SUSTAINABLE SLUDGE HANDLING

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I. PRINCIPLES OF SLUDGE HANDLING

I.1 PRINCIPLES OF SUSTAINABLE SLUDGE HANDLING

When the Brundtland Commission's "Our Common Future" was published in 1987, the concept of sustainable development rapidly became generally accepted. The definition of sustainability in the Brundtland report is: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The principles of sustainable management of water resources have been described by Hultman and Levlin (1998).

Harremoës (1996) gives the following interpretation of sustainability with a resource component and a pollution component:

- Society should use its resources such that the society can continue its mode of operation without exhausting its resources

- Society should protect the environment against irreversible damage, including protection of unique species and habitats

Sludge may be regarded both as a resource which should be recycled in a proper way and a threat to the environment. Different resources in the sludge include:

- Nutrients as phosphorus, nitrogen and potassium. Special consideration should be devoted to phosphorus due to a possible scarcity in the future.

- Organic material for soil conditioning, energy production, adsorption materials or production of organic compounds as organic acids.

- Inorganic material for reuse as precipitation chemicals, use in building materials and possible recovery of some valuable metals.

Harmful substances in the sludge may be divided into pathogens, organics (including oil and organic micropollutants) and toxic inorganics (heavy metals, asbestos, radioactive materials etc).

Sustainable sludge handling may therefore be defined as a method that meets requirements of efficient recycling of resources without supply of harmful substances to humans or the environment. The sludge handling should be performed in an energy and resource efficient way.

I.2 OPTIONS OF SLUDGE HANDLING

The different options that are available for handling chemicals (including sludge compounds) with respect to ultimate fate are few, namely no use, reuse, convert, contain and disperse (Harremoës, 1996). These options are illustrated for sludge handling (see Table 1).

Table 1. Illustration of different principal options for sludge handling

Option	Purpose	Application in sludge handling
No use	Stop use of an unwanted substance due to detrimental and irreversible effects to the environment	Effective control of industrial discharges, use of environmentally friendly consumer products etc to facilitate sludge use in agriculture and use of sludge products
Reuse	Decrease of the amount reaching the environment and of extraction of mineral resources by reusing the compound	Internal reuse of materials (as reuse of precipitation chemicals) and external reuse (as reuse of phosphorus as fertiliser)
Convert	Conversion of a substance from an obnoxious form to a form, acceptable for further transport by air, or water or in solid form	Conversion of organics to methane gas (for further use as energy source), solubilisation of sludge components for product recovery, conversion of sludge into compost etc
Contain	To contain the residues with as low leaching ability as possible	Separate containment of toxic substances in the sludge, inclusion or stabilisation of ashes from sludge incineration etc
Disperse	Dispersion into environment without negative impact	Effective dispersion of sludge in agricultural use, effective dispersion of treated flue gases in sludge incineration

The different options in sludge handling should be combined in an optimal way. Generally, an effective control of industrial discharges and use of environmentally friendly consumer products are prerequisites for an efficient sludge handling. Containment of pollutants should be restricted to a minor part of the products used in society due to increasing shortage of land.

II. PRACTICE IN SLUDGE HANDLING

II.1 MAIN METHODS

Sludge handling in a large centralised wastewater treatment plant consists of several possible steps:

- Preliminary treatment (screening, comminution)
- Primary thickening (gravity, flotation, drainage belt, centrifuges)
- Liquid sludge stabilisation (anaerobic digestion, aerobic digestion, lime addition)
- Secondary thickening (gravity, flotation, drainage belt, centrifuges)
- Conditioning (elutriation, chemical, thermal)
- Dewatering (plate press, belt press, centrifuge, drying bed)
- Final treatment (composting, drying, lime addition, incineration, wet oxidation, pyrolysis)
- Storage (liquid sludge, dry sludge, compost, ash)
- Transportation (road, pipeline, sea)
- Final destination (landfill, agriculture/horticulture, forest, reclaimed land, land building, sea, sale)

