3
Ferric	21	40.8	44	45.7
Alum	21.4	46.7	52.7	55.7
Unconditioned	51.3	75.9	78.9	80

Table E.9: Percentage water uptake of the 200 mg/g inorganic salt conditioned sludge at 30°C.

	1h	24h	48h	72h
Lime	35	39	40.5	41
Ferric	12.5	33.1	39.2	42.9
Alum	14.7	37.8	53	54.6
Unconditioned	51.3	75.9	78.9	80

Table E.10: Percentage water uptake of the 80 mg/g inorganic salt conditioned sludge at 105°C.

	1h	24h	48h	72h
Lime	11.7	36.1	38.1	40
Ferric	39.5	45.9	48.7	53
Alum	35.5	39.4	41.6	42
Unconditioned	29.5	57.9	63.3	68.4

Table E.11: Percentage water uptake of the 120 mg/g inorganic salt conditioned sludge at 105°C.

	1h	24h	48h	72h
Lime	15.1	25.5	27.9	30.7
Ferric	40.7	41.7	42	47.7
Alum	37.2	43.1	47.1	49.5
Unconditioned	29.5	57.9	63.3	68.4

Table E.12: Percentage water uptake of the 200 mg/g inorganic salt conditioned sludge at 105°C.

	1h	24h	48h	72h
Lime	21.5	27.3	29	31
Ferric	30	36.3	39.6	42.1
Alum	36.2	42	43.2	47.2
Unconditioned	29.5	57.9	63.3	68.4

Table E.13: Percentage water uptake of the unconditioned (Olifantsfontein) sludge.

Time	16 hours (73.5)	32 hours (95.5)	105°C (98.5)
1	46.8	47.9	66.3
24	58.6	65.0	68.3
48	62.6	66.0	71
72	65	67.8	72

( ): % solids

Table E.14: Percentage water uptake of the 2 mg/g Z7633 conditioned sludge as a function of % solids concentration.

Time	Undried (22)	4hrs (32)	8hrs (39.6)	16hrs (69)	32hrs (90.7)	24hrs* (95.8)
1	38.3	22.4	49	51.4	52.3	59.6
24	45	49.3	65	74.7	68.9	62.9
48	47.6	52	67.9	76.5	72.1	64.8
72	50.2	55.2	68.9	77.5	73.4	66.5

( ): % solids; * : Dried at 105°C

Table E.15: Percentage water uptake of the 4 mg/g Z7633 conditioned sludge as a function of % solids concentration.

Time	Undried (18.8)	4hrs (42)	8hrs (43.4)	16hrs (82)	32hrs (92.3)	24hrs* (95.8)
1	28.5	35.1	47.1	49.2	49.8	52.5
24	43.5	50.2	50.7	68	69.7	63
48	44.7	53.2	51.9	70	70.2	64.6
72	47.2	54	54	71.2	71.6	65.4

( ): % solids; * : Dried at 105°C

Table E.16: Percentage water uptake of the 8 mg/g Z7633 conditioned sludge as a function of % solids concentration.

Time	Undried (11.1)	4hrs (17.2)	8hrs (27)	16hrs (87.3)	32hrs (98.2)	24hrs* (92.8)
1	18.6	20.3	22.9	50.6	53.9	58.7
24	30.4	30.7	43.5	68.8	63.8	67.8
48	32.8	34.8	47.7	709	66.5	71.9
72	35.6	39.7	52.3	72.6	68.5	73.2

( ): % solids; * : Dried at 105°C

Table E.17: Percentage water uptake of the 2 mg/g Rheofloc 5356 conditioned sludge as a function of % solids concentration.

Time	Undried (19.6)	4hrs (15.2)	8hrs (32)	16hrs (52.9)	32hrs (79.3)	24hrs* (99.2)
1	14.9	15.8	15.6	22.4	26.6	44.2
24	38.3	33.1	32.5	41.8	50.1	60.44
48	45.1	38	41.8	48.7	56.9	61.4
72				49.5	59.9	61.4

( ): % solids; * : Dried at 105°C

Table E.18: Percentage water uptake of the 4mg/g Rheofloc 5356 conditioned sludge as a function of % solids concentration.

