



LABORATORY TESTING METHODS FOR CENTRIFUGAL SLUDGE DE- WATERING PROCESSES

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Bachelor's thesis
January 2013
Degree Programme in Environmental
Engineering

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ABSTRACT

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Laboratory Testing Methods for Centrifugal Sludge Dewatering Processes

Bachelor's thesis 30 pages, appendices 1 page.
January 2013

Sludge dewatering is an important part of the municipal and industrial wastewater treatment. The purpose of sludge dewatering is to reduce organic ingredients, as well as the volume and weight of the sludge. Sludge treatment removes odour, improves hygiene by removing pathogenic organisms and prepares sludge for further utilisation or disposal. Although different instrumentation and process steps vary from one wastewater treatment plant to another, the sludge dewatering part of the process remains one of the most costly parts of the process, and the most challenging in terms of the chemistry involved. It is also the most highly regulated area of the industry. During the last decade, centrifugal sludge dewatering has largely replaced a great number of other instrumentation set-ups such as belt filter presses or drying beds in the municipal wastewater treatment plants. Due to the high shear force environment, demanding performance requirements are created for the dewatering-aid chemicals used in centrifugal sludge dewatering.

The heart of the dewatering process lies in the detailed chemical composition of the sludge dewatering chemicals. The sludge dewatering chemicals are typically different compositions of charged acrylamide-co-polymers, with different structural elements such as charge, molecular weight and structuring. The application research and product development are highly dependent on accurate laboratory methods, fine-tuned to describe the process environment with the real application.

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GLOSSARY

BFP	Belt Filter Press
BOD ₅	The biochemical Oxygen Demand of wastewater during decomposition occurring over a 5-day period.
CST	Capillary suction time
NTU	Normalized Turbidity Unit
PAM	Polyacrylamide
TS	Total Solids

1 INTRODUCTION

Sludge is the final product after wastewater purification processes; its quality depends on used purification methods and the source of wastewater. The sludge consists of nutrients, such as nitrogen, phosphorous, micronutrients and organic matter, why treated sludge can be used as a fertilizer and as an organic soil improver. The amount of potassium in sludge in general is low. Besides, sludge contains heavy metals, poorly biodegradable trace organic compounds and potential pathogenic organisms like viruses and bacteria. These pathogen organisms are removed in sludge treatment. The amount of heavy metals varies depending on the sludge quality of the municipality and industry. Also the characteristics of industrial sludge depend on the branch of industry and the treatment processes that are used. (Pöyry Environment Oy 2007, 4)

The concentration of the total solid substance in digested sludge has an impact on the total quantity of the consisting sludge. When the dewatering process is optimized, less sludge need to be transported to dumping grounds or incineration, and great cost savings can be achieved. The aim of this thesis work is to find out optimal parameters for centrifugal sludge dewatering process. In this work it is investigated, whether the instrumental techniques typically used for determination of the polymeric sludge dewatering ability can point out flock strength properties.

The highest flock strength evidently leading to higher sludge dry solids can be accomplished with acrylamide polymers possibly carrying some amount of structuring agent in the chemical composition. The characteristics of different polymer products used in sludge dewatering were also an object of interest. In this study, two acrylamide polymer “families”, linears and structured, are used in laboratory tests. The laboratory work was done in Kemira research center in Espoo.

2 BACKGROUND

2.1 Sludge quantities and characteristics

The annual amount of sludge consisting in water treatment plants in Finland is approximately 840 000 t/a, which equals to 160 000 t TS/a. (Total Solids, TS). Agriculture is the biggest producer of sludge; according to the number of cattle, agricultural sludge is generated about 20Mm³/a every year. Other sources of sludge are domestic use of water, industries such as pulp and paper processing, food and beverage processing, metal and chemical processing. (Pöyry Environment Oy 2007, 4)

Municipal sludge is handled at municipal wastewater treatment plants, but also sludge from cesspits and septic tanks from sparsely populated areas are transported to municipal wastewater treatment plants. At some plants also sludge from industry and fisheries, garden waste, manure from farms and horse stable, and other bio waste are treated. Sludge collected and concentrated on the wastewater treatment plants is dried mechanically with chemical aid typically with spin-dryer (Pöyry Environment Oy 2007, 5).

The most common way to treat agricultural sludge is drying with dehydrating agent. Another common treatment is to treat manure as manure sludge. Manure is utilized as fertilizer on fields, but in large farms storing and utilizing manure may be problematic (Pöyry Environment Oy 2007, 6-7). Before using sludge in agriculture, it must be treated for example by digesting or lime stabilization, to decrease the number of harmful bacteria, odour and other health and environment related disadvantages. Also the amount of heavy metals in sludge or the cultivating area shouldn't overstep set secure limits. There are also some restrictions regarding the type of cultivation where the sludge can be utilized; sludge can be used as fertilizer when growing corn, sugar beet, oil plant and plants that are not grown for human food. The amount of sludge for fertilizing is proportioned always to the cultivating field and the nutrient need of plants. (Lohiniva et al. 2001, 30.)

Sludge from food and beverage processing includes often lots of organic material and is thus applicable for the raw material of digestion. Part of organic waste is utilized in feed production. Some sludge from food industry can be used as raw material in regional biogas production sites. Other industrial sludge can be composted, if there's no possibility for digestion or bio gas production. Sludge generated in forest industry is often treat-

ed at wastewater plants of the industrial sites, and finally incinerated at the sites. (Pöyry Environment Oy 2007, 6-7)

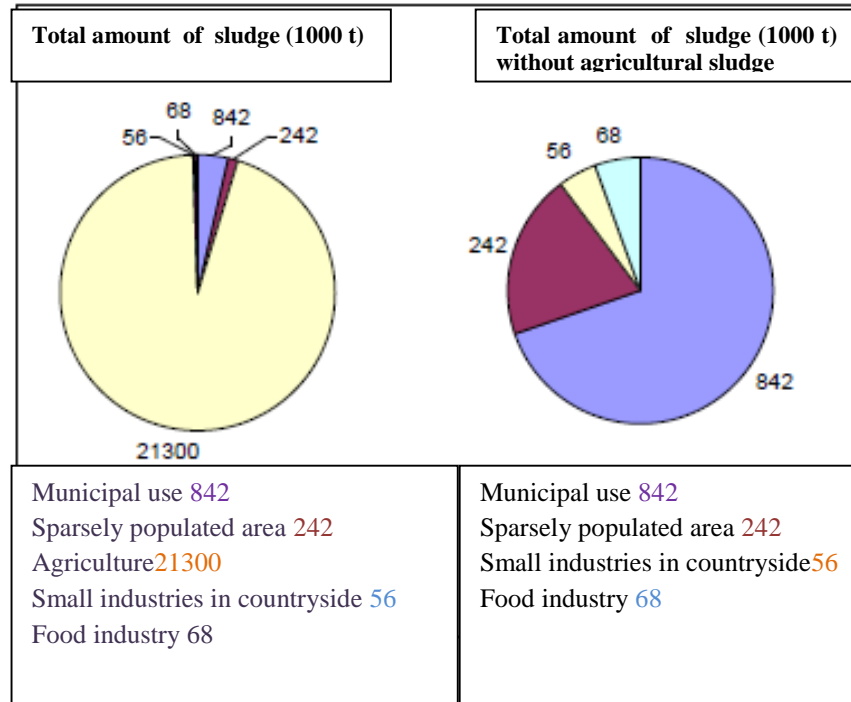


FIGURE 1. Total sludge amounts. Image adapted from Pöyry Environment Oy 2007, 4.

