TRENDS IN SWEDISH SLUDGE HANDLING

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ABSTRACTS

Trends in sludge handling are described based on the need for sustainable sludge handling. One way is to improve source control and existing sludge technology. The sludge may then be used in agriculture. Difficulties may be more stringent requirements and to get acceptance for the agricultural use by public and the food industry. Separation of wastewater streams may improve possibilities for resources recovery and to diminish risks for contamination of the sludge. Products recovery from sludge has many promising possibilities and is examplified in case of phosphorus.

KEYWORDS

Phosphorus recovery, sludge handling, sludge products, sludge use, source control, Sweden, sustainability.

PRESENT SITUATION

Sweden has a population of about 8.8 million people. The percentage of people living in urban areas is about 83% and the rest live in rural agglomerations (3%) or in sparsely populated areas (14%). More than 1/3 of the urban dwellers live in the three main metropoletan areas of Stockholm, Gothenburg and Malmö. There are now approximately 2,000 municipal wastewater treatment plants and 95% of the population in towns and agglomerations with more than 200 inhabitants are served by plants with tertiary treatment with biological and chemical treatment. The remaining percentage has only chemical treatment and these plants are especially located in northern Sweden.

Wastewater treatment plants has been built successively in Sweden with focus on mechanical treatment between 1930 and 1950, biological treatment between 1950 and 1970, and chemical treatment with mainly iron and aluminium salts between 1970 and 1990. After 1990 main focus has been given to nitrogen removal by use of nitrification and denitrification (Hultman 1998).

Sludge produced at small plants or septic sludge obtained from local areas with septic tanks is normally transported to larger treatment plants. Dewatering and stabilisation of sludges are requirements for plants with more than 2,000 persons connnected. Each year the municipal wastewater treatment plants in Sweden produce approximately 1 million m^3 dewatered sludge with a corresponding dry solids content of 180,000 tonnes (VAV, 1991).

Centrifuges are the most common by used dewatering equipment followed by belt screens. Filter presses have only a minor usage and vacuum filters are no longer in use. The dominating conditioning agent is organic polyelectrolytes. Other conditioning methods as use of acids, heat, iron salts, lime etc have only a minor use. The KREPRO process (Water Quality International, 1996a) uses sludge conditioning by use of acids and heat and is practiced in full scale at the wastewater treatment plant in Helsingborg. At present there is a growing interest to more efficiently use natural and biological dewatering methods, for instance by use of reeds.

Sludge is stabilised by the following methods: Anaerobic digestion (70%), lime stabilisation (15%), aerobic digestion (3%), and composting (6%). Only 3% of the sludge is not stabilised (Wittgren, 1996). All large treatment plants use anaerobic digestion, while the other methods are used at small and medium-sized plants.

Heat drying has been installed at Himmerfjärden treatment plant south of Stockholm (Dahlberg et al., 1995). Incineration is not practiced at present but is considered as a future possibility for large treatment plants.

Co-treatment of municipal wastewater treatment sludges with solid wastes has recently obtained an increased interest and with the following applications:

- Sludge incineration together with municipal solid wastes or biofuels (Hultman et al., 1998)
- Anaerobic digestion of sludge together with other organic materials
- Large-scale composting of sludge together with other organic materials. In Stora Vika, 60 km south of Stockholm, Rondeco has had a pilot plant for one year. A permit has been issued for a 1,000 tonnes per day facility (Minestry of Foreign Affairs and SEPA, 1999).

Sludge disposal in Sweden in 1988 and in the European Union is shown in Table 1.