Time	Undried (8.3)	4hrs (9.7)	8hrs (14.8)	16hrs (33.7)	32hrs (77.6)	24hrs* (97.3)
1	24.3	25.2	19.2	30.6	66.2	64.1
24	29	33.2	32.6	44.9	72.7	68.5
48	31.8	35	39.9	50	74.3	70.3
72	32.7	35.8	39.9	52.7	76.4	71.9

( ): % solids; * : Dried at 105°C

Table E.19 Percentage water uptake of the 8 mg/g Rheofloc 5356 conditioned sludge as a function of % solids concentration.

Time	Undried (11.3)	4hrs (11.5)	8hrs (15.3)	16hrs (68.6)	32hrs (74.8)	24hrs* (99)
1	28.9	21.1	22.5	46.3	43.8	61.7
24	34.42	25	31.5	64.7	66.8	69.3
48	34.9	28.8		66.9	67.6	71.3
72	35.9	30.8	39.12	67.4	68.9	72.4

( ): % solids; * : Dried at 105°C

Table E.20: Percentage water uptake of the 2 mg/g Z7680 conditioned sludge as a function of % solids concentration.

Time	Undried (20)	4hrs (18)	8hrs (25.7)	16hrs (38.6)	32hrs (73.2)	24hrs* (99.7)
1	17.0	13.7	15.0	21.1	23.1	54.3
24	36.6	33.5	29.2	50.0	51.1	59.3
48	39.7	43.3	45.4	51.1	57.1	61.3
72			48.0	53.8	63.1	63.7

( ): % solids; * : Dried at 105°C

Table E.21: Percentage water uptake of the 4 mg/g Z7680 conditioned sludge as a function of % solids concentration.

Time	Undried (15)	4hrs (16.2)	8hrs (23)	16hrs (26.8)	32hrs (39.0)	24hrs* (97.5)
1	21.7	16.7	16.8	14.4	25.3	68.1
24	33.0	36.6	34.1	38.1	49.9	71.3
48	33.0	45.9	43.8	44.5	53.2	72.1
72	33.0	48.8	44.3	50.0	55.6	73.1

( ): % solids; * : Dried at 105°C

Table E.22: Percentage water uptake of the 8 mg/g Z7680 conditioned sludge as a function of % solids concentration.

Time	Undried (9.9)	4hrs (11.5)	8hrs (16.5)	16hrs (44.1)	32hrs (85.8)	24hrs* (98.4)
1	30.1	26.6	24.6	30.7	66.6	55.1
24	36.8	37.2	34.1	57.6	74.6	60.7
48	37.2	42.4	38.8	61.3	76.1	66.0
72	37.2	43.8	40.5	61.4	76.5	66.4

( ): % solids; * : Dried at 105°C

Table E.23: Percentage water uptake of the 60 mg/g ferric chloride conditioned sludge as a function of % solids concentration.

Time	Undried (13.2)	4hrs (14.5)	8hrs (16.7)	16hrs (95.4)	32hrs (96.3)	24hrs* (98.8)
1	23.5	22.1	38.7	51.0	41.6	42.9
24	36.2	35	51.5	59.6	62.1	51.0
48	40.1	39.3	54.4	62.8	63.4	53.0
72	42.5	43.2	56.6	65.1	65.5	56.4

( ): % solids; * : Dried at 105°C

Table E.24: Percentage water uptake of the 80 mg/g ferric chloride conditioned sludge as a function of % solids concentration.

Time	Undried (21.6)	4hrs (29.5)	8hrs (43.4)	16hrs (79.4)	32hrs (86.9)	24hrs* (97.8)
1	17.7	32.5	47.1	48.5	44.2	42.9
24	31.4	43.8	50.7	53.8	57.1	51.1
48	41.8	45.3	51.9	57.7	59.6	53.0
72	44.3	47.4	54.0	59.4	69.1	56.4

( ): % solids; * : Dried at 105°C

Table E.25: Percentage water uptake of the 120 mg/g ferric chloride conditioned sludge as a function of % solids concentration.