The main sludge handling technology in Sweden is for larger treatment plants: Primary thickening (mainly by gravity), liquid sludge stabilisation (mainly by anaerobic digestion), conditioning (mainly by use of polyelectrolytes), dewatering (mainly by centrifuges and belt presses), transportation (mainly by road), and final destination (mainly agriculture, landfill, land building, and land reclamation). Sludge drying is only used in two Swedish plants. Sludge incineration has not yet come into use. Thermal conditioning together with acids is used in one treatment plant as a part of a sludge product recovery system based on the KREPRO process (Water Quality International, 1996a).

II.2 RESTRICTIONS OF SLUDGE HANDLING

Sludge handling methods are restricted by several reasons such as regulations from authorities, acceptance from different groups, technical problems, and costs. Some restrictions for the final sludge destination are described in Table 2.

Table 2. Examples of restrictions for final sludge destination (cf Mossakowska et al., 1998)

Final sludge destination	Restrictions
Agricultural use	o Limiting values of metal concentrations in sludge use. These are in Sweden as mg/kg DS: Pb 100, Cd 2, Cu 600, Cr 100, Hg 2.5, Ni 50, and Zn 800 o Guidance values for indicator organic compounds. These are in Sweden as mg/kg DS: Nonyl phenol 50, toluen 5, total PAH 3, and total PCB 0.4. o Maximum yearly amount of nutrients allowed to agricultural land from sewage sludge (for Swedish conditions see SEPA, 1995) o Limiting values of the yearly amount of metals that may be supplied to agricultural land as g/ha and year (for Swedish conditions see SEPA, 1995) o Acceptance from food industry (food industry may not buy agricultural products grown on land fertilised with sewage sludge) o Public acceptance
Land disposal	o Availability of land disposal areas o Limitation of maximum percentage of organic materials in the sludge before disposal (which may necessitate the use of incineration) o Fees for disposal of sludge on landfill (the fee will in Sweden be 250 SEK/metric ton)
Land building and reclamation	o Availability of land areas o Environmental impact of application of sewage sludge
Incineration	o Permit to build an incineration plant o Difficulties to find a suitable plant for co-incineration of sewage sludge (with municipal solid wastes, biofuels, coal, cement, brick etc) including permits o Restrictions related to treatment of flue gases o Restrictions related to further handling of produced ashes

Agricultural use of sludge is often regarded as the best alternative if the pollutants in the sludge is below limiting and guidance values. However, lack of acceptans from food industry and the public may make it difficult to use sludge for agriculture. Many attempts have been done to find agreements for agricultural use of sludge. Thus, a national consultation group has been formed in Sweden to stimulate the use of sludge in agriculture and to agree upon different actions and voluntary precautionary measures to prevent the supply of unwanted chemicals and substances into the sewer net. The group consists of representatives from the National Organization of Agricultural Workers (LRF), the Swedish Water and Waste Works Association (VAV), and the Swedish Environment Protection Agency (SEPA). Although this group has reached agreements, the future of agricultural use of sludge is uncertain and under debate. A discussion is going on concerning the availability of phosphate to plants of precipitated iron or aluminium phosphates.

Landfill of sludges will probably be restricted considerably in the future. In several countries (as Germany) only sludges with a low percentage content of organics will be allowed for land deposit. Land deposit of sludges can contribute to diffusive spread of materials as phosphorus and metals due to leakage and emission of materials such as methane gas (a green house gas), methylated metal compounds (such as methylated mercury) and odours. In order to reduce landfill deposit of sludges a fee must be paid in Sweden of 250 SEK/metric ton of sludge. The use of sludge for land building, restoration of land and use for covering of landfills may be limited in the future due to lack of land and possible negative environmental effects.

