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Evaluation and testing of different pre-treatment procedures for making sludge liquor suitable as a nutrient source for growth of microalgae

University of Stavanger

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1. Abstract

The objective for this thesis is to find a proper pre-treatment for sludge liquor for the purpose of growing microalgae in the treated solution. Sludge liquor (also called reject water) is the reject/centrate after the dewatering of the sludge after it has undergone anaerobic digestion, and is normally recycled to the inlet. It is characterized as a high turbid and high content of solids I addition to a high nitrogen load (especially ammonium) and phosphorous.

Sludge liquor from four different wastewater treatment plants was characterized and different pre treatment methods were conducted. The different pre-treatment methods tested was aeration, oxidation, coagulation and flocculation (by testing different polymers), mediafiltration and centrifugation. Combinations of these were also tested. The efficiency of treatment was measured in % transmittance, which gives an indication of the light penetration properties of the solution which is crucial for microalgae growth, and also turbidity and solids removal.

Oxidation and aeration did not improve the transmitting properties of the sludge liquor samples. The best treatment method was coagulation and flocculation by polymers, combined with centrifugation.

Microalgae did grow in pretreated sludge liquor (diluted 1:5.5) added phosphate, so with optimization of pre-treatment and finding a optimal growth media, growth of microalgae in sludge liquor can be enhanced.

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3. Introduction and background

This thesis is a sub part of a bigger project focusing on developing a sustainable process to capture and store CO_2, to produce more renewable bioenergy using waste nutrients. The goal is to utilize waste nutrients from wastewater treatment plants to grow photosynthetic organisms and harvest the biomass. The harvested biomass will be co-digested with sludge in existing anaerobic digesters for more biogas production. The sludge liquor which is the reject after dewatering of the anaerobic sludge, which is normally recycled into the wastewater stream, will be used as the growth medium for photosynthetic organisms, as microalgae, this resulting in a higher biomass production. Sludge liquor is high in nutrients like nitrogen and phosphorous. The challenge lies in treatment of the sludge liquor which in addition to high nutrient content has high suspended solid concentrations, high COD levels and cause of its dark colour and high turbidity it has low light penetration properties. For microalgae growth, in addition to nutrients, light penetration is one of the key parameters. Treatment to lower SS, turbidity and give higher transmittance properties and still hold on to the waste nutrients in the sludge liquor is the principal focus of this thesis.

3.1 Introduction:

In a municipal wastewater treatment plant the sludge that is formed during chemical and or biological treatment contains a lot of organic and inorganic and toxic substances and pathogenic microorganisms. Sludge is formed as a dilute suspension that contains 0,25-12% solids depending on operation and processes used. The further treatment of sludge is intended to reduce smell and reduce the quantities of organic solids and eliminate pathogens and is carried out through thickening, stabilization and dewatering before storage, transportation or further utilization.

Thickening of the sludge is the first process after sedimentation, thickening is separation of water and sludge before anaerobic digestion to reduce the sludge volume. The free water in the sludge is separated here, and the solid content can get as high as 10%. Process used is depended on sludge characteristics and separation method used before thickening. The most used thickening methods are;
- Gravitation: Sedimentation through compression over an extended time period.
- Flotation: addition of air-bubbles that attaches to the particles that assembles on the surface.
- Centrifugation: separation of particles based on weight.
- Belt-press: sludge is covered on a cloth and with vacuum applied underneath water is let through.

Digestion of sludge is a stabilization process widely used involving partial conversion of organic and inorganic matter into gas and a stabilized residue with help of bacteria in absence of molecular oxygen (anaerobic) or in presence of oxygen (aerobic).

The processes in anaerobic digestion:

1. Hydrolysis: Organic matter is hydrolyzed to monomers.
2. Acidogeneis/fermentation: Decomposition of organic monomers to fatty acids and alcohol.
3. Acetogenesis: production of acetic acid and hydrogen gas from the fermentation products.
4. Methanogenesis: Production of methane by organisms that uses acetic acid and hydrogen gas as substrate.

The methane gas produced is rich on energy and is used as biogas.

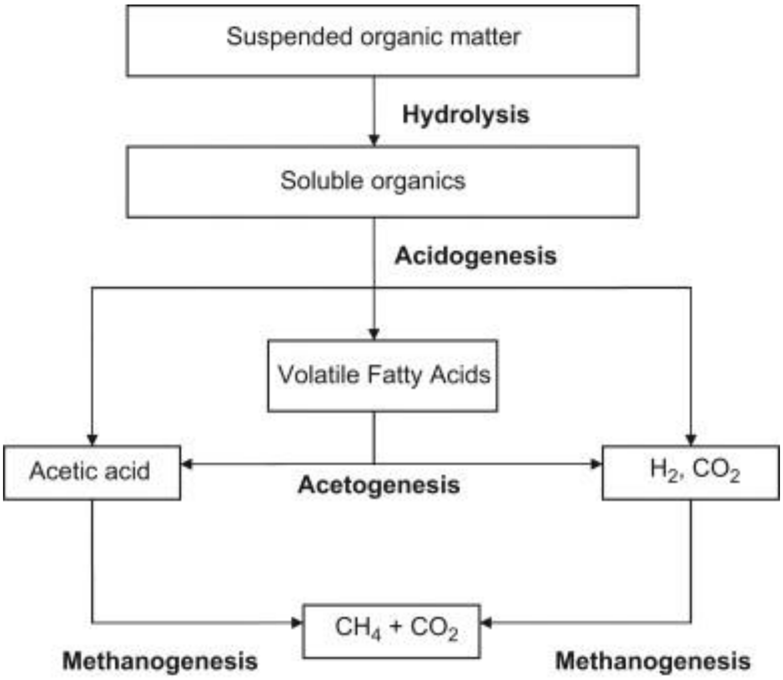


Figure 1. Subsequent steps in the anaerobic digestion process, Appels et al. 2008

Dewatering is normally the last treatment before handling, transportation and disposal. Dewatering is used in wastewater treatment to reduce water content in sludge. It reduces the total volume of sludge, which reduces costs, makes it easier to handle and dispose, and increases calorific value of the sludge. The water trapped in interstices of flocc particles is removed by mechanical dewatering, the solid content can get as high as 40 % with centrifugation as the dewater mechanism. Mechanical dewatering is rapid and most space beneficial and is therefore widely used. Selection of dewatering device is determined by type of sludge, characteristics of product and space availability. The main dewatering process is centrifugation with chemical conditioning; the centrifuges separate liquids of different density and remove solids. Dewatering can increase the solid concentration from 10% to 25-40% depending on the process, (thickening of sludge, which is done before dewatering, increases the solid content from 5% to 10%).

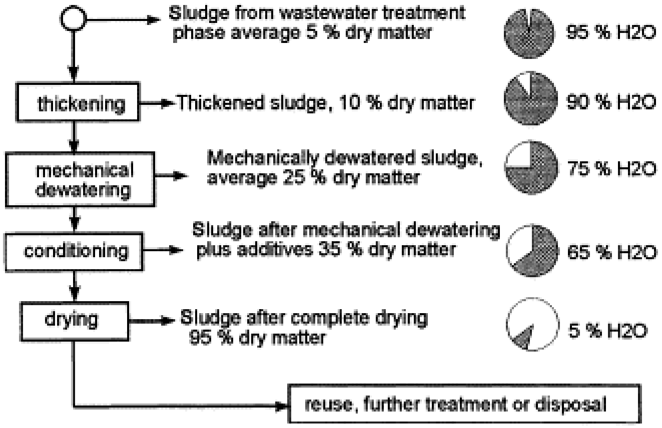


Figure 2. Material balance: water–solid mass according to Manzel 1989.

The water that is rejected in this process is what we call sludge liquor (also called reject water), and is characterized by high ammonia and nitrogen levels (see table 1). The sludge liquor is normally recycled, and increases the total nutrient loading on the wastewater plant. This recycled reject water can contribute to increased maintenance costs due to higher use of coagulation chemicals that also contribute to higher operational costs when recycled to inlet (NORVAR, 2000). Wastewater treatment plants which have a separate treatment for the sludge liquor are normally carried out to reduce to nitrogen load on the plant, since it improves overall nitrogen elimination by lowering the nitrogen inlet load, and reduce the total nitrogen concentration in the final effluent (Fux et. al, 2005).

Table 1; typical sludge liquor values

Parameters	**mg/l**
NH_4-N	500-1500
Total-N	300-1000
NO_3-N	0,5-1
NO_2-N	0,01-0,05
PO_4	20-40
TP	25-40
COD	500-1500
sCOD	300-1000
TSS	400-800
VSS	300-700
pH	7-9
Alkalinity (mmol/l)	20-40

Source: Berends et al. 2005, Dosta et al. 2007, Ghyoot at al. 1998.

Biological CO_2 mitigation has attracted attention because it leads biomass energy by CO_2-fixation through photosynthesis (Kondili and Kaldellis, 2007) and algae are viewed upon as valuable co-products in energy production and energy optimization on mass cultivation by photosynthetic CO_2-fixation (Brennan et al., 2010). Microalgae are a group of fast growing unicellular and simple multicellular photosynthetic organisms that has the ability to fix CO_2 10 to 15 times greater then terrestrial plants and completely recycle CO_2 (Li et. al 2008). Microalgae structures are good for energy conversion and they easily adapt to difficult environmental conditions (Lee et al. 2010), microalgae are easy to cultivate provided that nutrients are easily available and don't need much attention (Mata et al. 2010).

3.2 Objectives:

The overall objective of this study is:

1. Characterize sludge liquor from four different wastewater plants after dewatering.
2. Investigate the key parameters needed for algae growth
3. Investigate a pre-treatment method of sludge liquor that will reduce TSS, turbidity and COD, but still contain nitrogen and phosphorous compounds that can support algae growth.
4. Characterization the pre treated sludge liquor.
5. Grow microalgae using pre-treated sludge liquor
6. Investigate the feasibility of the concept

4. Literature review

Wastewater treatment is based on removal of BOD, COD, suspended solids, lower turbidity and removal of nutrients such as nitrogen and phosphorous.

Total suspended solids measurement is one of the most important characterization methods for wastewater analysis. The filtration separates the suspended and the dissolved solids and the values of the suspended solids will vary with the pore size used, normal range is between 0,45-1,6µm (Scragg 2004).
Turbidity is a measure of light transmitting properties, which indicates the quality of wastewater according to colloidal and residual suspended matter. It is based on comparison of light scattering intensity with a reference suspension standard. Colloidal matter will scatter or absorb light and affect the light transmitting properties (Metcalf and Eddy 2004).

The chemical oxygen demand (COD) is defined as the quantity oxidant consumed is expressed in terms of the oxygen equivalence. Higher oxygen equivalence gives higher COD and higher pollution potential. It is calculated by amount of specific oxidant ($Cr_2O_7^{2-}$) that reacts with the sample;

$$6\,Cl^- + Cr_2O_7^{2-} + 14H^+ \rightarrow 3Cl_2 + 2Cr^{3+} + 7H_2O \qquad (1)$$

Removal of COD and suspended solids is commonly done by coagulation, flocculation and sedimentation (see section 4.3 for more details). Turbidity is reduced when suspended solids are removed from solution.

Nitrogen removal is based on aerobic nitrification;

$$8NH_4^+ + 16O_2 \rightarrow 8NO_3^- + 8H_2O + 16H^+ \qquad (2)$$

followed by anaerobic heterotrophic denitrification;

$$8NO_3^- + 5CH_3COOH + 8H^+ \rightarrow 4N_2 + 10CO_2 + 14H_2O \qquad (3)$$

Also aerobic oxidation of ammonium to nitrite;

$$8NH_4^+ + 12O_2 \rightarrow 8NO_2^- + 8H_2O + 16H^+ \qquad (4)$$

combined with anaerobic oxidation of ammonium by nitrite;

$$8NH_4^+ + 8NO_2^- \rightarrow 8N_2 + 16H_2O \qquad (5)$$

The removal of phosphate is normally performed by chemical precipitation using ferric chloride or ferric sulfate with addition of lime as pH-stabilization (Guo et al. 2010).

4.2 Sludge liquor and sludge liquor treatment

Separate treatments of reject water which is currently studied are, according to Jenicek, 2005;

- Controlled discharge in mainstream of wastewater
- Physical- and chemical treatment
- Use of reject water for bio-augmentations
- Biological treatment

Most treatments conducted on sludge liquor are done to remove nitrogen and phosphorous, the sludge liquor recycled to the influent of the wastewater treatment plant, only contributes to approximately 2% of the total influent flow but can contribute with up to 25% of the total inlet nitrogen load (Janus and Van der Roest, 1997). The most effective way to reduce phosphorous and nitrogen release after wastewater treatment is to treat reject water before recycling through a separate treatment procedure. Reject water is characterized by high concentrations of nutrients and organics. Sludge liquor can contain from 750-1500mg/l NH_4-N (Berends et al. 2005) and 40mg/l PO_4-P (Pitmann, 1991). As nitrogen and phosphorus are nutrients that give wastewater plants a high nutrient loading, these are the parameters in focus when treating sludge liquor.
For nitrogen removal in sludge liquor different combinations of nitrification, denitrification, and anaerobic oxidation of ammonium is used (described in more detail in section 4.1) (Guo et al. 2010). In Australia, biological treatment through a sequencing batch reactor has eliminated the nitrogen load significantly (Wett et al. 1998, Fux et al. 2006) Ion exchange, with different types of zeolites, as treatment of sludge liquor reduced ammonium loads from 700mg/l to 27-36 mg/l ammonium (Thornton et. al 2007).

For combined ammonium and phosphate removal in sludge liquor struvite crystallization has been conducted with good results (Battistani et al. 1997).

Flocculants are used to increase sludge separation efficiency (Nguyene 2008), the reaction between sludge and flocculants results in clusters of sludge particles. The amount of flocculant dose added influences the suspended solids content in the sludge liquor. Boran et al. (2010) found that SS content in sludge liquor decreased with higher polymer dosage, the flocculant dose impacted the sludge liquor characteristics more then the sludge characteristics.

4.3 Coagulation and flocculation as a pretreatment method

The aim of coagulation-flocculation is to remove colloidal matter. Is a process of aggregating dispersed particles into larger units called flocs, and involves three principal steps;

1. Destabilization of the suspended particles, elimination of interparticle repulsion that occurs due to electric charges opposing aggregation.

2. Floc formation and growth, particle-particle interaction, collision and adhesion that develop aggregates.
3. Floc degradation, mechanical breakage of aggregates due to turbulence.

The charge on the particles dispersed in water typically arises from electrochemical interactions, and can be controlled through pH. Other ways of elimination of charge is high presence of high concentration of ions in solution that compresses the electrical double layer letting them approach to the range where attractive forces dominates. Polymeric substances function as a highly charged ionic species but act through a charge-path mechanism in which molecules adsorb on opposite charged surfaces forming regions of opposite charge to the surface (Gregory, 1973). Aggregation occurs by interaction with bare regions on other particles. Lower molecular weight polymers function good as dispersants, high molecular weight polymers are not effective for destabilization but are important in floc development.

Destabilization makes particles to adhere to each other during contact. Flocs grow as a result of collision between particles moving due to;
- Brownian motion (from thermal energy in the suspended fluid).
- Velocity gradients in mechanically agitated suspension
- Different settling of particles or flocs

Recently the use of synthetic polyelectrolytes as flocculants (polymeric flocculants) in wastewater treatment for removal of SS has grown (Ebeling et al. 2005). Especially high molecular weight polymers have given high improvement in separation processes (Walker and Kelley, 2003).

Acrylamide is a polyfunctional molecule containing a vinyl carbon-carbon double bond and an amide group with a deficient double bond that is susceptible to a wide range of chemical reactions (Girma et al. 2005). The advantage of polymeric flocculants is their property of give good settling compared to what is achieved by coagulation by producing large and, dense, compact and strong flocs and require lower dosages. The performance is also less pH dependent, and alkalinity is maintained. The performance of the polymer is depended on the type and molecular weight, ionic charge and wastewater charachteristics (Qian et al. 2004), and the advantages for polymers is that they can be design for exact purpose. High molecular weight polymer flocculants appear to play a significant role in the floc breaking process, they serve primarily as binding agents as they bridge many small particles (Ebeling 2005), enhance the floc strength and reduce breaking rates; thereby permitting growth of large sizes. They are effective in promotion of floc growth in previous destabilized suspension. They adsorb strongly and irreversible onto solid surfaces (Fleer et al. 1993).

Organic polymers can be cationic (positively charged), anionic (negatively charged) and non ionic (no charge). Effectiveness depends on the efficiency of each stage (coagulation, flocculation and sedimentation) and;

- Polymer concentration
- Polymer charge
- Polymer weight and charge density
- The treated wastewater characteristics.
- Physical properties (mixing, flocculation energy, duration).

(Ebeling et al. 2005).

The phosphate is incorporated in solids and reduction of solids gives phosphorous removal. Nitrogen removal due to coagulation-flocculation reduces nitrogen compounds contained in natural compounds as proteins and peptides, and also synthetic organic compounds, since it is related to the colloidal matter of solution and proteins are partially hydrophobic and hydrophilic. Ammonium is not directly removed by this process (De Renzo, 1978).

Wong et al. (2006) tested out cationic and anionic polyacrylamides with different molecular weights and charge densities on paper mill wastewater. Paper mill wastewater is characterized by high BOD, COD (due to high content of tannins and lignins), SS and organic halides (Lacorte at al. 2003). Effectiveness was measured based on turbidity and COD reduction, and TSS removal. The most effective polymer was a high molecular weight and low strength cationic polymer, which reduced turbidity, TSS and COD by 95%, 98% and 93% with optimum dose at 5mg/l. And concluded that a single-polymer can be used, without addition of inorganic coagulant, since the efficiency is remarkable Walker and Kelley (2003) tested flocculation efficiency on pig waste slurry and found the polymer efficiency to vary between 10-500mg/l, 62-125mg/l was optimal for TSS, SS and COD while amounts of 375-750 was optimum for nitrogen and phosphorous reduction.
According to Ebeling 2005, there is no type of polymer flocculant (regarding family, charge or molecular weight) that predicts the performance as flocculation aid.

4.4 Use of oxidation as pretreatment method

Chemical oxidation is oxidation of pollutant complex substances into non-toxic simple substances by the use of a chemical oxidant. Chemical oxidations of organic substances are similar to biological oxidation with CO_2 as end-product.

The chemical oxidation is classified based on degradation:

- Primary degradation – a structural change in compound that leads to biological degradable compounds
- Acceptable degradation (defusing) – to a lower and acceptable toxicity
- Complete degradation (mineralization) – total degradation to non-harmful inorganic compounds.

Reaction rate determines necessary contact time between oxidant and liquid and are influenced by dosage, pH, temperature, TSS (can reduce reaction rate), and competing reactions.
Complete oxidation/degradation requires high dosage and with lower dosages degradation to intermediate compounds can be achieved, which can be utilized for example by microalgae. (Lecture note, L. Ydstebø)

4.4.1 Hydrogen Peroxide:

A strong oxidant used for chemical oxidation and for odor control, widely used in for wastewater treatments in the past. It has no known byproducts and has been found to effectively treat wastewater requiring less stringent oxidation conditions (Ayling and Castrantas, 1981). It has been used for odor control, corrosion control, sludge-bulking control and bacterial reduction. Application of hydrogen peroxide alone to wastewater gives the problem of low rates for applications involving complex materials (Fung et. al. 2000).

The use of hydrogen peroxide alone not a recommendable option according to (Gogate and Pandit 2004) for the treatment of complex compounds, and the concentration and amount of it used cannot be increased to some certain levels because it act as an pollutant in to large amounts. Excessive amounts give create negative effect on removal efficiency due to formation of H_2O_2, formed by hydroxyl radicals and excess hydrogen peroxide, and is a less effective radical.

$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$ (6)

Hydrogen peroxide is today used in combination with other processes, as UV, $TiO_{2,}$ ferrous-salts (Fenton process). The pH is also important for efficiency, and a low pH (3-6) is found to give best efficiency of oxidation (Yonar et. al, 2006), and turbidity removal (filtration) as pretreatment increases the COD removal efficiency.

4.4.2 Fenton process:

Fenton`s reagent is a mixture of H_2O_2 and ferrous ion.
Fenton oxidation is an effective pretreatment to improve biodegradability of wastewater and wastewater sludge prior to further treatment (Andrews et al. 2006). It is an advanced oxidation process and the fenton process involves Fe^{2+} and Fe^{3+} mediated catalytically decomposition of H_2O_2 that generates hydroxyl radicals; Fe^{2+} initiates and catalyze the decomposition;

$Fe^{2+} + H_2O_2 \rightarrow Fe^3 + OH\bullet + OH^-$ and $HO_2\bullet$ (7)

The formed ferric ions catalyzes and contribute to decompose hydrogen peroxide into water and hydrogen;

$Fe^3 + H_2O_2 \rightarrow Fe\text{-}OOH^{2+} + H^+$ (8)

$Fe\text{-}OOH^2 \rightarrow HO_2\bullet + Fe^{2+}$ (9)

$HO_2\bullet$ is a very strong oxidizing agent, a radical.

$HO_2\bullet + Fe^{2+} \rightarrow Fe^3 + HO_2^-$ (10)

$Fe^3 + HO_2\bullet \rightarrow Fe^{2+} + O_2 + H^+$ (11)

$OH\bullet + H_2O_2 \rightarrow H_2O + HO_2\bullet$ (12)

Hydroxyl radicals can oxidize organic matter by abstraction of protons producing organic radicals, which can be further oxidized (Walling and Kato, 1971).

By accounting for the dissociation water a simplified Fenton reaction can be made (Wailing, 1975):

$2Fe^{2+} + H_2O_2 + 2H^+ \rightarrow 2Fe^3 + 2H_2O$ (13)

Acidic pH levels are optimal for the Fenton oxidation process (Hickey et al. 1995). The Fenton process has also been applied to enhance anaerobically digestibility as well as dewaterbility of wastewater sludge. The $H_2O_2/FeSO_4$ ratio influence the functions. If Fe^{2+} exceeds H_2O_2 the process seems to have an chemical coagulation effect, if the ratio is opposite it accts like an oxidation process (Neyens and Baeyens 2003).

4.4.3 Peracetic acid (PAA)

Peracteic acid is the peroxide of acetic acid, its produced from the reaction of acetic acid and acetic anhydride with hydrogen peroxide in the presence of sulfuric acid that acts like a catalyst (Block, 1991);

$$CH_3CO_2H + H_2O_2 \rightarrow CH_3CO_2H + H_2O \qquad (14)$$

PAA is a strong oxidant and disinfectant, it requires lower concentrations then conventional hydrogen peroxide (Kitis, 2004). Peracetic acid has combined the active oxygen characteristics of peroxide within an acetic acid molecule. PAA has a higher activity at lower pH.

4.5 Filtration media as pretreatment:

Anthracite contains over 90% carbon, mostly in the form of large polycyclic aromatic sheets. That results in properties as high microporosity pore volume which makes it useful in water filtration applications (Andresen et al. 2004). Anthracite is used as granular media filter, alone and combined, to remove particulate matter as clay, silt, microorganisms and colloidal substances in seawater (Mitrouli et al. 2009). With respect to particulate parameters granular media filters are an inexpensive solid-liquid separation process. Particulates ranging from 0,01-100µm can be captured by granular media provided that the right surface chemical conditions for attachment to media is present. The effectiveness of a granular media depends on physical parameters as pore size, shape, porosity, depth and surface area of media. Also the chemical properties of both media and particulates are important (Boller and Kavanaugh 1995). In drinking water treatment filtration through granular media after coagulation and flocculation is common, and is used as a final polishing process for the potable water process (Zouboulis et al. 2007). Direct filtration through anthracite without pretreatment is considered best for low turbidity waters, for anthracite or anthracite in a dual media the influent should have low initial turbidity (Chuang and Li, 1997).

Activated carbon can be made from anthracite, but this is a challenging process compared to making it from bituminous coals which has applications in both water and air purification. It is used in water treatment for removal of organic compounds, odor control and removal of color (Magic-Knezev and Kooij, 2004). PAC/GAC for other uses then odor and taste control is poorly documented. The extent of adsorption of synthetic organic chemicals is depended on what type of compounds being removed. In (Kim et al. 2002) pretreatment of secondary effluent from a combined industrial and municipal wastewater plant was pretreated before enter as feed in RO memebrane filtration. The combination of GAC and anthracite and coagulation-flocculation with a cationic polymer before GAC/Anthracite media was tested. The combined GAC and anthracite plus the coagulation before the dual media had good effects on color, COD, TOC and BOD removal, approximately 75%, 70%, 60%, 50%. Nitrogen was removed in some extent, while phosphorpus removal was not as efficient, cause of the negative charge of phosphate it does not get adsorbed by GAC. Activated carbon combined with limestone was used for removal of NH4-N, and showed effective removal at very low cost (Hussain et al. 2006). Studies show that GAC combined with MF reduces COD, TOC, and turbidity significantly and give less removal of total nitrogen and phosphorous (Kim et al. 2009). All these cases are low turbidity waters as rivers, drinking water and seawater.