Time	Undried (28.1)	4hrs (29.7)	8hrs (38)	16hrs (79.6)	32hrs (79.6)	24hrs* (40.5)
1	23.4	25.5	35.4	47.2	43.5	40.5
24	32.0	33.9	40.1	54.8	56.9	50.2
48	34.8	37.4	43.4	55.9	61.1	51.6
72	38.4	43.4	44.2	57.1	68.8	53.8

( ): % solids; * : Dried at 105°C

APPENDIX F: AMMONIFICATION OF SLUDGE

Table F.1: Average extracted NH_4^+-N (mg/kg) at 30°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
0	0.0	0.0	0.0	0.0
1	163.4	152.3	182.5	213.1
3	291.1	297.5	410.9	324.5
7	401.5	504.1	490.6	535.7
14	393.1	392.6	463.2	416.7
28	320.9	243.9	309.8	228.1
42	108.8	116.6	124.5	110.0
56	75.9	88.8	111.1	78.1

Table F.2: Average extracted NH_4^+-N (mg/kg) at 105°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
0	0.0	0.0	0.0	0.0
1	89.3	93.4	137.1	171.5
3	439.9	617.2	427.0	396.1
7	637.6	778.8	693.0	676.7
14	441.6	472.6	636.5	577.5
28	346.7	342.6	431.4	389.7
42	204.2	280.3	373.2	360.7
56	180.1	190.6	141.6	208.6

Table F.3: Average extracted NH_4^+-N (mg/kg) from Olifantsfontein sludge dried at 105°C

Time	Unconditioned	Filter press
0.0	3.2	-0.2
1.0	130.15	245.9
3.0	231.7	524.9
7.0	409.3	752.6
14.0	363.85	599.4
28.0	132	240.7
42.0	63.9	152.4
56.0	42.3	73.5
60.0	18.1	31.3

Table F.4: Average extracted NH_4^+-N (mg/kg) from Durban sludge dried at 105°C

Time	Unconditioned	Filterpress	Pellets
0.0	3.2	-0.2	1.7
1.0	112.2	230.5	128.2
3.0	314.1	422.5	153.3
7.0	434.6	527.4	246.6
14.0	259.9	307.9	318.2
28.0	110.0	129.2	108.2
42.0	59.6	82.6	77.8
56.0	29.7	40.1	36.7
60.0	22.2	18.7	15.1

[1] After correction by subtracting control

Table F.5: Average extracted NH_4^+-N (mg/kg) from Cape Town sludge dried at 105°C

Time	Unconditioned	Filterpress	Pellets
0.0	3.2	-0.2	1.7
1.0	279.6	240.85	119.8
3.0	349.2	279.85	211.0
7.0	476.8	426.3	420.4
14.0	362.75	358.85	323.1
28.0	86.47	121.9	132.9
42.0	69	86.7	69.6
56.0	27.55	54.4	20.7
60.0	22.5	29.1	13.9

Table F.6: Average extracted NH_4^+-N (mg/kg) from Daspoort sludge dried at 105°C

Time	Unconditioned	Pellets
0.0	3.2	-0.2
1.0	218.4	1489.3
3.0	309.5	2338.1
7.0	429.1	2065.9
14.0	378.4	1068.2
28.0	209.4	868.8
42.0	89.9	643.7
56.0	70.1	473.0
60.0	51.7	370.9

APPENDIX F.1: CALCULATION OF TOTAL NH_4^+-N EXTRACTED FROM THE SOIL

The trapezoid method was used to calculate the area under the curves, using the formula:

$$\sum_{i=1}^{n-1} \frac{(f_i + f_{i+1})}{2} \times (x_{i+1} - x_i)$$

The following are the results of the above formula

Table F.7: Average extracted NH_4^+-N at 30°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
1	81.7	76.2	91.2	106.6
3	454.5	449.8	593.3	537.6
7	1385.2	1603.1	1802.9	1720.4
14	2781.1	3138.3	3338.3	3333.2
28	4997.7	4455.2	5411.0	4513.3
42	3007.6	2523.2	3040.1	2366.7
56	1292.9	1437.8	1649.2	1316.7
∑	14000.5	13683.4	15926.0	13894.4