Sludge incineration has gained much interest as a method for final handling of sewage sludges (Jungvik, 1998). This technology is not yet practiced to a significant extent in Sweden. The investment and operational costs are rather high and there may also be a problem to obtain a permit to build an incineration plant. Therefore, attention has been directed towards co-incineration in already existing incineration plants. Co-incineration may be applied in an incineration plant for municipal solid wastes, for biofuels (wood, peat etc), coal or plants producing building materials at high temperatures (cement, brick etc). Some experiments have been done with co-incineration of sewage sludge together mainly with municipal solid wastes. The experiments have in general been positive although some problems have been obtained related to sintering of ashes and increased concentration of sulphur dioxide, nitrogen oxides and volatile metals (mercury and cadmium) in the flue gases. The need for complementary investments, if co-incineration is practised, in flue gas treatment or handling of ashes need to be further studied. Possibilities to recover phosphorus from ashes have not yet been evaluated. Studies have, however, started in this area.

During the last years an increased interest has been devoted to extraction of products from sludge (cf Mossakowska et al., 1998). Two commercial systems are mainly under consideration in Sweden, namely the KREPRO (Water Quality International, 1996a) and Cambi (Water Quality International, 1996b) processes. Both of these methods have their roots in old process technologies (as the Zimpro and Porteous processes; US EPA, 1979). Different substances are dissolved from the sludge by heat and pressure treatment (and in addition acids as in the KREPRO process). Main reasons in the old technologies were to diminish the sludge amount and condition the sludge before dewatering, while the liquid stream with different dissolved substances was mainly regarded as a problem (Mossakowska et al., 1997). The Cambi and KREPRO processses aim to see the dissolved substances as resources as improved methan production in the digester (Cambi) or reuse of precipitation chemicals, production of a fertiliser (ferric phosphate), and separate removal of heavy metals in a small stream (KREPRO).

The Cambi and KREPRO processes may be performed with different modifications and extensions. Both of the processes use dissolution technologies of sludge compounds in one stage. At the division of Water Resources Engineering, KTH, research has been directed towards selective dissolution of sludge compounds. The general idea is that selective dissolution of compounds from the sludge facilitates recovery of resources from the sludge. In addition, the KTH studies try to find better use of internal sludge products to facilitate and improve the wastewater treatment. Ideas behind the KTH studies are presented below in a separate section.

II.3 DISCUSSION OF SLUDGE HANDLING PRACTICES

Main practises of sludge handling have been discussed above. In addition a lot of other methods have been studied, although the methods have not been used significantly in practice. Some restrictions of the methods based on sustainability are shown in Table 3.

Table 3. Some restrictions of sludge handling methods based on sustainability

Sludge handling method	Restrictions
Agricultural use (similar restrictions for horticulture and forests)	o Restrictions based on sludge components (metals, toxic organics, pathogens etc) o Restrictions based on nutrients and metals supply to land o Restrictions based on acceptance from food industry and public o Technical restrictions (handling of the sludge etc)
Land deposition	o Restrictions based on maximum organic contents in the sludge o Restrictions due to costs based on fees o Restrictions due to scarcity of land o Restrictions related to permits of new land fill areas o Restrictions due to recycling requirements (i.e. phosphorus recycling)
Land building and reclamation	o Restrictions due to availability of suitable land o Restrictions due to transportation distance to suitable land o Restrictions due to environmental impact o Restrictions due to recycling requirements (i.e. phosphorus recycling)
Incineration	o Restrictions due to permits of building an incineration plant o Restrictions due to possibilities of co-incineration o Restrictions due to costs (including costs for treatment of flue gases and ashes)
Product recovery from sludge	o Acceptance from users of the sludge products (market considerations) o Needs of resources for product recovery (chemicals, energy, costs etc) o Restrictions due to technical problems