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

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

Main sludge disposal in Sweden is to agriculture or landfill similar to practice used in the European Union. The authorities have encouraged the use of sludge on agricultural land if the sludge quality fulfils certain requirements concerning heavy metals and some key organic substances (Minestry of Foreign Affairs and SEPA, 1998). However, the Federation of Swedish Farmers (LRF) recommended its members not to use sludge after January 1, 1990. Later on a national consultation group has been formed in Sweden between LRF, the Swedish Water and Waste Water Works Association (VAV) and the Swedish Environment Protection Agency (SEPA). This group has reached agreements concerning agricultural use of sludge. The future agricultural use of sludge is, however, uncertain and under debate. Landfill of sludge will be restricted in the future and will only be allowed for sludges containing a low fraction of organic material.

DRIVING FORCES FOR CHANGES IN SLUDGE HANDLING

The Brundtland Commission's report "Our Common Future" and "Agenda 21" have influenced actions to find sludge handling methods that are sustainable. In addition to earlier requirements for sludge handling related to odour problems, hygienisation, volume reduction, cost-effectiveness etc more focus will be given to recovery of nutrients and other materials, energy recovery, use of energy efficient methods and destruction or separation of harmful substances in the sludge. Three different ways may be used to reach these goals:

(1) Use of source control and improvements of existing technology

(2) Use of source control and separation of streams
(3) Use of source control and product recovery from sludge

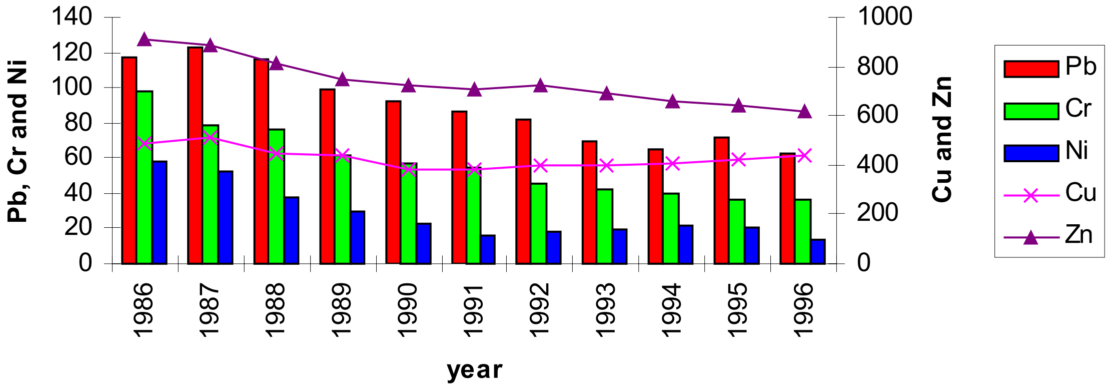
These three methods will be briefly discussed in the following.

SOURCE CONTROL AND IMPROVEMENTS OF EXISTING TECHNOLOGY

The purpose of the source control is to reduce the amount of supplied harmful substances into the sewer net as much as possible. Different actions involved are:

- Stringent control of industrial discharges into the sewer net
- Information campaigns to households to avoid discharges of toxic materials into the toilet, recommendations to use environmentally friendly consumer goods etc
- Avoidance of discharges of polluted stormwater into the sewer net

By these actions the metal concentration in the sludge has been reduced significantly during the last decade. This is illustrated for the largest treatment plant (Henriksdal) in Stockholm (see Figure 1). The improvements of the sludge quality has been followed by much more stringent requirements for the metal concentrations in the sludge for agricultural use (see Table 2).