4.6 Centrifugation as a pretreatment

Centrifugation is widely used for liquid/liquid separation and solid separation (Metcalf and Eddy, 2004). Centrifuges achieve separation by an accelerated gravitational force achieved by rapid rotation. (Sutherland 2005). The separation is similar to what is achieved in a sedimentation process, but with a much higher driving force due to the rotation. The suspended particles in the incoming liquid settle down die to gravitational force while liquid is moved through the centrifuge. Centrifuge performance is affected by operating and design variables, operating variables include; particle size, flow rate, fluid/particle density differential and fluid viscosity. Design variables includes rotational speed, height and radius which effect residence time or centrifugal force. Rotational speed has a high effect on separation efficiency, efficiency fourfold when speed doubles (Gorham and Dudrey, 2006).

4.7 Aeration as pretreatment

Aeration in wastewater treatment is used for maximize the supply of oxygen and avoid oxygen limitation of growth by inducing air in the liquid. It’s the main principles for an activated sludge process which is the most common of the suspended growth processes. The aeration in presence of microbial suspension gives a solid-liquid separation due to microbial metabolization of suspended and soluble organic matter (Scragg, 2005).
The process is depended on the existing microbial community and their metabolization capabilities.

4.8 Microalgae

Microalgae represent a diverse group of prokaryotic and eukaryotic photosynthetic organisms of high ecological importance and are one of the most efficient converters of solar energy to biomass (Masojídek and Torzillo, 2008). Microalgae composition is important to apprehend their digestion potential, major components in microalgae is carbon, nitrogen and phosphorous. They grow rapidly and can grow in harsh conditions because of their unicellular or simple multicellular structure (Mata et al. 2010). They represent a big variety of species (estimated 50.000) living in a wide range of environmental conditions. They are divided in seven phyla; the largest is the chlorophyta (also known as green algae) and includes species like *Chlorella* and *Scendsemus*. *Chlorella* is used in commercial production for human nutrition, aquaculture and cosmetic purposes (Spolaore et al. 2006).
Microalgae is widely used for biodiesel production, because of high lipid content and high growth rate under right conditions. Average proportions are 6-52% protein, 7-23% lipids and 5-23% carbohydrates with high proportions of glucose (21-87%), this is all strongly species depended (Brown et al. 1997).

4.8.2 Current use of microalgae for wastewater treatment

Wastewater has large quantities of different nitrogen forms and high phosphorous concentration. Combination of wastewater treatment and microalgae has been conducted due to savings of chemicals (nutrients already provided) and environmental benefits (Mallick 2002). The process involves removing nutrients or pollutants from wastewater while producing algal biomass. Mostly secondary and tertiary wastewater is used for algae cultivation and wastewater treatment, but it has been difficult to differentiate between the microalgae and other microorganism role in nutrient utilization (de-Bashan 2010). Microalgae has been used in wastewater treatment to remove organic matter (BOD) and inorganic nutrients and heavy metal removal (Munoz and Guyiesse, 2006). *B.Braunii* has been used to remova nitrogen and phosphorous from secondarily treated wastewater, eliminating settled and organic matter (Yun et al. 2007). *C. Vulgaris* is commonly used for tertiary wastewater treatment, de-Bashan et al. (2004) describes a combination of microalgae (*C. Vulgaris*) and microalgae growth promoting bacteriato remove nitrogen and phosphorous from municipal wastewater. *C. Vulgaris* was also capable of removing as much as 55% of phosphorous from dairy and pig farming wastewater (Gonzales 1997).

4.8.3 Growth and cultivation of microalgae:

The solar energy stored in algal biomass as a result of photosynthetic reaction can be released as methane through anaerobic digestion. Commersial cultivation of microalgae has been done for over 40 years with the species of *Chlorella* and *Spirulina*, the main problem of commercial for microalgae production is high costs due to excessive light expenses and slow growth rate (Borowitzka 1999). Cultivation of microalgae in aerated pig manure was conducted in Martin et al. 1985, the microalgae strain was a *Scendermus sp.* The result obtained with aerobically fermentation of the manure over 8 days as an algae substrate showed it as a good way to produce biomass. It did not effect algae growth with high initial ammonium concentrations. Aeration-agitation (stirring and air bubbling) optimization for wastewater treatment in removal of ammonium and phosphate in addition to algae cultivation was conducted by Pouliot et al. 1988. Results showed that aeration at a 14/24 hour basis was optimum for removal of ammonium and phosphate, giving removal of 95% and 62%. Nitrate addition to culture helped on algae growth. Stirring was not a good option for algae growth. The rate of aeration was not as important as thought for biomass growth but enrichment of CO_2 up to 5% gave good biomass growth (Noue et al. 1984). *Chlorella sp* cultivation and growth in a lab scale photobioreactor for CO_2 removal in stack gas was conducted by Watananbe and Saiki 2007. 10% CO_2 enriched air was added and the CO_2 utilization efficiency was at 21,9% and NO removal rate at 85%. Maximum increase in biomass 21,5g dry biomass/m^2d or 0,68 dry biomass/Ld. Pohl et al. (1987) tried seawater diluted in distilled water as growth media for freshwater microalgae, 10 % seawater the rest distilled water, the only nutrient added was phosphate with good results.

Growth medium must provide sufficient nutrients; carbon, nitrogen, phosphorous and sulfur are the most important parameters. Other essential elements are iron, magnesium and silicon. Also salinity, temperature, pH, light and dissolved oxygen effect growth.
N and P is essential for algae growth and Mostert and Grobbelaar (1987) found that optimum N and P values for microalgae growth was when they exceeded 25 and 2 mg/l in a culture Phosphate is relevant to all growth and metabolism, and is essential elements for DNA, RNA, ATP and cell membrane materials, phosphorous should be added in excess.
Ammonium at high concentrationshas toxic effects on microalage growth (Lourenzo et al. 2002). CO_2 is the usual source for carbon for photosynthetic culture of microalgae (Grima et al. 1999).

In dense microalgae cultures, light penetration is impeded by light absorption (Frolich et al. 1983). Availability and intensity of light are major factors controlling productivity of photosynthetic cultures (Lee and Low, 1992). One cannot increase light intensity over a certain limit because a high light energy per cell will photo inhibit the photosynthetic cells (Lee et al. 2005). Chlorofyll a has a maximum light absorbance at 670-680nm (Werner, 1977)

5. Sampling and sample sites

Sludge liquor was collected after dewatering from four different plants, Frevar, Gardermoen (GRA), Søndre Follo (SFR) and Nordre Follo (NFR) wastewater treatment plants, which lies near the Oslo region.

Table 2; Overall process overview over each wastewater plant sampled

	FREVAR	**Gardermoen Renseanlegg -GRA**	**Nordre Follo Renseanlegg -NFR**	**Søndre Follo Renseanlegg -SFR**
Location	1630 Gamle Fredrikstad	2050 Jessheim	1407 Vinterbro	1540 Vestby
Dimmensioned load (P.E)	100.000	50.000	41.000	17.000
Mechanical treatment	Coarse screens Grit removal	Coarse screens Grit removal Pre-sedimentation	Coarse screens Grit removal Pre-sedimentation	Coarse screens Grit removal
Chemical treatment/ Precipitation agent	Flocculation and sedimentation. $FeCl_3$ + Seawater 3%	Flocculation and flotation PAX 21 + cationic polymer as helping agent	Flocculation and flotation PAX + cationic polymer as helping agent	Flocculation and sedimentation. PAX-18 + a cationic polymer as helping agent
Biological treatment	none	Nitrogen removal by anoxic and aerobic reactors (Moving Bed Biofilm reactor)	Nitrogen removal by anoxic and aerobic reactors	none
Sludge thickening	Rotary drum thickener + addition of polymer	Thickening	Gravity thickening	Thickening
Pasterurisation	Pasteurisation	none	Pasteurisation	Pasteurisation
Digestion	Anaerobic digestion (thermophile)	Anaerobic digestion (thermophile)	Anaerobic digestion (thermophile)	Anaerobic digestion (thermophile)
Dewatering	Centrifuge	Centrifuge	Centrifuge and belt-filter press	Centrifuge

Table 3; Sample location

Sample location	Sample collection point	Polymer used for dewatering
FREVAR	Under centrifuge outlet	C-491K
Gardermoen Renseanlegg (GRA)	From a storage containing reject water from dewatering by centrifuge	ZG 8110
Nordre Follo Renseanlegg (NFR)	Under centrifuge outlet	SF 603 CL
Søndre Follo Renseanlegg (SFR)	Under centrifuge outlet	SF 640 CL

Description of sample site.

6. Materials and methods:

6.1 Characterization/Analytical procedures

6.1.1 Physical parameters

pH
pH was measured by using a WTW SenTix 41 connected to a WTW 340i portable set.

Conductivity
Conductivity was measured by using a WTW TetraCon 325 connected to a WTW 340i portable set.

DO
Dissolved oxygen was measured by using a WTW CellOx 325 connected to a WTW 340i portable set.

Alkalinity
Conducted as described in Standard method 2320B (standard methods for water and wastewater, 1992). An ampoule with standardised 0.1M HCl was used, so there was no need for titration to determine concentration of HCl before the endpoint titration. pH was used for end point determination at pH: 4.5.

Turbidity

HACH 2100P, portable turbid meter, was used to measure turbidity. Values is given in NTU (nephelometric turbidity units).

Transmittance

Spectrophotometer used: DR 5000 (HACH). It was taken a full wavelength scan (200-1100nm), the absorbance and transmittance results at 670nm were used to compare the results. A 1 cm quarts cuvette was used to measure absorbance, and distilled water was used as a blank and zeroed against and to give 100% transmittance. The wavelength of 670 nm was chosen because algae growth is our main perspective for the pre-treatments and chlorophyll has the highest absorbance at 670nm (Cederstrand et al. 2003).

Particle size distribution

Malvern Mastersizer NS was used for detection of particle size distribution.
In electronic particle counting, diluted sample is passed by a laser beam. When passing by the laser beam the conductivity of the fluid changes and the change is correlated to the size of an equivalent sphere. Also when the particle passes the laser beam it reduces the intensity due to light scattering and that reduced intensity is correlated to the diameter of the particle. The volume fraction corresponding to the particle sizes can be can then be computed.

TS, TSS, VS and VSS

Standard method 2540B, 2540D and 2540E was used (Standard methods for water and wastewater). Whatman GF/C 1,2 μm filter was used. A known volume of sample is filtered through a Whatman GF/C 1,2 μm filter by the use of a Buchner flask connected to vacuum and dried at 105°C to find the TSS value. VSS is found after burning the sample at 555 °C.

VSS= TSS-FSS

For TS and VS values a known volume of the sample is incubated at 105 °C and 555 °C.

VS= TS-FS

Light measurement

Lux meter LX1010B was used for measuring light

6.1.2 Chemical parameters

The chemical parameters were analyzed by the use of Dr. Lange test kits and measured on DR 5000 spectrophotometer.

Table 4; chemical parameters and kit information

Chemical parameter	Kit number	Mehod description
COD	LCK 014 LCK 514	Oxidization able substances react with sulphuric acid potassium dichromate solution in the presence of silver sulphate as a catalyst. Chloride is masked by mercury sulphate. The green colorization of Cr^{3+} is evaluated. Based on ISO 15705.
TN	LCK 138 LCK 338	Inorganically and organically bonded nitrogen is oxidised to nitrate by digestion with peroxodisulphate. The nitrate ions react with 2,6-dimethylphenol in a solution of sulphuric and phosphoric acid to form nitrophenol.
NO_3-N	LCK 339	Nitrate ions in solution containing sulphuric and phosphoric acid react with 2,6-dimethylphenol to form 4-nitro-2,6-dimethylphenol.
NO_2-N	LCK 341	Nitrites react with primary aromatics amines in acidic solution to form diazonium salts. These combined with aromatic compounds that contain an amino group or a hydroxyl group to form intensively coloured azo dyes.
NH_4-N	LCK 302 LCK 303	Ammonium ions react at pH=12,6 with hypochlorite ions as salicylate ions in the presence of sodium nitroprusside as a catalyst to form indophenol blue.
TP	LCK 348 LCK 349 LCK 350	Phosphate ions react with molybdate and antimony ions in an acidic solution to form antimonyl phosphomolybdate complex, which is reduced by absorbic acid to phosphomolybdenum blue. Includes hydrolysis and all phosphate is measured.
PO_4 -P	LCK 348 LCK 349 LCK 350	Phosphate ions react with molybdate and antimony ions in an acidic solution to form antimonyl phosphomolybdate complex, which is reduced by absorbic acid to phosphomolybdenum blue. Happens without hydrolysis and only dissolved orthophosphate is measured.

(HACH Practice report 2008)

6. 2 Pretreatment of sludge liquor

Different pre treatment methods were tested on the sampled sludge liquors.

Treatment methods used:

- Aeration
- Oxidation; Peracetic acid, Hydrogenperoxide and Fenton reaction
- Chemical precipitation
- Filtration through Anthracite
- Filtration through GAC

The best treatment method was used further, and the two best results in form of % transmittance and turbidity was characterized and compared.

6.2.1 Aeration

Samples were aerated by inserting an air-tube and aquarium pump. Transmittance, pH, turbidity, DO and was measured after 2, 6 and 24 hours of aeration.

6.2.2 Oxidation

Different concentrations of H_2O_2, PAA and Fenton reagent were used to treat the sludge liquor. The sample added the specific oxidant concentrations were set on a magnetic stirrer and parameters were measured after given times. Supernatant was taken and analyzed for given parameters in table 5.

Table 5; Concentration of oxidants added to samples

	Chemical composition	**Concentration 1 (mg/l)**	**Concentration 2 (mg/l)**	**Concentration 3 (mg/l)**
Hydrogen Peroxide	H_2O_2	40	80	150
Peractic acid	CH_3CO_3H	20	40	100
Fenton Reagent	H_2O_2 + $FeSO_4$ (1:0,1 molar ratio)	150	-	-

Table 6; parameters measured

Reaction time	**0,5 hours**	**2 hours**	**4hours**	**24 hours**
Parameters measured for oxidation with PAA and H_2O_2	pH, turbidity, transmittance, NH4, NO3, COD	pH, turbidity and transmittance.	pH, turbidity and transmittance.	pH, turbidity, transmittance, NH4, NO3, COD
Parameters measured for Fenton oxidation	pH, turbidity, transmittance	-	-	pH, turbidity, transmittance

Parameters measured after given times during oxidation

6.2.3 Chemical precipitation

Chemical coagulation tests were conducted with a Jar-testing apparatus, Kemira flocculator 90. The process proceeded with rapid mixing for 10 seconds at 400rpm, mixing slowly for 10 minutes at 40rpm and with 20 minutes of sedimentation. 8 different polymers were tested; 5 cationic and 3 anionic polymers. Concentrations at 1, 10 and 25mg/l of all polymers from a prepared stock solution at 0,1% was tested. The 2 most promising polymers based on turbidity and transmission results were further used to find the optimum polymer dose. Further analysis was then conducted to characterize the treated sludge liquor, all physical parameters as pH, alkalinity, particle distribution, conductivity and chemical parameters as COD, nitrogen and phosphorous.

Table 7; Properties of polymers used for coagulation

Polymer	Flocculant type	Flocculant	Chemical supplier
A-120	Anionic	Polyacrylamide flocculant	KEMIRA
C-492	Cationic	Polyacrylamide flocculant	KEMIRA
C-496	Cationic	Polyacrylamide flocculant	KEMIRA
Magnafloc 155	Anionic	High molecular weight polyacrylamide	CIBA
Magnafloc 342	Anionic	High molecular weight polyacrylamide	CIBA
Magnafloc 919	Anionic	Non-toxic, high molecular weight polyacrylamide	CIBA
ZetaG 7550	Cationic	Polyacrylamide	CIBA
ZetaG 8125	Cationic	Synthetic high molecular weight polyacrylamide. Low cationic charge.	CIBA

(CIBA; Technical information).

6.2.4 Filtration through Anthracite

600 grams of anthracite was weighed and placed in a cylinder with a controlled outlet valve. The column specifications were 9.2 cm high and had a diameter of 8 cm. Both original sludge liquor from the wastewater plants and treated sludge liquor with polymers were filtered through anthracite. Turbidity and transmittance results were measured to evaluate the effect of the filtration. The particle size of the used anthracite was 1mm-2.4mm.

6.2.5 Filtration through activated carbon

Activated carbon in the size range of 0.5-1mm was weighed and putted in a cylinder. 40 grams GAC was weighed, the cylinder height was 6.2 cm high and had a diameter of 6.6 cm. Volumes of 10-15 ml sample was filtered of original sludge liquor. Turbidity and transmittance results were measured to evaluate the effect of the filtration.

6.2.6 Coagulation with polymer plus anthracite filtration

The optimum polymer dose decided after coagulation and flocculation procedure of sludge liquor as described in 6.2.3 was further filtrated through anthracite, as described in 6.2.5. Further analysis was then conducted to characterize the treated sludge liquor, all physical parameters as pH, alkalinity, particle distribution, conductivity, turbidity, transmittance and chemical parameters as COD, nitrogen and phosphorous.

6.2.7 Centrifugation

Samples were centrifuged for 10 minutes at 4000 rpm for centrifugal separation. Further analysis was then conducted to characterize the treated sludge liquor, all physical parameters as pH, alkalinity, particle distribution, conductivity, turbidity, transmittance and chemical parameters as COD, nitrogen and phosphorous.

6.2.8 Coagulation with polymer plus centrifugation

The optimum polymer dose decided after coagulation and flocculation procedure of sludge liquor as described in 6.2.3 was further centrifuged as described in 6.2.7. Further analysis was then conducted to characterize the treated sludge liquor, all physical parameters as pH, alkalinity, particle distribution, conductivity, turbidity, transmittance and chemical parameters as COD, nitrogen and phosphorous.

6.3 Microalgae growth

Algae growth was based on mg dry weight per litre per day, a specific volume of algae growth medium was dried at 105^0C and weighed.
Algae specie used was *Chlorella sp.* and was given by our collaboration partners at UMB. The standard nutrient medium that our treated sludge was compared against was also given by UMB, and the content of that and our treated sludge is given in table 7. As a test medium, treated sludge from Frevar, by the use of polymer and anthracite, diluted with outlet from Frevar wastewater plant was used.

The algae culture was cultivated under 24hour light, 8000 Lux, 500 ml of culture in 1000ml sample glass bottles, volume was kept constant so the surface area was constant throughout the cultivation period. Oxygen was added during cultivation.

The treated sludge liquor (90ml) was added 40ml KH_2PO_4 (41mg/l) and diluted in 370ml of water from outlet at Frevar.

Table 8; nutrient values in growth media.

Nutrients in mg/l	**Standard growth medium (“Superba grønnsak”)**	**Treated sludge liquor (Frevar) diluted with water from outlet (1:5,5)**
TN	92	90
NO_3-N	92	2,33
NH_4-N	0	44,25
TP	45	2,73
PO_4 -P	40,5	4,55

7. Results

7. 1 Characteristics of sludge liquor from the different wastewater treatment plants

This section (figure 3 to15) includes comparison of all parameters, chemical and physical, for the sludge liquor samples from the different wastewater treatment plants.

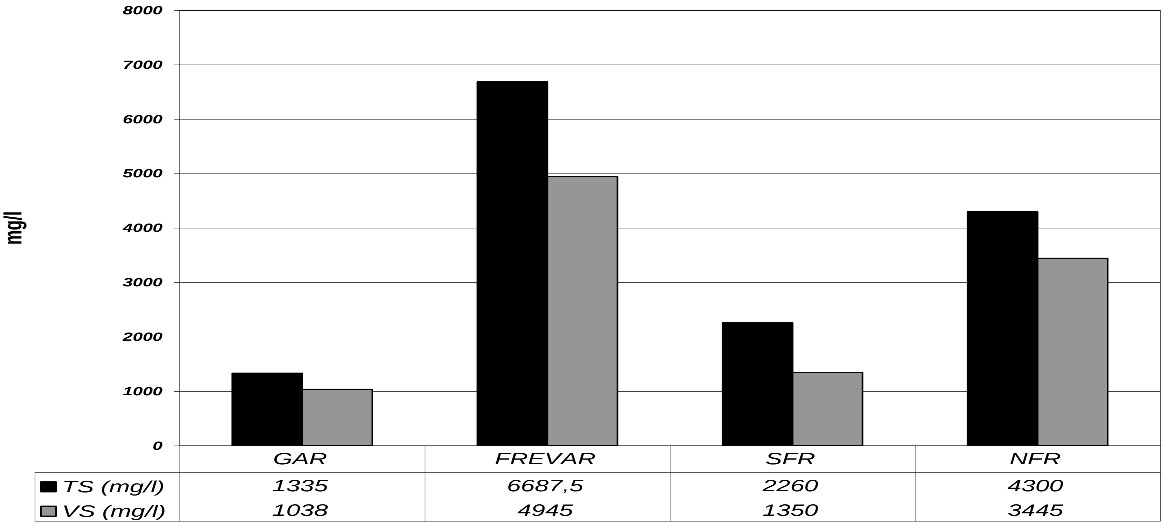


Figure 3; Total solids and volatile solids in sludge liquor samples.

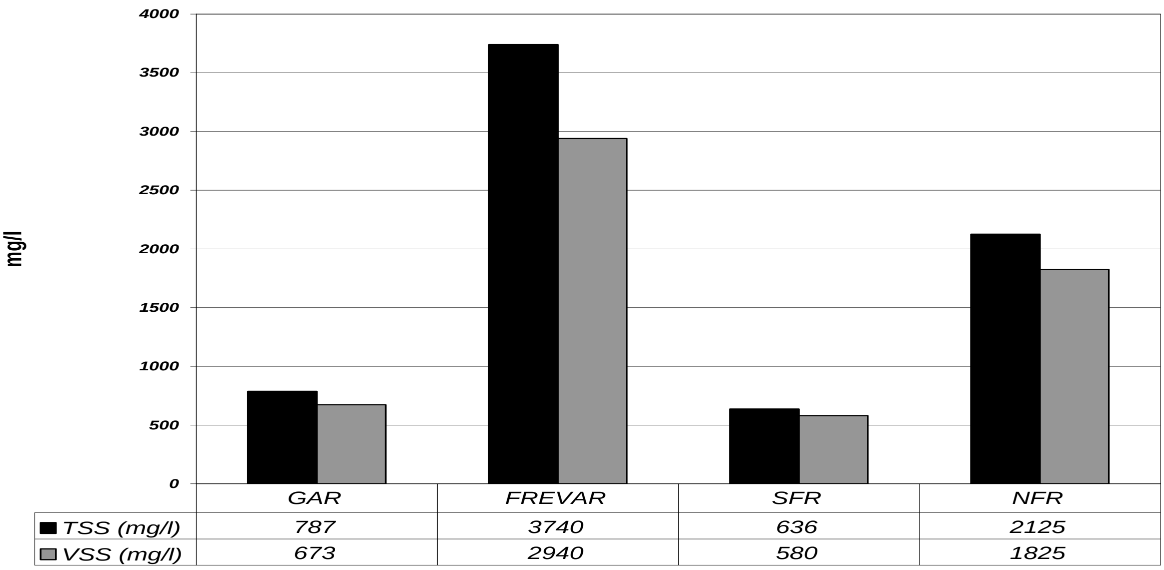


Figure 4; Total suspended solids and volatile suspended solids in sludge liquor samples.

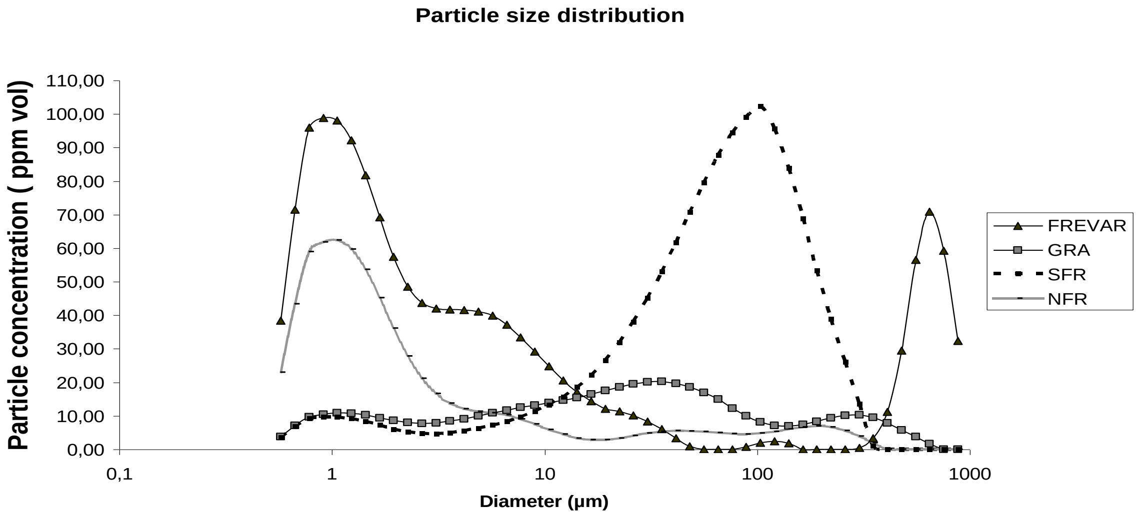


Figure 5; Particle size distribution in sludge liquor samples, measured by the use of Malvern mastersizer.