Table F.8 Average extracted NH_4^+-N at 105°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
1	44.7	46.7	68.6	85.8
3	529.2	710.6	564.1	567.6
7	2154.9	2791.9	2240.0	2145.6
14	3777.2	4379.6	4653.1	4389.7
28	5517.8	5706.1	7474.6	6770.4
42	3856.0	4360.3	5631.9	5252.8
56	2690.1	3296.3	3603.6	3985.1
∑	18569.7	21291.3	24235.8	23197.0

Table F.9: Average extracted NH_4^+-N from Durban sludge dried at 105°C

Time(days)	Unconditioned	Filter press	Pellets
1	57.7	115.2	65.0
3	426.2	653.0	281.5
7	1497.2	1899.6	799.6
14	2430.6	2923.2	1976.6
28	2589.3	3059.4	2984.8
42	1187.2	1482.6	1302.0
56	625.1	858.9	801.5
60	103.8	117.6	103.6
∑	8917.1	11109.4	8314.5

Table F.10: Average extracted NH_4^+-N from Cape Town sludge dried at 105°C

Time	Unconditioned	Filter press	Pellets
1	141.4	120.3	60.7
3	628.8	520.7	330.8
7	1652.0	1412.3	1262.8
14	2938.4	2748.0	2602.1
28	3144.5	3365.3	3191.7
42	1088.3	1460.2	1417.5
56	675.9	987.7	631.8
60	100.1	167.0	69.1
∑	10369.4	10781.5	9566.4

Table F.11: Average extracted NH_4^+-N from Daspoort sludge dried at 105°C

Time	Unconditioned	Pellets
1	110.8	744.6
3	527.9	3827.4
7	1477.1	8807.9
14	2825.9	10969.2
28	4114.3	13558.7
42	2095.1	10587.5
56	1120.0	7816.9
60	243.6	1687.8
∑	12514.6	57999.8

Table F.12: Average extracted NH_4^+-N from Olifantsfontein sludge dried at 105°C

Time	Unconditioned	Filter press
1	66.7	122.9
3	361.9	770.8
7	1282.0	2554.9
14	2706.0	4731.8
28	3471.0	5880.7
42	1371.3	2751.7
56	743.4	1581.3
60	120.8	209.6
∑	10123.0	18603.7

APPENDIX G: NITRIFICATION OF SLUDGE

Table G.1: Average extracted NO_3^--N (mg/kg) at 30°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
0	0.0	0.0	0.0	0.0
1	56.3	0.0	42.6	8.2
3	124.3	46.7	87.0	12.9
7	104.7	95.7	121.4	100.4
14	12.8	12.3	84.0	57.2
28	10.8	7.0	47.3	37.3
42	11.2	7.7	20.4	17.1
56	7.5	4.2	13.9	12.3

Table G.2: Average extracted NO_3^--N (mg/kg) at 105°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
0	0.0	0.0	0.0	0.0
1	9.4	7.0	16.4	18.1
3	57.8	56.6	41.2	30.4
7	92.8	72.7	93.4	64.2
14	23.9	102.7	165.7	158.7
28	18.1	49.0	24.3	42.0
42	14.0	28.7	7.2	23.5
56	10.7	19.2	6.3	16.8

Table G.3: Average extracted NO_3^--N (mg/kg) from Olifantsfontein sludge dried at 105°C

Time	Unconditioned	Filter press
0.0	0.0	0.0
1.0	-5.4	13.7
3.0	0.6	24.1
7.0	5.1	30.4
14.0	29.4	31.3
28.0	22.1	33.3
42.0	85.7	88.1
56.0	88.7	98.9
60.0	88.6	102.5

Table G.4: Average extracted NO_3^--N (mg/kg) from Durban sludge dried at 105°C

Time	Unconditioned	Filterpress	Pellets
0.0	0.0	0.0	0.0
1.0	0.2	2.1	5.7
3.0	2.4	3.9	11.9
7.0	4.4	3.8	11.6
14.0	2.8	2.5	10.9
28.0	-4.4	11.0	7.6
42.0	22.6	31.2	55.7
56.0	24.2	31.4	57.3
60.0	24.0	31.4	56.1

