RECOVERY OF MICROBIAL ACTIVITY IN A BIOFILM WASTEWATER TREATMENT PROCESS

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ABSTRACT

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ABSTRACT

The government decree on treating domestic wastewater in areas outside sewer networks will come into effect on 1.1.2014. With this new decree the use of small scale sewage treatment plants will increase. The purification effectiveness of small scale treatment processes has been questioned for some time and now manufacturers have to pay attention how to make the small scale treatment processes work more effectively in the Finnish environment.

The aim of this thesis was to examine the stability of the biofilm process in a small scale treatment plant and the recovery of microbial activity after a shutdown period. During the work process especially nitrification and nitrogen removal efficiency was examined. The biofilm process was examined during a six-month period in normal operation followed by a three-month shutdown period when wastewater was not fed into the process. During the normal operation and shutdown period the state of biofilm process and the recovery of microbial activity were examined with sampling and analyses from incoming and outgoing purified wastewater. The followed parameters were biological and chemical oxygen demand, total nitrogen and phosphorus, ammonia nitrogen reduction and nitrate nitrogen concentration. Also pH and temperature were examined.

The client of the thesis was Clewer Ltd. The company manufactures small scale treatment plants and they have developed a biological process called the Rotating Bed Biofilm Reactor (RBBR). Clewer RBBR purification process is based on the carrier material technology, where the microbes operate on the surface of carriers. The process was tested in Suomenoja research station in Espoo. Purification and functionality requirements were examined from the point of view of the government decree (542/2003) and CEN standard (12566-3:2005). The work showed that the microbial activity of RBBR process recovered to its normal operation in less than one week after the shutdown period. The purification results corresponded to the requirements of the government decree 542/2003.

Keywords Wastewater, nitrification, biofilm process, small scale treatment plant, RBBR.

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TIIVISTELMÄ

Valtioneuvoston uusi asetus talousjätevesien käsittelystä vesihuoltolaitosten viemäriverkostojen ulkopuolisilla alueilla tulee voimaan 1.1.2014. Asetuksen myötä jäteveden pienpuhdistamojen käyttö kasvaa. Pienpuhdistamojen toimivuutta ja puhdistustehokkuutta on kyseenalaistettu jo pitkään ja nyt laitevalmistajien onkin kiinnitettävä entistä enemmän huomiota siihen, miten puhdistusprosessit saadaan toimimaan tehokkaammin Suomen vaihtelevissa olosuhteissa.

Työn tarkoituksena oli tutkia jäteveden pienpuhdistamon biofilmiprosessin stabiiliutta ja mikrobitoiminnan palautumista ennalleen pysäytysjakson jälkeen. Työssä seurattiin erityisesti prosessin nitrifikaation ja typenpoiston tehokkuutta. Aluksi prosessin stabiiliutta tarkasteltiin ns. normaaliajossa puolen vuoden ajan, jonka jälkeen jätevesisyöttö keskeytettiin kolmen kuukauden ajaksi. Normaaliajossa ja pysäytysjakson jälkeen prosessin tilaa ja mikrobitoiminnan käynnistymistä seurattiin näytteenotoin ja analyysein sekä tulevasta että lähtevästä, puhdistetusta jätevedestä. Seurattavia parametreja olivat biologisen ja kemiallisen hapenkulutuksen, kokonaistypen ja – fosforin ja ammoniumtypen vähenemä, nitraattitypen pitoisuus ulosvirtaavasta vedestä sekä veden pH ja lämpötila.

Työn toimeksiantaja oli pienpuhdistamoja valmistava Clewer Oy, joka on kehittänyt biologisen Rotating Biofilm Bed Reactor (RBBR) -puhdistusprosessin jätevesille. Prosessi perustuu kantoaineteknologiaan, jossa mikrobikasvusto toimii kantoaineen pinnalla. Puhdistusprosessia testattiin Suomenojan tutkimusasemalla Espoossa. Pienpuhdistamoille asetettuja puhdistus- ja toimivuusvaatimuksia tarkasteltiin hajajätevesiasetuksen (542/2003) ja CEN-standardin (SFS-EN 12566-3) näkökulmista. Työ osoitti, että RBBR -prosessin mikrobitoiminta palautui alle viikossa ennalleen kolmen kuukauden pysäytysjakson jälkeen ja prosessin puhdistustulokset vastasivat asetuksen 542/2003 vaatimuksia.

Avainsanat Jätevesi, nitrifikaatio, biofilmiprosessi, pienpuhdistamot, RBBR.

Sivut 52 s. + liitteet 4 s.

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1 INTRODUCTION

Over 80 percent of Finnish people live in a centered district of sewerage and wastewater purification. This means that wastewaters are treated in centralized biological-chemical purification treatment plants. The remaining 20 percent of the people live in rural areas where small scale wastewater treatment systems are needed. A new government decree concerning wastewater treatment in areas outside sewer networks will come into effect on 1.1.2014. The ordinance demands better purification levels than what the old settling wells can achieve. Many households will have to meet these demands during the upcoming four years, either by building a new wastewater treatment system or renewing the old ones.

In case a household does not have the opportunity to join municipal sewerage, the option is to get a small scale sewage treatment system in their yard. Currently there are about 30 small scale sewage treatment systems for wastewater on the market. Most of them are based on the biological active sludge method. One example of the latest technologies is the so called carrier process. In this process bacteria do not grow freely in suspension as in active sludge processes, but they are attached to a suitable carrier material. Remarkably fast decomposition of organic matter and impurities in wastewater has been achieved with this method. The carrier process is especially applied to reduction of nitrogen in wastewaters.

The aim of this thesis was to examine how the nitrification and stability in a biofilm process will recover after a shutdown period of three months. The work was done during winter 2009 and spring/summer 2010. The experimental part of this project was done in Suomenoja research centre in Espoo with pilot equipment. Information about the functioning and condition of the process was studied with the help of samplings and analyses. The organic matter, ammonium-nitrogen, pH, total nitrogen and total phosphorus contents of wastewater were followed before and after the purification treatment.

The biofilm process was running until a steady and certain level of purification was reached. After that the process was stopped. The process was shut down for three months and then run again to full action. The state of the purification process was followed over time and demonstrated with graphics.

2 CLEWER LTD.

2.1 Company

The client of this thesis was Clewer Ltd located in Riihimäki. The company`s founder and Managing Director is Esa Mäkinen. Clewer Ltd. is a subsidiary of the parent company Pineline Group, which was founded in 1987. Since 1994 Pipeline has conducted biological and chemical research in the areas of water treatment methods. Pipeline has developed an innovative water treatment method successfully used in industrial solutions since 1995. The method can be used to clean landfill runoff water, chlorinated swimming pool water, dirty water from carwashes, and poisons of various industrial processes.

Clewer Ltd. has developed an effective and environmental-friendly purification method for wastewaters. This horizontal small scale treatment plant is known to improve the purification effectiveness so that the energy consumption is even 90 percent less than vertical purifiers on the market. Other benefits of Clewer process are higher filling level and more efficient water treatment. In Clewer horizontal treatment plants the carrier technology is used. Together with Clewer® Biofilm and Clewer® Nutrient technologies they form a very effective biological water treatment system.

Because the carriers in Clewer's treatment plants are in constant movement, the sludge does not accumulate inside the bioreactor. The sludge exits the system with water and can be removed with a clarifier or other corresponding technology.

2.2 Rotating Bed Biofilm Reactor

The wastewater treatment system by Clewer uses carrier technology, as mentioned above. In addition, the Clewer technology represents the so called bed process, i.e. the carrier material with microbes form a moving bed. The bed can be bubbling, circulating, or as here, rotating. In a traditional moving-bed process, either bubbling or circulating, bubbles move directly up from the aerator. In Clewer's Rotating Bed Biofilm Reactor, RBBR, only a fraction of the air bubbles exit the reactor immediately, instead the bubbles attach themselves to the plastic carriers and continue to revolve inside the reactor. This results in more efficient aeration with low energy consumption. Bubbles that remain inside the bioreactor eventually attach themselves to the carrier and begin to revolve around, feeding the carriers with oxygen. The bubbles also travel to the centre of the bioreactor bringing oxygen there as well. In oxygen-demanding applications, such as decreasing high BOD levels, different membrane or micro bubble technologies can be included or added for even better aeration. (Clewer Oy 2009)

RBBR is a centrifuge container (Figure 1) in which plastic media is added to support the biological layer. Low-power air pumps are used to feed water into the bioreactor, activating the plastic media, in which they come into contact with the wastewater (using different bacteria for different types of effluent) and the bacteria disperse the pollutants.

FIGURE 1 *RBBR technology by Clewer. (Fortuny Aqua 2009)*

2.3 Clewer Always Ready process

The Clewer Always Ready 800 process (Figure 2) is based on centrifugal force technology. The centrifugal force allows for a completely maintenance free process where sludge is concerned. Due to the centrifugal force, the process cleans itself and forces the sludge to stay in the sludge tank. The Clewer Always Ready horizontal treatment plant does not need to be emptied for long periods of time because the waste water tank fills with suspended matter only, as the purified water exits the system. (Clewer Oy 2009)

These treatment plants are activated with the help of Clewer STARTUP Universal enzymes combined with clean plastic carriers. These enzymes start up the microbiological process in bioreactors. Microbes create a powerful biofilm on the carrier’s surface. Enzymes effectively remove soaps and nitrogen and organic loading from the wastewater. (Clewer 2009)

The wastewater flows through four parts of a biological unit during the treatment process. Each part holds its own special bacteria, which treat specific pollutants such as phosphorus, nitrogen and organic matter. The organic load of wastewater is reduced with biological degradation. Phosphorus load is reduced by binding the phosphorus with a chemical precipitant and nitrogen load of wastewater is reduced with a biological nitrification process. Bacteria are attached to the carriers. In this way the bacteria remain abundant and they are not flushed along with the sewage with sudden changes in the load. Thus the biological treatment plant remains operating in all conditions. (Clewer 2010)

FIGURE 2 *Clewer 800 process. In addition to the biological part shown in the picture, the treatment plant includes a septic tank (5m3) (Clewer 2009).*