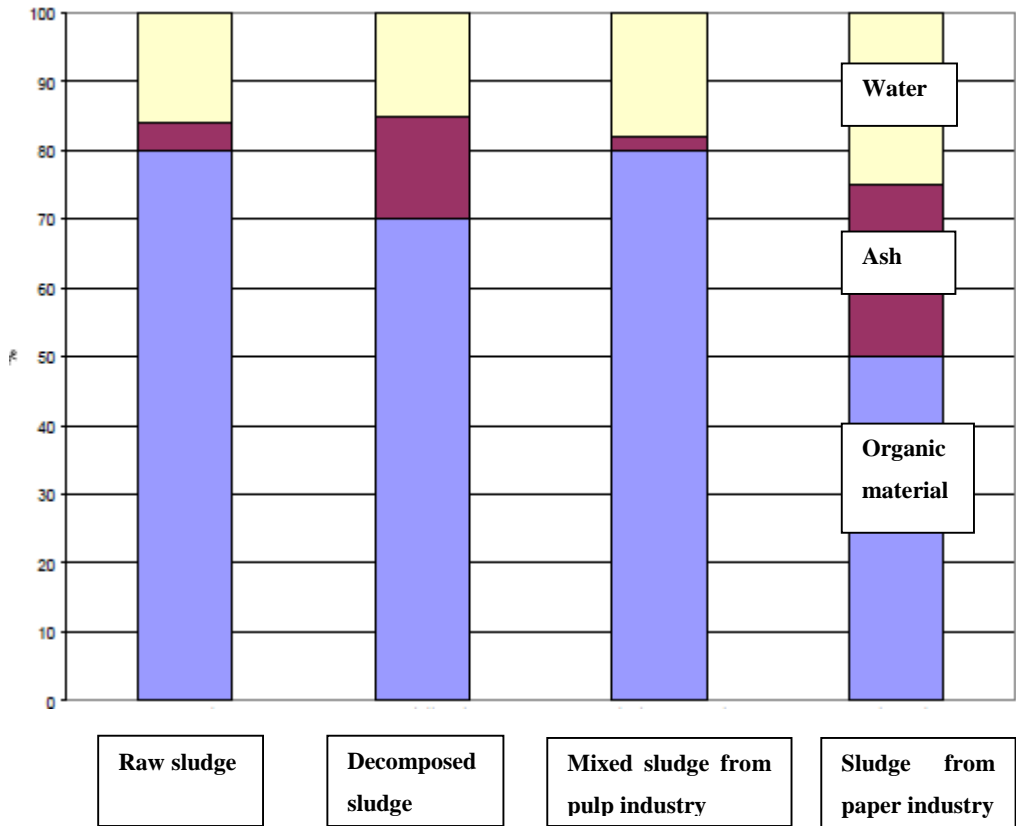


FIGURE 2. Sludge contents after mechanical wastewater treatment.

Image adapted from Pöyry Environment Oy 2007, 19.

2.2 Sludge types

Types of sludge and other solids in wastewater, such as screenings, grit and scum vary according to the type of plant. Most of the medium and large sized wastewater treatment plants in Finland and Europe are activated sludge plants. An activated sludge treatment process is illustrated in figure 1. There are three separate phases used in the treatment process; mechanical (primary), biological (secondary) and chemical (tertiary) treatment. The sludge which is not treated biologically or chemically for volatile solids or pathogen reduction is called raw sludge. Raw sludge contains dry solids (3-5%), which consist mostly of organic materials (70%). Sludge produced can be later digested by aerobic or anaerobic biologic process in order to reduce the amount of sludge and the pathogens including the sludge. After the treatment of the sludge, it can be classified by the treatment such as aerobically digested, anaerobically digested, alkaline stabilized, composted and thermally dried. Wastewater treatment process at Suomenoja is represented in appendices 1. (Lohiniva et al. 2001, 17-18.)

2.2.1 Primary sludge

Primary sludge is the product after gravity settling at the beginning of the process in wastewater treatment plant. At first, raw sludge is treated mechanically to remove large particles in screening and grit removal. In primary sedimentation large particles are settling in the ground, and obtained primary sludge is fed to sludge processing in pre-thickening. In mechanical treatment 50-70% of total solids and 35-40 % BOD₅ can be removed. (Lohiniva et al. 2001, 17-18.) Primary sludge can be dewatered faster than biological and chemical sludge because it is comprised of discrete particles and debris.

2.2.2 Secondary sludge

Biological treatment follows mechanical treatment. The concept of biological treatment is simple: small organic particles are removed as a bacteria feedstock. These bacteria are

often referred to as activated sludge bacteria. Thus biological sludge is produced after primary settling when the bacteria consume soluble and insoluble organics.

Activated sludge and trickling filter sludge contain solids concentration of 0.4 to 1.5% and 1 to 4% in dry solids weight, respectively. (Turovskiy et al. 2006, 32.) Solid organic material is converted to gas and cell tissue. Since cell tissue is lighter than water, it can be removed from top of the sludge reservoir. Nitrogen removal is done in microbial simultaneous nitrification-denitrification process, where heterotrophic organisms are responsible for denitrification and reduction of nitrate NO_3^- to nitrogen gas N_2 . These heterotrophic organisms use carbon from organic compounds in the sludge. (Lohiniva et al. 2001, 18.)

Although the concept of biological treatment by activated sludge is simple, the control of the treatment process is complex. There are numerous variables affecting the process, such as changes in the composition of bacterial flora of the treatment tanks and changes in the sewage passing into the plant. The influent wastewater may vary in flow rate, in chemical composition, pH and temperature. Toxic chemicals may also inhibit the functioning of the activated sludge bacteria or kill them.

2.2.3 Tertiary sludge

Tertiary sludge, also called chemical sludge is obtained from the processes of chemical precipitation and filtration. Chemicals are used in precipitation and removal of hard-to-remove substances, and in improvement of suspended solids removal. Phosphorus is a typical example of chemical precipitation. Phosphorus is removed by precipitation with ferric sulfate or aluminum sulfate. Chemicals can be added in the biological process with the biological sludge, but in most treatment plants chemicals are applied to secondary effluent, when tertiary clarifiers or tertiary filters are used in chemical precipitate removal. Added chemicals may cause unwanted side effects like depression of pH and alkalinity of wastewater. Addition of alkaline chemicals can be used then to adjust these parameters. (Turovskiy et al. 2006, 32-33.)