Table 9; Particle concentrations and size distribution in percentage

WWT Plant	Measured particle concentration (mg/l)	d0.1	d0.5	d0.9
GRA	525	1,23	20,03	210,29
FREVAR	1500	0,72	2,26	571,17
SFR	1380	9	64,13	161,73
NFR	700	0,68	1,39	144,9

Values corresponding to d0.1, d0.5 and d0.9, means the particle size, in µm, that is represented in 10%, 50% and 90% of the particles.

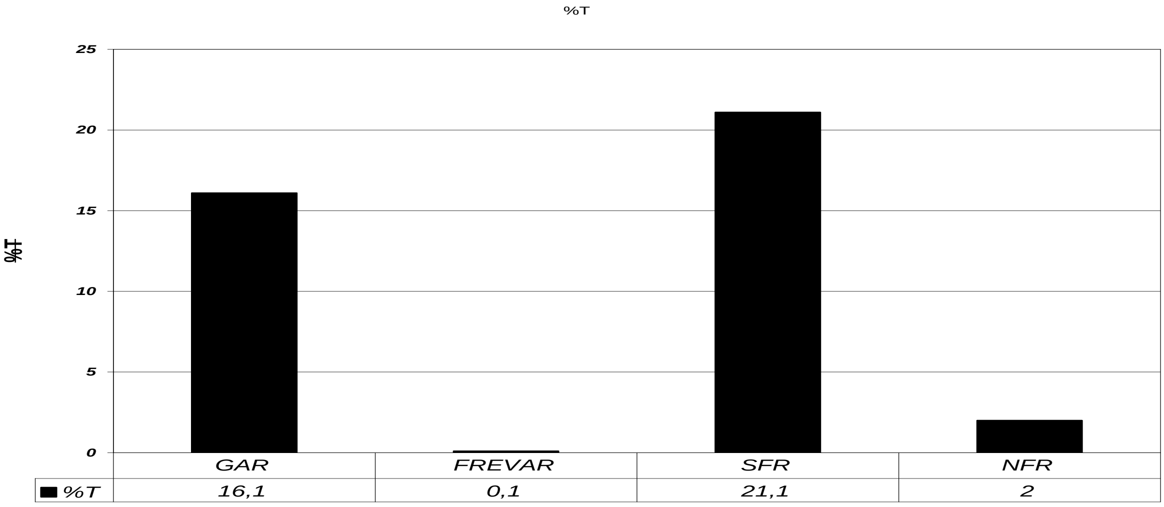


Figure 6; Transmittance in sludge liquor samples, measured at 670nm.

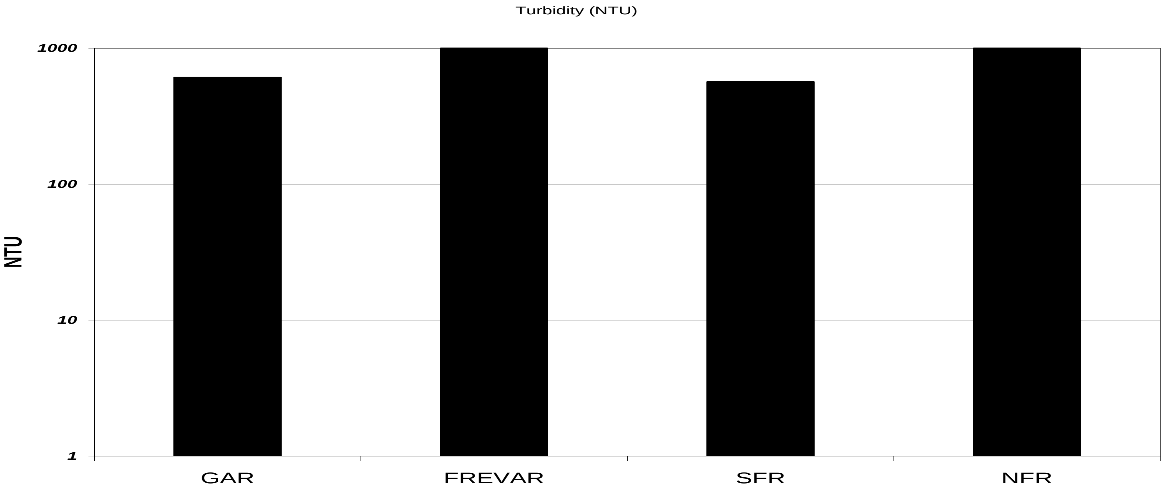


Figure 7; Turbidity in sludge liquor samples, values over 1000 NTU could not be measured, and are illustrated here by reaching over 1000 NTU. GRA and SFR had a value of 611 and 566 NTU.

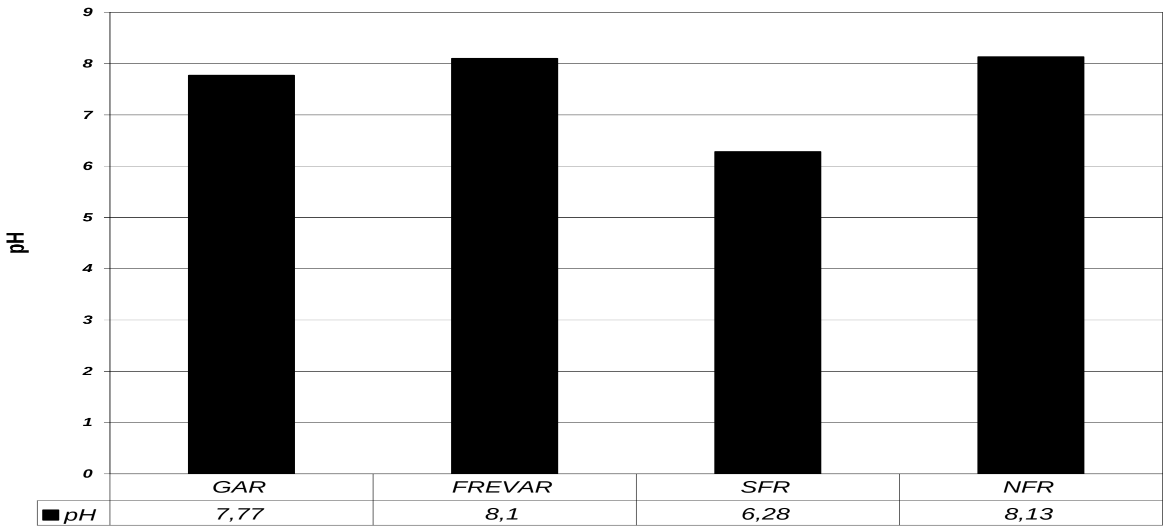


Figure 8; pH in sludge liquor samples.

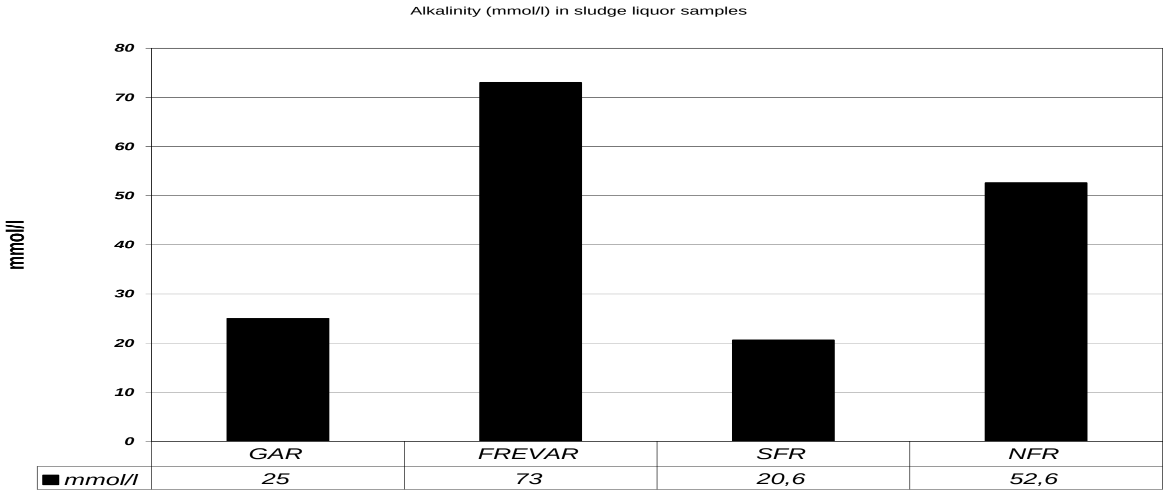


Figure 9; Alkalinity in mmol/l in sludge liquor samples

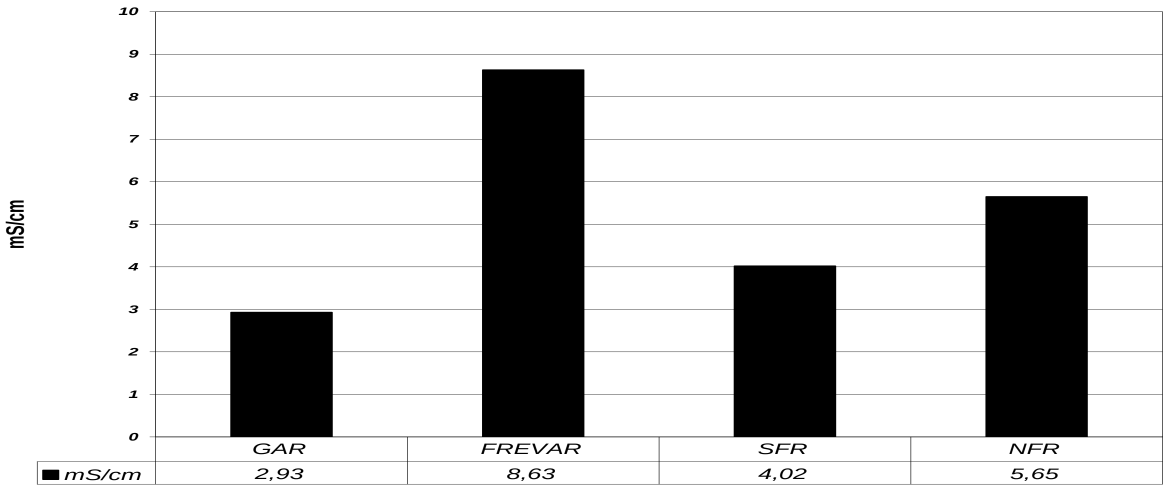
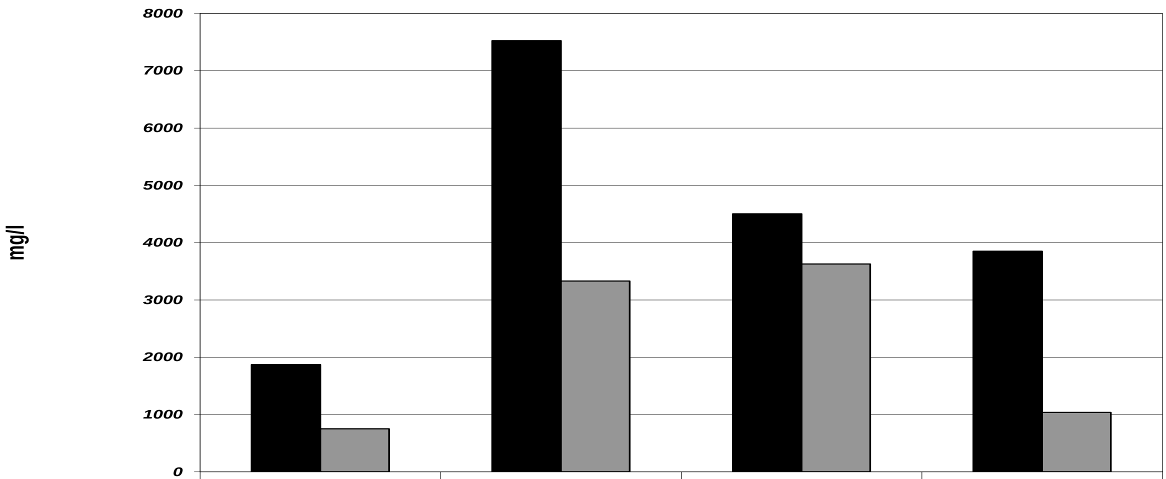
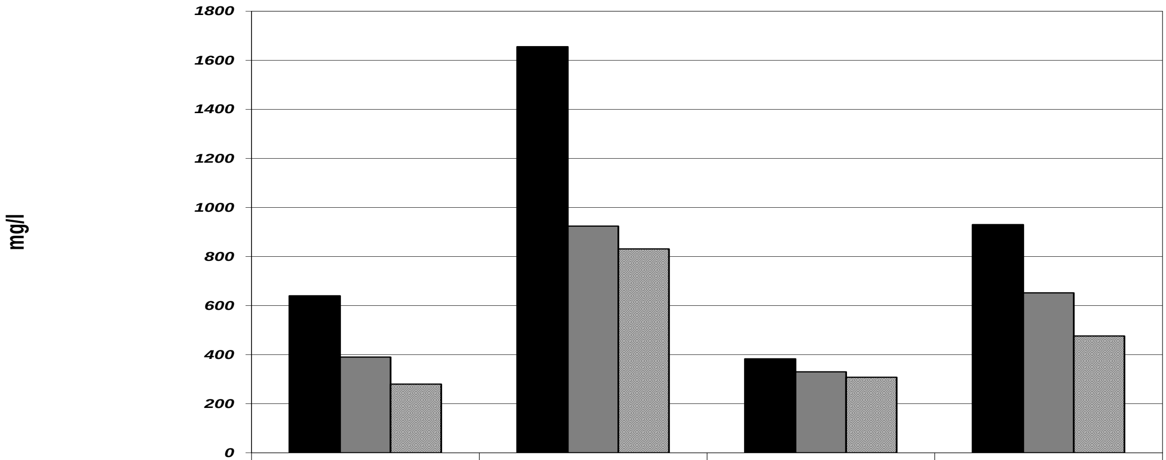


Figure 10; Conductivity in mS/cm in sludge liquor samples



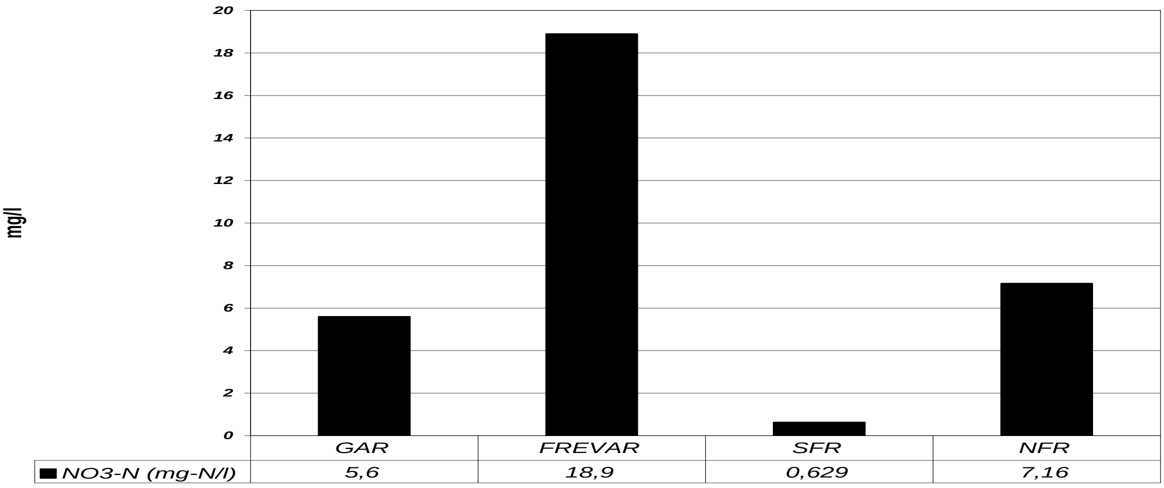
	GAR	FREVAR	SFR	NFR
■ COD mg/l	1872	7525	4503	3850
▨ sCOD mg/l	751	3330	3627	1037

Figure 11; Chemical oxygen demand and soluble chemical oxygen demand (filtered through 1.2µm filter) in sludge liquor samples.



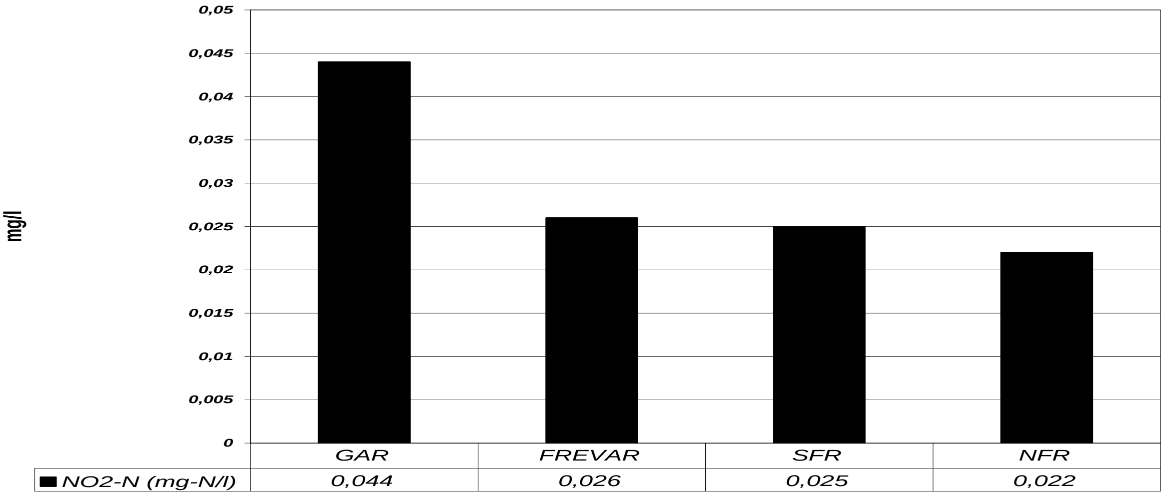
	GRA	FREVAR	SFR	NFR
■ TN (mg-N/l)	640	1655	383	930
▨ sTN (mg-N/l)	390	924	330	652
▨ NH4-N (mg-N/l)	280	831	308	476

Figure 12; Total nitrogen, soluble nitrogen and ammonium values in sludge liquor samples



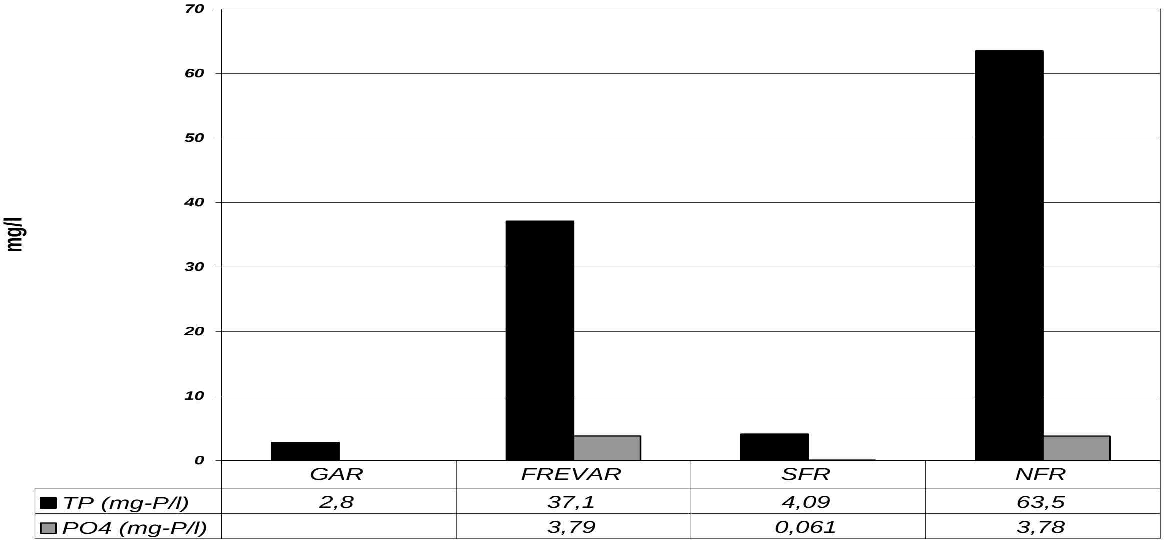
	GAR	FREVAR	SFR	NFR
■ NO3-N (mg-N/l)	5,6	18,9	0,629	7,16

Figure 13; Nitrate values in sludge liquor samples



	GAR	FREVAR	SFR	NFR
■ NO2-N (mg-N/l)	0,044	0,026	0,025	0,022

Figure 14; Nitrite values in sludge liquor samples



	GAR	FREVAR	SFR	NFR
■ TP (mg-P/l)	2,8	37,1	4,09	63,5
▨ PO4 (mg-P/l)		3,79	0,061	3,78

Figure 15; Total Phosphate and Ortho-phosphate values in sludge liquor samples. Phosphate in GRA was under the detectable range of 0,05mg/l.

7.2 Centrifugation as pre-treatment

Centrifugation as described in section 6.2.7 was tested to see if it was suitable as pre-treatment alone. The result is presented in % transmittance.

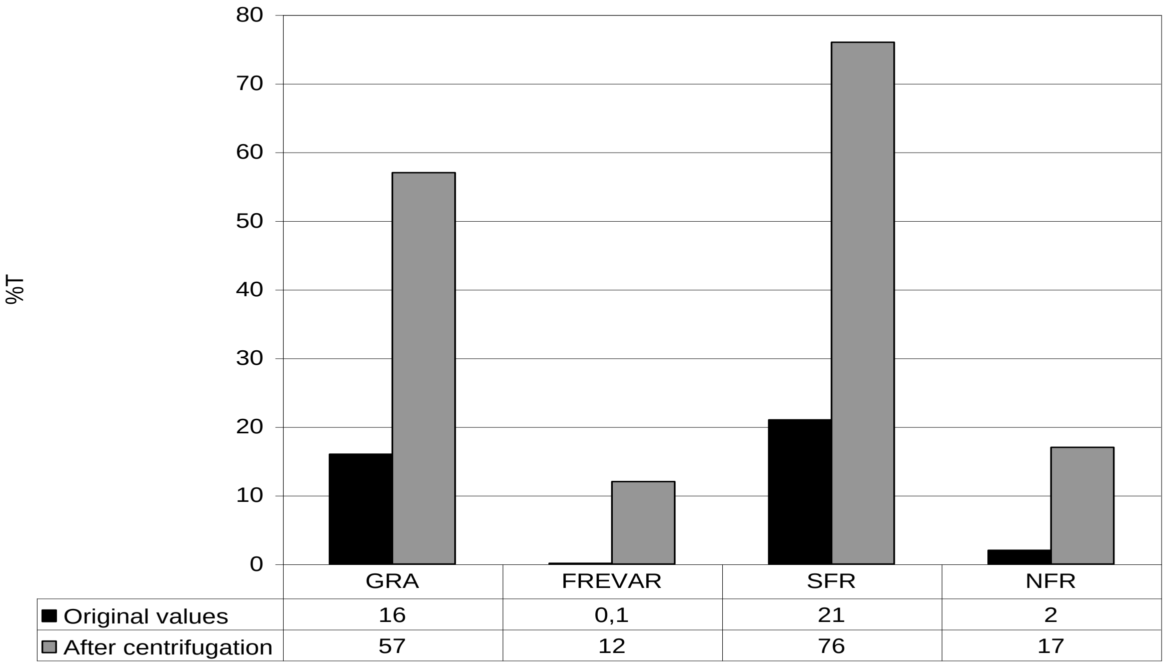
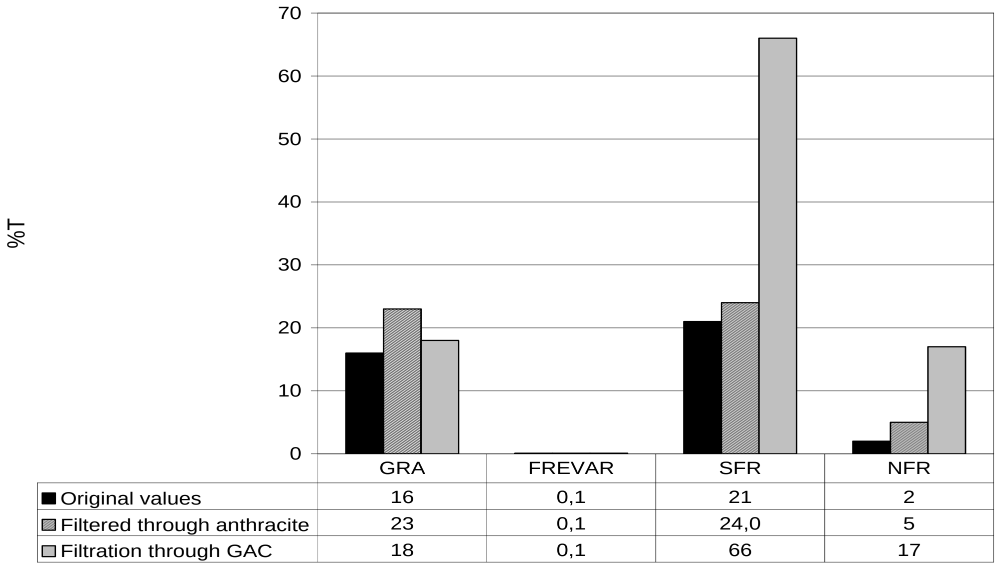


Figure 16; Transmittance values (%T) at 670nm after centrifugation compared with original values

7. 3 Media filtration of sludge liquor from the different wastewater plants

Media filtration was conducted (see section 6.2.4 and 6.2.5), and as media filtration as pre-treatment alone only transmittance was measured.