The sludge handling methods in Table 3 may be modified in many ways to comply with requirements. Different examples are given below:

o Agricultural use:
- Hygienisation of the sludge
- Removal of metals by treatment of sludge for instance by acids
- Improvement of sludge handling properties (composting, drying etc)
- Addition of alkaline materials (lime, cement dust etc)
- "Dilution" of sludge by addition of different materials (co-composting with other materials, addition of weighting materials, addition of special conditioning materials or rest products etc)

o	Land filling	- Improvement of sludge handling properties - Decrease of leaching from sludges and ashes
o	Land building and reclamation	- Improvement of sludge handling properties - Decrease of leaching from sludges and ashes
o	Incineration	- Pre-treatment of sludges before incineration - Improvement in incineration technology - Improvement of flue gas treatment - Improvement of handling of ashes (including resources recovery and leaching from ashes)
o	Product recovery	- Improvement of product quality - Decrease in use of chemicals and energy in product recovery - Acceptance of products from industry and public - Removal of toxic substanses as a sidestream

A wastewater treatment plant should have a flexibility in sludge handling. The different options shown in Table 3 should be considered. Sludge use for agriculture is often considered as the best alternative but may have difficulties to be accomplished due to many restrictions. Landfills, use of sludge in land building and land reclamation and incineration have limits related to resources recovery and environmental impact. Product recovery from sludges is still in a development phase but has the potential of both recover resources and destruct pollutants or remove them into a small concentrated stream. The potential of products recovery from sludges will therefore be discussed in more detail in the following.

III. PRODUCT RECOVERY IN SLUDGE HANDLING

III.1 DIFFERENT PRODUCTS

A large number of products may be produced from sludges. The products may be used for internal or external purposes (see Table 4 and 5).

Table 4. Examples of products in sludge handling used for internal purposes

Type of product	Use of product
Gases	
Carbon dioxide	Neutralisation of wastewater by use carbon dioxide produced for instance from anaerobic digestion or incineration
Methane gas	Energy production (heat, electricity)
Gases from pyrolysis	Energy production (heat, electricity)
Liquids	
Organic acids	Production of methane gas, improvement of denitrification and biological phosphorus removal
Nitrate	Decrease of odour problems
Metal ions as aluminium, ferrous or ferric ions	Reuse as precipitation chemicals
Solids	
Compost	Decrease of odour problems (compost filters)
Activated carbon	Adsorption of organic materials on activated carbon produced in pyrolysis of sludge
Nitrification bacteria	Seeding of nitrification bacteria produced in nitrification of supernatant
Sludges with a low volatile fraction	Use as weighting materials to improve sedimentation in for instance the activated sludge process

Table 5. Examples of products in sludge handling used for external purposes

Type of product	Use of product
Gases	
Methane gas	Energy production (heat, electricity), use as fuel in vehicles
Gases from pyrolysis	Energy production (heat, electricity)
Liquids	
Oil from pyrolysis	Energy production (heat, electricity)
Solids	
Sludge	Use in agriculture (with different possibilities to improve the sludge quality), reclamation of land, land building, heat production in incineration etc
Compost	Use as soil conditioner, fertiliser etc
Nutrient salts	Use as fertilisers for instance as ammonium sulphate, magnesium ammonium phosphate and calcium phosphates (Bertin et al., 1997, Dorre, 1998, Hultman et al., 1997, and Morse et al., 1998)
Special products	Calcium magnesium acetate for use as de-icing salt or reduction of nitrogen oxides in flue gases, etc
Inorganic part of the sludge	Use as building materials (cement, brick, glass ceramics, etc)

III.2 PRINCIPLE METHODS FOR SLUDGE PRODUCT RECOVERY

The main sludge handling practice in large plants in Sweden includes sludge thickening, digestion, sludge conditioning by polyelectrolytes, dewatering, and transport of sludge to its final destination. The sludge handling diminishes the sludge volume mainly by the thickening and dewatering steps and decreases partly the organic part of the sludge during the anaerobic digestion. This step produces a valuable product in the gas phase (methane gas) that can be used for energy production and as a fuel for vehicles. The solid phase (digested sludge) is, however, a mixture of different substances that can be used as products (nutrients, organics, inorganic materials) and different pollutants (heavy metals, toxic organics, etc). Sludge product recovery, therefore, aims at separating sludge components into different fractions that can be used as products and fractions with pollutants that can be destructed or separated from the sludge (Kabacinski et al., 1998, and Mossakowska et al., 1998).