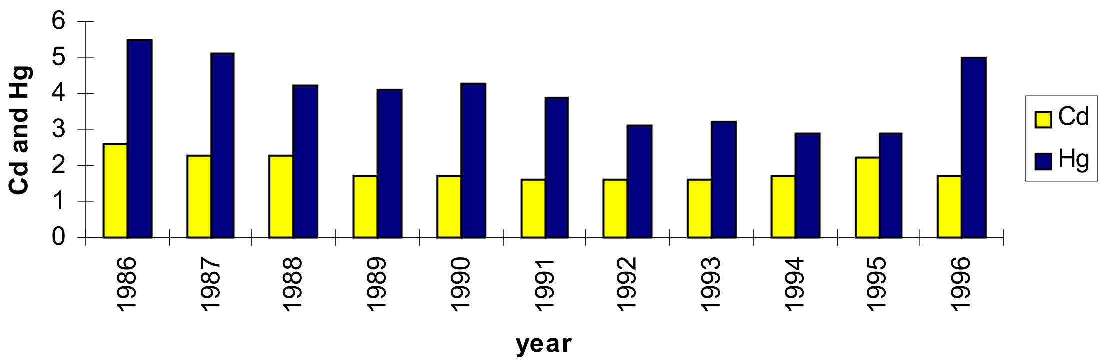


Figure 1. Metal concentration (mg/kg DS) in sewage sludge from Henriksdal 1986-1996 (Mossakowska et al., 1998).

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

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

Figure 1 illustrates some of the problems related to source control. The increase of mercury in the sludge in 1996 compared with 1994 and 1995 depended on illegal discharges from a small company and illustrates that even a small company can significantly worsen the sludge quality at a large treatment plant. Other components may be difficult to influence at a shorter time interval without excessive costs. The discharges of copper is mainly dependent on copper tubes inside houses. Replacement of copper pipes is very costly and different actions to change water quality with regard to copper corrosion is also costly.

Short term discharges from industries due to accidents etc can be handled with respect to agricultural use by use of an efficient sludge quality control. At Henriksdal the sludge quality is measured by use of automatic samplers for digested sludge and dewatered sludge. If analyses of the digested sludge show too high values of metals, the sludge is transported to an intermediary sludge deposit or directly to landfill (Mossakowska et al. 1998). The long-term discharges of pollutants for instance from building materials are more difficult to effect and may inhibit agricultural use of sludge if more stringent requirements will be applied.

The combined use of efficient source control and measurements of sludge quality makes it possible to use the sludge in a controlled way for agriculture provided the sludge quality fulfils the requirements. In this way resources in the influent wastewater can be recovered, i.e. most of the phosphorus, a fraction of the nitrogen (about 20%) and part of the organics that can be used for soil improvements. Improved sludge handling methods can result in energy savings and energy production from biogas.

The way to successively improve source control and existing sludge treatment processes and use of sludge in agriculture may be a long range solution for sustainable sludge handling. If more stringent requirements should be used in the future these may be difficult to fulfil with present technology. Acceptance of agricultural use of sludge by public, food industry and environmental groups is important to achieve.

SOURCE CONTROL AND SEPARATION OF STREAMS

The ideas behind this way are normally focusing on some limitations of traditional sludge handling and that source control should be combined with separation of streams. Possible improvements are:

- The amount of harmful substances may be diminished if pollutant sources from industries and polluted stormwater will not influence household wastewater

- Most of the nutrients are in toilet water and thereby especially in urine. Separate handling of urine may recover about 60% of the phosphorus and 80-90% of nitrogen from household wastewaters.

Separation of streams is widely used in internal handling of wastewaters in industries. In Sweden research has started on the use of separation of different wastewater streams. In a booklet by Olof Eriksson (1996) "Re-build Sweden for sustainability"' a substantial substitution was proposed of existing toilet system into urine separation toilets. Olof Eriksson was a special adviser in environmental issues for the prime minister and the ideas gave rise to an intensive discussion and resulted in some research and development works. Some objections to the use of urine separation toilet were the high costs involved and possible problems with odour and public acceptance.

Separation of streams is a possible way to improve obtained sludge qualities and to use resources from wastewaters in a more efficient way. A far-reaching change of existing wastewater handling infrastructure into separated wastewater streams would be very costly. However, results from different research and development works may lead to an increased use of separation of wastewater streams, especially at new-built and condensation areas. Several "ecological villages" have been built for better eco-cycling of resources.