	GRA	FREVAR	SFR	NFR
■ Original values	16	0,1	21	2
▨ Filtered through anthracite	23	0,1	24,0	5
□ Filtration through GAC	18	0,1	66	17

Figure 17; transmittance (%T) after filtration through anthracite and activated carbon, compared with original values.

7. 4 Aeration as pre-treatment of sludge liquor from the different wastewater plants

As described in section 6.2.1, samples were aerated and parameters measured to evaluate the effect. The change in transmittance, pH, DO can be seen in figure 18-20.

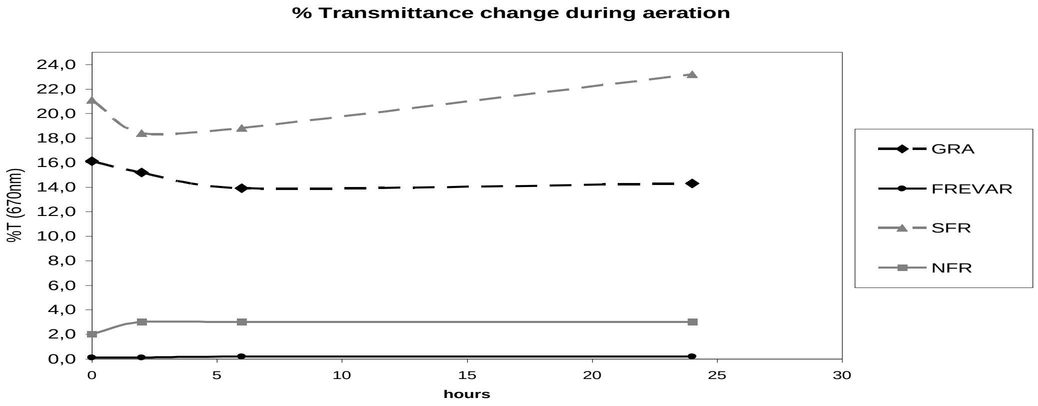


Figure 18; Change in transmittance during aeration as pre-treatment.

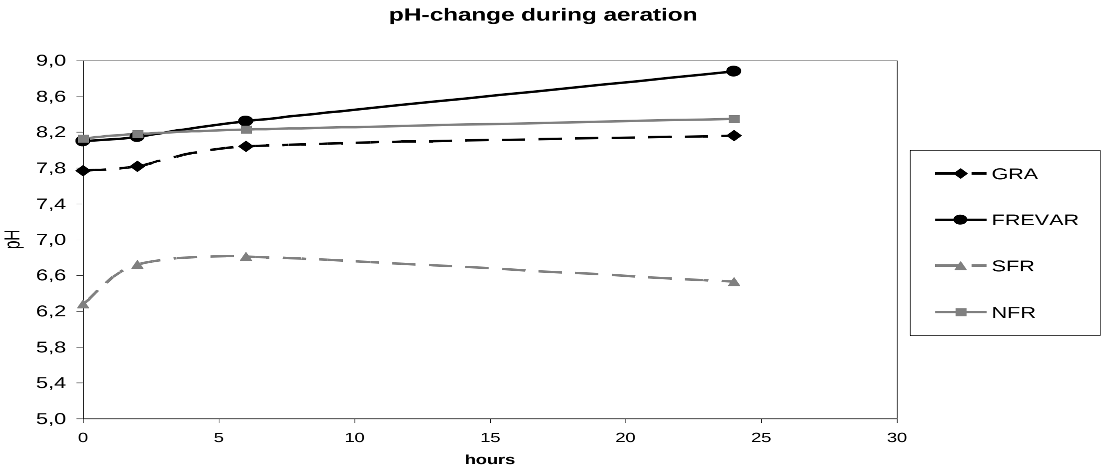


Figure 19 Change in pH during aeration as pre-treatment

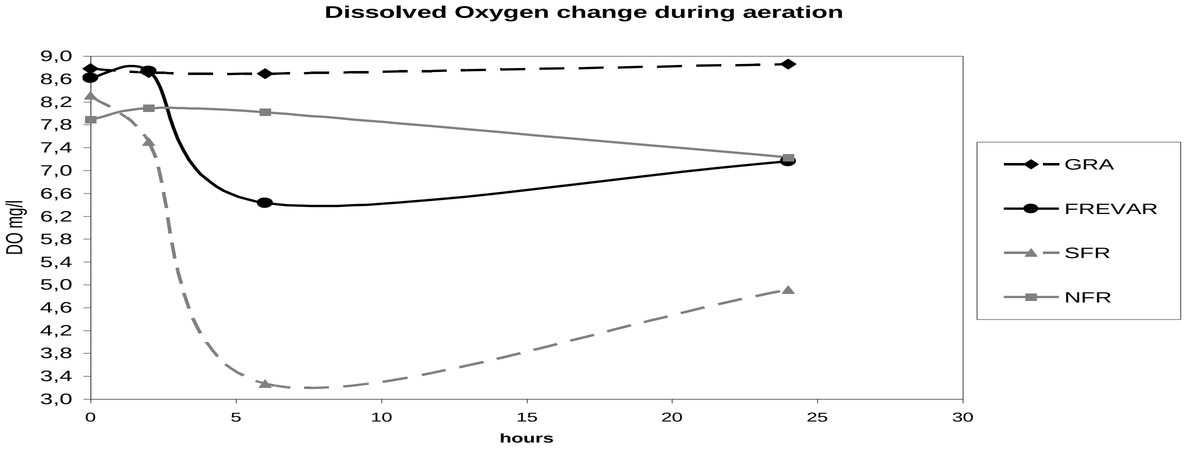


Figure 20; Change in DO concentrations during aeration as pre-treatment

7. 5 Oxidation as pre-treatment of sludge liquor from the different wastewater plants

In section 6.2.2, the oxidation procedure is described. Parameters was measured for different concentrations of PAA and H_2O_2. There was not much difference in the tested concentrations for PAA or H_2O_2, and the change in %T and pH for the concentrations of 40mg/l, 80mg/l and 150mg/l for PAA, H_2O_2 and Fenton is showed in figures 21-25.
Measured values for COD, NH_4-N and NO_3-N are showed in tables 10-21.

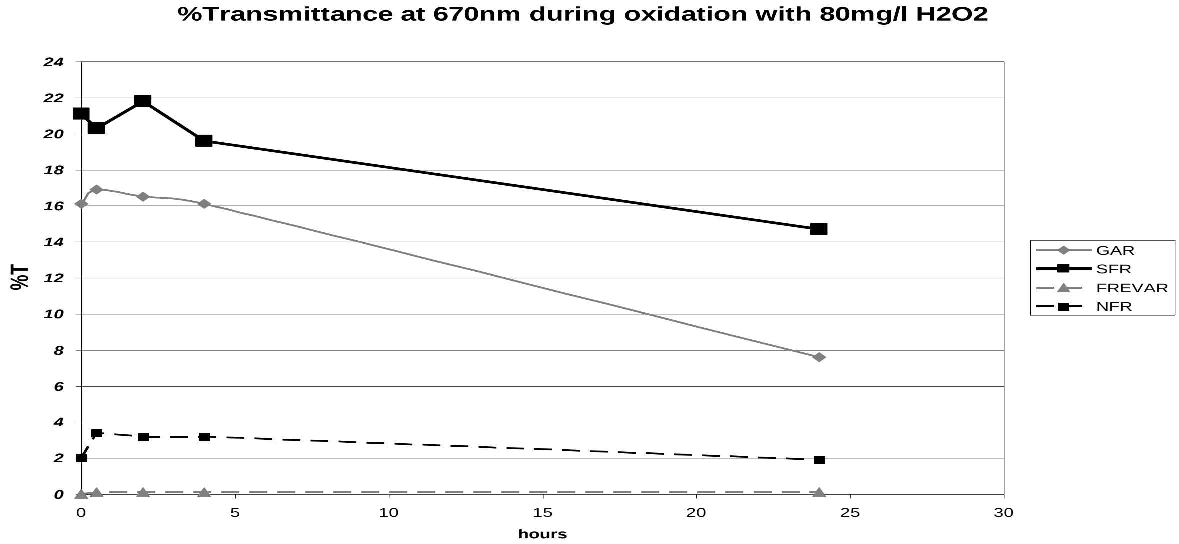


Figure 21; Change in transmittance during oxidation with hydrogen peroxide, as pre-treatment.

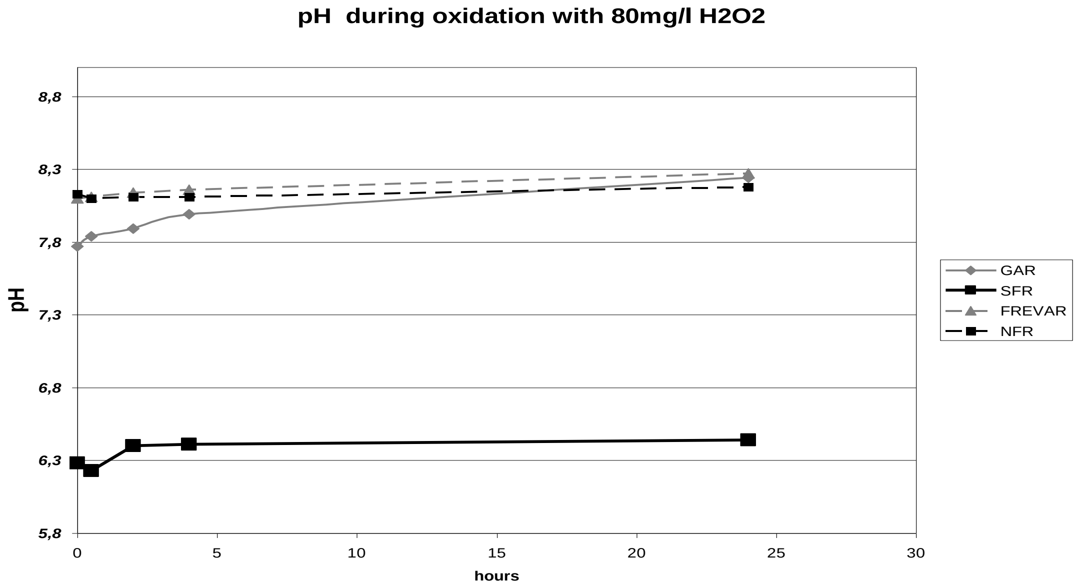


Figure 22; Change in pH during oxidation with hydrogen peroxide as pre-treatment.

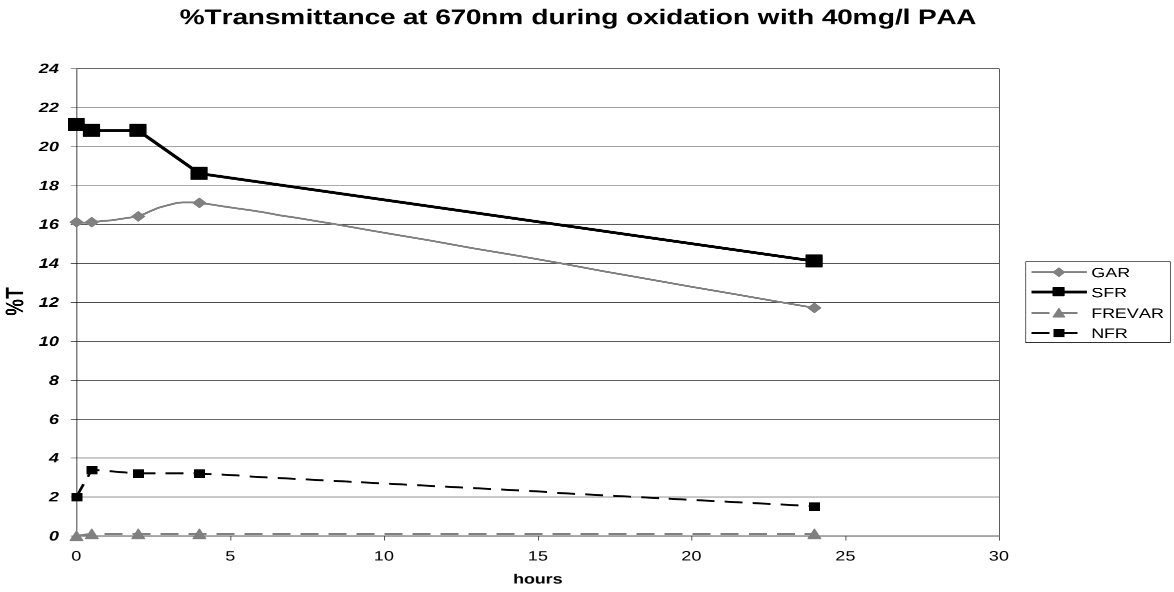


Figure 23; Change in transmittance during oxidation with peracetic acid, as pre-treatment.

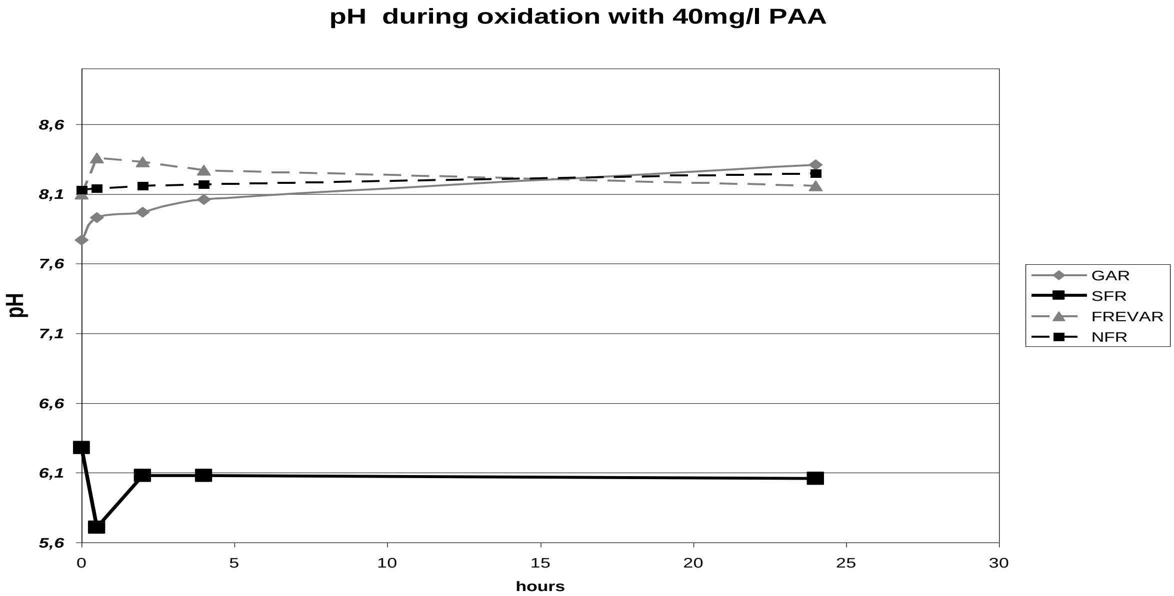


Figure 24; Change in pH during oxidation with peracetic acid, as pre-treatment.

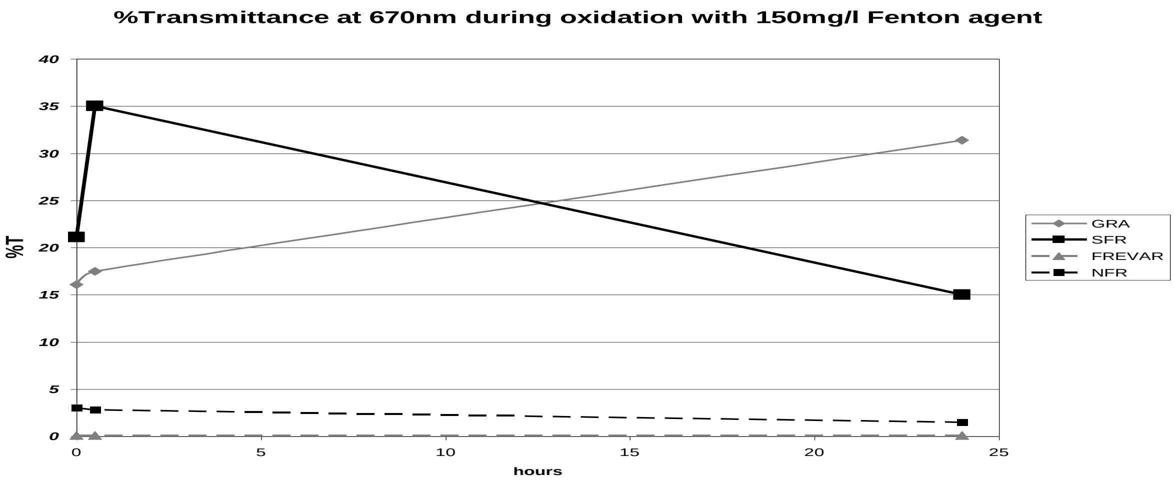


Figure 25; Change in transmittance during oxidation with Fenton reagent, as pre-treatment.

Table 10; Control during oxidation (GRA)

Gardermoen wastewater treatment plant						
Control						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	1872	0	280	0	5,6	0
0,5h	1665	11,1	228	18,6	5,49	2,0
24h	2008	-7,3	135	51,8	5,29	5,5

Table shows values and percentage reduction for the control sample

Table 11; Oxidation with hydrogen peroxide (GRA)

Gardermoen wastewater treatment plant						
H2O2 80mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	1872	0	280	0	5,6	0
0,5h	1577	15,8	182	35,0	5,5	1,8
24h	1941	-3,7	170	39,3	4,3	23,2

Table shows values and percentage reduction for GRA during oxidation with 80mg/l H_2O_2

Table 12; Oxidation with peracetic acid (GRA)

Gardermoen wastewater treatment plant						
PAA 40mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	1872	0	280	0	5,6	0
0,5h	1643	12,2	238	15,0	5,1	8,9
24h	1960	-4,7	182	35,0	3,4	39,3

Table shows values and percentage reduction for GRA during oxidation with 40mg/l PAA

Table 13; Control during oxidation (FREVAR)

Frevar wastewater treatment plant						
Control						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	7525	0	831	0	18,9	0
0,5h	7701	-2,3	1160	-39,6	29,6	-56,6
24h	7908	-5,1	1120	-34,8	23	-21,7

Table shows values and percentage reduction for the control sample

Table 14; Oxidation with hydrogen peroxide (FREVAR)

Frevar wastewater treatment plant						
H2O2 80mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	7525	0	831	0	18,9	0
0,5h	7000	7,0	1080	-30,0	22,8	-20,6
24h	7047	6,4	739	11,1	37,4	-97,9

Table shows values and percentage reduction for FREVAR during oxidation with 80mg/l H_2O_2

Table 15; Oxidation with peracetic acid (FREVAR)

Frevar wastewater treatment plant						
PAA 40mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	7525	0	831	0	18,9	0
0,5h	8042	-6,9	726	12,6	39,3	-107,9
24h	7625	-1,3	742	10,7	25,5	-34,9

Table shows values and percentage reduction for FREVAR during oxidation with 40mg/l PAA

Table 16; Control during oxidation (SFR)

Søndre Follo wastewater treatment plant						
Control						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	4503	0	308	0	0,629	0
0,5h	4477	0,6	480	-55,8	1,08	-71,7
24h	5694	-26,4	570	-85,1	1,42	-125,8

Table shows values and percentage reduction for the control sample

Table 17; Oxidation with hydrogen peroxide (SFR)

Søndre Follo wastewater treatment plant						
H2O2 80mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	4503	0	308	0	0,629	0
0,5h	4326	3,9	436,5	-41,7	1,42	-125,8
24h	5277	-17,2	545	-76,9	1,39	-121,0

Table shows values and percentage reduction for SFR during oxidation with 80mg/l H_2O_2

Table 18; Oxidation with peracetic acid (SFR)

Søndre Follo wastewater treatment plant						
PAA 40mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	4503	0	308	0	0,629	0
0,5h	4641	-3,1	466	-51,3	1,13	-79,7
24h	6137	-36,3	600	-94,8	1,56	-148,0

Table shows values and percentage reduction for SFR during oxidation with 40mg/l PAA

Table 19; Control during oxidation (NFR)

Nordre Follo wastewater treatment plant						
Control						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	3850	0	476	0	7,16	0
0,5h	3995	-3,8	665	-39,7	8,86	-23,7
24h	4795	-24,5	409	14,1	12	-67,6

Table shows values and percentage reduction for the control sample

Table 20; Oxidation with hydrogen peroxide (NFR)

Nordre Follo wastewater treatment plant						
H2O2 80mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	3850	0	476	0	7,16	0
0,5h	3510	8,8	605	-27,1	8,63	-20,5
24h	5050	-31,2	377	20,8	10,4	-45,3

Table shows values and percentage reduction for NFR during oxidation with 80mg/l H_2O_2

Table 21; Oxidation with peracetic acid (NFR)

Nordre Follo wastewater treatment plant						
PAA 40mg/l						
Reaction time	COD mg/l	% COD reduction	NH4-N (mgN/l)	%NH4-N reduction	NO3-N (mgN/l)	%NO3-N reduction
0h	3850	0	476	0	7,16	0
0,5h	4265	-10,8	409	14,1	10,9	-52,2
24h	3455	10,3	630	-32,4	9,02	-26,0

Table shows values and percentage reduction for NFR during oxidation with 40mg/l PAA

7.6 Testing of polymers and combining coagulation-flocculation with filtration

Pre-treatment testing for each sample site is described in separated sections, showing results of coagulation-flocculation by several polymers and optimal dose of selected polymer. The results of the best combined treatment are compared by values and percentage reduction.

7.6.1 Gardermoen wastewater treatment plant

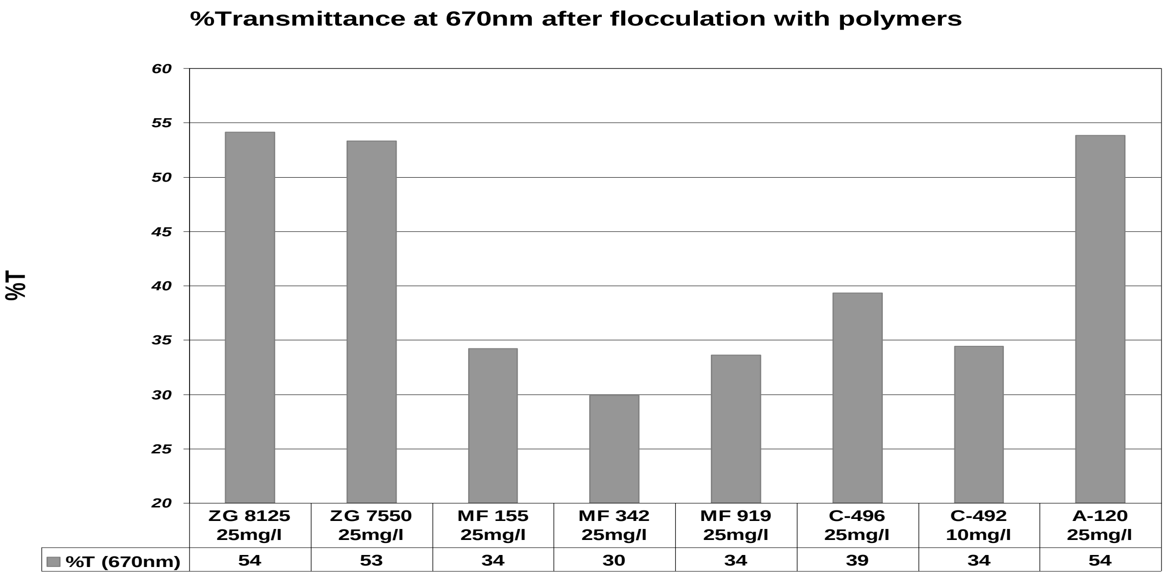


Figure 26; The results in transmittance properties after coagulation flocculation with all polymers, with the best result for 1, 10 and 25mg/l for GRA.