A sludge handling system with product recovery may involve the following steps:

- o Dissolution of sludge components by different methods (Wale, 1993, and Fujii, 1997) such as:
  - Physical (heat, pressure etc)
  - Mechanical (disruption of cells by mechanical devices, use of ultrasonics, etc)
  - Biological (anaerobic treatment for production of organic acids, use of enzymes, etc)
  - Chemical (use of acids, bases, oxidising chemicals as hydrogen peroxide and ozone, etc)

- o Direct use of the treated sludge (such as heat treatment of the sludge followed by enhanced methane gas production in the digester as in the Cambi process) or separation of the liquid phase from the sludge phase (such as separation after the digester of supernatant with a high contents of nutrients from the digested sludge)

- o Product recovery from the liquid stream (such as precipitation of magnesium ammonium phosphate (Bertin, 1998) by the addition of magnesium salts and sodium hydroxide to the supernatant from the digester). The product recovery may include several steps in order to obtain clean products without contamination of different pollutants (cf the KREPRO process).

IV. STUDIES OF SLUDGE HANDLING AT KTH

IV.1 MAIN GOALS

At the div. of Water Resources Engineering, KTH, studies have been going on during the last years to find solutions for a sustainable sludge handling at centralised municipal wastewater treatment plants (Hultman et al., 1997 and Rybicki, 1997). Main ideas for the sludge handling are:

- o The sludge handling scheme should consider most of the sludge components as resources suitable for manufacturing of products, while the pollutants should be separated into a small stream or be destructed.

- Main resources in the sludge for external use are:
  - Nutrients that can be produced as salts
  - Organics for energy use (fuel for vehicles, production of heat and electricity)
  - Inorganic materials for production of building materials (Lubarski et al., 1996)

- Main resources in the sludge for internal use are:
  - Organic acids for methane production or use in denitrification or biological phosphorus removal
  - Release from the sludge of ammonium that can be nitrified to produce nitrate (possible use for prevention of hydrogen sulphide) and nitrification bacteria (for seeding purposes) (Li and Hultman, 1997)
  - Aluminium ions released from zeolites in acid conditions
  - Aluminium or iron ions obtained from treatment of sludges from chemical precipitation or water works sludges (Juhna, 1997)
  - Sludges with a low volatile fraction for use as weighting agents (Li and Hultman, 1997, and Piirtola, et al., 1998)
  - Special sludge products as compost (use for odour reduction in compost filters) and pyrolysed sludge (used for adsorption)

- Pollutants in the sludge that should be separated or destructed are (Levlin et al., 1996):
  - Pathogens (may be destroyed by heat)
  - Toxic organics (may be destroyed at high temperatures)
  - Heavy metals (may be separated into a small stream)

- The sludge handling may consist of at least two steps for dissolution of sludge products in order to facilitate further recovery of sludge products

- The costs for sludge products manufacturing should be compensated due to:
  - Less sludge from the plant (due to for instance increased conversion of organic materials in the sludge into methane gas)
  - Internal use of products (organic acids, nitrification bacteria, precipitation chemicals, weighting agents, etc) which will lead to less costs for wastewater treatment in the main stream
  - Better conditioning effects for the sludge (for instance improved dewatering compared with conventional technics)
  - Less costs due to transportation and deposition of sludge
  - Value of sludge products for external use