SOURCE CONTROL AND PRODUCT RECOVERY

The idea of this way is to solve the problem of having a sludge mixture containing both resources and harmful substances. By splitting up the sludge into fractions that can be used as products (nutrients, organic substances for energy production and inorganic materials for use as building materials) and one fraction that contains the harmful substances that not been destructed during the sludge handling. This fraction must be deposited in a controlled way. Product recovery is facilitated if an efficient source control is used and the fraction with harmful substances will be diminished.

In the Nordic countries two systems are in use for product recovery, namely KREPRO and Cambi (Water Quality International, 1996a and 1996b). The KREPRO system has been installed at the municipal plant in Hälsingborg, Sweden, and Cambi at the municipal plant at Hamar, Norway.

The KREPRO system uses acids, high temperature and pressure in order to transfer components in the sludge into a liquid phase. This phase will contain substances as phosphates, metal ions suitable for precipitation and heavy metals. Different methods can be used to separate the components for instance precipitate heavy metals as sulphides and recover phosphate as ferric phosphate. The remaining sludge contains certain inorganic compounds and organic materials mainly consisting of cellulose. This sludge may be used for heat production in incineration.

The Cambi system treats sludge before the digestes by use of steam and pressure. This causes release of different components in the sludge as phosphates, ammonium and certain organic substances and makes the sludge more biodegradable. The main objectives of the process are to increase biogas production and decrease sludge production. Supernatant from the digester contains high concentrations of nutrients that can be recovered by different methods.

Different options for sludge fractionation are shown in Table 3. A general scheme for sludge fractionation and product recovery is illustrated in Figure 2. Sludge fractionation may also be performed at different stages of the sludge handling process: Handling of separate streams as anaerobic treatment of primary sludge, secondary sludges, for instance to decrease sludge production and recovery of post-precipitated sludges; Treatment of combined sludges before anaerobic digestion (as in Cambi); Treatment of digested sludge for recirculation to the digester to increase gas production and decrease sludge volume; Treatment of digested sludge for product ecovery and removal of heavy metals (as in the KREPRO-process).

A research project has recently started at the div. of Water Resources Enginering, KTH, to evaluate the feasibility of sludge fractionation. Focus will be given on biological methods and phosphorus recovery. Results obtained so far and some ideas for future studies will be presented in next section.

Table 3. Different options for sludge fractionation.

Methods	General purpose
Physical	
Heat/pressure	Solution of sludge components, sludge conditioning
Mechanical	
Mechanical devices, ultrasonics	Disruption of cells for improved sludge degradation
Biological	
Enzymes	Solution of sludge components, increased biodegradabilty of the sludge
Anaerobic treatment	Production of organic acids, release of phosphates
Sulphate reducing bacteria	Production of sulphides for release of phosphates and precipitation of metals
Sulphur sulphide and ferrous oxidising bacteria	Production of hydrogen ions for release of metals from sludge
Chemical	
Acids, bases, oxidising agents (ozone, hydrogen peroxide etc.)	Hydrolysis of sludge, release of different sludge components, conditioning of sludge, increased biodegradability of sludge
Complexing agents	Release of metals etc. from sludge