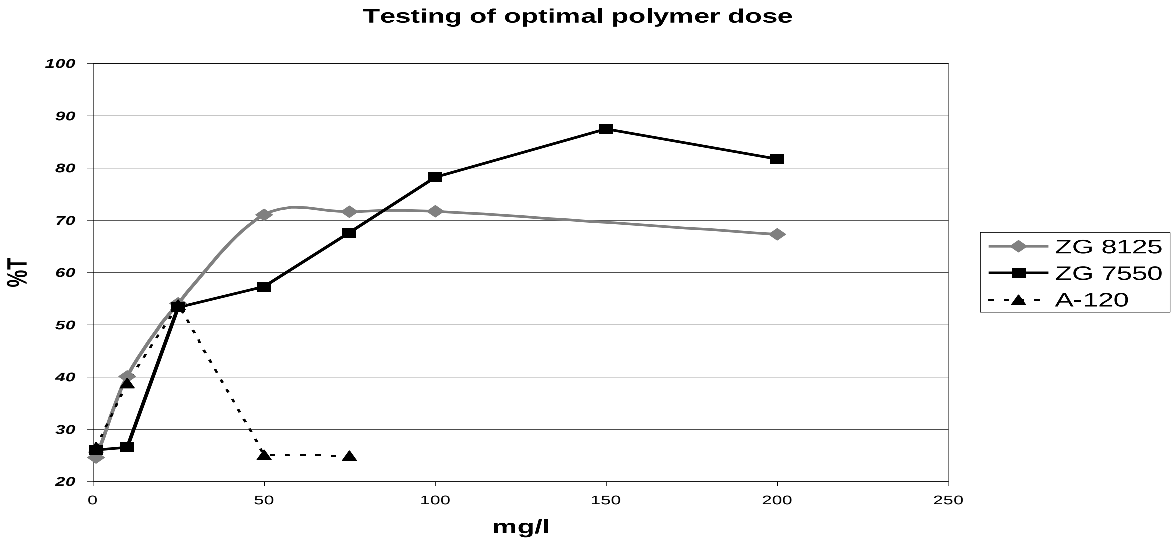


Figure 27; testing the optimal polymer dose of the polymers who worked the best in first testing (GRA)

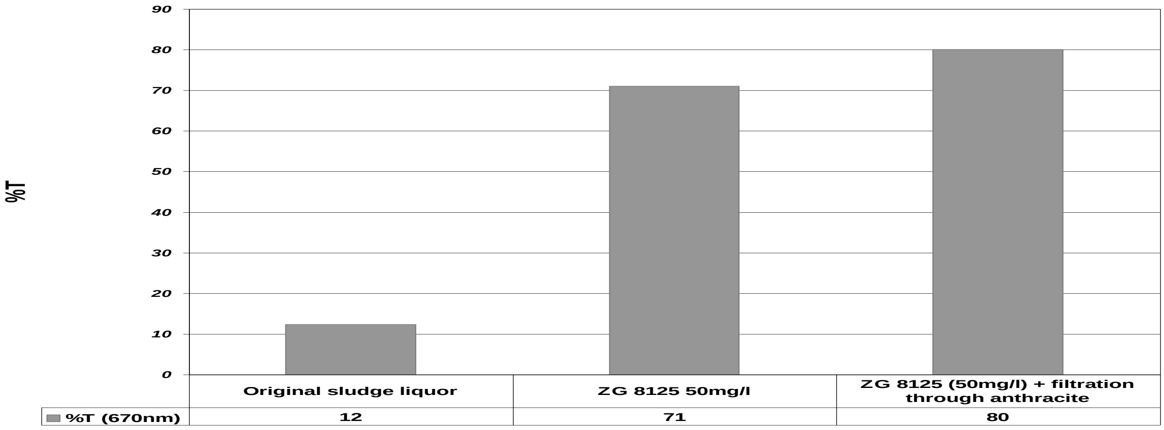


Figure 28; comparing original value of sludge liquor from GRA with best polymer and polymer dose, and polymer addition combined with filtration through anthracite.

Table 22, chemical parameters, before and after treatment (GRA)

Chemical Parameters	Original	ZG 8125 50mg/l	% removal	ZG 8125 50mg/l + filtration through anthracite	% removal
TSS (mg/L)	787	104	87	93	88
VSS (mg/L)	673	84	88	87	87
COD (mg/L)	1872	937	50	600	68
sCOD (mg/L)	751	660	12	480	36
Tot-N (mg/L)	640	518	19	508	21
NO3-N (mg/L)	5,6	0,32	94	0,4	93
NO2-N (mg/L)	0,044	0,036	18	0,021	52
NH4-N (mg/L)	280	248	11	244	13
Tot-P (mg/L)	2,8	1,09	61	1,02	64
PO4-P (mg/L)	<0,05	<0,05	-	<0,05	-

Table shows values and % reduction of parameters after treatment.

Table 23, physical parameters, before and after treatment (GRA)

Physical parameters	Original	ZG 8125 50mg/l	ZG 8125 50mg/l + filtration through anthracite
Turb	611	60,9	20
Alkalinity (mmol/L)	25	23	20,2
Conductivity (mS/cm)	2,93	2,74	2,69
% T (670 nm)	16,1	68,4	85
pH	7,77	7,59	7,64

Table shows values and % reduction of parameters after treatment.

Table 24; Particle concentrations and size distribution in percentage (GRA)

	Measured particle concentration (mg/l)	d0.1	d0.5	d0.9
Original	525	1,23	20,03	210,29
ZG 8125 50mg/l	50	0,88	7,66	32,4
ZG 8125 50mg/l + filtration through anthracite	45	1,2	3,1	28

Values corresponding to d0.1, d0.5 and d0.9, means the particle size, in µm, that is represented in 10%, 50% and 90% of the particles.

7.6.2 Frevar wastewater treatment plant 22.03

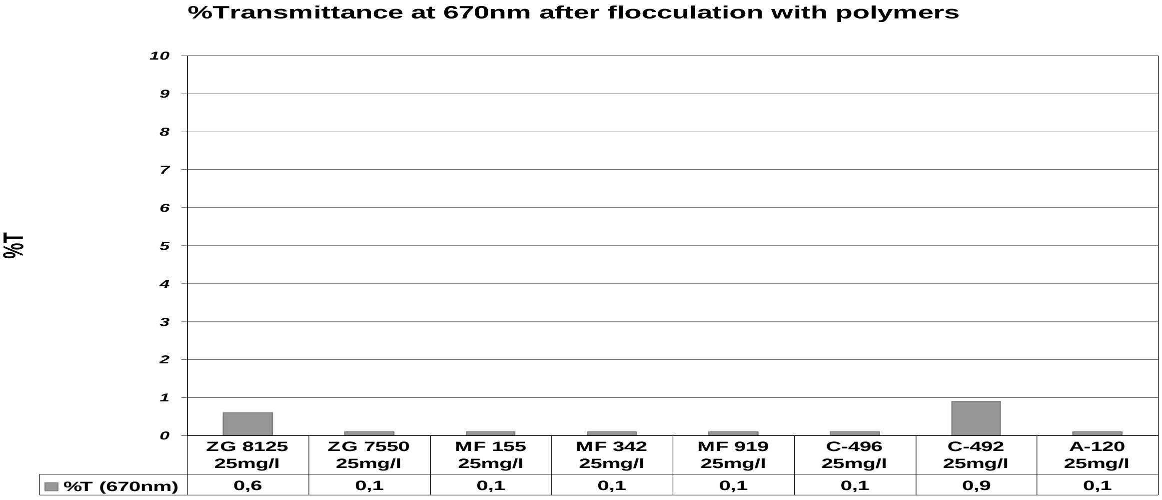


Figure 29; the results in transmittance properties after coagulation and flocculation with all polymers, with the best result for 1, 10 and 25mg/l for Frevar.

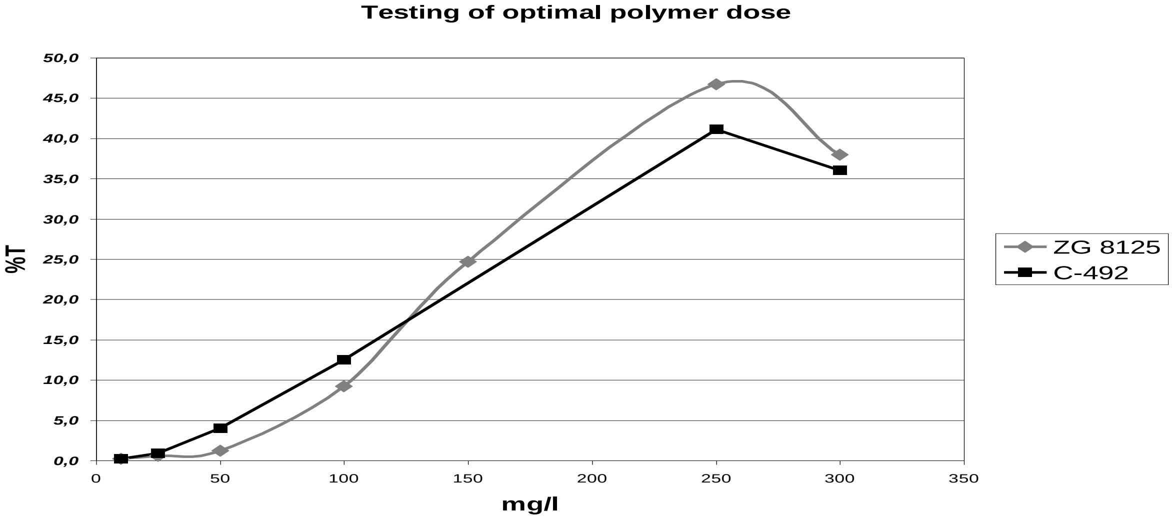


Figure 30; testing the optimal polymer dose of the polymers which worked the best in first testing. Frevar.

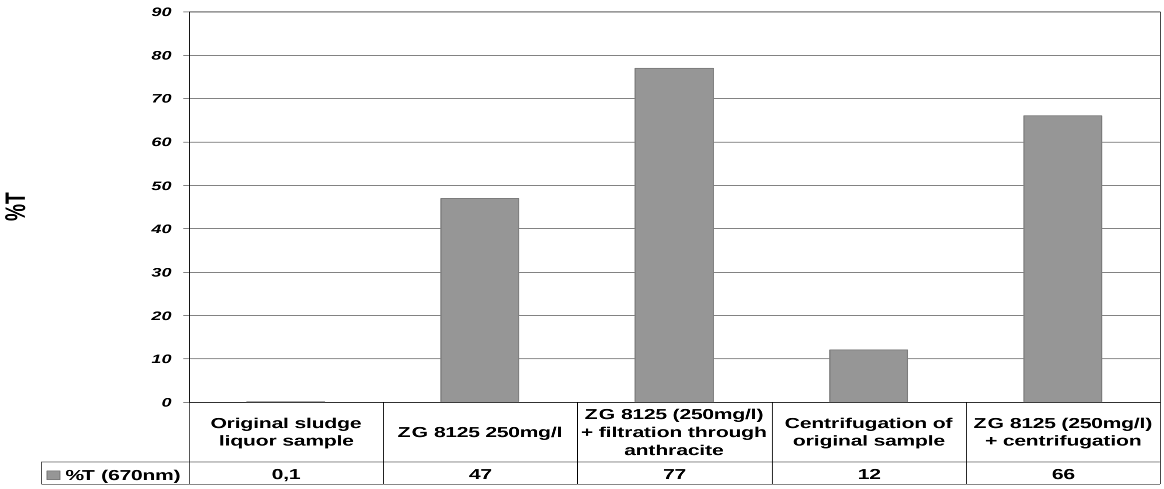


Figure 31; comparing original value of sludge liquor from Frevar with best polymer and polymer dose, and polymer addition combined with filtration through anthracite and centrifugation.

Table 25, chemical parameters, before and after treatment (FREVAR)

Chemical Parameters	Original	Centrifuge	% removal	ZG 8125 250mg/l + filtration through anthracite	% removal	ZG 8125 250mg/l + centrifugation	% removal
TSS (mg/L)	3740	313	92	64	98	122	97
VSS (mg/L)	2940	237	92	52	98	107	96
COD (mg/L)	7525	5326	29	1888	75	3957	47
sCOD (mg/L)	3330	3272	2	1800	46	3390	-2
Tot-N (mg/L)	1655	1370	17	517	69	997	40
NO3-N (mg/L)	18,9	12,1	36	13,8	27	18,7	1
NO2-N (mg/L)	0,026	**-**	-	0,019	27	0,023	12
NH4-N (mg/L)	831	612	26	370	55	640	23
Tot-P (mg/L)	37,1		100	1,83	95	3,24	91
PO4-P (mg/L)	3,79	1,48	61	0,087	98	1,18	69

Table shows values and % reduction of parameters after treatment.

Table 26, physical parameters, before and after treatment (FREVAR)

Physical parameters	Original	Centrifuged	ZG 8125 250mg/l + filtration through anthracite	ZG 8125 250mg/l + centrifugation
Turb	>1000	503	28	35,4
Alkalinity (mmol/L)	73	-	32	49
Conductivity (mS/cm)	8,63	-	4,05	7,19
% T (670 nm)	0,1	12,4	76,9	65,9
pH	8,1	8,19	8,14	8,22

Table shows values and % reduction of parameters after treatment.

Table 27; Particle concentrations and size distribution in percentage (FREVAR)

	Measured particle concentration (mg/l)	d0.1	d0.5	d0.9
Original	1500	0,72	2,26	571,17
Centrifuge	120	0,6	0,89	1,4
ZG 8125 250mg/l + filtration through anthracite	25	0,66	1,17	4,79
ZG 8125 250mg/l + centrifugation	30	0,67	1,31	11

Values corresponding to d0.1, d0.5 and d0.9, means the particle size, in µm, that is represented in 10%, 50% and 90% of the particles.

7.6.3 Søndre Follo wastewater treatment plant

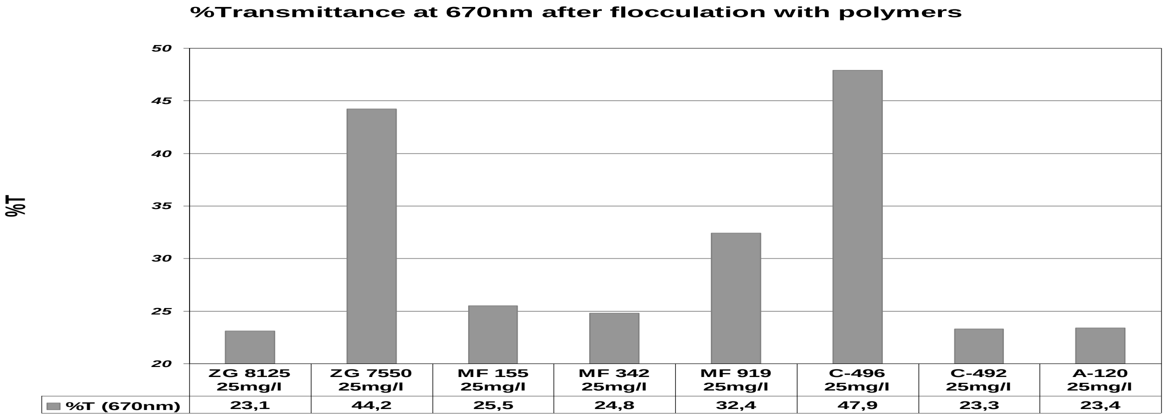


Figure 32; the results in transmittance properties after coagulation and flocculation with all polymers, with the best result for 1, 10 and 25mg/l for SFR.

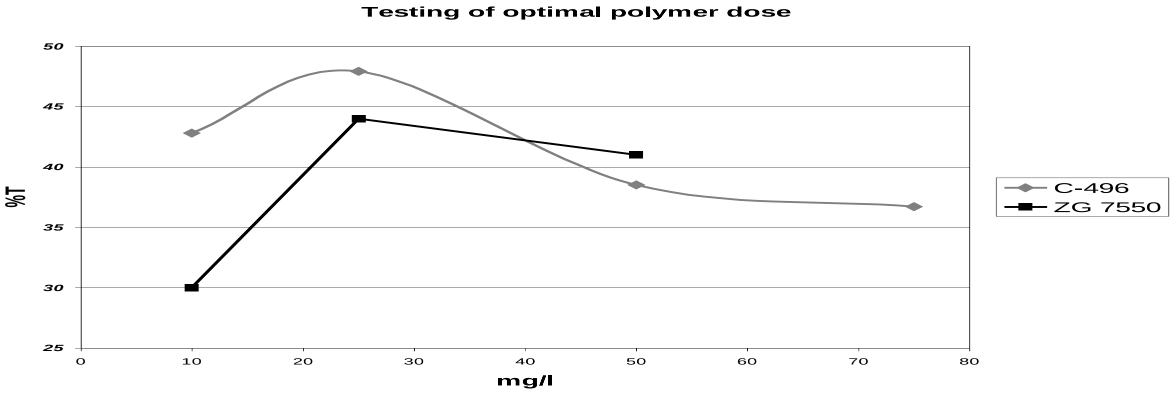


Figure 33; testing the optimal polymer dose of the polymers which worked the best in first testing. SFR.

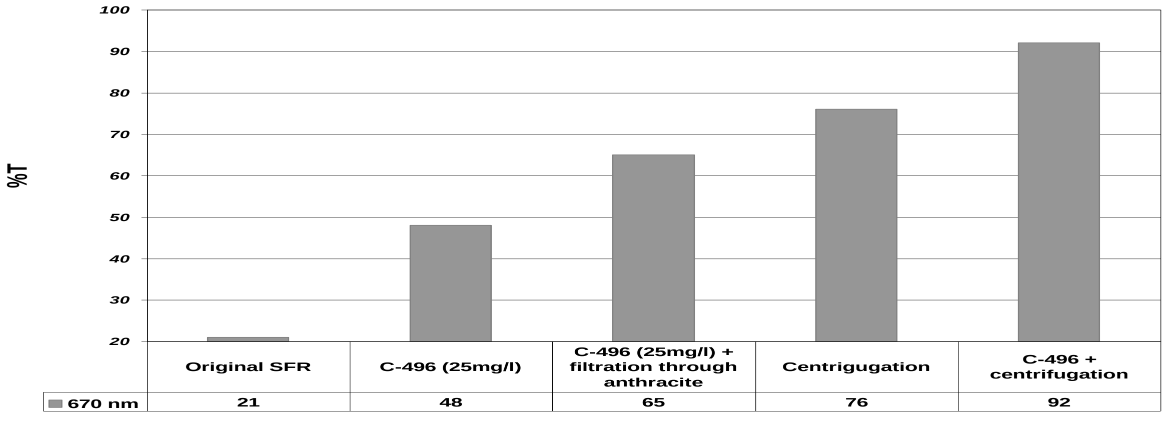


Figure 34; comparing original value of sludge liquor from SFR with best polymer and polymer dose, and polymer addition combined with filtration through anthracite and centrifugation.

Table 28, chemical parameters, before and after treatment (SFR)

Chemical Parameters	Original	Centrifuge	*% reduction from original sample*	C-496 25mg/l + centrifugation	*% reduction from original sample*	C-496 25mg/l + filtration through anthracite	*% reduction from original sample*
TSS (mg/L)	636	73	*89*	32	*95*	130	*80*
VSS (mg/L)	580	63	*89*	26	*96*	106	*82*
COD (mg/L)	4503	4139	*8*	3892	*14*	4542	*-1*
sCOD (mg/L)	3627	3391	*7*	3745	*-3*	3607	*1*
Tot-N (mg/L)	382,5	371	*3*	347	*9*	327	*15*
NO3-N (mg/L)	0,629	0,71	*-13*	0,664	*-6*	0,59	*6*
NO2-N (mg/L)	0,025	0,031	*-24*	<0,015	-	<0,015	-
NH4-N (mg/L)	308	339,5	*-10*	340,5	*-11*	306	*1*
Tot-P (mg/L)	4,09	0,956	*77*	0,385	*91*	0,874	*79*
PO4-P (mg/L)	0,061	0,083	*-36*	<0,05	-	<0,05	-

Table shows values and % reduction of parameters after treatment.

Table 29, physical parameters, before and after treatment (SFR)

Physical parameters	Original	Centrifuge	C-496 25mg/l + centrifugation	C-496 (25mg/l) + Anthracite
Turb	556	70,3	19,3	85,5
Alkalinity (mmol/L)	20,6	20	21,7	17,3
Conductivity (mS/cm)	4,02	3,98	3,74	3,86
% T (670 nm)	21,1	75,9	92,3	64,6
pH	6,28	6,25	6,74	6,86

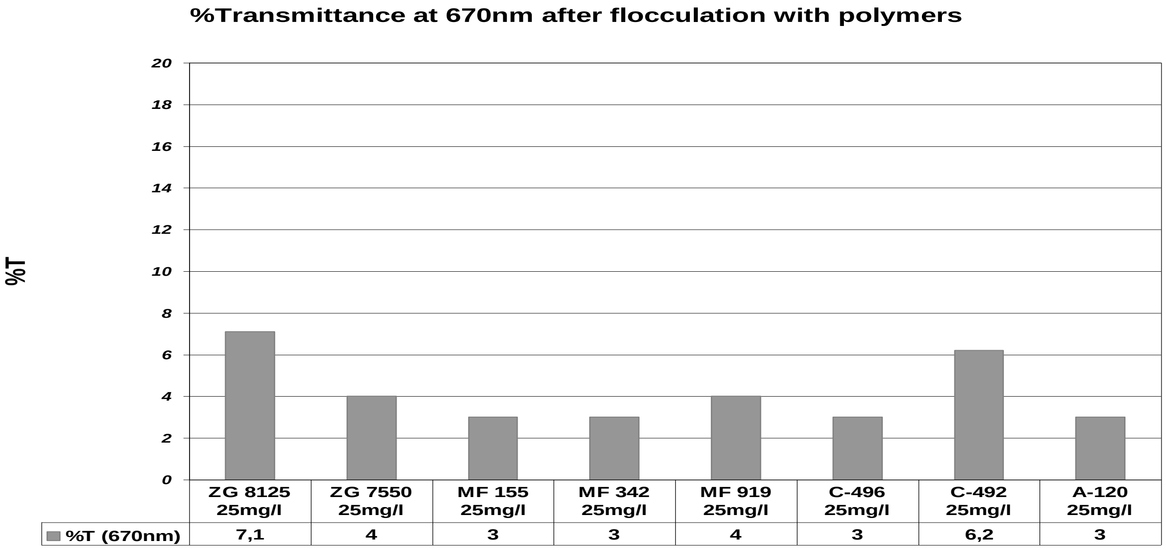
Table shows values and % reduction of parameters after treatment.

Table 30; Particle concentrations and size distribution in percentage (SFR)

	Measured particle concentration (mg/l)	d0.1	d0.5	d0.9
Original	1380	9	64,13	161,73
Centrifuge	15	0,66	1,16	23,42
C-496 25mg/l + centrifugation	10	0,71	2,03	14
C-496 (25mg/l) + Anthracite	40	0,78	3,19	14,86

Values corresponding to d0.1, d0.5 and d0.9, means the particle size, in µm, that is represented in 10%, 50% and 90% of the particles.