Clewer Always Ready 800 purification system is installed underground (Figure 3). It works efficiently even in large households. All of the household's wastewater can be directed into the purification system and it does not need any filter beds. The purification process is based on the utilization of microbe populations, which are isolated from nature and which break down harmful compounds. (Clewer 2009) The Clewer 800 treatment plant is made from PE/PP plastic by a conventional rotational molding system. It contains pumps, PLC (automation system), compressors, a control panel and other systems that guarantee the perfect purification of wastewater in single family homes and small communities that are not connected to the general sewage system. (Fortuny Aqua 2009)

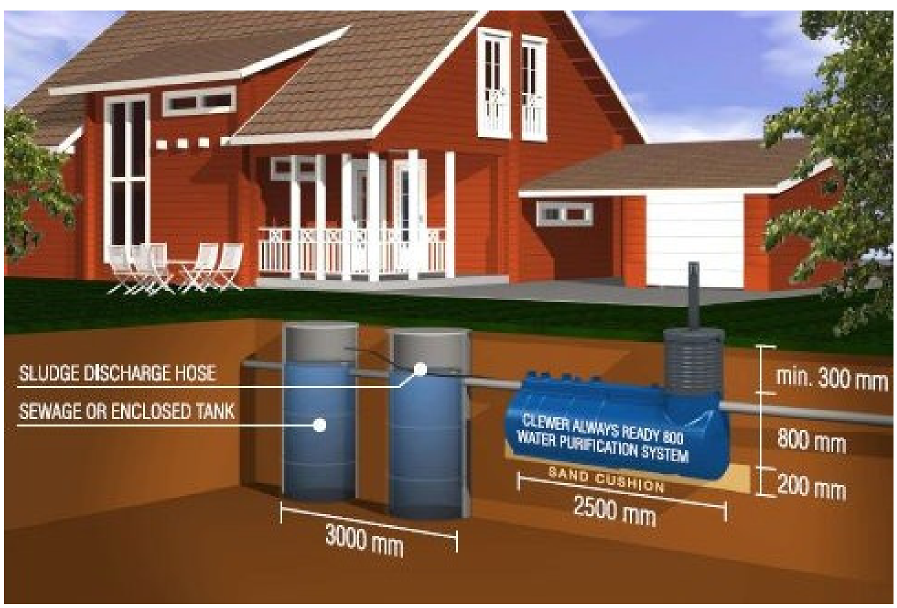

FIGURE 3 *Installation picture of Clewer 800 model (Clewer 2009).*

Clewer 800 treatment plant:
- installed underground, 800 mm (diameter) x 2500 mm (length) sized treatment plant
- gross profit 1050 liters/day
- suited for 1-7 persons household
- electricity consumption 65 W

The normal use and maintenance operations of the Clewer Always Ready 800 wastewater treatment plant are removal of sludge, addition of a precipitating chemical and regular monitoring of the plant's operations by observing the control station monitor, indicator lights and pumps.

The treatment plant includes a 30-litre tank for the precipitating chemical. During the EN testing in SYKE, the average consumption of the chemical was 0.181 l/m^3. The septic tank was emptied once during the test, after about 8 months` operation time. The electrical equipment of the Clewer 800 wastewater treatment plant includes two air fans and four pumps (recycling, extraction, surface sludge and chemical pumps). With the test flow (1200 l/day), the treatment plant used 3.77 kWh/day on average, which means that the annual electricity consumption is about 1 376 kWh. (Vilpas 2010).

2.4 Test results for Clewer 800 process

Test results shown in Table 1 have been achieved using Clewer Always Ready process in wastewater treatment. The water temperature was 6,5 °C, which was the same as the ground temperature at the time. This test was done by Clewer Ltd.

TABLE 1 *Purification effectiveness of Clewer 800 process (Clewer 2009).*

	BOD_7	**N total**	**P total**
Clewer 800 process	99 %	71 %	97 %

The Finnish Environment Institute (SYKE) has carried out preliminary testing of the Clewer wastewater treatment plant in accordance with the standard CEN 12566-3:2005 including tests in accordance with Annexes A (water tightness) and B (treatment efficiency). The CEN testing results obtained by SYKE are presented in Appendix 2.

3 THE GOVERNMENT DECREE ON TREATING DOMESTIC WASTEWATER IN AREAS OUTSIDE SEWER NETWORKS (542/2003)

The decree on treating domestic wastewaters in areas outside sewer networks came into effect on 1.1.2004 and it is ordained to project the lake system from wastewater load caused by rural areas. Besides households the decree concerns summer cottages. This decree contains the minimum requirements for domestic wastewater treatments and it also forbids the release of non-purified domestic water into nature. New properties must build purification or recovery equipments for wastewater, a decanting tank, small scale treatment plant or leaching bed. Old households that are outside of centered district of sewerage have to arrange their wastewater purification so that complies with ordinance at the latest in 31.12.2013.

The decree has a minimum purification requirement for small scale treatment plants` organic matter, the reduction of which must be at least 90 % compared to non-purified wastewater, total phosphorus (reduction at least 85 %) and total nitrogen (reduction at least 40 %). (Finlex, 2010)

When comparing the requirements for small scale wastewater treatment plants, the government decree (542/2003) requires purification effectiveness results from small scale treatment plants, contrary to CEN standard that requires only that the CEN testing for small scale treatment plants is done by the standard. One must also take into account that purification reductions reported in the CE mark are not directly comparable to purification requirements in the government decree 542/2003. In the decree the reduction percentage values are calculated from average load values, whereas reduction percentage values in the CE mark are calculated from test analysis results. (Suomen Ympäristökeskus, 2010)

The government decree 542/2003 does not list the right technology for small scale treatment plants, but only determines purification requirements in percentage, therefore no maximum concentrations are determined.

3.1 Mitigated and tightened purification requirements in municipalities

Municipalities have the possibility to tighten their purification requirements, based on the environmental legislation or special needs. Usually these special needs relate to areas that are next to water supplies, ground water areas, sensitive riparian areas or valuable recreational areas. Municipalities also have the right to mitigate the purification requirements. Generally the mitigated requirements are used outside riparian and densely populated areas, where the wastewater load is low. (Koskinen, 2008)

Table 2 shows the normal and mitigated wastewater purification requirements of the government decree 542/2003.

TABLE 2 *The reduction requirements for wastewaters in areas outside sewer networks. (Kujala-Räty 2005)*

Parameter	**P total**		**N total**		**BOD_7**	
District	A	B	A	B	A	B
Reduction requirement (%)	85	70	40	30	90	80
Incoming load (g/person/day)	2,2	2,2	14	14	50	50
Maximum emission to environment (g/person/day)	0,33	0,66	8,4	9,8	5	10
Incoming concentration (mg/l)	20	20	127	127	455	455
Outgoing concentration (mg/l)	3	6	76	89	45	91

District A = general requirements of the decree.
(Decree 542/2003, 4§, the first moment)

District B = mitigated requirements given by the environmental protection regulation of municipality
(Decree 542/2003, 4§, the second moment) (Kujala-Räty 2005)

3.2 Responsibilities

The designer of the wastewater treatment system is responsible that the household has a proper treatment system suitable for their purposes and that it is designed accordingly to the requirements. The property owner and the site supervisor are responsible that the treatment system is built according to plan. Proper use and maintenance of the treatment system are also the responsibility of the property owners. In the end, property owners are always primarily responsible that the wastewater treatment system of their property is designed and built according to the requirements.

The building authority of the municipalities approves construction plans for wastewater treatment systems in context of building licence. The building authority also assesses whether the treatment system designers are qualified enough and whether the planned treatment system fulfils the requirements of the decree 542/2003. In addition, the building authority also ensures that treatment systems in new properties are built according to plan.

The environmental protection authority of the municipality supervises the state of the environment and observance of the decree 542/2003. In addition, the environmental protection authority can interfere with observed negligence.

The municipality is responsible for the overall development of the district`s water supply and sewerage and for its regional general planning. The municipality also establishes a water supply and sewerage development plan in co-ordination with water supply and sewerage plant. (Pohjois-Pohjanmaan Ympäristökeskus 2007)

4 CEN STANDARD, TESTING AND CE MARKING

Finnish Environment Institute (SYKE) is an institute for environmental research and development. It studies phenomena that are related to changes in the environment and searches for answers to control the changes. It is also responsible for certain administrative tasks. SYKE produces useful data on the state of the environment in Finland, including significant environmental trends and the factors behind them, and it estimates alternative future trends and develops solutions to promote sustainable development. SYKE compiles processes and publish a wide range of environmental data, while meeting Finland's reporting obligations under the European Union`s environmental legislation and other international agreements. SYKE is also responsible for various aspects of water resource management and use in Finland.

SYKE is the official testing institute for small scale wastewater treatment plants. These tests are done according to CEN 12566-3:2005 standard, which is published in Finland as SFS-EN 12566-3: Small Wastewater Treatment Systems up to 50 PT – Part 3: Packaged and/or site assembled domestic wastewater treatment plants. Treatment plants tested in SYKE are factory-made and/or installed on the spot, manufactured from concrete, steel, plastic (PE, PP, PVC) or fibreglass material, installed into the ground and capable of processing all domestic wastewaters. SYKE testing is not for small scale treatment plants that process only sanitary water. This testing is suitable for various processes. (Suomen Ympäristökeskus 2009)

4.1 Testing according to standard CEN 12566-3

Two tests that are required by product standard CEN 12566-3 and made by SYKE are water tightness and purification effectiveness. Structural features are tested by Technical Research Centre of Finland, VTT. The testing is paid by the manufacturer and the test results are always confidential.

Purification effectiveness testing is done as follows; quality requirements are set to incoming wastewater and the test is followed by BOD/COD, nitrogen, phosphorus and solid analyses. Daily flow must follow a certain scheme and testing is done with different circumstances: normal, subload, overload, possible vacations (usually two weeks` period) and power cut (usually 24 h). (Santala 2009)

Compulsory testing parameters are:

- COD
- BOD
- suspended solids
- wastewater temperature
- energy consumption
- daily flow

National requirements are:

- pH
- electrical conductivity
- nitrogen parametres
- total phosphorus
- flow per hour
- solubility of oxygen
- sludge profit
- air temperature

As a result of testing the reduction effectiveness of BOD, COD, SS, phosphorous and total nitrogen are reported. The reductions are based on the analysis results of incoming and outgoing wastewater. The reductions are compared with the requirements set by the government decree 542/2003 (see chapter 3). In Finland one must only use purifiers that fulfil the requirement of the decree. (Santala 2009)

4.2 CE marking

CE marking has been available for small scale wastewater treatment plants since 1.11.2005. The period of transition lasted until 31.7.2008. After that the validity of small scale wastewater treatment plants has no longer been possible to indicate with national standards. In practice this means that all small scale wastewater treatment plants which are marketed overseas must have CE marking (Figure 4).