2.3 Sludge treatment

The main target of sludge management is to produce clean biosolids that could be used beneficially later. The moisture content of final sludge has to be limited for lower costs, and to decrease environmentally harmful impacts caused by pathogen organisms. It is also beneficial to gather valuable nutrients such as phosphorus and nitrogen for nutrient reuse. Sludge is also a valuable source for the reuse of inorganic material and energy production.

2.3.1 Sludge conditioning

To enhance solid-liquid separation, sludge is treated biologically, chemically or physically before thickening and dewatering of the sludge. This process is called sludge conditioning. Sludge conditioning can be made by inorganic or organic chemicals, power plant or sludge incinerator ash, or by physical processes such as heating, elutriation, freezing and thawing. Sludge characteristics which affect thickening and dewatering and which determine thus needed conditioning method, are source of sludge (primary, waste activated sludge, chemical sludge, digested biosolids), solids concentration, surface charge and degree of hydration, particle size and distribution, pH and alkalinity.

The source of sludge indicates suitable amounts of conditioner doses for thickening and dewatering. Primary sludge, in general, requires less chemical conditioning than biological sludge. Aerobically and anaerobically digested sludge has usually similar conditioning requirements as secondary digested biological sludge. Conditioning requirements for different chemical sludge again vary a lot.

Solids concentration is related to the activity of interaction; when the concentration of solids increases, also the interaction increases. Sludge conditioning is often about neutralization of the surface charge of sludge particles by oppositely charged organic polyelectrolytes or inorganic chemical complexes. Thus coagulant dose is expressed as a percentage of dry solids or as kilograms of coagulant per ton of dry solids of the sludge.

Sludge solids repel one another, because of surface charge and hydration. There's a layer of water binding the surface of a solid preventing close approach between other sol-

ids. Sludge solids are also negatively charged, why conditioning is to overcome both the effects of hydration and electrical repulsion.

When determining the dewaterability of sludge, particle size is probably the most important factor. Increased surface area of small sludge particles increases the hydration and chemical demand, increasing the resistance to dewatering as well. Therefore the interest in conditioning is to increase particle size by combining small particles into large ones.

pH and alkalinity affect mainly the use of inorganic conditioners. Inorganic conditioners, such as iron and aluminum reduce the water pH.

Some physical factors such as storage, pumping, mixing and other sludge treatment processes affect the characteristics of sludge, and thus, the process of thickening and dewatering. Pumping and mixing processes with high shear forces decreases the size of sludge particles, which also increases chemical demand and increases resistance to dewatering. (Turovskiy et al. 2006, 62-64.)

2.3.2 Thickening and dewatering

Thickening is a process for increasing the solids concentration of sludge and for decreasing its volume by removing water. Decreasing the volume of sludge is important because of efficiency and to decrease the costs of following sludge-processing steps. Dewatering is also removing water from sludge, where the volume reduction is greater than in thickening. After dewatering the sludge is solid-semisolid material and easier to handle. Dewatering is required before thermal drying or incineration, so that less energy is required for evaporation the excess moisture (Turovskiy et al. 2006, 61).

The volume of water that can be removed during dewatering depends on the sludge quality and the physical water distribution in the sludge, and the dewatering process. (Lohiniva et al. 2001, 52.) In sewage sludge suspension different types of water can be distinguished; surface water, which is bound on the surface of the particle by adsorption or adhesion and interstitial water, which is bound by capillary forces between the sludge particles or trapped inside the flocks of solids. Interstitial water can be removed with a strong mechanical force. Free water is not bound to sludge particles, and it can be re-

moved during mechanical dewatering. Intracellular water is chemically bound. (Viitanen 2006, 25-26)

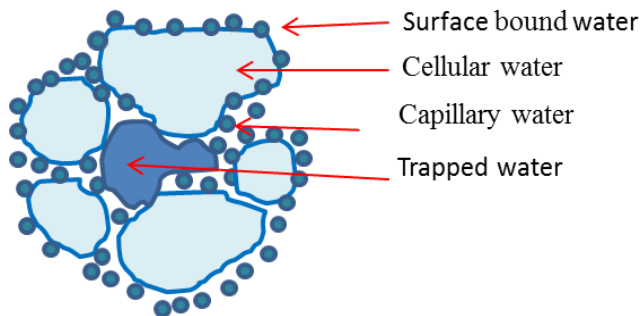


FIGURE 3. Various water phases in sludge. Image adapted from Viitanen 2006, 26.

After reducing the sludge volume, the costs for transporting sludge to disposal sites become lower. Dewatering of sludge is necessary before composting to improve airflow and texture, and to reduce requirements for additives. Since the year 2001, it has been obligatory to treat sludge by thickening and dewatering before disposing it in landfills. Dewatering limits leachate production at the landfill site, and prevents the spread of harmful waste. (Viitanen 2006, 12.)

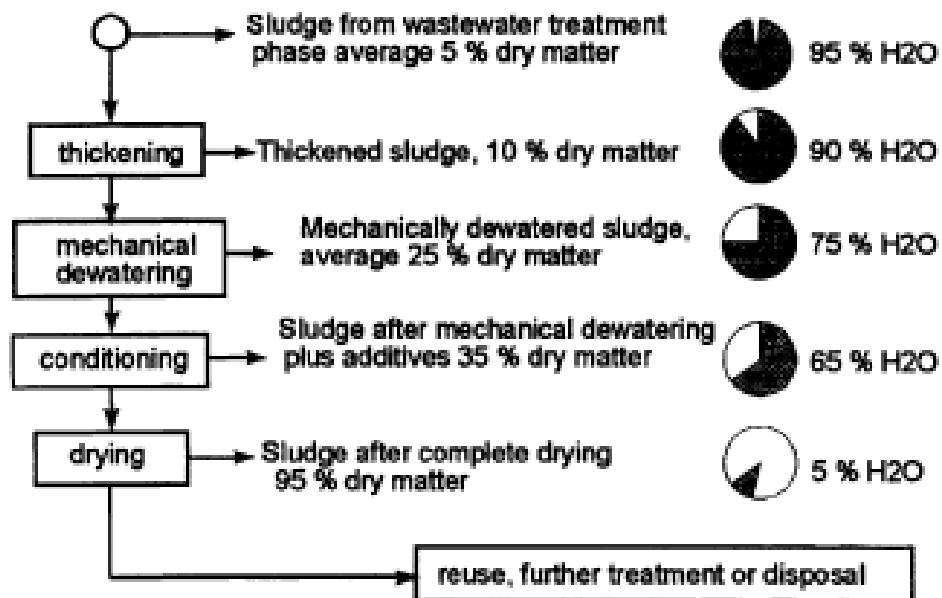


FIGURE 4. Dry solids contents of sludge after different treatment steps. Image reprinted from Lohiniva et al. 2001, 52.