7.6.4 Nordre Follo wastewater plant



	ZG 8125 25mg/l	ZG 7550 25mg/l	MF 155 25mg/l	MF 342 25mg/l	MF 919 25mg/l	C-496 25mg/l	C-492 25mg/l	A-120 25mg/l
▨ %T (670nm)	7,1	4	3	3	4	3	6,2	3

Figure 35; the results in transmittance properties after coagulation and flocculation with all polymers, with the best result for 1, 10 and 25mg/l for NFR

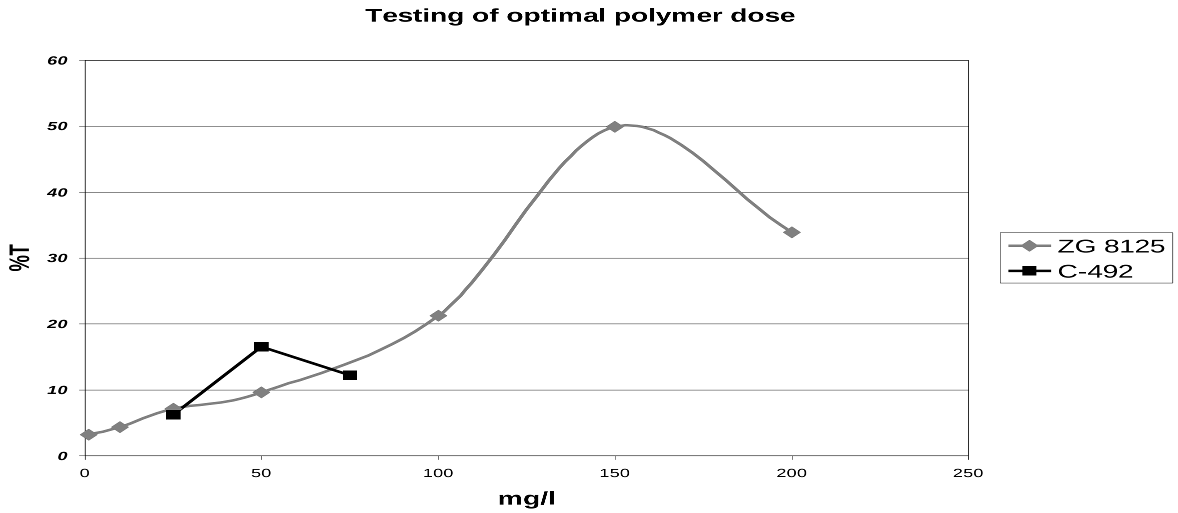


Figure 36; testing the optimal polymer dose of the polymers which worked the best in first testing. NFR.

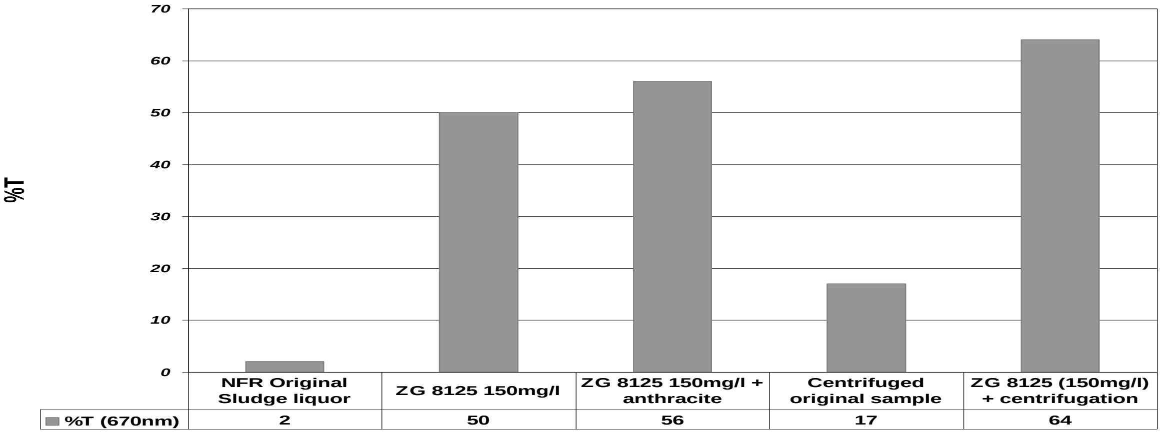


Figure 37; comparing original value of sludge liquor from NFR with best polymer and polymer dose, and polymer addition combined with filtration through anthracite and centrifugation.

Table 31; chemical parameters, before and after treatment (NFR)

Chemical Parameters	Original	Centrifuged	% reduction	ZG 8125 150mg/l + centrifugation	% reduction	ZG 8125 150mg/l + Anthracite	% reduction
TSS (mg/L)	2125	634	70	255	88	750	65
VSS (mg/L)	1825	524	71	243	87	670	63
COD (mg/L)	3850	2774	28	1660	57	2165	44
sCOD (mg/L)	1037	1867	-80	1240	-20	1300	-25
Tot-N (mg/L)	930	860	8	875	6	934	0
NO3-N (mg/L)	7,16	4,41	38	5,07	29	6,06	15
NO2-N (mg/L)	0,221	**0,123**	44	0,091	59	0,086	61
NH4-N (mg/L)	476	747	-57	600	-26	620	-30
Tot-P (mg/L)	63,5	37,6	41	5,26	92	12,3	81
PO4-P (mg/L)	3,78	1,8	52	0,758	80	0,715	81

Table shows values and % reduction of parameters after treatment.

Table 32; physical parameters, before and after treatment (NFR)

Physical parameters	Original	Centrifuge	Polymer + centrifugation	Polymer + Anthracite
Turb	>1000	629	192	331
Alkalinity (mmol/L)	52,6	48,2	36,6	43,0
Conductivity (mS/cm)	5,65	5,41	4,11	4,9
% T (670 nm)	2	17	64	56
pH	8,13	8,22	8,46	8,51

Table shows values and % reduction of parameters after treatment.

Table 33; Particle concentrations and size distribution in percentage (NFR)

	Measured particle concentration (mg/l)	d0.1	d0.5	d0.9
Original	700	0,68	1,39	144,9
Centrifuge	90	0,64	1,03	96,9
Polymer + centrifugation	30	0,65	1,09	8,71
Polymer + Anthracite	150	0,69	1,53	13,03

Values corresponding to d0.1, d0.5 and d0.9, means the particle size, in µm, that is represented in 10%, 50% and 90% of the particles.

7.7 Microalgae growth

Chlorella sp. was grown in diluted treated sludge liquor (from FREVAR), see section 6.3. Growth pattern was compared with growth in a standard nutrient media (figure 38-41). The relationship between loss of nutrients and growth is shown in figures 42-46. The relationship between pH and DO during growth is shown in figure 47.

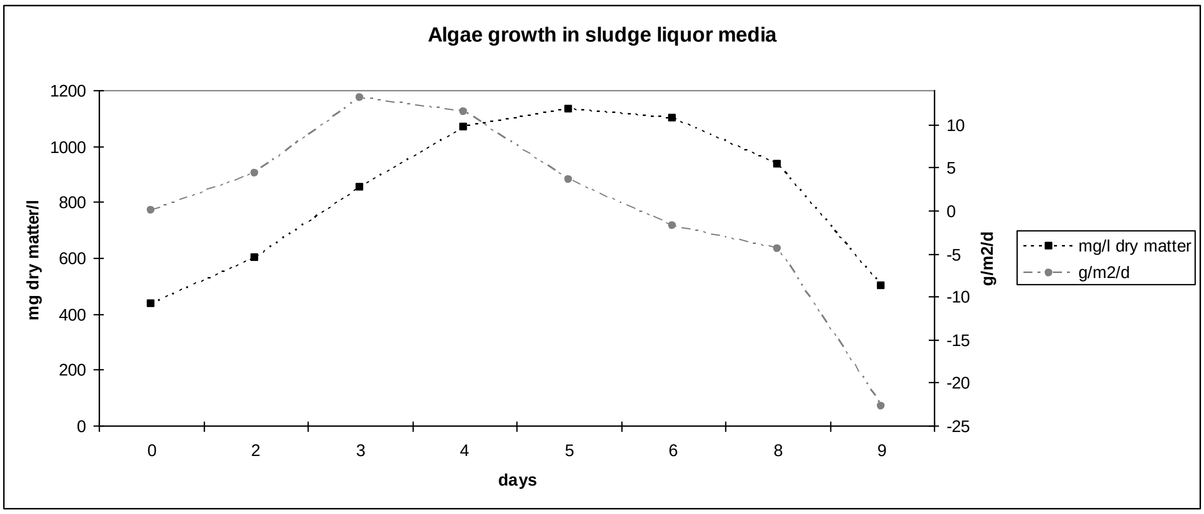


Figure 38; growth of *Chlorella sp*. in sludge liquor media

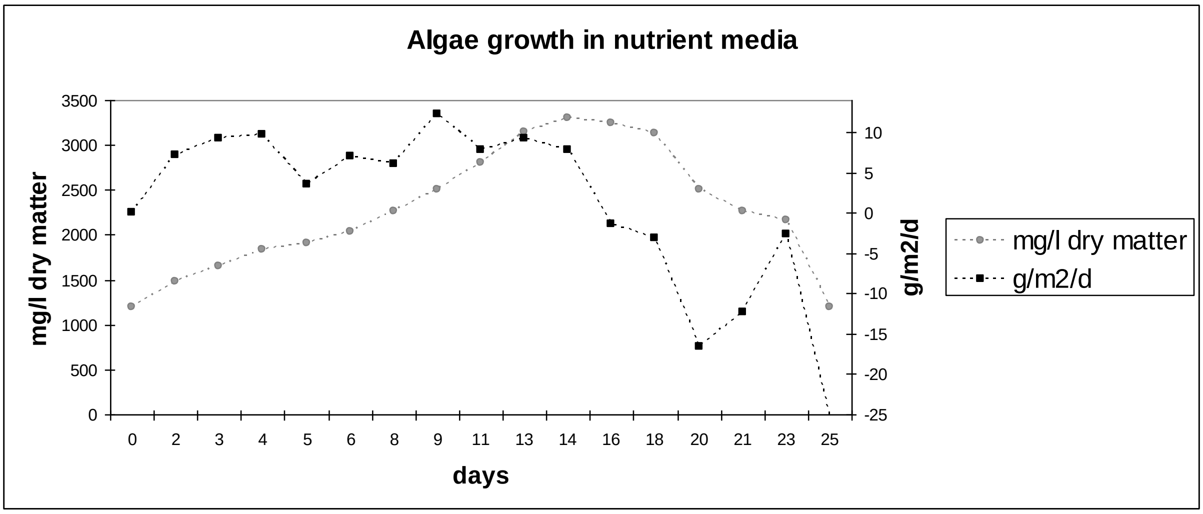


Figure 39; growth of *Chlorella sp*. in standard nutrient media.

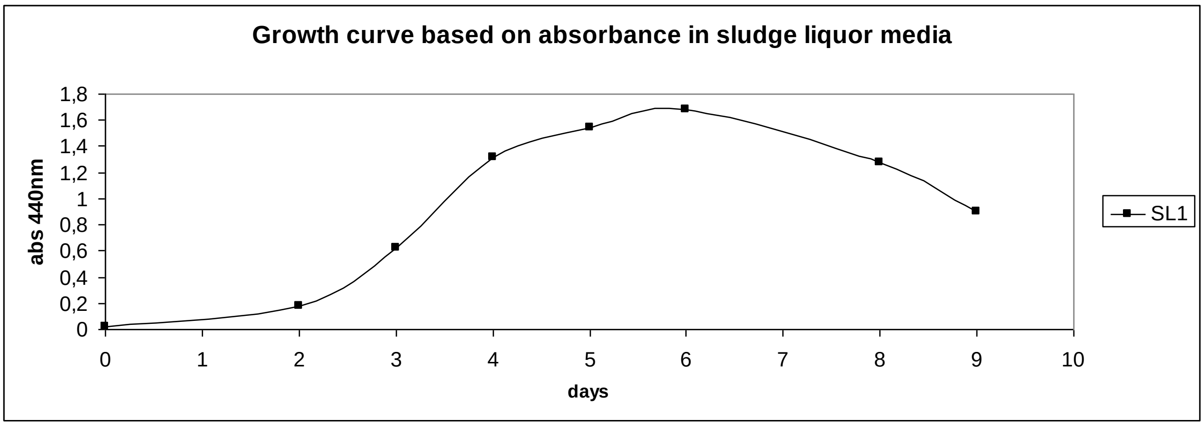


Figure 40; growth of *Chlorella sp*. in sludge liquor media based on absorbance at 440nm

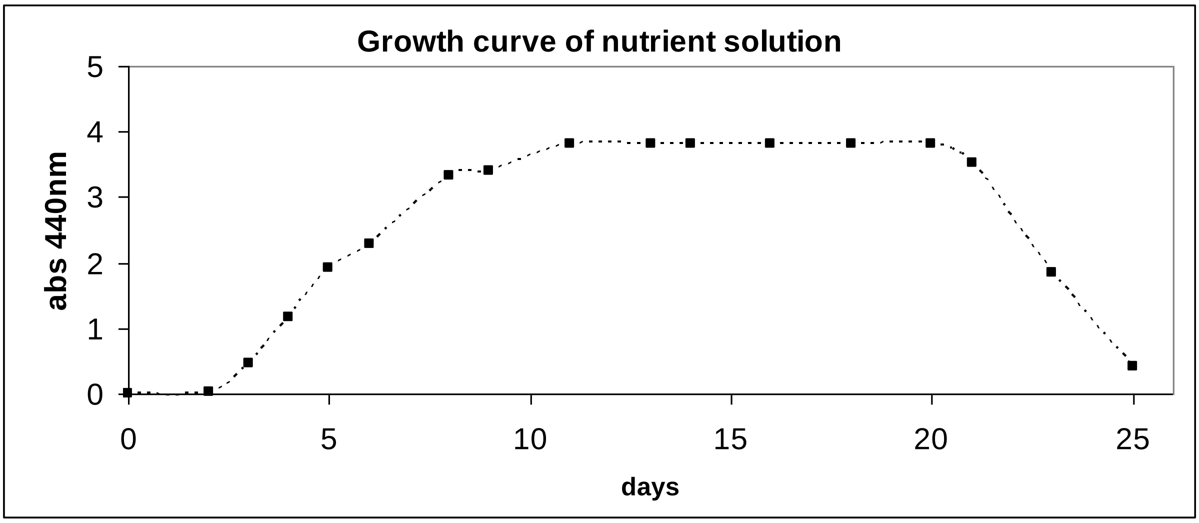


Figure 41; growth of *Chlorella sp*. in standard nutrient media based on absorbance at 440nm

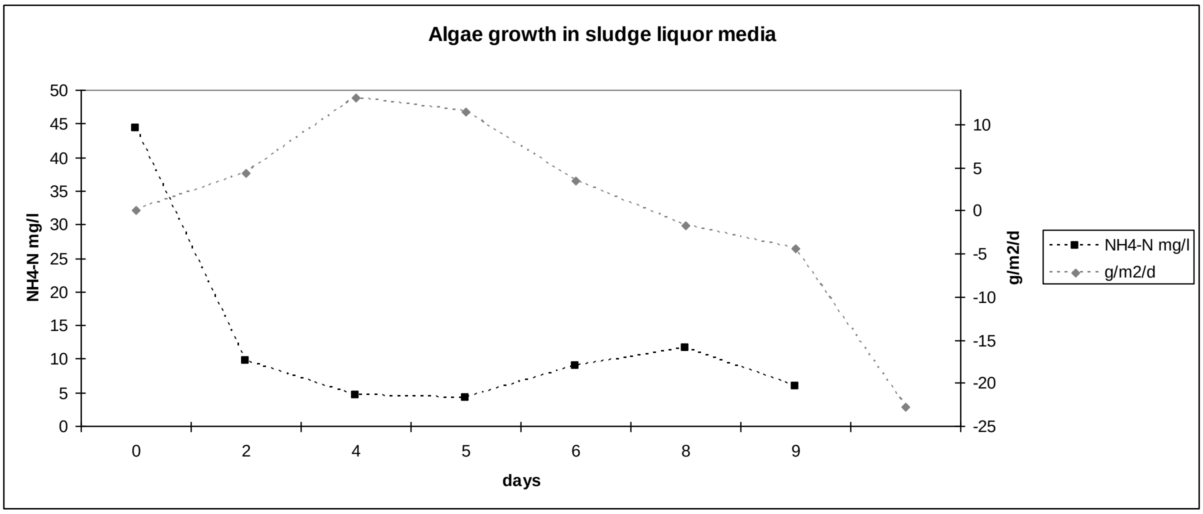


Figure 42; Changes in NH_4-N concentration during growth of *Chlorella sp*. in sludge liquor media

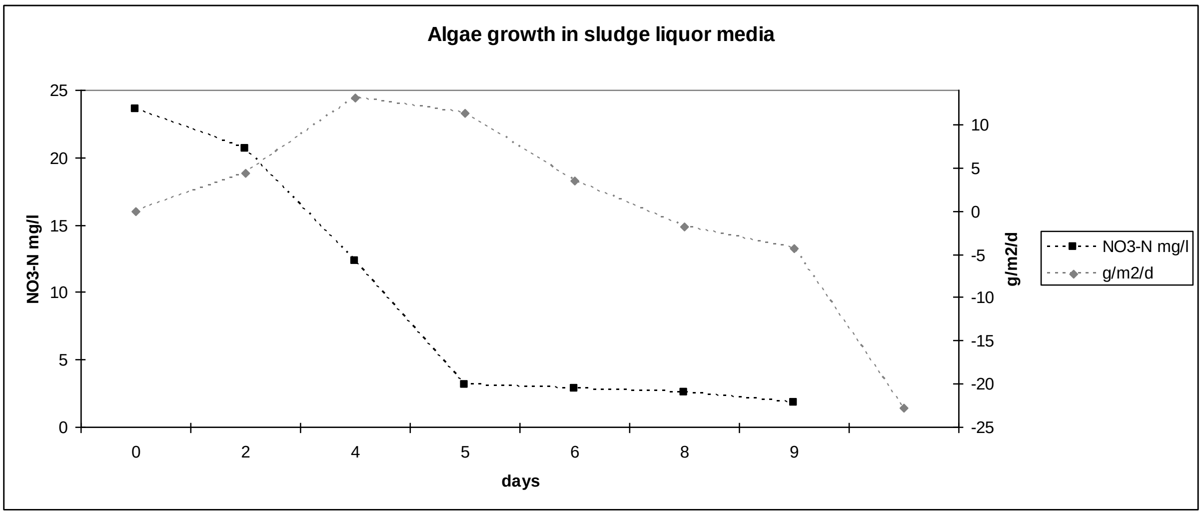


Figure 43; Changes in NO_3-N concentration during growth of *Chlorella sp*. in sludge liquor media

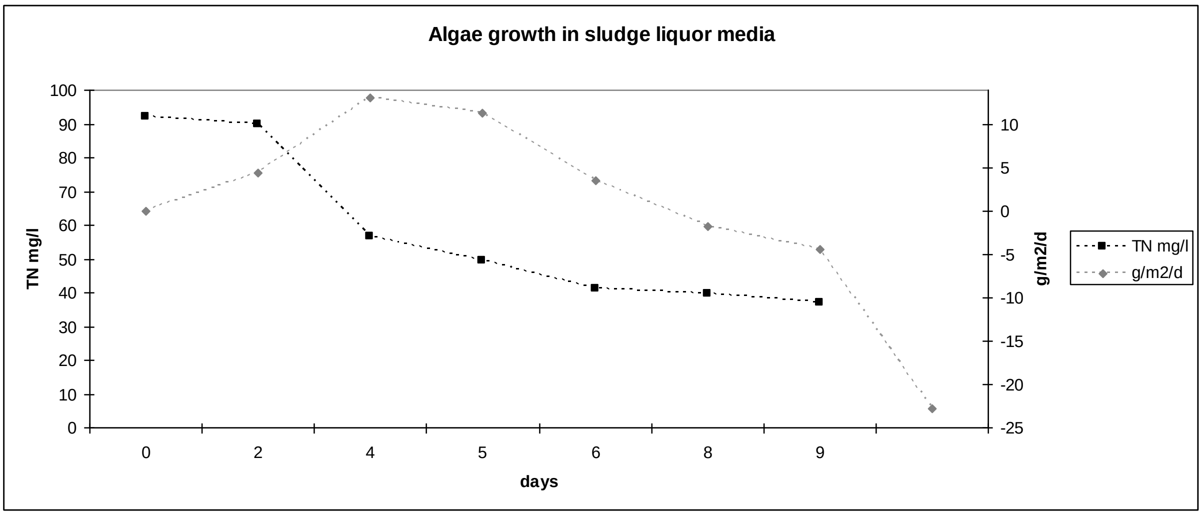


Figure 44; Changes in total nitrogen concentration during growth of *Chlorella sp*. in sludge liquor media

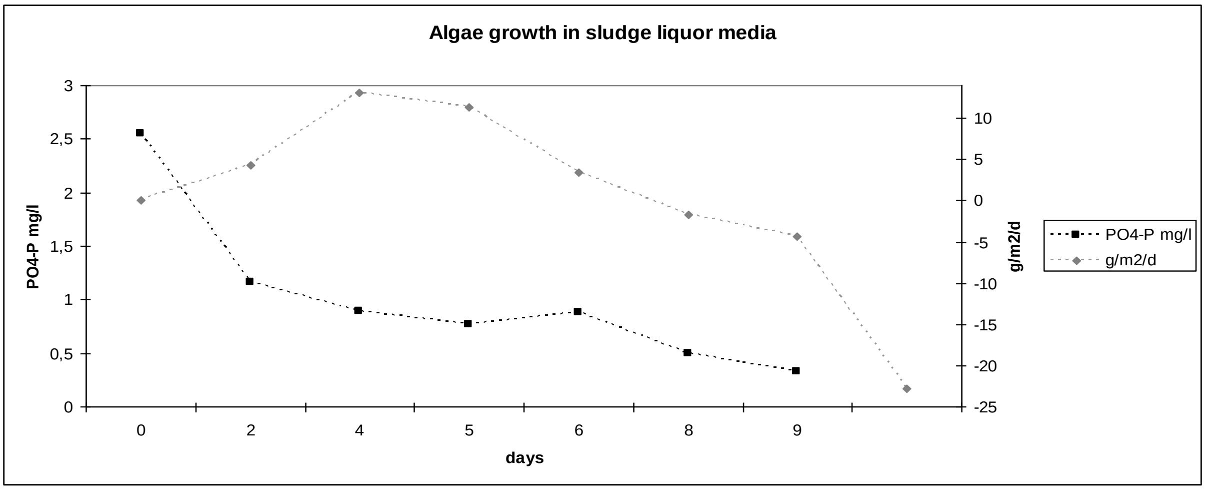


Figure 45; Changes in PO_4-P concentration during growth of *Chlorella sp.* in sludge liquor media

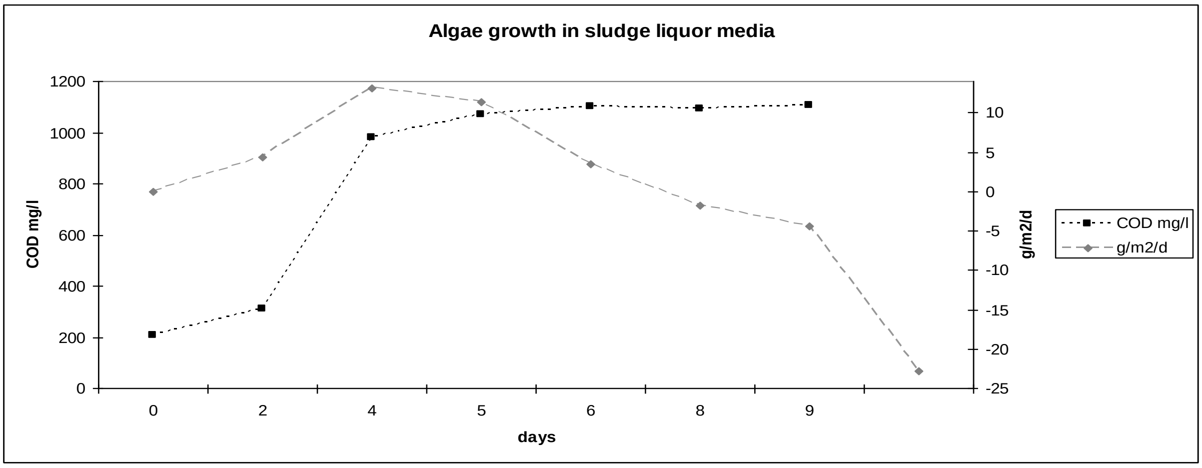


Figure 46; Changes in COD concentration during growth of *Chlorella sp.* in sludge liquor media

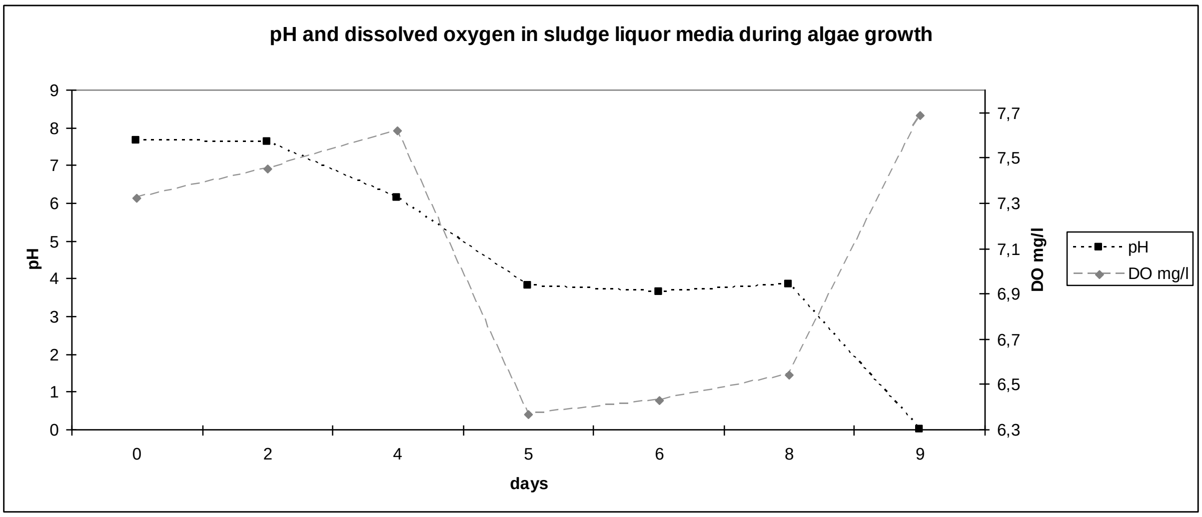


Figure 47; Changes in pH and DO concentrations during growth of *Chlorella sp.* in sludge liquor media

8. Discussion

8.1 Characterization

Frevar has the highest TS and SS values. SFR has considerably higher TS content then SS, only 28% of the total solids are suspended solids, meaning that SFR has a higher ratio of dissolved solids, while the other sites has a ratio of approximately 50%. By comparing the solid analysis (figure 3 and 4) against the particle distribution analysis measured on Malvern mastersizer (figure 5), the numbers are not corresponding. The higher the TS and TSS values are, the larger the difference in particle concentration measured by Malvern. One reason for this might be during dilution of the samples done before particle size analysis, excluding the bigger particles and thereby lowering the total particle concentration. In solid analysis of SFR it shows that SFR has a high % shear of dissolved solids, in the graph for particle size distribution done by Malvern, the peak lies in the range of 75-200µm and less then 10% is under 1.2µm. Most lightly there has been an error during measurement in Malvern, bubbles or other objects disturbing the particle content and distribution. While looking at the particle size distribution in figure 3, Frevar and NFR have the highest particle concentrations and have a higher distribution in the lower range (0.5-2µm), a higher distribution of dissolved solids.