The CE marking tells the customers that the treatment plant fulfils the qualification approval that the CEN product standard 12566-3 requires. The testing with CEN product standard and the government decree on treating domestic wastewater in outside areas are two totally different things. They both have their own requirements.

The manufacturer of small scale wastewater treatment plants can attach the CE mark when the product fulfils the requirements of the CEN product standard. The purification effectiveness and water tightness testing that SYKE does to these small wastewater treatment plants are just one part of the requirements in the standard. In the CEN product standard there are no demands or limit values for the purification effectiveness and so the manufacturer can attach the CE mark even if the purification effectiveness values are below the limits that are shown in the government decree (542/2003). It is enough that the treatment plant is tested according to CEN standard. SYKE does not give CE markings because the responsibility is on the manufacturer, they only do the CEN tests. Products with CE mark are good for sale in the European economic zone. The CE mark certifies that a product has met EU consumer safety, health or environmental requirements. (Suomen Ympäristökeskus 2009)

CE	
"Company info" **09**	
EN 12566-3	
"The name of the treatment plant"	
Organic daily load:	x kg BOD/d
Hydraulic daily load:	1,2 m3/d
Material:	PE
Watertightness:	Approved
Breaking resistance:	Approved
Purification effectiveness:	COD: 90 %
	BOD 88 %
	SS: 85 %
Electricity consumption:	2,1 kWh/d
Total phosphorus:	86 %
Total nitrogen:	53 %
Temperature:	12 °C

FIGURE 4 *CE marking. (Suomen Ympäristökeskus 2010)*

Currently the government decree on treating domestic wastewater in areas outside sewer networks affects the CE mark testing in the way that the small treatment plants sold in Finland must have the purification effectiveness values also for total nitrogen and total phosphorus along with the purification effectiveness for organic matter (chemical oxygen demand and biological oxygen demand).

CE testing is one of the ways to estimate the functionality of the treatment plant conformable to the government decree. Along with the purification effectiveness during the estimation one should also take into account the emissions that get into the environment. The purification effectiveness (%) from the testing varies between the treatment plants because the incoming wastewater load is different in different places. (Suomen Ympäristökeskus 2009)

Small wastewater treatment plants are construction products so the directive 89/106/ETY (Construction Products Directive) must also be taken into account.

5 SMALL SCALE SEWAGE TREATMENT PLANT

When processing smaller amounts of wastewater the treatment processes are similar to the processes used in large scale wastewater treatment plants. In practice, small scale treatment plants are usually just implemented more simply and single lined. Purification of waste water can be more difficult in small scale treatment plants because of the variation of wastewater load and quality (Kujala-Räty 2005).

Small scale sewage treatment plants are factory-made treatment systems for household wastewaters. Wastewater purification is based on biological processes where the bacteria and other microbes decompose organic matter. The phosphorus in wastewater is usually precipitated by chemicals.

Most types of the small scale sewage treatment plants achieve good purification results if the treatment of the system is professional and regular. If the treatment system is not handled properly, the purification results are the same as in old settling wells. Many of the small scale sewage treatment plants are more sensitive to disturbances than e.g. buried sand filters but they require less space. Each small scale sewage treatment plant has its own structural features, installation instructions and different purification effectiveness. (Nurmijärven kunta 2009)

When choosing a small scale sewage treatment system, the following things must be considered:

- aim and demand for purification
- wastewater load
- need of consultant in maintenance
- building and operation costs
- necessity and possibility of mechanical care

Also when choosing the location for a small scale sewage treatment plant, the following things must be taken into account:

- need for pumping
- location of the emptying point
- electricity and water pipe connections
- location of the roads near by
- safe distance of the water intake
- possible smell and noise impacts

The most efficient way of wastewater purification with a small scale sewage treatment plant is to use both treatment processes; biological and chemical purification. Usually this means using active sludge process or biofilm, and precipitation of phosphorus. Using only a biological treatment plant, one cannot meet the basic demands that the ordinance for domestic wastewater requires for nutrient removal. At the same time the use of chemical purification alone does not fulfil the purification requirements for organic matter. (Nurmijärven kunta 2009) In the following chapter small scale biological treatment processes are presented in detail.

6 BIOLOGICAL SEWAGE TREATMENT PROCESSES

The main purpose of biological processes in wastewater treatment is removal of organic material, nitrification and denitrification, removal of phosphorus and nitrogen and making the composed sludge harmless and useful. Two important requirements for successful aerobic biological processes are fulfilling the need for nutrients and oxygen. Other important factors are water temperature, pH value and possible toxic compounds. (Alander 2007)

For households in rural areas there are many alternative processes of small scale treatment plants for wastewater treatment. Small scale treatment plants can be designed for one family or even 100 persons` use, in which case the flow dimensioning is between 1 and 20 m^3/day. When treatment plants are designed for over 100 persons and the wastewater flow gets higher, one must normally use a biological rotating container or active sludge treatment plant. Purification processes are mainly based on batch treatment and biological filtering. (Saralehto 2004.)

The state of a biological process can be estimated based, among other things, on its odour. Usually a well working biological purification process smells slightly stale, not necessarily bad. However, if the odour gets really bad it can be a sign that the degradation process does not have enough oxygen to use. Reducing concentrations in wastewaters is one of the important functions of treatment plants but equally important is the decreasing of harmful environmental effects, like bad odours. The appearance of purified wastewater is normally clear or slightly coloured; with the colour varying from yellow to brown. It can also be bleary grey. The colour can also be one of the indicators when studying purification level, although only chemical analyses from wastewater tell the exact state of the process. A small scale treatment plant works biologically only if it gets enough oxygen, i.e. aerobic process. Ventilation should be installed so that it works properly. (Kujala-Räty 2005)

6.1 Active sludge processes

The active sludge process, seen in Figure 5, is the most common biological method in municipal wastewater treatment plants and also in rural areas in small scale treatment plants. The microbe mass is suspended in water and creates a so called activated sludge. Biological purification utilizes microbes’ ability to degrade organic matter.

The process in purification plants consists of active sludge pool/aeration pool where the wastewater and the microbes are being mixed continuously. Active sludge processes are aerobic, i.e. the sludge-wastewater mixture is being aerated. The air is blown into the pool in small bubbles. This ensures sufficient oxygen supply and proper mixing (Kuokkanen 2008; Pleym 1991, 224). Influent wastewater or more usually settled wastewater is aerated for a period of 6 to 10 hours. During the aeration the microorganisms in the wastewater multiply by assimilating part of the influent organic matter.

In this process, part of the organic matter is synthesized into new cells and part is oxidized to derive energy (Srinivas 2008, 76).

Mixing is important so that the sludge will not descend into the lower part of the pool. After the aeration pool there is a secondary sedimentation pool, where the purified water and microbe mass are separated. In this point the sludge can descend and part of the sludge flows back to the aeration pool so that the decomposition of the organic matter would be more effective. (Kuokkanen 2008; Pleym 1991, 224.) The activation of the process usually takes a couple of weeks but it can be speeded up with active sludge from another purification plant (Kujala-Räty, Mattila, Santala 2008, 83).

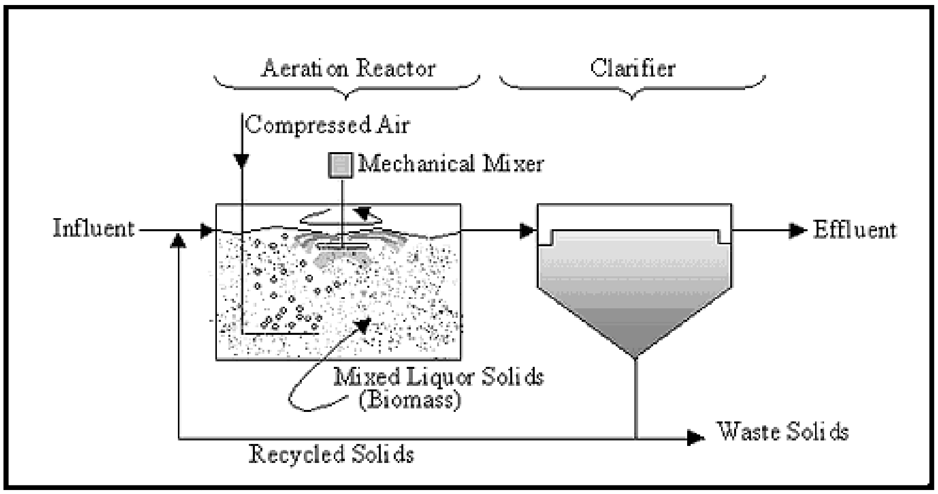

FIGURE 5 *A general picture of the active sludge process (Ayoub 2000).*

The majority of small scale active sludge processes on the market are based on batch treatment. In batch treatment plants wastewater is treated by batches (portions) and a separate settling pool will not be needed. A certain amount of wastewater is pumped into the process reactor where the aeration comes from the bottom of the reactor. During oxidation the organic matter that uses oxygen degrades. After aeration a chemical precipitant is fed into the process to precipitate the phosphorus in the wastewater. The final stage in the active sludge process is an anaerobic settlement (denitrification) where nitrogen can be removed from the wastewater and it evaporates into the atmosphere as N_2. From the clarified surface of the container, purified wastewater is pumped into the ground. There is always active sludge with necessary microbes in a container. Surplus sludge is constantly removed from the process. A batch treatment plant includes automation, pumps, a compressor and also a container for the chemicals. All of these require constant maintenance. (Saralehto 2004).