There are several techniques used in dewatering devices; dewatering can be done either with the help of presses or centrifuges, which is referred as mechanical dewatering. Other common processes used are filtration and physical and biological processes in drying beds. Mechanical dewatering and filtration often require the use of chemicals (coagulants and flocculants) to enhance the process. The main differences between different dewatering processes are solids concentration and flow rate of the feed stream, chemical demand, the solids concentration of the dewatered sludge cake, and side stream. The selection of certain dewatering process is based on the type and volume of sludge to be dewatered, characteristics such as dryness required of the dewatered sludge, and space available at the site. (Turovskiy et al. 2006, 106).

Belt Filter Press

A belt filter press (BFP) is a continuous-feed sludge dewatering machine, which has two porous moving belts including a gravity drainage zone and mechanically applied pressure zones. Belt filter presses have been used first for dewatering paper pulp, later also for dewatering wastewater sludge. It can dewater secondary sludge economically and its energy consumption is lower compared to centrifuges. Belt filter press is one of the most used dewatering equipment in the world. (Turovskiy et al. 2006, 110).

Belt filter press includes several combined processes and applications such as chemical conditioning, gravity drainage and mechanical shearing and compression for removing water and dry up of the sludge. Chemical conditioning is the first step in the process: polymer is added into a sludge-polymer mixer placed in the feed line to the press. The conditioned sludge is then fed into the gravity drainage section, where the sludge is thickened further. Most of the water is removed there and the water is collected in a sump. From the gravity drainage section, the sludge is transferred through a conveyor belt driven by a series of rollers, which apply pressure to expel almost all free water from the slurry. At the last roller, the final sludge cake is removed by using mechanical scrapper blades. (WasteWater System 2009).

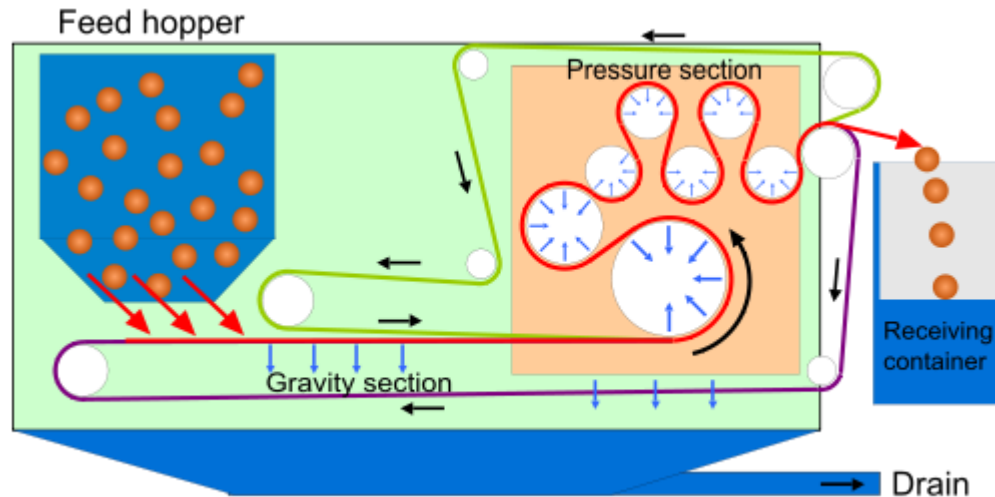


FIGURE 5. Schematic of a belt filter press. Source of the picture: Wikiwayman 2009.

Pressure Filter Press

Pressure filter press dewatering is a batch process where water is forced from the sludge under high pressure. As the result, the achieved final sludge cake is drier compared to other dewatering alternatives. Disadvantages include high capital cost, relatively high operation and maintenance costs, high chemical costs and a large area requirement for the equipment in small wastewater treatment plants. Pressure filter press is a good choice when the sludge has poor dewaterability or when it's needed to dewater sludge to solids content of greater than 35%. (Turovskiy et al.2006, 116-118).

Drying Beds

Drying beds are most widely used method of municipal wastewater sludge dewatering in the United States. In Russia and other Eastern Europe countries, more than 80% of the municipal wastewater plants use drying beds. The advantages of sludge drying beds are low capital cost, low energy consumption, low chemical consumption, low operator skill and attention is required. Disadvantages include large space requirement, since a large open space area away from residential population is needed to avoid odour complaint. With the use of greenhouse setup, the weather conditions and odour won't be restrictions anymore (Turovskiy et al. 2006, 121).

Centrifugal dewatering

Centrifugal dewatering is widely used in municipal wastewater treatment plants in the United States and Europe. The main components of a solid bowl centrifuge are shown in Figure 6. The conveyor scroll fits inside the rotating bowl, and it rotates at slightly lower or faster than the bowl. The difference in speed between the bowl and the conveyor scroll enables the solids to be conveyed from the feed pipe to the dewatering beach, where the sludge cake is discharged. The differential speed is controlled by the gear unit and the back drive.

Many physical conditioning methods have been used for centrifugal dewatering, but the most effective method has been polymer conditioning. Positively charged polyacrylamides (cationic polymers) are used as flocculation chemical in centrifugal dewatering. Performance of a centrifuge is measured by the dewatered cake solids concentration and the determination of total solids content (Turovskiy et al. 2006, 106-110).

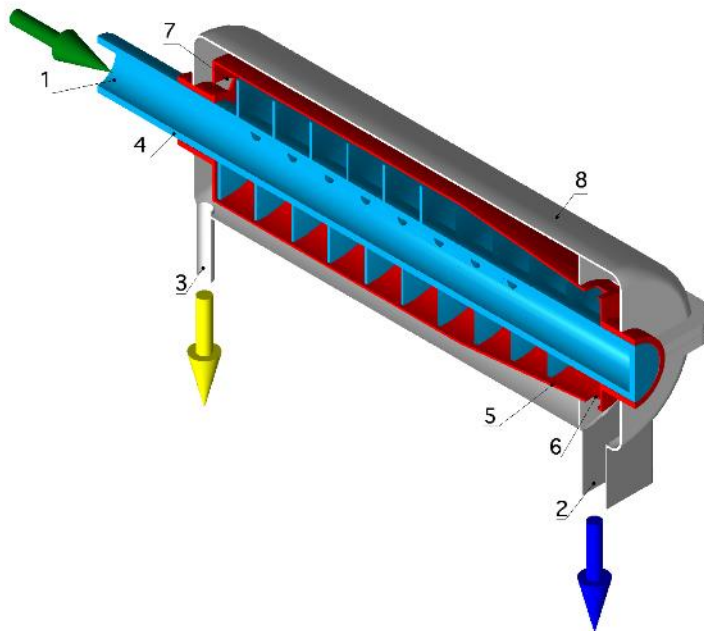


FIGURE 6. Schematic of a solid bowl centrifuge. The sludge feed enters through the large diameter end of the bowl, and the sludge cake is conveyed toward the opposite end. Source of the picture: R. Castellano 2005.