IV.2 IMPLEMENTATION OF MAIN GOALS

An example of sludge handling system with sludge products recovery is illustrated in Figure 1. The system is based on recovery of products after two different steps. Sludge from a biological phosphorus removal process will release both phosphates and ammonium during anaerobic digestion. After separation of the digested sludge, the liquid stream may be used for the production of for instance magnesium ammonium phosphate. Increased release of ammonium, phosphate and organics will occur if the sludge is treated by heat before the digester (as in the Cambi process). Recycling of digested sludge back to the aeration basin of the activated sludge may decrease the amount of organic material in the sludge and the digested sludge may act as a weighting material (cf Carrio et al., 1985, and Torpey et al., 1984). Another possibility to decrease the sludge amount of organic materials from the digester is to treat the digested sludge in a separate stage with chemicals as acids or bases and recycling of the treated digested sludge back to the digester (cf Meunier et al., 1996, and Takashima et al., 1996).

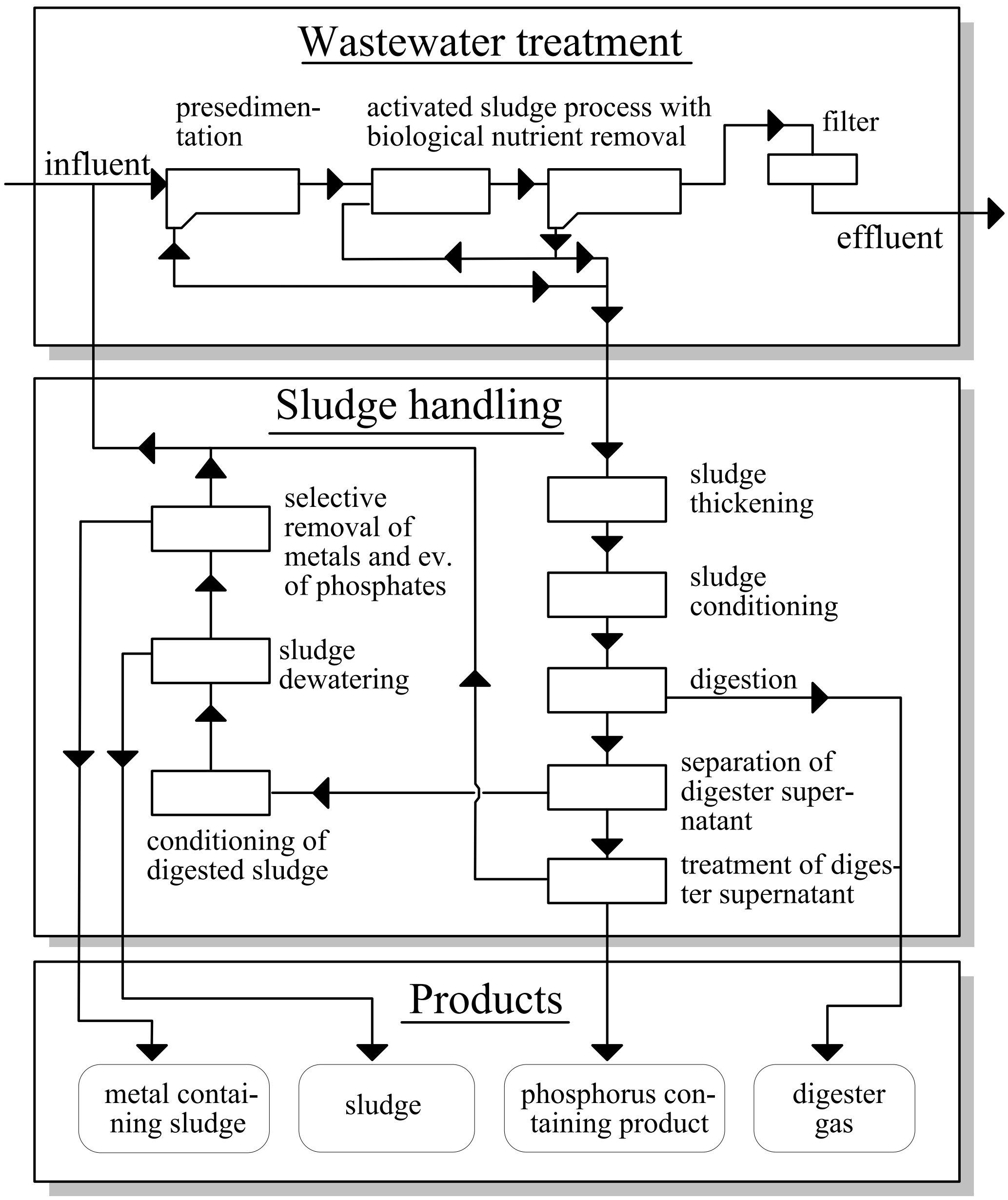

Figure 1. Modified sludge handling for product recovery.

The digestion process has released or removed a large fraction of the organics, nitrogen and phosphorus and the degree depends on pre-treatment of sludges before the digester and if a special post-treatment of the digested sludge with recycling is used. However, sludge from the digester contains both valuable materials as phosphorus and precipitation chemicals and pollutants as heavy metals and organic micropollutants.

In order to dissolve these compounds from the sludge other technologies may be used as:

- Use of heat, acids and pressure as in the KREPRO process

- Dissolution of phosphates from iron phosphates by addition of hydrogen sulphide (the hydrogen sulphide may also be produced biologically) (cf Ripl et al, 1988). Formed iron sulphide may then be used to release metals from the sludge in a biological reactor oxidising the ferrous sulphide to ferrous sulphate and sulphuric acid.

Toxic metals may be recovered in a small stream and remaining sludge containing inorganic materials and persistent organics may be used as a resource in the building industry.