Uponor 7 is an example of a typical small scale batch type active sludge process. It is composed of three 1m^3-sized polythene containers (Figure 6). The wastewater is first clarified in two primary settling tanks, after which it is pumped by batches to the third tank, which is the process tank. The process tank includes aeration, clarification and pumping the clarified water into a discharge pipe. During the aeration the precipitant chemical is pumped into the process. Part of the active sludge is pumped back to the settling tank, when the other part stays in the process tank and is mixed with the next batch of wastewater. From time to time the active sludge is removed through the primary settling tank. The organic load of wastewater is decreased by biological decomposition. The phosphorus load is reduced with the help of chemical precipitant and nitrogen is bound to the sludge. (Suomen Ympäristökeskus 2009)

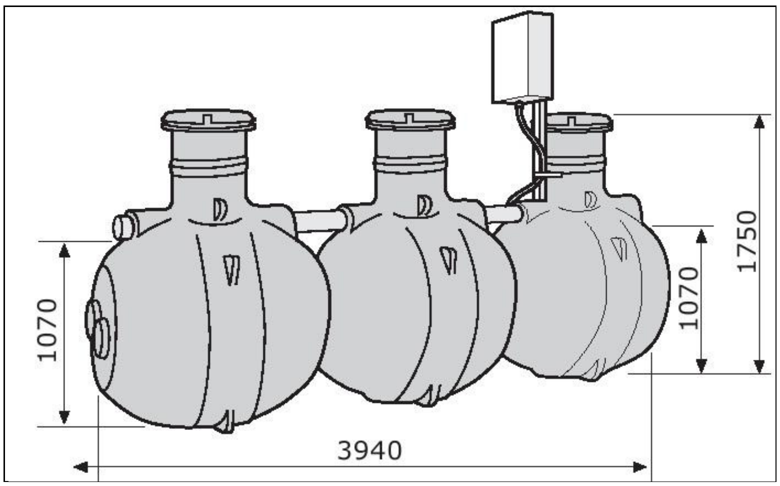

FIGURE 6 *Uponor 7, the batch treatment plant. (Suomen Sakokaivo 2007)*

Uponor 7 is installed underground as usual, but it can also be installed partly above the ground. The treatment plant is designed for 1-7 persons. (Suomen Ympäristökeskus, 2009)

Standard CEN 12566-3 test results in Table 3, show the purification effectiveness for wastewater in Uponor 7 process. The results are average values from analysed samples.

TABLE 3 *Purification effectiveness of Uponor 7 process. (Suomen Ympäristökeskus, 2009)*

	BOD_7	**P total**	**N total**
Uponor 7	98 %	96 %	50 %

6.2 Biofilm processes

The major part of the microbes in biofilm processes live attached to a carrier/substrate material. Biofilm reactors with substrate carriers represent a novel technology. Rotating Biological Contactors (RBC) and Trickling Bio Filters (TBF) are the most well-known processes in biofilm technology. In the biofilm process each process segment has its own biomass attached to the carriers selected for a certain purification task. Therefore e.g. the segment that carries out nitrification has a lot of nitrification bacteria. (Huhtamäki 2007)

6.2.1 Rotating Biological Contactor (RBC)

A rotating biological contactor is a horizontal, cylinder shaped device used in the secondary treatment of wastewater. Secondary wastewater treatment is the second stage of wastewater treatment that takes place after the primary treatment process. RBC technology allows wastewater to come into contact with a biological medium in order to facilitate the removal of contaminants. The forming of biomass is based on this rotating movement where the contactor is in contact with air and wastewater by turns. There are several different designs available, but in its simplest form RBC consists of a series of discs mounted on a shaft, which is driven so that the discs rotate at right angles to the flow of settled sewage (Figure 7).

The discs are usually made of plastic (polythene, PVC, expanded polystyrene) and are contained in a trough so that about 40 percent of their area is immersed. The discs are arranged in groups or packs with baffles between each group to minimize surging or short-circuiting. With small units the trough is covered and large units are often housed within buildings. This is to reduce the effect of weather on the active biofilm which becomes attached to the disc surfaces. Depending on the wastewater load these contactors can be installed concurrently or one after the other. Usually wastewater is recycled into RBC from the beginning or end of the settling pool. Chemical treatment is added into the process by using the co-precipitation or post-precipitation. RBC consumes less energy than an active sludge process and it is assumed to endure biotoxics better. (Kujala-Räty 2005)

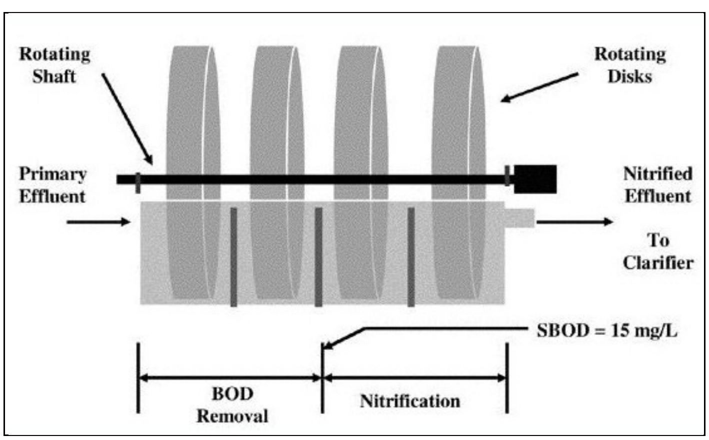

FIGURE 7 *Rotating biofilm contactor scheme (McGraw-Hill 2005, 63).*

Klargester BioDisc® treatment plant is an example of RBC processes (Figure 8). Its operational principle is very simple. Wastewater is clarified in a separate tank, from where it is moved into a two-stage biological rotating contactor and after that into secondary sedimentation. The biomass that is formed into the rotating biological contactor purifies the wastewater from pollutants. Precipitation of phosphorus is done by PAX chemical. There are only three electronic devices in BioDisc: the motor that rolls the discs, dosing pump for chemicals and a sensor that drives the dosing pump. (Klargester 2009)

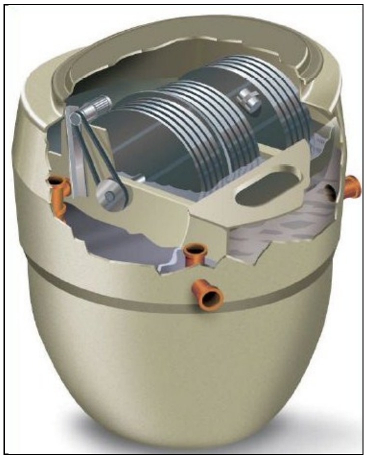

FIGURE 8 *BioDisc®, Rotating Biological Container from Klargester. (Klargester 2009)*

BioDisc treatment plant is tested accordance with the standard CEN 12566-3. The results are shown in Table 4.

TABLE 4 *Purification effectiveness results for Klargester BioDisc. (Klargester, 2010)*

	BOD_7	**COD**	**P total**	**N total**	**SS**	**NH_4**
Klargester, BioDisc	93 %	87 %	90 %	49 %	90 %	63 %

6.2.2 Trickling Biological Filter (TBF)

Trickling biological filter treatment plants are small scale factory-made treatment plants, where the purification is based on biofilm that forms, from the wastewater`s own microbe trait, onto the surface of the filter. The material of biodiscs varies depending on the model and size of the treatment plant. Usually there is also a chemical precipitant process for phosphorous along with the trickling filter process and that is why this process is well comparable to batch treatment processes. (Niemi, Myllyvirta 2007)

Trickling filters are used to remove organic matter from wastewater. It is an aerobic treatment system that utilizes micro-organisms attached to a medium to remove organic matter from wastewater (Figure 9).

This type of system is common to a number of technologies such as rotating biological contactors and packed bed reactors (biotowers). The trickling filter consists of a bed of highly permeable medium to which micro-organisms are attached and through which wastewater is percolated or trickled. The liquid wastewater is distributed over the top of the bed by a rotary distributor as sprays. The wastewater trickling from the top comes into contact with the biological medium and gets rid of its nutrients. Filters are constructed with an underdrain system for collecting the purified wastewater and biological solids detached from the medium. The underdrain system is important both as a collection unit and as a porous structure through which air can circulate. The collected liquid is passed to a settling tank where the solids are separated from the purified wastewater. Trickling filters enable organic material in the wastewater to be absorbed by a population of micro-organisms attached to the medium as a biological film or slime layer. As the wastewater comes into contact with the medium, micro-organisms of the wastewater attach themselves to the plastic surface to form a film. The organic material is then decomposed by the aerobic micro-organisms in the outer part of the biological layer. (Srinivas 2008)

The common problem in these processes is the non-uniform trickling into filters. The trickling can be directed only to a small part of the filter, in which case the maximum purification effectiveness is not reached. Also the micro-organism on the surface of the filter die rapidly if constant water flow/trickling is not available. (Niemi, Myllyvirta 2007)

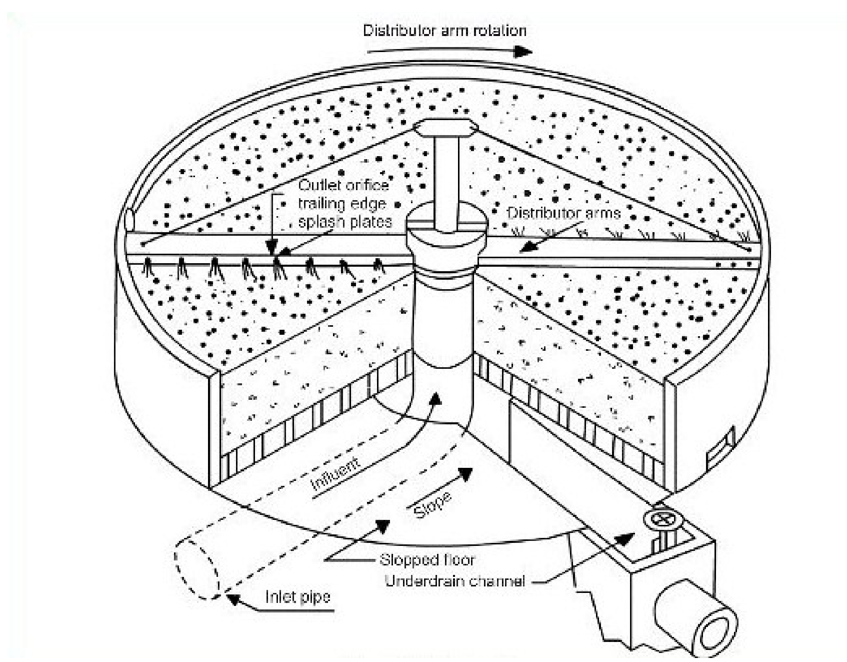

FIGURE 9 *Trickling filter process (Srinivas 2008).*

Bioclere® is an example of a biological wastewater treatment plant with biofilters. The system copes with small to medium amounts of wastewater, from single-family homes to sites with a population of up to 2000 people.