2.3.3 Use of polymers in sludge treatment

Organic polyelectrolytes are type of polymers; they are common applied as sludge-conditioning agents. In sludge treatment, they have several cost saving advantages over inorganic chemicals. Polymers are easy to handle and their feeding system takes less space. Needed polymer doses are several times smaller than doses of inorganic chemicals.

Organic polyelectrolytes are water-soluble organic molecules in a long chain. They consist of small units, monomers. If the monomer units have ionizable groups, they can become charged. Sludge-conditioning polymers are classified according to their electrical charge as anionic (negative), cationic (positive) and nonionic (uncharged). There may be great differences in charge density. Polymers are also classified by form as dry, liquid, emulsion and gel. Molecular weight of polymer varies from a few thousand up to several millions monomer units. By structure they are either linear or have branching. (Turovskiy et al. 2006, 75).

Sludge conditioning with polymers is to destabilize small particles aggregating them into bigger particles. This process is called flocculation.

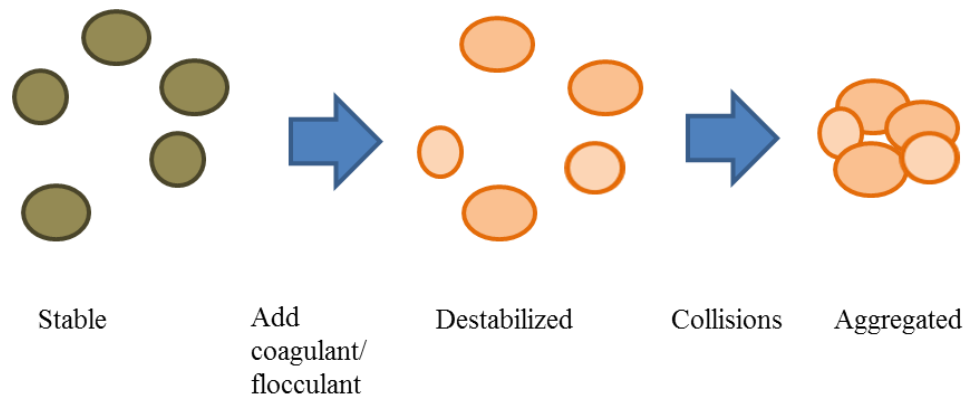


FIGURE 7. Destabilization and aggregation of particles.

Factors affecting flocculation are the type of sludge, the polymer dose and type, electrical charges, mixing rate and time. In flocculation, polyelectrolytes are thought to form bridges between sludge particles. The strength of aggregates formed in polymer conditioning influence the efficiency of dewatering. Thus sludge particles which are conditioned with polymer flocculants form more rigid structures; polymer bridging produces strong flocs that can grow quite large. Adding polymer to sludge breaks the jelly-like layer of sludge particles, which enables the water to be released and separated. In flocculated activated sludge, the water is fragmented in interfloc and intrafloc parts. The binding energy needed for water is smaller than for bound water. Further more, the total network energy is lower at the optimum polymer dose, when more water is released within flocs.

The optimum polymer dose is determined more by the colloidal material in sludge than by the floc solids. (Viitanen 2006, 14-16.) Although polymer conditioned flocs are strong and withstand high shear forces, they may not reform if the flocs get broken. Polymers with high molecular weight are found to be more effective flocculants than polymers with low molecular weight. For a given molecular weight, linear polymers are found to be more effective than branched or cross-linked structures. Highly charged chains tend to adopt a more expanded configuration and might thus be more effective bridging agents. For some signs of charge (anionic polyacrylamides, PAM, and negative particles) highly charged polyelectrolytes are less readily adsorbed, which is related to less effective flocculants. For this reason, there may be an optimum charge density for most effective flocculation. (Gregory 2006, 139-140)

Particles in natural waters, effluents and in most industrial suspensions are negatively charged. In these cases the most effective flocculants are positively charged cationic polyelectrolytes, since they attract negatively charged particles. The cationic groups of polyelectrolytes stick to the negatively charged part of sludge flocs, linking them together and closer to each other. This way the water is pressed out from the flocs and the sludge becomes dryer. Thus, cationic polymers seem to be the most effective conditioner for wastewater sludge. If aluminum and ferric salts have been predosed excessively, anionic polymers may give a better result. (Gregory 2006, 139-140)

If the role of cationic polyelectrolyte is to neutralize particle charge, then the charge density of the polyelectrolyte should be more important factor affecting flocculating than molecular weight. Adsorption is sometimes so strong that it continues beyond the point of charge neutralization causing charge reversal. This confirms the thought mentioned above that there's an optimum polymer dosage for the most effective flocculation. (Gregory 2006, 139-140)

3 MATERIALS AND METHODS

The testing methods presented below are common procedures used for determining sludge conditioning effectiveness for thickening and dewatering. The changes in sludge dewaterability during flocculation and floc breakage were tested with Capillary suction time, gravity filtration and centrifugal filtration. Sludge used in the tests is decomposed municipal sludge from Suomenoja wastewater treatment plant. The solids content of the sludge was measured before running each method. This is done by weighing approximately 10g of sludge in a cup, drying the sludge sample at 105°C from 15 to 24h, then cooling down in a desiccator and weighing the sludge sample again.

The formula for calculating total solids (TS) content:

$$X = ((m_2 - m_1) / m) * 100\%$$

X= Total solids (TS), %

m₁= mass of the cup, g

m₂= mass of the cup and dried sludge sample, g

m= mass of the total sludge sample, g

3.1 Capillary suction time, CST

Capillary suction time (CST) is a fast and simple method for screening dewatering aids, and commonly used for determining the optimal dose of polymer. The dewaterability of sludge was mainly tested with this method. The CST test relies on gravity and capillary suction time of a piece of thick filter paper to draw out the water from a sample of conditioned sludge.

First 100g of sludge is mixed with polymer for a certain time (15s) in a beaker (Figure 10). Then a sludge sample (4,5 ml) was taken by a pipette and placed in a cylindrical cell, which is centered in the middle of two concentric electrodes resting on a filter paper (Figure 11). The electrodes are located at diameters D1 and D2. The time in seconds it takes for the water in sludge to spread from the inner electrode D1 to the outer electrode D2 (about 10mm distance) is the CST. The CST is recorded electronically. The CST is written down, also the size of flocs and free water in the sludge are observed and described. After this, CST was measured from the same sample after mixing another 15 seconds. This is called CST 30 s. CST 60 s means a CST result after 60 s of total mixing, likewise CST 90 s after 90 s mixing. Rotation speed was set as 1000 rpm for the

first CST measurement, and after that rotation speed was raised up to 1500 rpm. (Viitanen 2006, 46)



FIGURE 9. Triton CST device. Photo taken by Kaisa Kätkä.



FIGURE 10. Mixer. Photo taken by Kaisa Kätkä.