Frevar and NFR has almost no light penetration, with a transmittance as low as 0.1% and 2%, and both with a turbidity over 1000 NTU (see figure 6 and 7). Visually the liquid was very black for both Frevar and NFR but Frevar was darkest. GRA and SFR show significantly better light penetration properties with having less turbidity (611NTU and 566NTU) and higher transmittance of 16% and 21%. Visually the sample from SFR was a yellow-brown liquid and separated itself by its light colour. Solid content is the main character that affects the transmittance negatively and increase turbidity (Metcalf and Eddy, 2004). In pH (figure 8), SFR has a unexpected low pH of 6,28 (expected pH for reject water lies at 7-9 (Thornton et al. 2008). Not surprisingly Frevar has a high alkalinity and conductivity. The conductivity (figure 10) values shows a relation to the measured dissolved solid concentrations (DS= TS-SS), and this suit good with theory as the conductivity increases with increased dissolved solid concentration.

SFR has a very high fraction of soluble COD and soluble nitrogen compared to the total COD and nitrogen concentrations, (81% and 86%), while the soluble COD and soluble nitrogen fraction for the other lies around 50-60% and 40-50%. NH_4 percentage of total nitrogen is around 50% except for SFR which ammonium stands for 80% of total nitrogen and 93% of all soluble nitrogen (see figure 11 and 12). This can be related to the solid concentrations, where SFR shows a high fraction of dissolved solids. Frevar also distinguish by having a high percentage of ammonium of the soluble nitrogen (90%). Frevar has high nitrate concentration, and GRA has a very high nitrite concentration compared to the others. SFR is significantly low in nitrate concentration. NFR has a very high phosphate concentration and.

The sample collected from Frevar shows the most resemblance to sludge liquor as described in literature, NFR and GRA also stays within the range that characterize sludge liquor; high pH, alkalinity, conductivity, SFR is the sample that deviates from described literature. Differences in sludge liquor comes from the variations in inlet flow, treatment proceure, dewatering procedure and efficiency and polymer addition.

8.2 Centrifugation

Centrifugation alone gave good results (see figure 16), the maximum speed we could achieve on available centrifuge was 4000 rpm. With higher speed there could have been achieved better results.

8.3 Aeration

Aeration as pre-treatment did not change much in the samples, as seen in graph 14 the transmittance hardly change. pH (see graph 15) slightly increase with time but not significantly, the dissolved oxygen concentration slightly changes, for SFR its decreases rapidly after 0,5 hours for then to slowly increase. Aeration of the samples did not change properties of the sludge liquor to any extent. Increased oxygen rate should give increased activity of microbial digestion. Since the sludge has been through an anaerobic digestion, most micro organisms are anaerobic, and thereby the aerobic degradation will not be that efficient. And the aeration time (24 hours) might have been to short to for the aerobic algae to adapt. Aeration has no effect as pre-treatment method

8.4 Oxidation

Oxidation of the samples with hydrogen peroxide, peracetic acid and Fenton showed little effect. Transmittance was lowered during oxidation for all three oxidation methods (see graph 18 and 20). There was no significantly difference between H2O2, PAA, or Fentons reagent, visually the samples looked more turbid after oxidation, with larger particles. COD increased after 24 hours of oxidization for both PAA and H2O2, at 0,5 hours the samples oxidized with H2O2 (see tables 10-21), decreased in COD concentrations, while with PAA it increased already after 0,5 hours (except for Frevar). The reason for the increase in COD after 24 hours may be the physical agitation the stirring is creating. Also in the controls there are COD increase up to 40%, indicating that the stirring itself is because of that. Comparing the values to the controls it is seen that there is a slightly decrease in COD after addition of hydrogen peroxide, and its decreased the most after 0,5 hours, except for SFR where COD removal increased with time. With addition of PAA the COD values compared to the control also decreases slightly, but the COD removal increases with time. Ammonium increases during agitation as it is shown on the control taken, that without addition of oxidants only stirring the samples gives increased ammonium values, this happens for all controls, except for the control of GRA. Comparing the ammonium values of the oxidized samples to the controls the ammonia level has slightly been reduced for both PAA and H2O2. Comparing the other oxidized samples with the control shows that they have increased of GRA to the control, ammonium has increased. Nitrate is also increased based on comparing the results against the control that has increased nitrate concentration, except for GRA. The uneven results makes it hard to draw a conclusion of the effect of oxidization, the stirring itself seems to have influenced the measured parameters significantly, and the oxidation concentration used may have been to low to get a good result. This indicates that oxidation is not a good solution for treating sludge liquor.

The main reason can be that pH was not lowered before oxidization, studies show that oxidation improves it effectiveness with decreasing pH in the solution getting oxidized. For Fenton reaction pH 3 is optimal for best results for oxidation.

8.45 Media filtration

The media filtration shows that activated carbon has a good effect, but varies with the different samples. Anthracite also shows good effect on some of the samples, variances here can lye in that the anthracite was not dried after each run, so even sample was run through once before sampling, water can have still been remaining in the voids of the anthracite contributing to a dilution effect.
Media filtration with anthracite and/or activated carbon is also normally used for drinking water treatment (Zouboulis et al. 2007) and sludge liquor may have to high nutrient composition and a too high solid content for media filtration alone as pretreatment.

8.6 Coagulation and flocculation

The testing of different polymers for GRA showed that ZG 8125, ZG 7550 and A-120 gave the best results, using concentrations of 1, 10 and 25mg/l , and was tested further for optimal polymer dosage. ZG 8125 was the most effective polymer, even if ZG 7550 reached higher transmittance results, ZG 8125 achieved a good transmission result with a much less polymer dose (se figure 27), considering the economical aspect ZG 8125 at the concentration of 50mg/l was further treated at tested. Filtration after coagulation was done and improvement from 71% to 80% transmission after filtration through anthracite. There was achieved a higher reduction of soluble COD after anthracite filtration, from 12% to 36% reduction (see table 22) and nitrite was also decreased significantly more after anthracite filtration then with only flocculation. In general the treated sludge liquor from GRA had high reduced values of solids, turbidity, COD, nitrate and phosphorous. There was little change in alkalinity, conductivity and pH. Centrifugation after coagulation and flocculation was not done, this might have been better then coagulation and flocculation combined with anthracite.

Testing out polymers and doses for the sludge liquor from Frevar, ZG 8125 and C-492, both cationic, gave best transmittion results with very similar results, but ZG 8125 was slightly better. The optimal polymer dose was 250mg/l, something that is very high, considering Frevar had a very bad start with a original sample, having only 0,1% in transmittance, it needs such a high polymer dose to achieve acceptable light penetration properties. Achieved transmittance with flocculation was 47%, centrifugation after flocculation gave 66% transmittance and filtration through anthracite increased transmittance to 77% (figure 31). There is high reduction in solids for all three methods; centrifugation, flocculation and centrifugation, flocculation and anthracite filtration, but only flocculation combined with anthracite filtration reduces COD and soluble COD significantly. Total nitrogen, ammonium and phosphate are reduced during this treatment (table 25 and 26) compared to the others; also conductivity alkalinity is decreased a lot compared to the others. Since the conductivity and alkalinity is decreased as much as one can see here, it implies that there has been a diution of the sample. This can have happened because water has been left over in voids of the anthracite filter and have interfered with filtration of sample.

For SFR, two cationic polymers showed the best result, ZG 7550 and C-496. The sludge liquor form this site has a very high initial transmittance (21%) and low turbidity and visually its brown to yellow, and separates from the other (see section 8.1). Centrifugation alone gives a transmittance at 76% (see figure 34). The optimum polymer dose is quit low, 25mg/l, and C-496 seems to be the best polymer. Centrifugation after flocculation gives higher transmittance values then flocculation combined with anthracite filtration, 92% transmittance is achieved by flocculation and centrifugation, centrifugation alone gives higher transmittance then combined flocculation and anthracite filtration. The treatment methods, centrifugation, flocculation and centrifugation, flocculation and anthracite filtration gives high removal of solids but not that much COD removal, anthracite filtration after flocculation remove a lot of the total nitrogen compared to the others, but little ammonium or nitrate is removed. The total phosphorous content is significantly reduced. Initial pH for SFR was very low, 6,28, and increased with flocculation combined with centrifugation and flocculation combined with filtration. There was little reduction in alkalinity and conductivity (see table 29).

Two cationic polymers of the tested showed best results in transmission results after flocculation of the NFR sample, C-492 and ZG 8125. Optimal polymer and dosage was 150 mg/l ZG 8125 as seen in figure 36. Treatment after flocculation gives best results combined with centrifugation; 64 % transmittance is achieved (see figure 37). Flocculation combined with anthracite filtration gives higher reduction in solids removal and COD, while soluble COD and ammonium values are increased (with all treatments). Total phosphorus and phosphate is reduced after flocculation and combined treatment.

NFR and SFR achieved best results with the combination of coagulation and flocculation combined with centrifugation. FREVAR showed highest transmittance values with anthracite filtration, but this sample indicates that dilution has occurred under filtration. There was not done centrifugation after polymer addition for GRA. This makes the combination of coagulation and flocculation combined with centrifugation to seem the most feasible option for sludge liquor pre-treatment.

8.7 Microalgae growth

Growth of *Chlorella sp.* in standard nutrient media showed an expected growth curve, both based on absorbance at 440nm and mg/l dry weight, with a lag phase, log phase and a long stationary phase, then death phase. 440 nm was used since the highest absorption occurred here. The calculated growth rate g/m^2/d, is a bit uneven. The growth curve based on absorbance shows a longer lag phase, probably because the algae needs longer time to adapt to the sludge liquor media. The growth curve is of a very shorter time-period compared to the nutrient solution media, this because of the limitations of nutrients in the sludge liquor media as nitrogen and phosphorous compounds. Light penetration is also less then in the nutrient media, but the lack of nutrients are probably more significant to the algae growth. Total nitrogen and nitrate first slowly decrease, then after 2 days when growth rate increases they rapidly decrease and then after 5 days they slowly decreases as growth rate slows down. Ammonium decreases rapidly instantly until 2 days, where it slowly decreases until death phase.

Inhibition of nitrate uptake is caused by high ammonium concentrations (Cochlan and Harrison, 2003), here we see that before the total nitrogen and nitrate is consumed rapidly, ammonium is utilized and rapidly decreased. This may also be a reason for the long lag phase in sludge liquor media.

The study shows that microalgae grow in diluted sludge liquor with addition of phosphorus. The growth can be further induced by adding more phosphate and other nutrients as phosphorpus and nitrogen are the limiting nutrient, affecting algae growth (Kunikane at al, 2003). Also nitrogen in the form of urea can be added, Pustizzi et al. 2004; found that algae has higher growth in low light conditions with addition of nitrogen in the form of urea then without.

9. Conclusion

The characteristics of sludge liquor vary between different wastewater treatments plants due to variation in inlet flow, treatment methods and dewatering methods. But they share similarities as high TSS, COD and ammonium levels.

Oxidization and aeration did not improve light penetration properties, as removing solids and reducing COD, in fact the transmittance and turbidity increased cause of the mechanical agitation. The doses of oxidizing agents added also might be to low to get any wanted effect, still the effect over oxidization of higher doses is doubtful. The pH was not lowered before addition and therefore the efficiency decreased even more.
Values after media filtration, either anthracite or activated carbon, varied a lot in effectiveness as treatment. Because of the variations and only some good results for media filtration it is not recommended as a single pretreatment procedure for such dark sludge liquor. Centrifugation alone gave high transmittance results, but not significantly enough to recommend as pre-treatment alone.
The pre-treatment that occurred feasible was coagulation and flocculation by addition of polymers combined with centrifugation. It increased the transmittance and lowered turbidity and reduced COD and TSS with around 80% of original value.
There are difficulties with reducing TSS, COD and turbidity without removing nutrients as nitrogen and phosphorous. Addition of nutrients to microalgae growth media is needed.

Algae grew in diluted (1:5.5) pre-treated sludge liquor only added phosphate. It had a longer lag phase and shorter growth period compared to algae grown in a conventional nutrient media, but it gave a positive indication on the feasibility to use treated sludge liquor as nutrient media for algae growth.

Further objectives:

Further testing of coagulation and flocculation with polymers combined with dual media filtration; anthracite and activated carbon as pre-treatment.

Optimization of coagulation and flocculation with polymers combined with centrifugation, testing with higher speed.

Experiments of microalgae growth in treated sludge liquor with varying dilutions and nutrient additions, for optimization of media and growth rates.

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Appendix:

1A.

I.	Tests GARDERMOEN	Conc mg/l	TSS (mg/L)	VSS (mg/L)	TS (mg/L)	VS (mg/L)	COD (mg/L)	sCOD (mg/L)	% T (670 nm)
Original			787	673	1335	1038	1872	751	16,1
Centrifuge			272	224	-	-	987	354	57,1
Aeration	**2 hours**		-	-	-	-	1850	-	15,2
Aeration	**24 hours**		-	-	-	-	1902	-	14,3
H2O2	**0,5hours**	**80**	-	-	-	-	1577	-	16,9
H2O2	**24hours**	**80**	-	-	-	-	1941	-	7,6
PAA	**0,5hours**	**40**	-	-	-	-	1643	-	16,1
PAA	**24hours**	**40**	-	-	-	-	1960	-	11,7
Fenton	**24hours**				-	-		-	31,4
DAF	**-**	**-**	**-**	**-**	-	-	**-**	**-**	**-**
Filtration	**1.2 um**		-	-	-	-	-	751	91,6
	Antracit		-	-	-	-	-	-	23
	GAC		-	-	-	-	-	-	17,8
Polymers	**ZG 8125**	**50**	104	84	-	-	937	660	68,4
	ZG 7550	**150**	49	47	-	-	549	438	87,5
	MF 155	**25**			-	-	1278		34,2
	MF 342	**25**			-	-	1104		29,9
	MF 919	**25**	363	327	-	-	1196		33,6
	C-496	**25**	460	344	-	-	1017		39,3
	C-492	**10**	668	532	-	-	962		34,4
	A-120	**25**	300	243	-	-	1240		53,8
Polymer + Antracite	**ZG 8125**	**50**	93	87	-	-	600	480	85

I.

	Tests GARDERMOEN	Conc mg/l	Particle size d10% (um)	Particle size d50% (um)	Particle size d90% (um)	Par conc (mg/L)	Tot-N (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	NH4-N (mg/L)
Original			1,23	20,03	210,3	525	640	5,6	0,044	280
Centrifuge			0,66	1,33	63,34	50	492	-	-	258
Aeration	**2 hours**		-	-	-	-	-		-	270
Aeration	**24 hours**		-	-	-	-	-		-	183
H2O2	**0,5hours**	**80**	-	-	-	-	-	5,5	-	182
H2O2	**24hours**	**80**	-	-	-	-	-	4,3	-	170
PAA	**0,5hours**	**40**	-	-	-	-	-	5,1	-	238
PAA	**24hours**	**40**	-	-	-	-	-	3,4	-	182
Fenton	**24hours**		-	-	-	-	-	-	-	
DAF	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Filtration	**1.2 um**		0,63	1,05	2,34	6	-	5,6	0,044	280
	Antracit		-	-	-	-	-	-	-	-
	GAC		-	-	-	-	-	-	-	-
Polymers	**ZG 8125**	**50**	0,88	7,66	32,4	50	518	0,32	0,036	248
	ZG 7550	**150**	0,86	3,8	16,86	20	490	0,58	0,022	274
	MF 155	**25**	-			-	-	-	-	308
	MF 342	**25**	-			-	-	-	-	278
	MF 919	**25**	-			-	-	-	-	290
	C-496	**25**	-			-	-	-	-	265
	C-492	**10**	-			-	-	-	-	255
	A-120	**25**	-			-	-	-	-	268
Polymer + Antracite	**ZG 8125**	**50**	1,2	3,1	28	45	508	0,4	0,021	244

I.	Tests GARDERMOEN	Conc mg/l	Tot-P (mg/L)	PO4-P (mg/L)	pH	Turb	DO (mg/l)	Alkalinity (mmol/L)	Conductivity (mS/cm)
Original			2,8	<0,05	7,77	611	8,78	25	2,93
Centrifuge			<2	<0,05	7,88	172	-	-	-
Aeration	**2 hours**		-	-	7,82	555	8,71	-	-
Aeration	**24 hours**		-	-	8,16	564	8,86	-	-
H2O2	**0,5hours**	**80**	-	-	7,84	659	-	-	-
H2O2	**24hours**	**80**	-	-	8,24	909	-	-	-
PAA	**0,5hours**	**40**	-	-	7,93	631	-	-	-
PAA	**24hours**	**40**	-	-	8,31	>1000	-	-	-
Fenton	**24hours**		-	-	-	-	-	-	-
DAF	**-**	**-**	**-**	**-**	**-**	**-**	**-**	-	-
Filtration	**1.2 um**		-	<0,05	-	19	-	-	-
	Antracit		-	-	-	-	-	-	-
	GAC		-	-	-	-	-	-	-
Polymers	**ZG 8125**	**50**	1,09	<0,05	7,59	60,9	-	23	2,74
	ZG 7550	**150**	<0,5	<0,05	7,56	18,2	-	16	2,44
	MF 155	**25**	-	<0,05	-	-	-	-	-
	MF 342	**25**	-	<0,05	-		-	-	-
	MF 919	**25**	-	<0,05	-		-	-	-
	C-496	**25**	-	<0,05	-		-	-	-
	C-492	**10**	-	<0,05	-		-	-	-
	A-120	**25**	-	<0,05	-		-	-	-
Polymer + Antracite	**ZG 8125**	**50**	1,02	<0,05	7,64	20	-	20,2	2,69

1B

GARDERMOEN (GRA)			**Polymer Matrix**							
	Units									
Polymer		**Value**	**ZETAG 8125**	**ZETAG 7550**	**MAGNA FLOC 155**	**MAGNA FLOC 342**	**MAGNA FLOC 919**	**CIBA C-496**	**CIBA C-492**	**CIBA A-120**
Density	g/cm3				0,75	0,75				
Total vol supplied	mL		50	50	50	50	50			
Conc	%		0,50 %	0,50 %	0,50 %	0,50 %	0,50 %			
State			Liquid	Liquid	Liquid	Liquid	Liquid	Granules	Granules	Granules
Type			Cationic	Cationic	Anionic	Anionic	Anionic	Cationic	Cationic	Anionic
Conc for stock soln	%		0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %
Amount added for dilution	mL		5	5	5	5	5			
Total volume of stock prepared	mL		25	25	25	25	25			
Weight of added granules	mg							100	100	100
Total volume	mL							100	100	100
Concentrations tested										
Conc 1	mg/L	1	X	X	X	X	X	X	X	X
Height of supernatant	cm		7,6	7,6	7,6	7,7	7,6	7,6	7,5	7,6
Height of flocs	cm		<0,1	<0,1	<0,1	<0,1	0,3	<0,1	<0,1	<0,1
Conc 2	mg/L	10	X	X	X	X	X	X	X	X
Height of supernatant	cm		7,7	7,7	7,6	7,7	7,8	7,8	7,7	7,6
Height of flocs	cm		0,3	0,4	<0,1	<0,1	0,3	0,5	<0,1	0,3
Conc 3	mg/L	25	X	X	X	X	X	X	X	X
Height of supernatant	cm		7,8	7,8	7,7	7,8	7,8	7,8	7,7	7,8
Height of flocs	cm		1	0,4	<0,1	<0,1	0,5	0,5	0,3	0.3
Conc 4	mg/L	50	X	X						X
Height of supernatant	cm		7,9	7,9						7,8
Height of flocs	cm		1	0,5						0.3
Conc 5	mg/L	75	X	X						X
Height of supernatant	cm		8,1	7,8						7,8
Height of flocs	cm		1	0,5						0.3
Conc 6	mg/L	100	X	X						
Height of supernatant	cm		8,1	7,8						
Height of flocs	cm		1	0,5						
Conc 7	mg/L	200	X							
Height of supernatant	cm		8,5							
Height of flocs	cm		1							

2A

Tests FREVAR		Conc mg/l	TSS (mg/L)	VSS (mg/L)	TS (mg/L)	VS (mg/L)	COD (mg/L)	sCOD (mg/L)	% T (670 nm)
Original			3740	2940	6688	4945	7525	3330	0,1
Centrifuge			313	237	-	-	5326	3272	12,4
Aeration	**2 hrs**		**-**	**-**	-	-	-	-	0,1
Aeration	**24 hrs**		**-**	**-**	-	-	-	-	0,2
H2O2	**0,5hrs**	**80**	**-**	**-**	-	-	7000	-	0,1
H2O2	**24hrs**	**80**	**-**	**-**	-	-	7047	-	0,1
PAA	**0,5hrs**	**40**	**-**	**-**	-	-	7625	-	0,1
PAA	**24hrs**	**40**	**-**	**-**	-	-	8982	-	0,1
Fenton	**24hrs**	**150**	**-**	**-**	-	-	8042	-	0,1
DAF	**-**	**-**	**-**	**-**	-	-	**-**	**-**	**-**
Filtration	**1.2 um**		-	-	-	-	-	3330	62,4
	Antracit		-	-	-	-	-	-	0,0
	GAC		-	-	-	-	-	-	0,4
	GAC		-	-	-	-	-	-	-
Polymers	**ZG 8125**	**250**	-	-	-	-	-	-	46,7
	ZG 7550	**25**	-	-	-	-	-	-	0,1
	MF 155	**25**	-	-	-	-	-	-	0,1
	MF 342	**25**	-	-	-	-	-	-	0,1
	MF 919	**10**	-	-	-	-	-	-	0,1
	C-496	**25**	-	-	-	-	-	-	0,1
	C-492	**250**	-	-	-	-	-	-	41,1
	A-120	**25**	-	-	-	-	-	-	0,1
Polymer + Antracite	**ZG 8125**	**250**	64	52	-	-	1888	1800	76,9
Polymer + centrifugation	**ZG 8125**	**250**	122	107	-	-	3957	3390	65,9

Tests FREVAR		**Conc mg/l**	**Particle size d10%(um)**	**Particle size d50%(um)**	**Particle size d90%(um)**	**Par conc (mg/L)**	**Tot-N (mg/L)**	**NO3-N (mg/L)**	**NO2-N (mg/L)**	**NH4-N (mg/L)**
Original			0,72	2,26	571,2	1500	1655	18,9	0,026	831
Centrifuge			0,6	0,89	1,4	120	1370	12,1	**-**	612
Aeration	**2 hrs**		-	-	-	-	-	-	-	-
Aeration	**24 hrs**		-	-	-	-	-	-	-	-
H2O2	**0,5hrs**	**80**	-	-	-	-	-	22,8	**-**	1080
H2O2	**24hrs**	**80**	-	-	-	-	-	37,4	**-**	739
PAA	**0,5hrs**	**40**	-	-	-	-	-	25,5	**-**	1080
PAA	**24hrs**	**40**	-	-	-	-	-	44,6	**-**	658
Fenton	**24hrs**	**150**	-	-	-	-	-	39,3	**-**	726
DAF	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Filtration	**1.2 um**		0,64	1,09	4,12	18	924	18,9	0,026	831
	Antracit		-	-	-	-	-	-	-	-
	GAC		-	-	-	-	-	-	-	-
	GAC		-	-	-	-	-	-	-	-
Polymers	**ZG 8125**	**250**	-	-	-	-	-	-	-	-
	ZG 7550	**25**	-	-	-	-	-	-	-	-
	MF 155	**25**	-	-	-	-	-	-	-	-
	MF 342	**25**	-	-	-	-	-	-	-	-
	MF 919	**10**	-	-	-	-	-	-	-	-
	C-496	**25**	-	-	-	-	-	-	-	-
	C-492	**250**	-	-	-	-	-	-	-	-
	A-120	**25**	-	-	-	-	-	-	-	-
Polymer + Antracite	**ZG 8125**	**250**	0,66	1,17	4,79	25	517	13,8	0,019	370
Polymer + centrifugation	**ZG 8125**	**250**	0,67	1,31	11	30	997	18,7	0,023	640