The treatment process comprises a septic tank for mechanical separation and a Bioclere® biofilter unit for biological treatment process (Figure 10). As wastewater trickles through the biological filter medium, organic material is transformed into biomass, which grows on the surface of the plastic Hufo® filtermedium. Treated effluent is separated from the biomass in the clarifier and can be discharged to the soil or surface waters. Supplementary stages can be added to provide fully nitrified final effluent or phosphate removal. (Bioclere 2010)

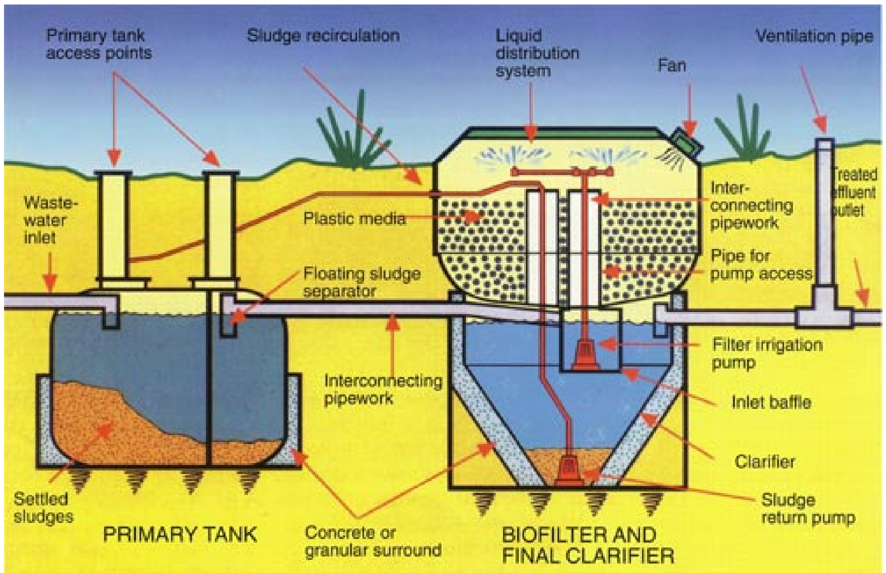

FIGURE 10 *Bioclere® process (Bioclere 2010).*

6.2.3 Activated bio-filter (ABF)

The activated bio-filter is a recent innovation in the biological treatment field. The ABF is a treatment process combining a trickling filter with an activated sludge system. ABF consists of the series combination of an aerobic column (bio-cell) with wood or other packing material, followed by an activated sludge aeration tank and secondary clarifier. Settled sludge from the clarifier is recycled to the top of the column. In addition the mixture of wastewater and recycled sludge passing through the column is also recycled around the column in a similar manner to a high rate trickling filter. No intermedium clarifier is utilized. Forward flow passes directly from the column discharge to the aeration tank. The use of the two forms of biological treatment combines the effects of both fixed and suspended growth processes in one system. (Wang, Hung, Shammas 2009, 632-633.)

The micro-organisms formed in the fixed growth phase are passed along to the suspended growth unit, where the suspended growth micro-organisms are recycled to the top of the fixed media unit. This combination of the two processes results in the formation of a highly stable system which has excellent performance and good settling biological flock when treating wastewaters that have variable loads. (Wang, Hung, Shammas 2009, 632-633.)

6.3 Plastic biocarriers

The biocarrier design is critical due to requirements for good mass transfer of substrate and oxygen to the micro-organisms. There are several manufacturers of this type of carriers. Although they each have their own specific dimensions, they each loosely resemble a “wagon wheel” (Figure 11 and 12). The biomass grows on the surface but is abraded from the outside surface of the carrier, leaving the active biomass on the inside of the wheel. (McGraw-Hill 2005, 90-91.)

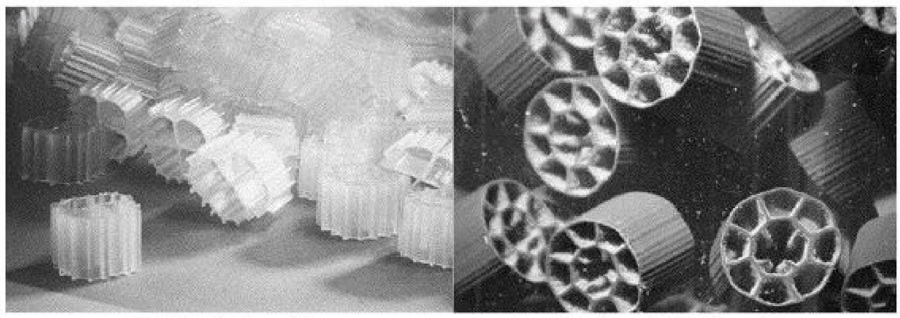

FIGURE 11 *Examples of different plastic carriers. (McGraw-Hill 2005, 91).*

FIGURE 12 *Plastic carrier by Clewer Ltd.*

During initial installation, the carrier has a tendency to float on the water surface until being thoroughly “wetted” out, although greater airflow into the aeration basin will promote media mixing (Figure 13). Airflow rates may be reduced once the biofilm is established. Depending on the wastewater temperature, the carrier will show signs of performance in two to four weeks from start-up. Foaming can occur during the initial weeks of start-up. During this time, an antifoam chemical may be used to mitigate foaming issues, or, if equipped, the plant may use its foam abatement system. Excessive foaming generally ceases once the microbiology is established. (McGraw-Hill 2005, 96.)

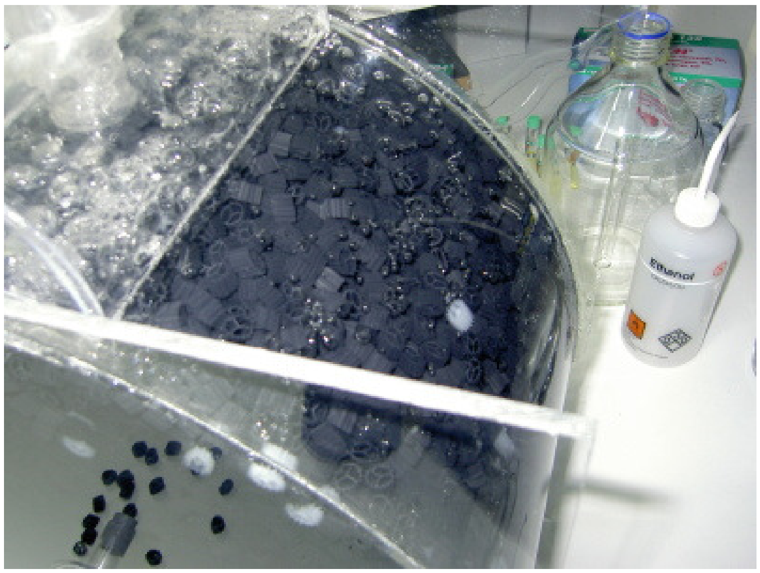

FIGURE 13 *Plastic carriers in action in Clewer RBBR demo system (Clewer 2009).*

7 HARMFUL EFFECTS OF WASTEWATER IN NATURE

Wastewater contains a lot of substances that are harmful to humans and the balance of nature, after getting into the environment. The utmost aim of wastewater treatment is a situation where the quality of purified wastewater which is led into the water system is similar to receiving natural state water. However, in practice the aim is to purify wastewater so that it does not harm human health or the environment`s ecological balance.

7.1 Chemical and biological oxygen demand, COD/BOD

Chemical oxygen demand is the amount of oxygen needed in chemical decomposition of wastewater. It describes the oxygen consumption caused by all organic matter, including slowly decomposing organic compounds. The amount of organic matter in wastewater can be measured by COD or by biological oxygen demand, BOD, which is the amount of oxygen needed in biological decomposition of wastewater. BOD is generally measured over a five-day period. The COD level can be determined more readily than BOD, but this measurement does not indicate how much of the organic matter can be decomposed by biological oxidation.

In nature organic matter in wastewater uses oxygen thus decreasing oxygen supply of fish and other aquatic life. If the oxygen supply runs out, it leads to the end of all organic life, which is hard to recover later on. Oxygen deficiency causes bad smells and decreases the value of water systems. In groundwater, oxygen deficiency causes the dissolving of metals from the ground into the water. (Kujala-Räty 2005)

7.2 Nutrients

7.2.1 Phosphorus, P

Most of the phosphorus in wastewater comes from excrements and detergents. Phosphorus appears as soluble phosphate in wastewater and it is a nutrient that increases the forming of organic matter in nature. This causes eutrophication. The formed matter uses the oxygen supplies of water. In Finland`s water system phosphorus is mainly a so called a minimum nutrient; this means that even a small amount of phosphorus can increase the gross production of vegetation that creates eutrophication. (Kujala-Räty 2005)

7.2.2 Nitrogen, N

Nitrogen comes to wastewater mainly from excrement and urine. When nitrogen leaves the settling well it is in ammonium form. Nitrogen is also a plant nutrient and it appears as a minimum nutrient in most of the European water systems. Organic or ammonium-formed nitrogen uses the oxygen supplies of the water system when oxidized to nitrate. Nitrogen can be transmitted into groundwater by wastewaters and also by fertilizers.

Too much nitrogen in drinking water is dangerous if it forms carcinogenic compounds with chlorine that is used in disinfection of drinking waters. (Kujala-Räty 2005)

7.2.3 Nutrient removal from wastewater

Biological nitrogen removal from wastewaters has for a long time been an everyday operation in most of the wastewater treatment plants. Instead, biological phosphorus removal without precipitant chemical is forthcoming technology. Simultaneous removal of nitrogen and phosphorus is still quite difficult. The biological mechanisms of phosphorus removal and its effects on nitrogen removal are so far unknown. Implementation of biological nutrient removal in Finnish environment is especially challenging because of the average lower temperature of wastewater and low concentration of carbon compounds, which facilitates the removal. The combining of these two nutrient removals in an optimal way affects the size of the treatment plant and therefore also the operating costs get higher. (Järvinen 2003)

7.3 Suspended solids, SS

Suspended solid in receiving water accumulates into sludge blankets and increases turbidity of water. Sludge blankets are substrate to organisms that consume oxygen. Turbidity debases the capability of light to permeate water layers, which leads to increased decomposing and decreased oxygen supply. Turbidity also disturbs the disinfection process in waste water treatment plants. (Kujala-Räty 2005)

8 NITRIFICATION AND DENITRIFICATION IN WASTEWATER

The most common forms of nitrogen in wastewater processes are ammonia (NH_3), ammonium ion (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and organic nitrogen. Municipal wastewater primarily contains ammonium and organic nitrogen, whereas some industrial wastewaters contain appreciable amounts of nitrate- nitrogen. In domestic wastewater, approximately 60% of the nitrogen is in the form of ammonium and 40% in an organic form. Organic nitrogen consists of a complex mixture of amino (NH_2^-) compounds, including amino acids and proteins. Organic nitrogen is easily converted to ammonium by bacterial decomposition in a process referred to as ammonification. Hydrolysis of urea transforms organic nitrogen to ammonium. Nitrification is an important part of wastewater purification. It is a microbial process which converts ammonium nitrogen into the form of nitrate. Nitrification is also a part of nitrogen recycling.
(McGraw-Hill 2005, 8-9.)