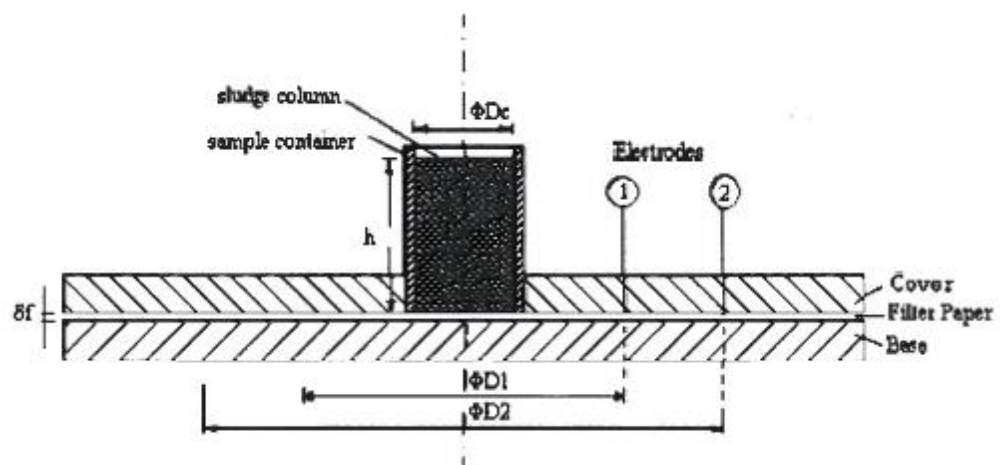


FIGURE 11. Schematic representation of CST apparatus. Source: Work instruction from Kemira research center.

Dilute sludge has usually a low CST value, why it's essential to compare CST values of sludge with similar suspended solids concentration. Addition of polyelectrolyte increases the viscosity of sludge water and the rate of adsorption time by filter paper decreases. CST for unconditioned sludge is about 200 seconds. A CST of 10 seconds or less is considered as a good value for excellent dewatering performance.

(Turovskiy et al. 2006, 64).

It is commonly believed that the sludge characteristic changes already during the first days. That's why the sludge from Suomenoja water treatment plant used in this research was always of same age: the sludge was got to the laboratory on Mondays and the tests were started on Tuesdays. Same sludge could be used until Friday, but new sludge had to be got on next week. Because one doesn't really know, how the sludge characteristic changes and what the actions of varying aged sludge on CST test results are, a test with ageing sludge with certain polymer products was also tested.

3.2 Gravity filtration, polytest

Gravity filtration, also called Polytest, is used for defining the optimal polymer dose for dewatering. At first, sludge sample is mixed with polymer by pouring the mixture between two beakers for several times. Mixing can be done also with an electric mixer as in CST test. Then the sludge sample is filtered via filtration funnel, and the filtration time is measured. After the filtration, turbidity of the filtrate is measured. (Viitanen 2006, 50)

Turbidity is a measure of the amount of scattering when light passes through water. It reflects the presence of suspended solids and their fineness, color and shape. Turbidity values are stated in turbidity units, NTU. Water treatment plants have often several on-line turbidimeters, which continuously



FIGURE 12. Gravity filtration measuring set-up. Photo taken by Kaisa Kätkä.

measure raw, filtered and treated water. (Binnie et al. 2002, 18-19.)

3.3 Centrifugal filtration

In centrifugal filters, pressure difference moves the fluid inside the filtration chamber. The pressure gradient changes with rotational radius and with time. Centrifugation-filtration doesn't require a density difference between the solids and the suspending liquid. Centrifugal filtration operates as follows: A similarly sized receiving cell is attached beneath a filter cell in centrifugation-filtration device. A filter medium is set between the filter and receiving cell. Sludge sample is set inside the filter, and during the rotational acceleration water is filtered through the filter media, accumulating in the receiving cell. Thus the dry sludge cake is formed inside the filter. Centrifugal filtration filters and cells are represented in figure 13. (Viitanen 2006, 40-41)



FIGURE 13. Centrifugal filtration filters and cells.

4 RESULTS AND DISCUSSION

Several laboratory tests were done by using previous mentioned methods CST, polytest and centrifugal filtration, of which only the most interesting results are presented below. In CST tests, the polymer dosage is mixed with sludge for a certain period of time when flocs are formed and CST is measured. In the experiment, the CST reaches a minimum value, indicating efficient release of free water from the sludge particles, and these values are of the main interest. The lower the minimum CST is, the better polymer flocculates after the respective mixing time. Minimum CST is recorded at the end of the minimum CST region in the CST curve. After minimum CST flocs resist the continuing mixing, and the formed flocs get broken. The lower the minimum CST is and the longer time the minimum CST is kept, the better the polymer works.

4.1 CST test with four polymer products

The data presented in the figure 14, describes four different polymer products tested with the CST method described earlier. These polymer products differ only a little from each other by their cationity level and molecular size. Under low shear forces, with rotation speed 1000 rpm and mixing time 15 s, all four polymers seem to react similarly. Product B seems to reach lower CST time (20 s) in the beginning as the others reach results between 35 and 40 s. When the shear forces are raised up, product B seem to succeed the best, since its CST time stays lowest and also its minimum CST time is kept the longest. Thus Product B works the best of these polymer products.

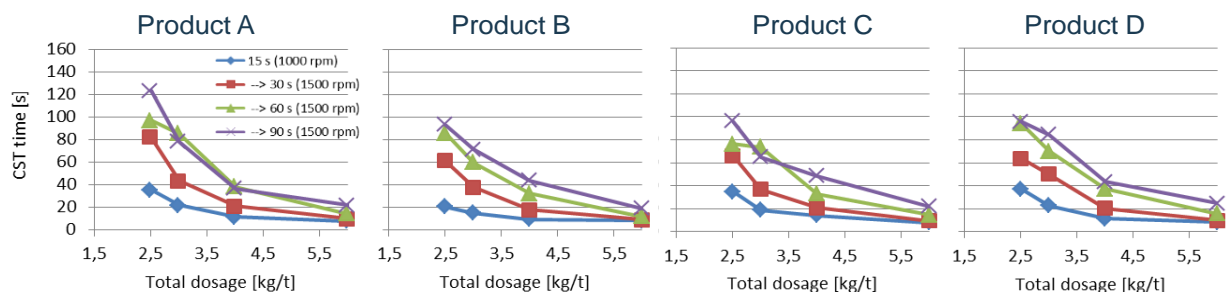


FIGURE 14. CST test results with four polymer products.

4.2 CST test with ageing sludge

In the following figure, CST tests with two polymer products A and D are performed with the same ageing sludge. Both products were tested on three consecutive days. Parameters for the test are same as for the previous one: blue line 15 s, 1000 rpm, red line 30 s 1500 rpm, green line 60 s 1500 rpm and violet 90 s 1500 rpm. In this experiment, there are no clear differences with the test results between three consecutive days. CST test results vary within the shear forces, but it's hard to see a significant, linear change in the CST curve between the three days. Therefore, based on this test, the sludge doesn't change in an explicable way affecting the CST results during three consecutive days.