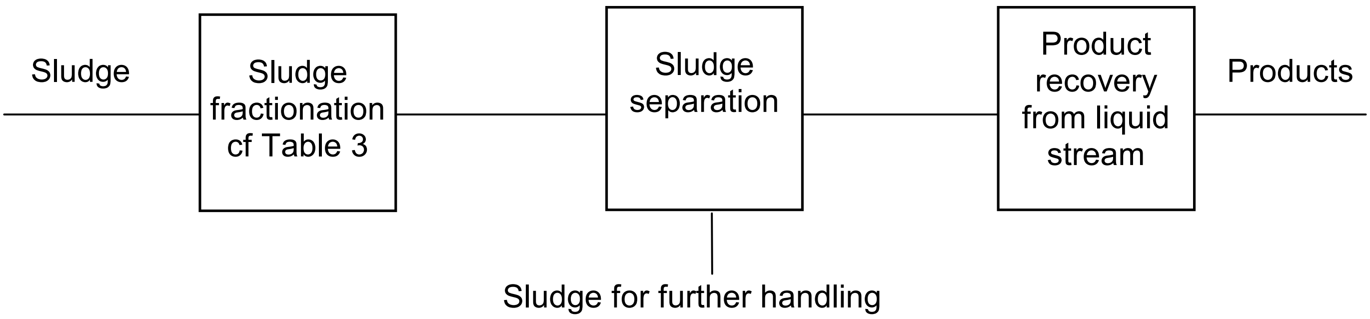


Figure 2. General scheme for sludge fractionation and product recovery.

PHOSPHORUS RECOVERY STUDIES AT KTH

A starting point of the phosphorus recovery studies was the modified sludge handling system shown in Figure 3. The system is based on recovery of products after two different stages. Sludge from a biological phosphorus removal process will release both phosphates and ammonium during anaerobic digestion. After separation of digested sludge, the liquid stream may be used for the production of for instance magnesium ammonium phosphate. By use of conditioning of the digested sludge with heat, pressure, acids etc additional materials are released from the sludge and different products may be recovered from the liquid phase (organic materials, precipitation agents etc) and toxic metals may be removed selectively. The remaining sludge has a high dry solids content after dewatering and may be used for instance for energy production.

The suggested system was designed to be flexible but can be modified in different ways. The total effect of sludge fractionation may be difficult to evaluate due to that sludge fractionation influences the sludge handling in many ways as:

- Diminishment of the sludge mass due to transfer of substances to the liquid phase
- Changes in sludge structure influencing its dewatering and biodegradability properties
- Special needs for handling the liquid phase for product recovery etc.
- Influence on safety and odour