During nitrification of wastewaters ammonia-nitrogen becomes oxidized to nitrate. The oxidation of ammonia into nitrite and the following oxidation to nitrate are mainly done by two different bacteria. The first step is done by a bacteria genus called *Nitrosomonas*, although other genera, including *Nitrosococcus* and *Nitrosospira* can also oxidize ammonia. The second step (oxidation of nitrite into nitrate) is done by *Nitrobacter*. All organisms are autotrophs, which means that they take carbon dioxide as their carbon source for growth.

In the first step of nitrification, ammonia-oxidizing bacteria oxidize ammonia to nitrite:

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e- \quad (1)$$

In the second step of the nitrification process, nitrite-oxidizing bacteria oxidize nitrite to nitrate:

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e- \quad (2)$$

(Pleym 1991, 223).

Because nitrification does not remove nitrogen from the wastewater, another process is needed for that. The conventional way of nitrogen removal is nitrification followed by denitrification. Denitrification is an anaerobic process that is carried out by denitrifying bacteria, which convert nitrate to nitrogen gas (N_2).

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (3)$$

In the final step nitrogen gas proceeds its way from the water to the atmosphere. (Harrison 2003)

Nitrification usually happens when the retention period (time that the sludge stays in the system) is long enough. A rise in the wastewater temperature will speed up the nitrification (Kujala-Räty 2005). The oxygen demand for complete nitrification is high, so the necessary oxygen supply and power requirements for the system will both be increased. Optimum pH for nitrifying bacteria to grow is in the range of 8 to 9. If the pH levels go below 7 it causes a notable reduction in nitrification activity. (Pleym 1991, 223)

In active sludge process the share of different microbes in sludge is almost constant in different segments of the process, even if their activity depends on e.g. oxygen levels in different segments. Whereas in biofilm processes, each segment of the process, where the biomass is attached to the plastic media, biomass is selected by the conditions of that segment. So e.g. the segment where nitrification is taking place the amount of nitrification bacteria is very voluminous. For that reason nitrification can happen in biofilm processes even if the apparent sludge age is not long enough. (Huhtamäki 2007)

A properly working nitrification may result in:

- low alkalinity
- low pH
- poor settling behavior of sludge
- poor phosphorus reduction

These disadvantages can be avoided by:

- a properly working denitrification treatment, which removes nitrogen well → denitrification returns alkaline process
- adding chemicals, such as lime or soda to increase the alkaline process
- adjusting the conditions (the time of aeration, oxygen) of nitrification so that it will not be depleted. (Rantanen 2008)

Nitrifiers are susceptible to wide changes in the concentration of inhibitory substances but may exhibit only minor effects if these substances are in low concentrations and consistently applied to the system. The nitrifier process can also be affected by heavy metals, including nickel, chromium and copper. (McGraw-Hill 2005, 43.)

8.1 Process requirements

Nitrification in wastewater treatment plants is a sensitive microbiological process, which can be disturbed e.g. by toxic substances, temperature, pH, biomass. Cold temperatures particularly affect nitrification because the organisms responsible for nitrification have slow growth rates. As their growth rates are further reduced at cold temperatures, the solids retention time must be increased to maintain the nitrifiers in the system (McGraw-Hill 2005, 23).

8.1.1 Temperature

The growth rates of *Nitrosomonas* and *Nitrobacter* are particularly sensitive to the liquid temperature in which they live. Nitrification has been shown to occur in wastewater temperatures from 4 to 45 °C, with an optimum growth rate occurring in the temperature range 35 to 42 °C. However, most wastewater treatment plants operate with a temperature between 10 and 25 °C. It is generally recognized that the nitrification rate doubles for every 8 to 10 °C rise in temperature. A number of relationships between maximum nitrifier growth rate (u_n-max) and wastewater temperature have been developed. The most commonly accepted expression for this relationship for wastewater over a temperature range from 5 to 30 °C is the following:

$$u_{n\text{-}max} = 0.47e^{0.098\,(T-15)}$$

where
$u_{n\text{-}max}$ = maximum specific growth rate of micro-organisms (g nitrifiers/g nitrifiers in system · d);
T = wastewater temperature (°C);
°C = (°F-32)/1.8

The relationship between maximum nitrifier growth rate and wastewater temperature is shown graphically in Figure 14. (McGraw-Hill 2005, 41.)

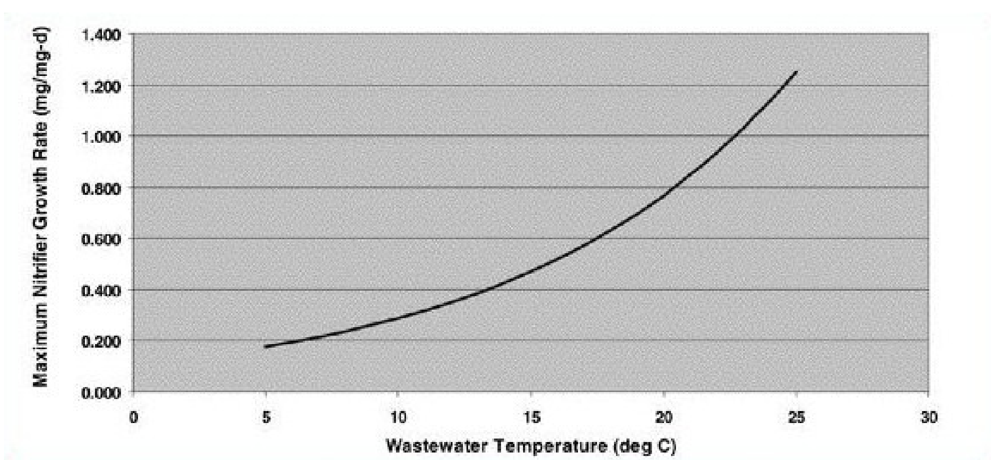

FIGURE 14 *Influence of temperature on nitrification (McGraw-Hill 2005, 42).*

There are two rates for nitrification during the nitrification process; potential nitrification rate and detected nitrification rate.

Potential nitrification rate

- Nitrification rate obtained in optimal conditions. This relates to the highest nitrification rate that the sludge can have in a certain temperature.

Detected nitrification rate

- Nitrification rate which is calculated from analysed or measured concentrations from the process. It is smaller than potential nitrification rate, because the process always has factors (availability of ammonium nitrogen, inhibitor substances from incoming water, pH, oxygen content or organic load) that limit the nitrification rate. (Hostikka, Rantanen 2003)

8.1.2 pH and alkalinity

pH levels in wastewater treatment plants have been shown to have a significant effect on the rate of nitrification. Wide changes in pH have been showed to be injurious to nitrification process, although acclimation generally allows good performance with consistent pH control within the range 6.5 to 8.0 pH units. It is generally recommended that sufficient alkalinity be present through the reactors by maintaining a minimum effluent alkalinity of at least 50 and preferably 100 mg/l. (McGraw-Hill 2005, 42.)

8.1.3 Flow and load variations

If the environmental conditions do not limit the growth of nitrifying organisms, the quantity or mass of *Nitrosomonas* and *Nitrobacter* that grow in the system will be a function of the applied ammonia load. A great variations in wastewater flow and nitrogen load in the system result either a significantly reduced hydraulic retention time (HRT) or increased pollutant load may result in an increase in effluent ammonia. Short HRT systems, such as many fixed-film processes, are more likely to experience this reduction in process efficiency, even during normal daily variations. (McGraw-Hill 2005, 43.)

9 EXPERIMENTAL SYSTEM AND ANALYSES

9.1 Test conditions

The testing was performed at Suomenoja research center in Espoo. The wastewater that comes to Suomenoja for EN testing has to fulfil the qualifications presented in Table 5. (Vilpas 2004) Wastewater with these requirements was used in this project in a pilot biofilm process by Clewer Ltd. The wastewater came from a detached house near Suomenoja, so no industry wastewater was used in this process.

TABLE 5 *Qualification requirements of incoming wastewater in CE testing.*

Parameter	Concentration (mg/l)
BOD_7 (OR)	150 - 500
COD_{Cr}	300 - 1000
Solids, SS	200 - 700
Total nitrogen (OR)	25 - 100
Ammonium nitrogen	22 - 80
Total phosphorus	5 - 20

The Clewer 800 model was used in testing the stability and recovery of microbial activity in a biofilm process. The test flow rate was approximately 1200 litres per day. The biofilm reactor was started on the 2^{nd} of April 2009. Several samples were taken and analyzed from the process before the shutdown period to find out the normal, stable operation results. The influent water flow was stopped for three months (the shutdown period) in March 2010. The water flow was started again in June 2010. Samples for analyses from incoming and outgoing water were taken during the following three weeks after the shutdown to find out the recovery state of the process.

9.2 Biofilm process used in this work

Every Clewer Always Ready 800 treatment plant has four tubular biological units, a clarifier and a technical section. At the beginning of the process, a primary tank is filled with wastewater. The primary sludge settles at the bottom of the septic tank and the rest of the wastewater continues to the biological units for purification. After biological purification, the sludge formed in the process is pumped every 15 minutes back into the septic tank. This creates a rest rotation, which purifies the water in the septic tank. When a new wastewater load comes into the process, an equivalent amount of water overflows from the post-clarifier into the pumping well and is removed with a pump. This pump is used for measuring the flow.

Clewer 800 treatment plant`s operation is intensified with the help of a chemical, the amount of which is controlled based on the wastewater flow rate. The water flow rate is measured from the outgoing water. The dosage of Clewer PAC precipitation chemical was 50 ml per 100 litres of outgoing water. A sensor that measures the rising fluid surface level is used to measure the flow. When the surface reaches a certain line in the buffer tank, 50-100 litres of clean water is pumped out of the process and at the same time a precipitant chemical is pumped into the process.