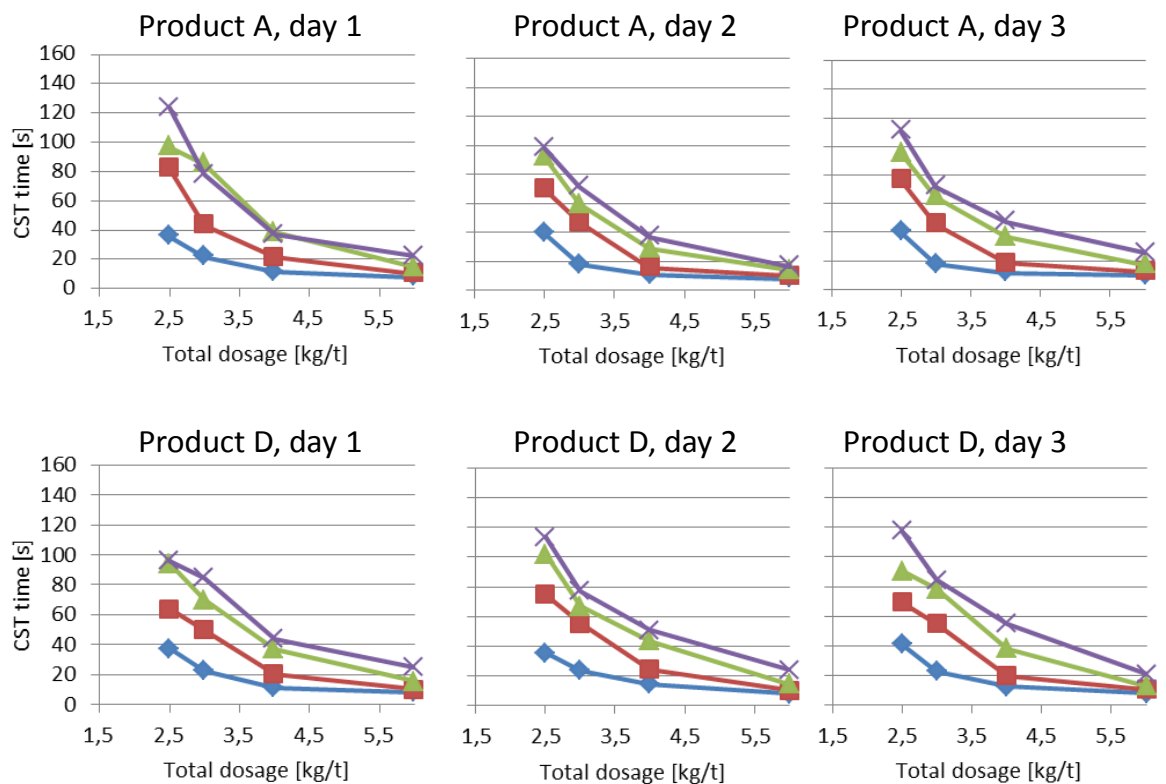


FIGURE 15. CST test results with ageing sludge.

4.3 Dewatering with polymer mixtures vs subsequent addition of the components

Usually polymer products are mixed together as a blend before adding them into the sludge. Compared to a blend, subsequent addition of polymer products into the sludge is not considered to be as efficient method. Thus, in this experiment the interest was to observe the influence of varying mixing order of products A and B on the CST test results. Figure 16 describes the CST test results after using product A, the blend of A and B, product A followed by B and product B followed by A. From the figures one can see that the product A is not good enough alone, but the blend of the products A and B gives the best CST result. In the experiment with the blend of A and B the minimum CST is the lowest and it is kept the longest time. When adding polymer products separately into the sludge (Product A followed by B, Product B followed by A), the CST time is higher, so the dewatering process is slower. This experiment substantiates the view that dewatering with polymer mixtures gives better results than dewatering by subsequent addition of the polymers.

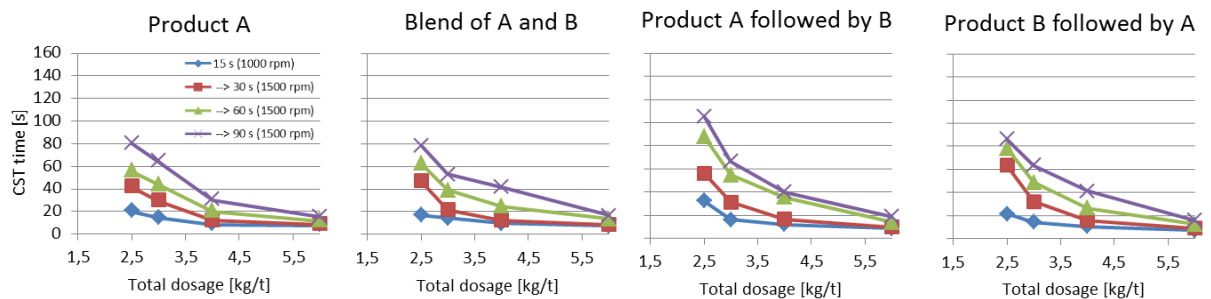


FIGURE 16. CST test results of the experiment “Dewatering with polymer mixtures vs subsequent addition of the components”.

4.4 Determination of optimum blending ratio

The test was performed for investigating an optimum blending ratio for products A and B. Products A and B differ from each other by their charge, molecular weight and structuring. The objective here is to combine the benefits of both products, bringing them together in a new product.

During blending from product A to product B, the flock strengths for blends c, d, e and f revealed to be close to each other. Blends d and e give interestingly very similar results. To see more differences between blends c, d and e, and to understand their characteristics, it's worth continuing studies with these mixtures. These kinds of tests give valuable information about product characteristics, and how product characteristics of two different products appear in their combinations.