CONCLUSIONS

- Sustainable sludge handling means that resources in the sludge are recycled, while pollutants in the sludge are destructed or removed from the sludge phase.

- Restrictions on traditionally used sludge handling methods as agricultural use, landfilling and incineration have increased the interest to use the sludge for different products.

- Products from sludge may have a value both for internal use to improve the wastewater treatment and for external use.

- A lot of possibilities are available to recover sludge products. At the div. of Water Resources Engineering, KTH, a system is proposed with sludge hydrolysis at two stages in order to facilitate sludge products recovery.

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REFERENCES

Bertin, P.D. (1998). Phosphate recovery from sewage sludge through MAP (struvite) formation. Master of Science Thesis in preparation, Div. of Water Resources Engineering, Royal Institute of Technology.

Brett, S., Guy, J., Morse, G.K. and Lester, J.N. (1997). Phosphorus removal and recovery technologies. Publ. Div. Selper Ltd, 79 Rusthall Avenue, Chiswick, London W4 1BN, UK, ISBN 0 948411 10 0.

Carrio, L.A., Lopez, A.R., Krasnoff, P.J. and Donnellon, J.J. (1985). Sludge reduction by in-plant process modification: New York City's experiences. J. Water Pollution Control Federation, 57, 2, pp. 116-121.

Dorre, A. (1998). Phosphorus removal and recovery. Review. Master of Science Thesis in preparation. Div. of Water Resources Engineering, Royal Institute of Technology.

Fujii, D. (1997). Waste activated sludge reduction by chemical hydrolysis, endogenous respiration, and predation. Master of Science Thesis, Div. of Water Resources Engineering, Royal Institute of Technology, AVAT-EX-1997-02.

Harremoës, P. (1996). Dilemmas in ethics: Towards a sustainable society. Ambio, 25, 6, pp. 390-395.

Hultman, B., Levlin, E., Löwén, M. and Mossakowska, A. (1997). Uthållig Slamhantering, Förstudie (Sustainable sludge handling, pre-study). Stockholm Water Co., R. Nr 23 Sept-97.

Hultman, B. and Levlin, E. (1998). Sustainability principles and water management. Sustainable water management, 2, The Baltic University Programme, Uppsala University.