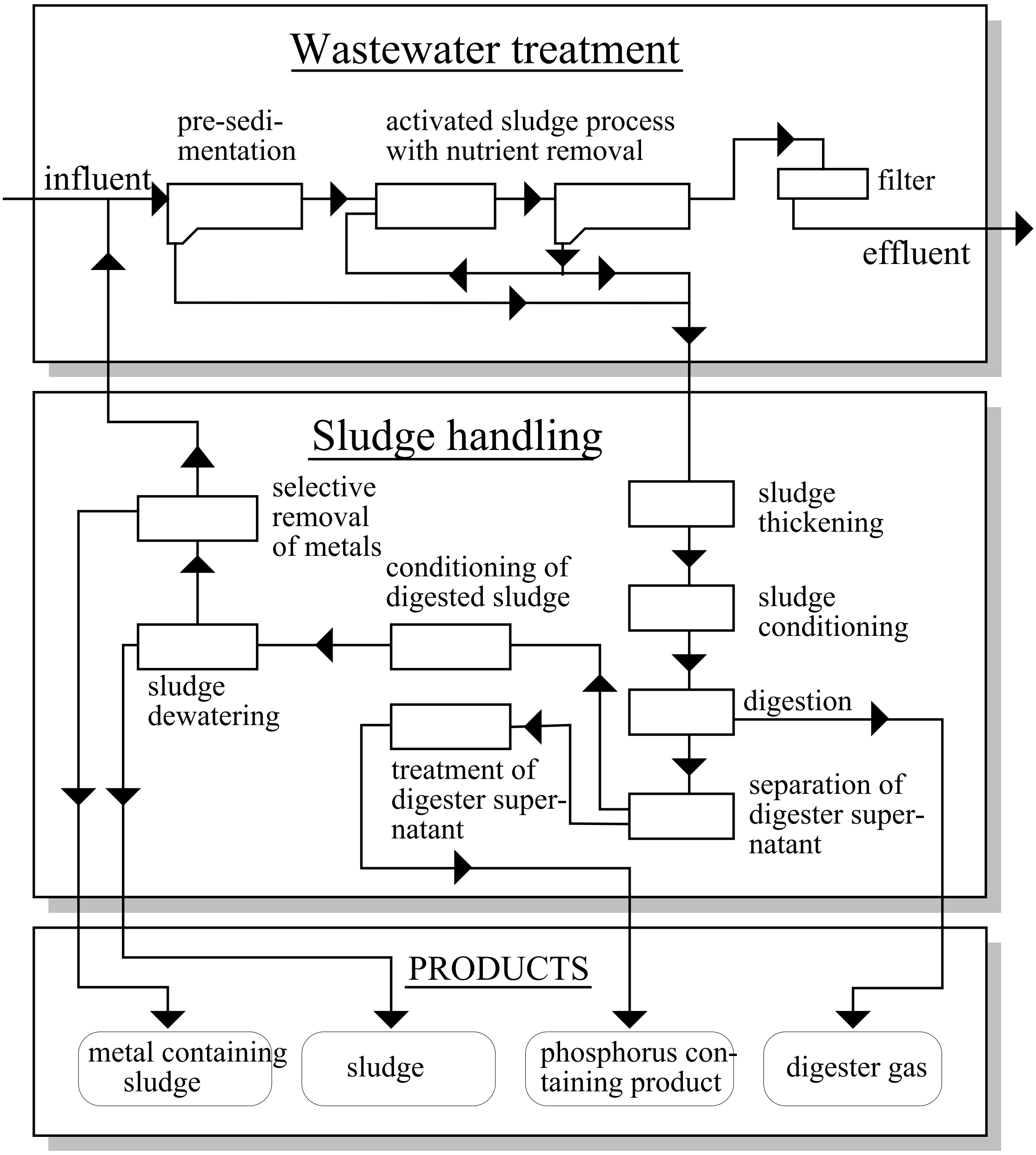


Figure 3 Modified sludge handling for product recovery (Hultman and Levlin, 1997, Mossakowska et al., 1998).

In order to recover phosphorus from the sludge a first step is to transfer sludge from the liquid phase from the sludge. The liquid phase can then be treated by precipitation chemicals to produce for instance calcium phosphates or magnesium ammonium phosphate or recovered as phosphoric acid by extraction.

Four methods have mainly been considered to release phosphates from sludges:

(1) Anaerobic treatment of excess sludge from a biological phosphorus step. This process is the most studied technology for phosphorus recovery. The anaerobic treatment of the sludge is performed in a digester. The liquid phase from the digester is rich in ammonium and phosphates and may be treated for phosphorus recovery (Rybicki, 1997, Schmidt, 1998). A higher release of ammonium and phosphates is obtained by use of special treatment before the digester as in the Cambi process.

The efficiency of biological phosphorus removal combined with anaerobic release in the digester is about 50% calculated on the supplied phosphorus in the influent to the treatment plant. This is due to the reasons that phosphorus is precipitated with certain metal ions and adsorbed on material surfaces and is therefore still bound in the sludge phase. For a more efficient phosphorus recovery the biological method should be complemented with a dissolution method of metal phosphates and adsorbed phosphates.

(2) Use of acids and bases. Both iron phosphates and aluminium phosphates dissolve at acid or high alkaline conditions. Zoppoth (1998) has studied release of phosphate by addition of acids and bases from post-precipitated sludge from the filtration stage at the wastewater treatment plant at Henriksdal. Addition of HCl to pH 2-3 resulted in a nearly complete dissolution of the inorganic material. The precipitation agent was ferrous phosphate. If sodium hydroxide was added to pH-values between 9 and 12 no significant release was obtained for phosphates. This may be due to binding of phosphates as calcium phosphates. Fujii (1997) have found that treatment of excess sludge with sodium hydroxide to pH 12 resulted in a decrease of the organic sludge concentration with about 30%.