Table G.5: Average extracted NO_3^--N (mg/kg) from Cape Town sludge dried at 105°C

Time	Unconditioned	Filterpress	Pellets
0.0	0.0	0.0	0.0
1.0	-5.2	-0.8	-2.1
3.0	-0.6	-0.6	0.9
7.0	0.1	4.9	3.8
14.0	-0.4	3.8	4.3
28.0	-0.8	-2.2	4.1
42.0	63.0	47.8	36.3
56.0	83.2	60.4	43.5
60.0	79.2	59.5	43.8

Table G.6: Average extracted NO_3^--N (mg/kg) from Daspoort sludge dried at 105°C

Time	Unconditioned	Pellets
0.0	2.2	1.2
1.0	12.7	4.3
3.0	24.1	6.9
7.0	32.7	33.6
14.0	37.6	38.5
28.0	44.1	39.6
42.0	93.3	112.8
56.0	95.6	132.5
60.0	98.8	136.9

APPENDIX G.1: CALCULATION OF TOTAL NO_3^--N EXTRACTED FROM THE SOIL

The trapezoid method was used to calculate the area under the curves. The following are the results of the formula

Table G.7: Average extracted NO_3^--N at 30°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
1	28.1	0.0	21.3	4.1
3	180.5	46.7	129.5	21.1
7	457.8	284.6	416.6	226.5
14	411.1	377.7	718.7	551.3
28	165.2	134.8	918.8	661.2
42	154.0	102.9	473.6	380.8
56	130.9	83.3	240.1	205.8
∑	1527.6	1029.9	2918.5	2050.6

Table G.8: Average extracted NO_3^--N at 105°C (Olifantsfontein)[1]

time(days)	0mg/g	2mg/g	4mg/g	8mg/g
1	4.7	3.5	8.2	9.1
3	67.1	63.6	57.6	48.5
7	301.0	258.5	269.1	189.0
14	408.3	613.6	906.5	779.8
28	293.7	1061.2	1329.7	1404.2
42	224.4	543.6	220.5	458.2
56	172.9	335.3	94.5	282.1
∑	1472.0	2879.2	2886.0	3170.8

Table G.9: Average extracted NO_3^--N from Durban sludge dried at 105°C

Time	Unconditioned	Filter press	Pellets
1	0.1	1.0	2.8
3	2.6	6.0	17.5
7	13.5	15.3	46.8
14	25.0	21.7	78.4
28	-11.2	94.2	129.2
42	127.4	295.4	443.1
56	327.6	438.2	791.0
60	96.4	125.6	226.8
∑	581.4	997.3	1735.6

Table G.10: Average extracted NO_3^--N from Cape Town sludge dried at 105°C

Time	Unconditioned	Filterpress	Pellets
1	-2.6	-0.4	-1.1
3	-5.8	-1.4	-1.2
7	-0.9	8.5	9.5
14	-1.1	30.3	28.4
28	-8.8	11.2	58.8
42	435.4	319.2	282.8
56	1023.4	757.4	558.6
60	324.8	239.8	174.6
∑	1764.6	1364.7	1110.5

Table G.11: Average extracted NO_3^--N from Daspoort sludge dried at 105°C

Time	Unconditioned	Pellets
1	7.5	2.7
3	36.8	11.1
7	113.6	80.9
14	246.1	252.4
28	571.9	546.7
42	961.8	1066.8
56	1322.3	1717.1
60	388.8	538.8
∑	3648.7	4216.5

Table G.12: Average extracted NO_3^--N from Olifantsfontein sludge dried at 105°C

Time	Unconditioned	Filter press
1	-2.7	6.8
3	-4.8	37.8
7	11.4	108.9
14	120.8	215.6
28	360.5	451.9
42	754.6	849.8
56	1220.8	1309.0
60	354.6	402.8
∑	2815.2	3382.5