Juhna, T. (1997). Water treatment residues handling at Daugava water treatment plant. Master of Science Thesis, Div. of Water Resources Engineering, Royal Institute of Technology, AVAT-EX-1997-09

Jungvik, E. (1998). Thermal treatment of municipal wastewater sludge. Master of Science Thesis in preparation, Div. of Water Resources Engineering, Royal Institute of Technology.

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. Paper accepted for the nineteenth biennal conference of the International Association on Water Quality (IAWQ), Vancouver, Canada.

Lass, E. (1997). Zeolithe in der Abwasserreinigung und ihre Löslichkeit in Abhängigkeit vom pH-Wert. Studienarbeit. Institut fur Siedlungswasserwirtschaft und Abfalltecknik, Universität Hannover.

Li, P. and Hultman, B. (1997). Effects of weighting agents and seeded nitrification bacteria on the activated sludge process - Evaluation by use of simple models. Vatten 53, 1, pp. 21-25.

Levlin, E., Westlund, L. och Hultman, B. (1996). Rening av avloppsslam från tungmetaller och organiska miljöfarliga ämnen (Removal of heavy metals and organic toxic contaminants from sewage sludges). VA-forsk 1996-08, ISSN 1102-5638, ISBN 91-88392-99-6.

Lubarski, V., Levlin, E. och Koroleva, E. (1996). Endurance test of aluminous cement produced from water treatment sludge. Vatten, Vol. 52, No. 1, pp. 39-42.

Menieur, N., Tyagi, R.D. and Blais, J.F. (1996). Traitement acide pour la stabilisation des boues d'épuration. Can. J. Civ. Eng., 23, 76-85

Morse, G.K., Brett, S.W., Guy, J.A. and Lester, J.N. (1998). Review: Phosphorus removal and recovery technologies. The Science of the Total Environment, 212, pp. 69-81.

Mossakowska, A., Hellström, B.G. and Hultman, B. (1998). Strategies for sludge handling in the Stockholm region. Paper accepted for the nineteenth biennal conference of the International Association on Water Quality (IAWQ), Vancouver, Canada.

Mossakowska, A., Reinius, L.-G. and Hultman, B. (1997). Nitrification reactions in treatment of supernatant from dewatering of digested sludge. Water Environment Research, 69, 6, pp. 1128-1133.

Piirtola, L., Hultman, B. and Löwén, M. (1998). Detergent zeolite in nitrogen removal activated sludge process. Paper accepted for the nineteenth biennal conference of the International Association on Water Quality (IAWQ), Vancouver, Canada.

Ripl, W., Stammert, B., Wiesmann, U. and Karimnia, M. (1988). Rückgewinnung von Phosphor und Fällungsmitteln (Eisen) aus Nachfällschlamm. Vom Wasser, 70, pp. 179-185.

Rybicki, S. (1997). Advanced Wastewater Treatment Report No. 1, Phosphorus removal from wastewater, A litterature review, Joint Polish - Swedish Reports. Div. of Water Resources Engineering, Royal Institute of Technology, TRITA-AMI REPORT 3042, ISSN 1400-1306, ISRN KTH/AMI/REPORT 3042-SE, ISBN 91-7170-247-4.

SEPA (1995). Användning av slam i jordbruket (Use of sludge in the agriculture). Report 4418, Naturvårdsverket (Swedish Environmental Protection Agency) Förlag, ISBN 91-620-4418-4.

Takashima, M., Kudoh, Y. and Tabata, N. (1996). Complete anaerobic digestion of activated sludge by combining membrane separation and alkaline heat post-treatment. Wat. Sci. Tech., 34, 5-6, pp. 477-481.

Torpey, W.N., Andrews, J. and Basilico, J.V. (1984). Effects of multiple digestion on sludge. J. Water Pollution Control Federation, 56, 1, pp. 62-68.

Wale, M. (1993). Kemiska och termiska metoder för slamkonditionering (Chemical and thermal methods for sludge conditioning). Master of Science Thesis, Div. of Water Resources Engineering, Royal Institute of Technology, TRITA-VAT-2933.

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

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