Tests FREVAR		**Conc mg/l**	**Tot-P (mg/L)**	**PO4-P (mg/L)**	**pH**	**Turb**	**DO (mg/l)**	**Alkalinity (mmol/L)**	**Conductivity (mS/cm)**
Original			37,1	3,79	8,1	>1000	8,62	73	8,63
Centrifuge				1,48	8,19	503	-	-	-
Aeration	**2 hrs**		-	-	8,15	>1000	8,74	-	-
Aeration	**24 hrs**		-	-	8,88	>1000	7,16	-	-
H2O2	**0,5hrs**	**80**	-	-	8,11	>1000	-	-	-
H2O2	**24hrs**	**80**	-	-	8,27	>1000	-	-	-
PAA	**0,5hrs**	**40**	-	-	8,16	>1000	-	-	-
PAA	**24hrs**	**40**	-	-	8,37	>1000	-	-	-
Fenton	**24hrs**	**150**	-	-	8,36	>1000	-	-	-
DAF	**-**	**-**	**-**	**-**	**-**	**-**	-	-	-
Filtration	**1.2 um**		-	3,79	-		-	-	-
	Antracit		-	-	-	-	-	-	-
	GAC		-	-			-	-	-
	GAC		-	-	-	-	-	-	-
Polymers	**ZG 8125**	**250**	-	-	-	-	-	-	-
	ZG 7550	**25**	-	-	-	-	-	-	-
	MF 155	**25**	-	-	-	-	-	-	-
	MF 342	**25**	-	-	-	-	-	-	-
	MF 919	**10**	-	-	-	-	-	-	-
	C-496	**25**	-	-	-	-	-	-	-
	C-492	**250**	-	-	-	-	-	-	-
	A-120	**25**	-	-	-	-	-	-	-
Polymer + Antracite	**ZG 8125**	**250**	1,83	0,087	8,14	28	-	32	4,05
Polymer + centrifugation	**ZG 8125**	**250**	3,24	1,18	8,22	35,4	-	49	7,19

2 B.

			Polymer Matrix							
FREVAR	**Units**									
Polymer		**Value**	**ZETAG 8125**	**ZETAG 7550**	**MAGNA FLOC 155**	**MAGNA FLOC 342**	**MAGNA FLOC 919**	**CIBA C-496**	**CIBA C-492**	**CIBA A-120**
Density	g/cm3				0,75	0,75				
Total vol supplied	mL		50	50	50	50	50			
Conc	%		0,50 %	0,50 %	0,50 %	0,50 %	0,50 %			
State			Liquid	Liquid	Liquid	Liquid	Liquid	Granules	Granules	Granules
Type			Cationic	Cationic	Anionic	Anionic	Anionic	Cationic	Cationic	Anionic
Conc for stock soln	%		0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %
Amount added for dilution	mL		5	5	5	5	5			
Total volume of stock prepared	mL		25	25	25	25	25			
Weight of added granules	mg							100	100	100
Total volume	mL							100	100	100
Concentrations tested										
Conc 1	mg/L	1								
Height of supernatant	cm									
Height of flocs	cm									
Conc 2	mg/L	10	X	X	X	X	X	X	X	
Height of supernatant	cm		7,8	7,8	7,6	7,6	7,8	7,8	7,7	
Height of flocs	cm		0,5	0,3	<0,1	<0,1	<0,1	0,3	0,5	
Conc 3	mg/L	25	X	X	X	X		X	X	X
Height of supernatant	cm		8	8	7,7	7,8		8	7,9	7,9
Height of flocs	cm		1	0,3	<0,1	<0,1		0,3	1	<0,1
Conc 4	mg/L	50	X						X	
Height of supernatant	cm		7,9						7,6	
Height of flocs	cm		1						1	
Conc 5	mg/L	75								
Height of supernatant	cm									
Height of flocs	cm									
Conc 6	mg/L	100	X						X	
Height of supernatant	cm		8,1						7,8	
Height of flocs	cm		1						1	
Conc 7	mg/L	150	X							
Height of supernatant	cm		8							
Height of flocs	cm		1							

Conc 8	mg/L	250	X						X	
Height of supernatant	cm		7,8						8	
Height of flocs	cm		1						1	

3A.

Tests SØNDRE FOLLO		**Conc mg/l**	**TSS (mg/L)**	**VSS (mg/L)**	**TS (mg/L)**	**VS (mg/L)**	**COD (mg/L)**	**sCOD (mg/L)**	**% T (670 nm)**
Original			636	580	2260	1350	4503	3627	21,1
Centrifuge			73	63	-	-	4139	3391	75,9
Aeration	**2 hours**		-	-	-	-	-	-	18,4
Aeration	**24 hours**		-	-	-	-	-	-	23,2
H2O2	**0,5hours**	**80**	-	-	-	-	4326	-	20,3
H2O2	**24hours**	**80**	-	-	-	-	5277	-	14,7
PAA	**0,5hours**	**40**	-	-	-	-	4641	-	20,8
PAA	**24hours**	**40**	-	-	-	-	6137	-	14,1
Fenton	**24hours**	**150**	-	-	-	-	5392	-	15,6
DAF	**-**	**-**	-	-	-	-	-	-	-
Filtration	**1.2 um**		-	-	-	-	3627	3627	91,8
	Antracit		-	-	-	-	-	-	24,1
	GAC		-	-	-	-	-	-	66,1
Polymers	**ZG 8125**	**10**	-	-	-	-	-	-	23,8
	ZG 7550	**25**	-	-	-	-	-	-	44,2
	MF 155	**10**	-	-	-	-	-	-	25,5
	MF 342	**25**	-	-	-	-	-	-	24,8
	MF 919	**25**	-	-	-	-	-	-	32,4
	C-496	**25**	-	-	-	-	-	-	47,9
	C-492	**25**	-	-	-	-	-	-	26,5
	A-120	**25**	-	-	-	-	-	-	23,4
Polymer + centrifugation	**C-496**	**25**	32	26	-	-	3892	3745	92,3
Polymer + centrifugation	**ZG 7550**	**25**	48	43	-	-	3978	3922	86,1
Polymer + Anthracite	**C-496**	25	130	106	-	-	4542	3607	64,6

Tests SØNDRE FOLLO		Conc mg/l	Particle size d10%(um)	Particle size d50%(um)	Particle size d90%(um)	Par conc (mg/L)	Tot-N (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	NH4-N (mg/L)
Original			9	64,1	162	1380	383	0,63	0,03	308
Centrifuge			0,66	1,16	23,4	15	371	0,71	0,03	340
Aeration	**2 hours**		-	-	-	-	-	-	-	-
Aeration	**24 hours**		-	-	-	-	-	-	-	-
H2O2	**0,5hours**	**80**	-	-	-	-	-	1,42	**-**	437
H2O2	**24hours**	**80**	-	-	-	-	-	1,39	**-**	545
PAA	**0,5hours**	**40**	-	-	-	-	-	1,13	**-**	466
PAA	**24hours**	**40**	-	-	-	-	-	1,56	**-**	600
Fenton	**24hours**	**150**	-	-	-	-	-	1,44	**-**	615
DAF	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Filtration	**1.2 um**		0,61	0,91	1,43	3	330	0,63	0,03	308
	Antracit		-	-	-	-	-	-	-	-
	GAC		-	-	-	-	-	-	-	-
Polymers	**ZG 8125**	**10**	-	-	-	-	-	-	-	-
	ZG 7550	**25**	-	-	-	-	-	-	-	-
	MF 155	**10**	-	-	-	-	-	-	-	-
	MF 342	**25**	-	-	-	-	-	-	-	-
	MF 919	**25**	-	-	-	-	-	-	-	-
	C-496	**25**	-	-	-	-	-	-	-	-
	C-492	**25**	-	-	-	-	-	-	-	-
	A-120	**25**	-	-	-	-	-	-	-	-
Polymer + centrifugation	**C-496**	**25**	0,71	2,03	14	10	347	0,66	<0,015	341
Polymer + centrifugation	**ZG 7550**	**25**	0,68	1,42	13,3	15	353	0,69	<0,015	350
Polymer + Anthracite	**C-496**	25	0,78	3,19	14,9	40	327	0,59	<0,015	306

Tests SØNDRE FOLLO		**Conc mg/l**	**Tot-P (mg/L)**	**PO4-P (mg/L)**	**pH**	**Turb**	**DO (mg/l)**	**Alkalinity (mmol/L)**	**Conductivity (mS/cm)**
Original			4,09	0,06	6,28	556	8,31	20,6	4,02
Centrifuge			0,96	0,08	6,25	70,3	-	20	3,98
Aeration	**2 hours**		-	-	6,72	575	7,5	-	-
Aeration	**24 hours**		-	-	6,53	496	4,91	-	-
H2O2	**0,5hours**	**80**	-	-	6,23	607	-	-	-
H2O2	**24hours**	**80**	-	-	6,44	671	-	-	-
PAA	**0,5hours**	**40**	-	-	5,71	615	-	-	-
PAA	**24hours**	**40**	-	-	6,06	761	-	-	-
Fenton	**24hours**	**150**	-	-	6	827	-	-	-
DAF	**-**	**-**	**-**	**-**	**-**	**-**	-	-	-
Filtration	**1.2 um**		0,58	0,06	-	19,1	-	-	-
	Antracit		-	-	-	514	-	-	-
	GAC		-	-			-	-	-
Polymers	**ZG 8125**	**10**	-	-	-	-	-	-	-
	ZG 7550	**25**	-	-	-	179	-	-	-
	MF 155	**10**	-	-	-	495	-	-	-
	MF 342	**25**	-	-	-	522	-	-	-
	MF 919	**25**	-	-	-	383	-	-	-
	C-496	**25**	-	-	-	128	-	-	-
	C-492	**25**	-	-	-	486	-	-	-
	A-120	**25**	-	-	-	514	-	-	-
Polymer + centrifugation	**C-496**	**25**	0,39	<0,05	6,74	19,3	-	21,7	3,74
Polymer + centrifugation	**ZG 7550**	**25**	0,51	<0,05	6,82	35,9	-	18,8	3,77
Polymer + Anthracite	**C-496**	25	0,87	<0,05	6,86	85,5	-	17,3	3,86

3B.

			Polymer Matrix							
SØNDRE FOLLO RENSEANLEGG	**Units**									
Polymer		**Value**	**ZETAG 8125**	**ZETAG 7550**	**MAGNA FLOC 155**	**MAGNA FLOC 342**	**MAGNA FLOC 919**	**CIBA C-496**	**CIBA C-492**	**CIBA A-120**
Density	g/cm3				0,75	0,75				
Total vol supplied	mL		50	50	50	50	50			
Conc	%		0,50 %	0,50 %	0,50 %	0,50 %	0,50 %			
State			Liquid	Liquid	Liquid	Liquid	Liquid	Granules	Granules	Granules
Type			Cationic	Cationic	Anionic	Anionic	Anionic	Cationic	Cationic	Anionic
Conc for stock soln	%		0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %
Amount added for dilution	mL		5	5	5	5	5			
Total volume of stock prepared	mL		25	25	25	25	25			
Weight of added granules	mg							100	100	100
Total volume	mL							100	100	100
Concentrations tested										
Conc 1	mg/L	1	X							
Height of supernatant	cm		8							
Height of flocs	cm		0,3							
Conc 2	mg/L	10	X	X	X	X		X	X	
Height of supernatant	cm		7,9	8	7,8	7,8		7,8	7,7	
Height of flocs	cm		0,3	0,1	0,2	0,1		0,4	0,3	
Conc 3	mg/L	25	X	X	X	X	X	X	X	X
Height of supernatant	cm		7,9	7,9	7,9	7,8	7,8	7,9	7,8	7,8
Height of flocs	cm		0,3	0,4	0,2	0,1	0,2	0,6	¨0,3	0,2
Conc 4	mg/L	50						X		
Height of supernatant	cm							7,9		
Height of flocs	cm							0,4		
Conc 5	mg/L	75						X		
Height of supernatant	cm							8		
Height of flocs	cm							0,4		
Conc 6	mg/L	100								
Height of supernatant	cm									
Height of flocs	cm									
Conc 7	mg/L	150						X		

Height of supernatant	cm							7,9		
Height of flocs	cm							0,4		

4A.

Tests NORDRE FOLLO		**Conc mg/l**	**TSS (mg/L)**	**VSS (mg/L)**	**TS (mg/L)**	**VS (mg/L)**	**COD (mg/L)**	**sCOD (mg/L)**	**% T (670 nm)**
Original			2125	1825	4300	3445	3850	1037	2
Centrifuge			634	524	-	-	2774	1867	17
Aeration	**2 hours**		**-**	**-**	-	-	-	-	3
Aeration	**24 hours**		**-**	**-**	-	-	-	-	3
H2O2	**0,5hours**	**80**	**-**	**-**	-	-	3510	-	3
H2O2	**24hours**	**80**	**-**	**-**	-	-	5050	-	2
PAA	**0,5hours**	**40**	**-**	**-**	-	-	3455	-	3
PAA	**24hours**	**40**	**-**	**-**	-	-	4880	-	2
Fenton	**24hours**	**150**	**-**	**-**	-	-	4265	-	2
DAF	**-**	**-**	**-**	**-**	-	-	**-**	**-**	
Filtration	**1.2 um**		-	-	-	-	-	1037	65
	Antracit		-	-	-	-	-	-	5
	GAC		-	-	-	-	-	-	17
Polymers	**ZG 8125**	**150**	-	-	-	-	-	-	50
	ZG 7550	**25**	-	-	-	-	-	-	4
	MF 155	**25**	-	-	-	-	-	-	3
	MF 342	**25**	-	-	-	-	-	-	3
	MF 919	**25**	-	-	-	-	-	-	4
	C-496	**25**	-	-	-	-	-	-	3
	C-492	**50**	-	-	-	-	-	-	17
	A-120	**25**	-	-	-	-	-	-	3
Polymer + centrifugation	**ZG 8125**	**150**	255	243	-	-	1660	1240	64
Polymer + centrifugation	**C-492**	**50**	447	390	-	-	1860	1255	32
Polymer + Anthracite	**ZG 8125**	**150**	750	670	-	-	2165	1300	56

Tests NORDRE FOLLO		**Conc mg/l**	**Particle size d10% (um)**	**Particle size d50% (um)**	**Particle size d90% (um)**	**Par conc (mg/L)**	**Tot-N (mg/L)**	**NO3-N (mg/L)**	**NO2-N (mg/L)**	**NH4-N (mg/L)**
Original			0,68	1,39	144,9	700	930	7,16	0,221	476
Centrifuge			0,64	1,03	96,9	90	860	4,41	**0,123**	747
Aeration	**2 hours**		-	-	-	-	-	-	-	-
Aeration	**24 hours**		-	-	-	-	-	-	-	-
H2O2	**0,5hours**	**80**	-	-	-	-	-	8,63	**-**	605
H2O2	**24hours**	**80**	-	-	-	-	-	10,4	**-**	377
PAA	**0,5hours**	**40**	-	-	-	-	-	9,02	**-**	630
PAA	**24hours**	**40**	-	-	-	-	-	11,8	**-**	429
Fenton	**24hours**	**150**	-	-	-	-	-	10,9	**-**	409
DAF	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Filtration	**1.2 um**		0,64	0,99	1,95	20	652	7,16	0,022	476
	Antracit		-	-	-	-	-	-	-	-
	GAC		-	-	-	-	-	-	-	-
Polymers	**ZG 8125**	**150**	-	-	-	-	-	-	-	-
	ZG 7550	**25**	-	-	-	-	-	-	-	-
	MF 155	**25**	-	-	-	-	-	-	-	-
	MF 342	**25**	-	-	-	-	-	-	-	-
	MF 919	**25**	-	-	-	-	-	-	-	-
	C-496	**25**	-	-	-	-	-	-	-	-
	C-492	**50**	-	-	-	-	-	-	-	-
	A-120	**25**	-	-	-	-	-	-	-	-
Polymer + centrifugation	**ZG 8125**	**150**	0,65	1,09	8,71	30	875	5,07	0,091	600
Polymer + centrifugation	**C-492**	**50**	0,64	1,12	11,48	60	912	6,07	0,086	625
Polymer + Anthracite	**ZG 8125**	**150**	0,69	1,53	13,03	150	934	6,06	0,086	620

Tests NORDRE FOLLO		Conc mg/l	Tot-P (mg/L)	PO4-P (mg/L)	pH	Turb	DO (mg/l)	Alkalinity (mmol/L)	Conductivity (mS/cm)
Original			63,5	3,78	8,13	>1000	7,89	52,6	5,65
Centrifuge			37,6	1,8	8,22	629	-	48,2	5,41
Aeration	**2 hours**		-	-	8,18	>1000	8,09	-	-
Aeration	**24 hours**		-	-	8,35	>1000	7,23	-	-
H2O2	**0,5hours**	**80**	-	-	8,17	>1000	-	-	-
H2O2	**24hours**	**80**	-	-	8,21	>1000	-	-	-
PAA	**0,5hours**	**40**	-	-	8,16	>1000	-	-	-
PAA	**24hours**	**40**	-	-	8,25	>1000	-	-	-
Fenton	**24hours**	**150**	-	-	8,2	>1000	-	-	-
DAF	**-**	**-**	**-**	**-**	**-**	**-**	-	-	-
Filtration	**1.2 um**		4,15	3,78	-	21,1	-	-	-
	Antracit		-	-	-	>1000	-	-	-
	GAC		-	-		830	-	-	-
Polymers	**ZG 8125**	**150**	-	-	-	312	-	-	-
	ZG 7550	**25**	-	-	-	>1000	-	-	-
	MF 155	**25**	-	-	-	>1000	-	-	-
	MF 342	**25**	-	-	-	>1000	-	-	-
	MF 919	**25**	-	-	-	>1000	-	-	-
	C-496	**25**	-	-	-	>1000	-	-	-
	C-492	**50**	-	-	-	649	-	-	-
	A-120	**25**	-	-	-	>1000	-	-	-
Polymer + centrifugation	**ZG 8125**	**150**	5,26	0,758	8,46	192	-	36,6	4,11
Polymer + centrifugation	**C-492**	**50**	9,04	0,695	8,33	356	-	38,4	4,78
Polymer + Anthracite	**ZG 8125**	**150**	12,3	0,715	8,51	331	-	43,0	4,9

4B.

			Polymer Matrix							
NORDRE FOLLO RENSEANLEGG	**Units**									
Polymer		**Value**	**ZETAG 8125**	**ZETAG 7550**	**MAGNA FLOC 155**	**MAGNA FLOC 342**	**MAGNA FLOC 919**	**CIBA C-496**	**CIBA C-492**	**CIBA A-120**
Density	g/cm3				0,75	0,75				
Total vol supplied	mL		50	50	50	50	50			
Conc	%		0,50 %	0,50 %	0,50 %	0,50 %	0,50 %			
State			Granules	Liquid	Liquid	Liquid	Liquid	Granules	Granules	Granules
Type			Cationic	Cationic	Anionic	Anionic	Anionic	Cationic	Cationic	Anionic
Conc for stock soln	%		0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %	0,10 %
Amount added for dilution	mL			5	5	5	5			
Total volume of stock prepared	mL			25	25	25	25			
Weight of added granules	mg		100					100	100	100
Total volume	mL		100					100	100	100
Concentrations tested										
Conc 1	mg/L	1	X							
Height of supernatant	cm		8							
Height of flocs	cm		0,3							
Conc 2	mg/L	10	X	X	X	X			X	X
Height of supernatant	cm		7,9	8	7,8	7,8			7,7	7,8
Height of flocs	cm		0,3	0,1	0,2	0,1			0,3	0,2
Conc 3	mg/L	25	X	X	X	X	X	X	X	X
Height of supernatant	cm		7,9	7,9	7,9	7,8	7,8	7,9	7,8	7,8
Height of flocs	cm		0,3	0,4	0,2	0,1	0,2	0,6	0,3	0,2
Conc 4	mg/L	50	X						X	
Height of supernatant	cm		8						7,9	
Height of flocs	cm		0,3						0,4	
Conc 5	mg/L	75							X	
Height of supernatant	cm								8	
Height of flocs	cm								0,4	
Conc 6	mg/L	100	X							
Height of supernatant	cm		7,9							

Height of flocs	cm		0,3							
Conc 7	mg/L	150	x					x		
Height of supernatant	cm		7,9					7,9		
Height of flocs	cm		0,3					0,4		
Conc 8	mg/L	200	X							
Height of supernatant	cm		7,9							
Height of flocs	cm		0,3							

5A

Date	Sampling time	Volume of sample	Light	Abs	Wavelength scan	Turbidity	pH	DO	Conductivity
		mL	lux	440nm	Yes/No	NTU		mg/L	mS/cm
30.apr	11:00	10	8000	0,018	Y	13,2	7,65	7,32	2,4
02.mai	12:00	6		0,175	Y	-	7,61	7,45	-
03.mai	10:45	6		0,624	Y	-			-
04.mai	11:00	6		1,32	Y	-	6,13	7,62	-
05.mai	10:30	6		1,547	Y	-	3,81	6,37	-
06.mai	10:30	10	8000	1,686	Y	>1000	3,64	6,43	0,63
08.mai	12:00	6		1,272	Y	>1000	3,85	6,54	-
09.mai	11:00	10	8000	0,896	Y	>1000	3, 56	7,69	0,698

Date	Sampling time	Volume of sample	Tweight of filter	weight after drying (105*C)	Vol of sample	dry matter mg/L	NH4-N	Tot-N
		mL	mg	mg	mL	mg/L	mg/L	mg/L
30.apr	11:00	10	1,1129	1,1145	3	533	44,25	92,1
02.mai	12:00	6	1,1187	1,1218	4	775	9,75	90
03.mai	10:45	6	1,1165	1,1202	4	925	-	-
04.mai	11:00	6	1,108	1,1109	3	967	4,6	56,6
05.mai	10:30	6	1,1025	1,1056	3	1033	4,2	49,4
06.mai	10:30	10	1,107	1,11	3	1000	8,91	41,2
08.mai	12:00	6	1,1121	1,1147	3	867	11,6	39,5
09.mai	11:00	10	1,092	1,0925	1	500	5,92	36,8

Date	Sampling time	Volume of sample	PO4-P	Tot-P	COD	sCOD	New volume added (SL + Nutrient)
		mL	mg/L	mg/L	mg/L	mg/L	mL
30.apr	11:00	10	2,55	2,73	207,5	-	10
02.mai	12:00	6	1,16	-	309	-	6
03.mai	10:45	6	-	-		-	6
04.mai	11:00	6	0,892	-	981	-	6
05.mai	10:30	6	0,765	-	1068	-	6
06.mai	10:30	10	0,881	1,32	1100	-	10
08.mai	12:00	6	0,501	-	1094	-	6
09.mai	11:00	10	0,325	1,65	1105	-	-

	Sludge liquor media		
DAYS	**mg/l dry matter**	**g/m2/d**	**abs 440nm**
0	533	0	0,018
2	775	6,360653	0,175
3	925	7,895984	0,624
4	967	2,193329	1,32
5	1033	3,509326	1,547
6	1000	-1,75466	1,686
8	867	-3,50055	1,272
9	500	-19,3188	0,896

5B.

	Nutrient solution		
DAYS	**mg/l dry matter**	**g/m2/d**	**abs 440nm**
0	1200	0	0,004
2	1475	7,237985	0,032
3	1650	9,211981	0,462
4	1833	9,650647	1,172
5	1900	3,509326	1,91
6	2033	7,018652	2,279
8	2267	6,141321	3,32
9	2500	12,28264	3,396
11	2800	7,895984	3,814
13	3150	9,211981	3,814
14	3300	7,895984	3,816
16	3250	-1,316	3,813
18	**3133**	-3,07066	**3,808**
20	**2500**	-16,6693	**3,802**
21	**2267**	-12,2826	**3,52**
23	**2167**	-2,63199	**1,856**
25	**1200**	-25,4426	**0,418**