In case the treatment plant is not fed in three days (no wastewater passes through), it goes into standby position where all the electronic devices (except the control unit) is switched off. Biological units are aerated weekly during the standby position. The process will start working normally when the wastewater flow begins. (Clewer 2010)

9.3 Analyses

In order to get the purification effectiveness determined correctly from the wastewater, it is important to take reliable samples of both incoming and outgoing purified water. This means that the incoming wastewater that comes to the treatment plant and the outgoing water should be the same when taking the samples. Because the retention period of wastewater in treatment plants can be several days, ”catching” the same water into both samples is, in practice, impossible. Therefore the aim can be set to take samples that represent the average quality of wastewater. (Kujala-Räty 2005)

The following statements are the most common used in function evaluation of small scale treatment plants:

- Most of the phosphorus (mg/l) in wastewater comes from excrements and detergents. Phosphorus appears as soluble phosphate in wastewater.

- Nitrogen (mg/l) comes to wastewater from excrement and urine. When nitrogen leaves the settling well it is in an ammonium form.

- Nitrate and nitrite nitrogen (mg/l) can be found in wastewater that leaves the treatment plant, if the purification process has had an oxidation of ammonium-nitrogen. (Kujala-Räty, 2005)

All analyses were done in Clewer laboratory in Riihimäki. The analyses were carried out by HACH LANGE rapid method and measured with Dr. Lange, Lasa 100 equipment.

9.3.1 Nitrate nitrogen, NO_3-N

Determination of nitrate nitrogen from samples was done by HACH LANGE analysis, test number: LCK-339.

Nitrate ions in solution containing sulphuric and phosphoric acids react with 2.6-dimethylphenol to form 4-nitro-2.6-dimethylphenol.

9.3.2 Total nitrogen

Determination of total nitrogen from samples was done by HACH LANGE analysis, test number: LCK-238.

Inorganically and organically bonded nitrogen is oxidized to nitrate by digestion with peroxodisulphate. The nitrate ions react with 2,6-dimethylphenol in a solution of sulphuric and phosphoric acid to form a nitrophenol.

9.3.3 Total phosphorus

Determination of total phosphorus from samples was done by HACH LANGE analysis, test number: LCK-349.

Phosphate ions react with molybdate and antimony ions in an acid solution to form an antimonyl phosphomolybdate complex, which is reduced by ascorbic acid to phosphomolybdenum blue.

9.3.4 Chemical oxygen demand, COD_{Cr}

Determination of COD from samples was done by HACH LANGE analysis, test number: LCK-314.

Oxidizable substances react with sulphuric acid, potassium dichromate solution in the presence of silver sulphate as a catalyst. Chloride is masked by mercury sulphate. The reduction in the yellow coloration of Cr^{6+} is evaluated.

9.3.5 Biological oxygen demand, BOD_7

Determination of BOD_7 from samples was done by HACH LANGE analysis, test number: LCK-555.

The dissolved oxygen is analysed in an alkaline solution with a pyrocatechol derivative in the presence of Fe^{2+}, under which conditions a red dye is formed.

9.3.6 Ammonia nitrogen, NH_4-N

Determination of ammonia nitrogen from samples was done by HACH LANGE analysis, test number: LCK-304.

Ammonium ions react at pH 12,6 with hypochlorite ions and salicylate ions in the presence of sodium nitroprusside as a catalyst to form indophenols blue.

10 RESULTS AND DISCUSSION

The aim of this work was to follow the stability of Clewer Always Ready 800 biofilm process before and after three months` shutdown period. The following analyses were done from the incoming and outgoing water samples:

- COD_{Cr} and BOD_7
- nitrate nitrogen, NO_3-N
- ammonium nitrogen, NH_4-N
- total nitrogen
- total phosphorus
- pH
- temperature

10.1 Normal operation of Clewer process

The period of normal operation of Clewer Always Ready process was carried out during springs 2009 and 2010. This one-year-long period guaranteed a stable and properly working process that gave a good starting point for this study. The collected results from the analyses are seen in Appendix 1.

10.1.1 Reduction of organic matter (COD_{Cr}, BOD_7)

The reduction of COD_{Cr} (Figure 15) and BOD_7 (Figure 16) in wastewater were over 90 % in all analysed wastewater samples. The reduction of BOD_7 correspond to the requirements (90 % reduction) of the government decree 542/2003. The COD_{Cr} reduction percentage of nine samples was 94 % and BOD_7 reduction 96 %. Sample no.3 had the highest BOD_7 and COD_{Cr} concentration. During the sampling of number three, the wastewater load was only 600 litres per day. All the other samples were taken when the wastewater load was 1200 l/d. The average COD_{Cr} concentration of inflow wastewater was 687,3 mg/l and BOD_7 was 312 mg/l. There were no major variations in the outflow`s COD_{Cr} and BOD_7 concentrations, the average concentration was 37,8 mg/l and the standard deviation was 5,9 mg/l.

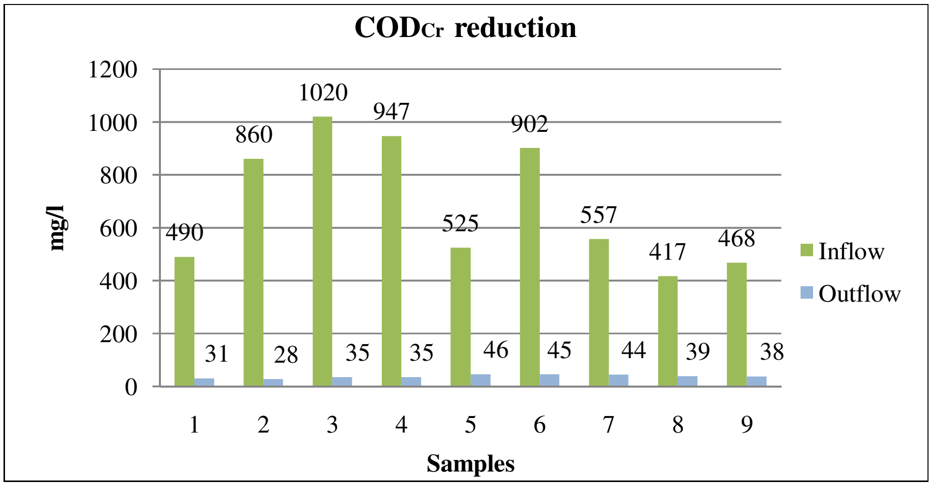

FIGURE 15 *COD_{Cr} reduction of wastewater in the Clewer system. Samples taken during a normal operation before the shutdown period.*

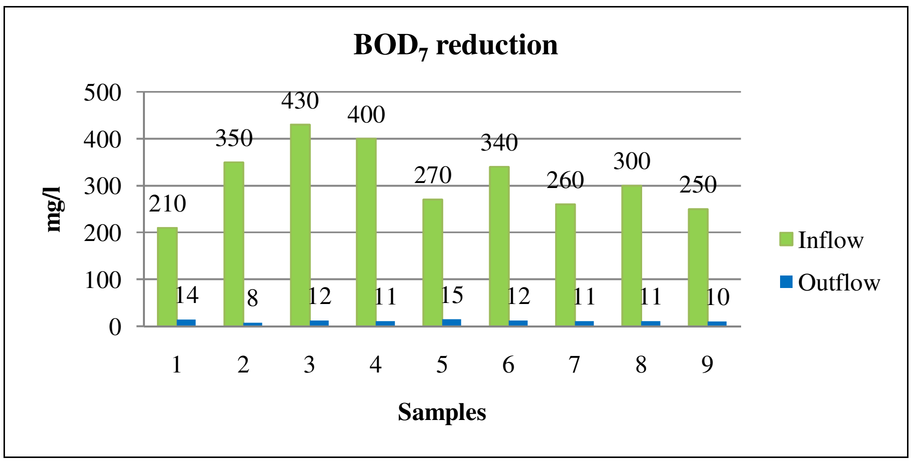

FIGURE 16 *BOD_7 reduction of wastewater in the Clewer system. Samples taken during a normal operation before the shutdown period.*

10.1.2 Total nitrogen reduction

The reduction of total nitrogen (Figure 17) was between 40 and 70 %. The average reduction of samples was ± 59 %. The average of total nitrogen concentration in inflow wastewater was 86,9 mg/l. Outflow water`s average of total nitrogen concentration was 35,1 mg/l. The Clewer Always Ready process had higher reduction values for total nitrogen removal than required (40 % reduction) in the decree 542/2003.

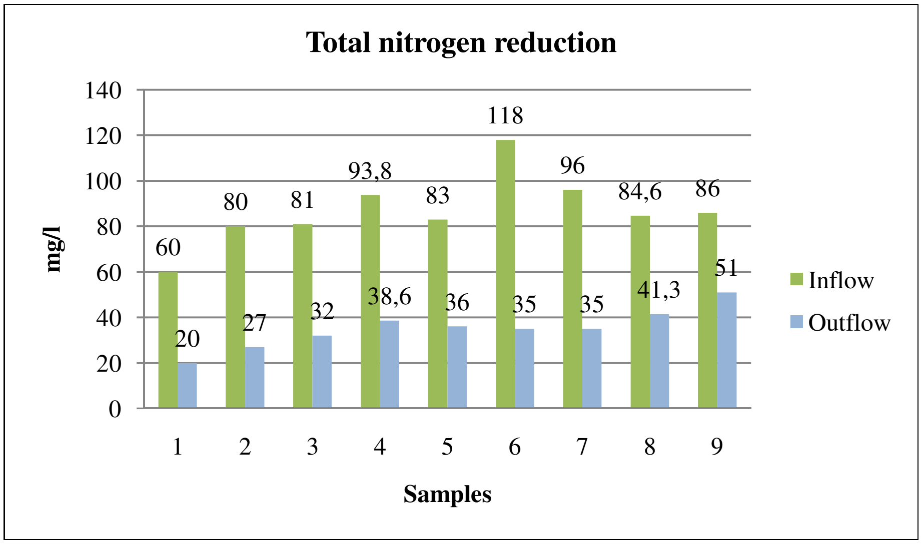

FIGURE 17 *Total nitrogen reduction of wastewater in the Clewer system. Samples taken during a normal operation before the shutdown period.*

10.1.3 Reduction of NH_4-N and concentration of NO_3-N

The reduction of ammonia nitrogen was on average ± 84 % (Figure 18). The average concentration of NH_4-N in inflow wastewater was 61,9 mg/l and the standard deviation was 6,0 mg/l. Outflow water parameters were: the average concentration 9,9 mg/l and the standard deviation was 2,9 mg/l.