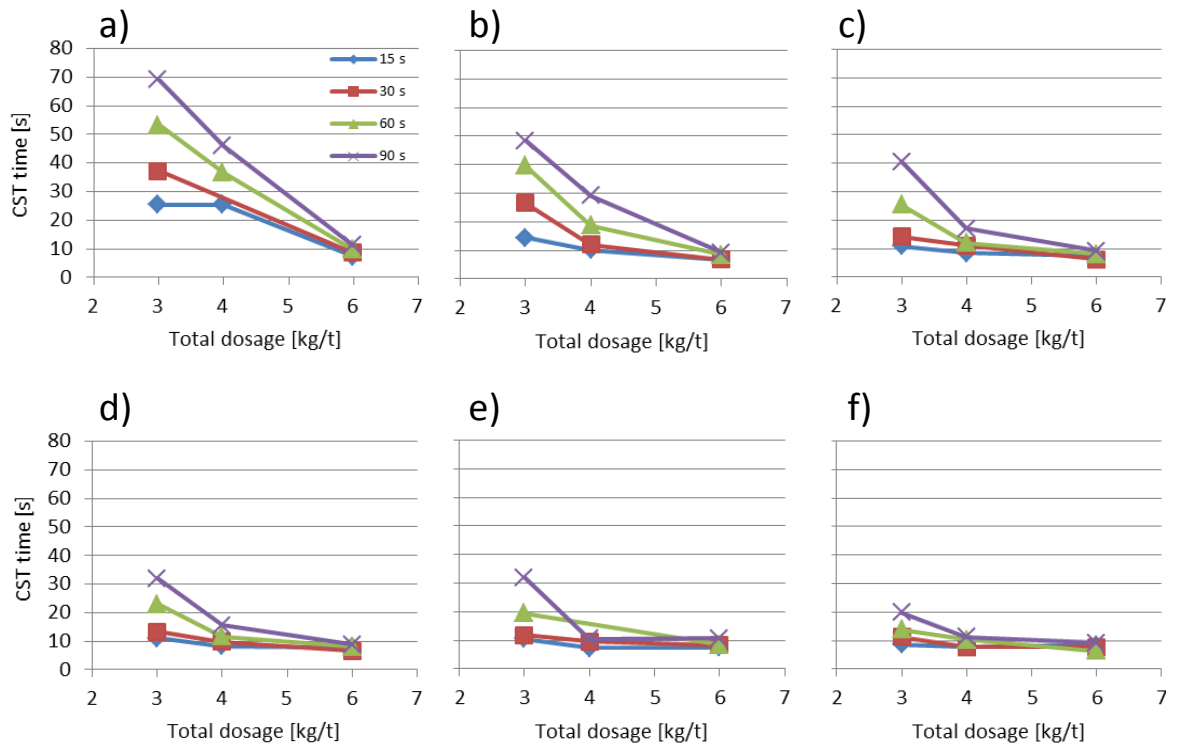


FIGURE 17. CST test results, when blending from product A to product B.

Product A was mixed with Product B in following ratios:

- a) Product A
- b) Product B/ Product A -20%
- c) Product B/ Product A -50%
- d) Product B/ Product A -70%
- e) Product B/ Product A -90%
- f) Product B

4.5 Polyttest with two polymer products

The polyttest method was applied to investigate the optimal polymer dose for dewatering. In this experiment, two different polymer products A and B were tested with Polyttest funnel to find out dewatering times for three polymer portions.

First a sludge sample was mixed with polymer using an electric mixer; the rotation time was 1500rpm, and the mixing times were 15, 30 and 60s. The portion of the products were 4, 6 and 7,5 kg/t. The sludge sample was filtered via filtration funnel for 30s, and during this time the filtration time (dewatering, s) was being measured.

According to the figure 18, polymer portion 4 kg/t for products A and B is probably too low, since differences between dewatering times after varying mixing times didn't come out. Polymer portions 6 kg/t and 7,5 kg/t again give significantly different results. To investigate flock strength and dewatering with products A and B further, it's beneficial to use polymer doses 6 kg/t and 7,5 kg/t and doses greater to these.

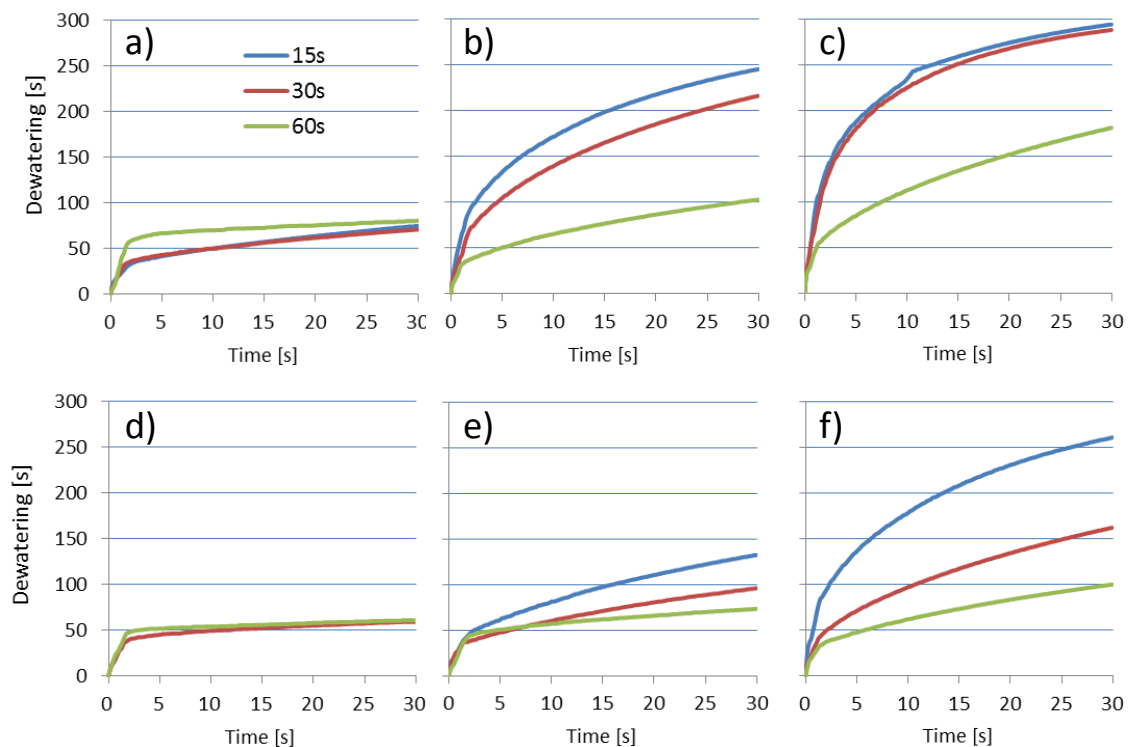


FIGURE 18. Polyttest with polymer products A and B.

- a) Product A, 4 kg/t
- b) Product A, 6 kg/t
- c) Product A, 7,5 kg/t
- d) Product B, 4 kg/t
- e) Product B, 6 kg/t
- f) Product B, 7,5 kg/t

5 CONCLUSIONS

Three instrumental techniques, CST test, Polytest and centrifugal filtration were used for determination of the polymeric sludge dewatering ability. Based to several tests that have been run during this experiment, CST test succeeded to point out flock strength properties the best. It was also confirmed that dewatering with polymer blends gives better results than dewatering by subsequent addition of the polymers into the sludge. Determining an optimal blending ratio for two different polymer products is an interesting test, but also challenging and time-consuming; after selecting polymer dosages and blending rations for the first test, one will continue tests by changing one parameter at a time and by comparing test results.

The tests run during this research work give valuable information for further studies to find out right polymer products and their doses, while maximizing the separation of water from the flock. Centrifugal dewatering of digested sludge is a complex process, and right polymer dosages for each sludge type can be found by continuous monitoring and measuring.

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APPENDICES

Appendix 1. Wastewater treatment process at Suomenoja.

http://www.hsy.fi/vesi/Documents/J%C3%A4tevedenpuhdistus/Wastewater_treatment_process_Suomenoja.pdf. Read 17.9.2012