(3) Use of sulphide reactions. The idea is similar to reactions in bottom sediments of eutrophied lakes there sulphide reacts with iron compounds to form iron sulphides and with a subsequent release of phosphates. Zoppoth (1998) also studied the effects of sulphide additions of post-precipitated sludge from the filter step at Henriksdal. I was found that only addition of sulphides at neutral pH-values did not cause any significant release of phosphates from the sludge. If the pH-value was lowered to 4 a phosphate release of about 80% could be obtained.

Instead of adding sulphide, it may be produced by sulphate reducing bacteria. In a on-going master thesis work this idea is tested where sulphate is added to excess sludge and primary sludge. The phosphate release seems to be low at neutral pH-values and and it seems necessary to reduce the pH-value to below about 4 to get an efficient release of phosphates.

Possibilities to use a two-stage bacterial process with sulphur reactions might be of interest. In the first step sulphate is reduced to produce sulphide and in the second step acid is produced by oxidising sulphides to sulphuric acid.

If sulphur reactions are used in phosphorus recovery it is important to consider safety risks and problems with odour and corrosion.

(4) Use of heat treatment. This technique is used both in the KREPRO and Cambi processes. At the div. of Water Resources Engineering, KTH, studies will be made at lower temperatures (up to 100 ºC). The purpose is to evaluate possible increases of sludge products release from the sludge and changes in sludge biodegradability. By use of hot water polyphosphates are transferred into orthophosphates (Uhlmann et al., 1990).

The suitability of a method to release phosphates from a sludge depends on how the sludge is bound. Similar methods as used in characterisation of how phosphorus is bound to sediments has been used for sludges (Löwén and Piirtola, 1998, and Manuilova, 1999).

So far only introductory studies have been done on phosphate recovery (Levlin, 1998). For a high degree of phosphate recovery it seems suitable to convert polyphosphates to orthophosphates by simple methods as anaerobic treatment or heat treatment to improve the conversion and by release of phosphates. Part of the phosphate may then be recovered by treatment of the supernatant from the digestion process. However, to improve the recovery it seems to be necessary to treat the digested sludge to release chemically bound and adsorbed phosphates. Possible processes thereby is the use of sulphur reactions or use of acids similar to the KREPRO process although it might not be necessary to use high temperatures and pressures. Phosphorus may also be recovered from ashes. These studies are described by Levlin (1999) in this seminar.

In order to facilitate phosphorus removal it is advantageous to diminish the sludge mass. This may be done by use of sludge fractionation methods described in Table 3. The sludge fractionation step may be located as a step before or after the digester as illustrated by Figure 3. It is also possible to use other locations as at a small stream of the return sludge in the activated sludge process (Fujii, 1997) or as a treatment step of a recycling stream from the digester where the stream is recycled back to the digester (Takashima et al., 1996).

SUMMARY

Trends in sludge handling will change from use of deposits for organic sludges. This may cause changes in technologies as more use of incineration and pyrolysis. In this paper main focus has been given to three ways to obtain sustainable sludge handling. An efficient source control is necessary in all cases.

The first way may be described as an improvement of existing methods for source control and sludge handling. It is then considered that the produced sludge will be suitable for agricultural use. Different difficulties are general acceptance from public and food industry of agricultural use of sludge and possibilities of increasing requirements of sludge quality. A second way may be to separate different wastewater streams to avoid decontamination of the produced sludge. The costs are, however, high for increasing the separation degree of wastewater streams in existing infrastructure. Product recovery is a third way to reach sustainable sludge handling. Systems as KREPRO and Cambi can be used for product recovery. However, a lot of other possibilities exist and should be evaluated.

Product recovery was examplified for phosphorus recovery. Systems with biological phosphorus removal, treatment of the excess sludge by digestion and recovery of phosphates from the digester supernatant will lead to a recovery of about half of the phosphorus. Release of the chemically bounded and adsorbed phosphates must be accomplished by complementary methods as the use of acids or sulphides.

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