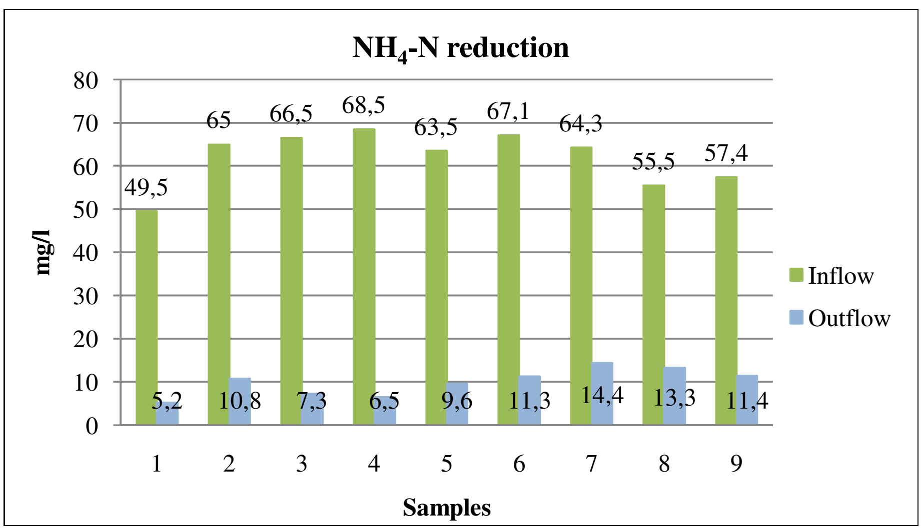

FIGURE 18 *Ammonia nitrogen reduction of wastewater in the Clewer system. Samples taken during a normal operation before the shutdown period.*

Figure 19 shows the comparison of concentrations of ammonia nitrogen and total nitrogen from inflow wastewater, before shutdown period. In these nine samples average 72 % of nitrogen is in the form of ammonia nitrogen.

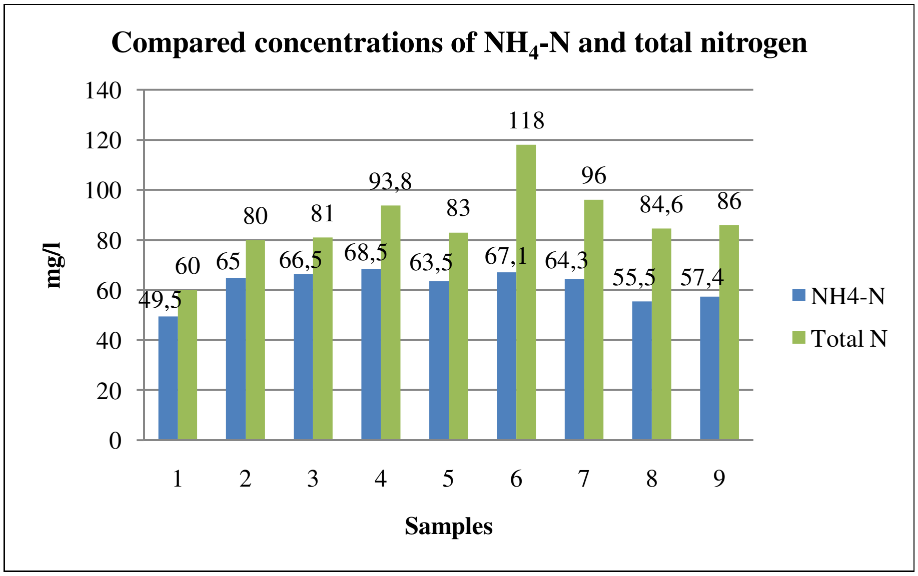

FIGURE 19 *Comparison of ammonia nitrogen and total nitrogen concentrations from inflow, before the shutdown period of 3 months.*

The average nitrate nitrogen concentration (Figure 20) of the samples was 23,4 mg/l and standard deviation 2,9 mg/l. Samples were taken only from outflow water, in which case ammonia is already oxidized to nitrate. The biofilm treatment plant used in this work does not have a denitrification process, so part of the NH_3-N stays in the outcoming purified water.

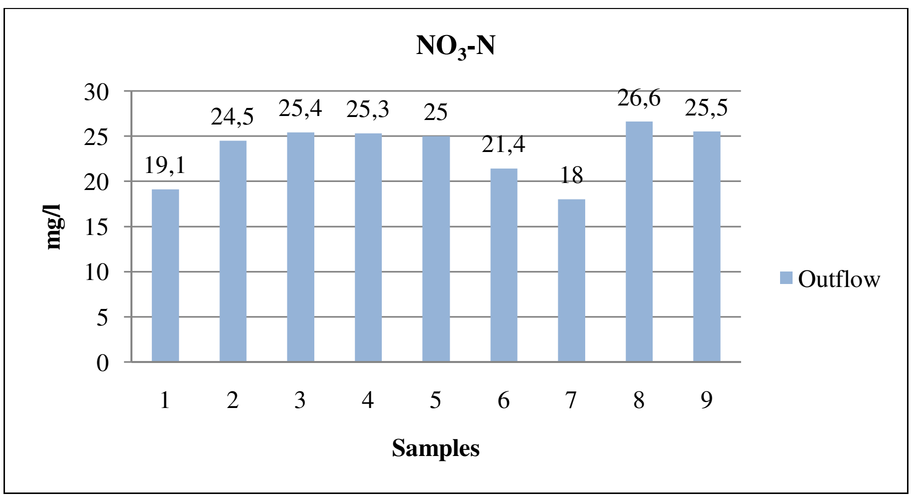

FIGURE 20 *Nitrate nitrogen concentration in outflowing water before shutdown.*

10.1.4 Total phosphorus reduction

Like COD_{Cr} reduction, the total phosphorus reduction percentage was also over 90. The average reduction was 93 % in all samples. This is higher than the government decree 542/2003 requirement (85 % reduction). Wastewater inflow concentration average was 11,1 mg/l and standard deviation 1,6 mg/l (Figure 21). Outflow had the average phosphorus concentration of 0,8 mg/l and standard deviation of 0,2 mg/l.

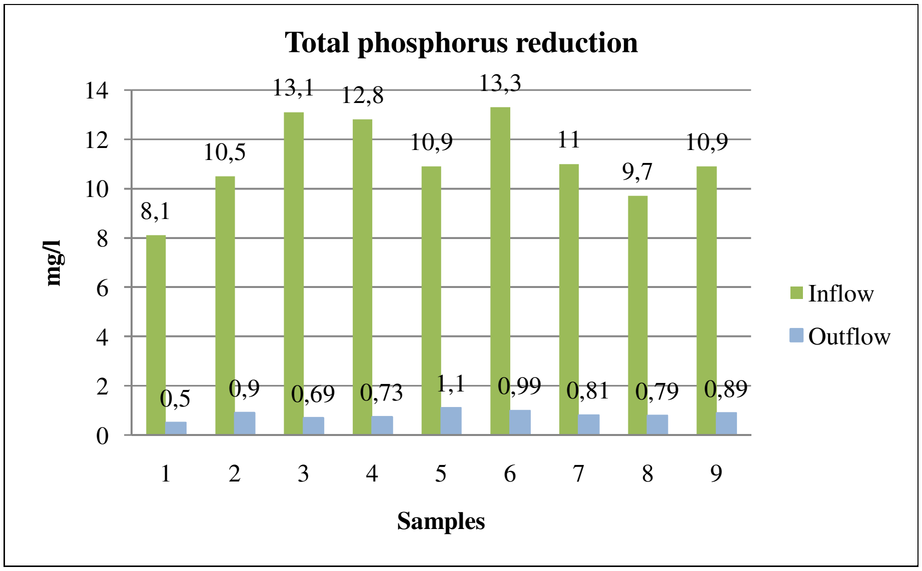

FIGURE 21 *Total phosphorous reduction of wastewater in the Clewer system. Samples taken during a normal operation before the shutdown period.*

10.1.5 pH and temperature

When comparing the incoming wastewater and outgoing purified water samples, there is only a small difference in pH (Figure 22). pH in the process has been steady, which is good for the nitrification process. The average pH in inflow wastewater was 7,4 and in outflow 6,2.

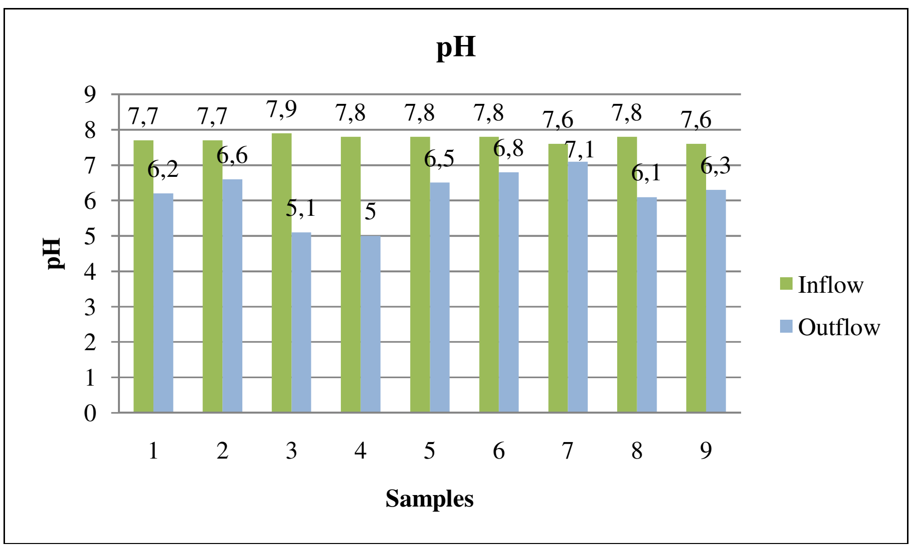

FIGURE 22 *Changes in pH in incoming wastewater and outgoing purified water.*

Temperatures seen in Figure 23 show that there were only a few variations between incoming and outgoing water. Temperatures were between 9 and 12 °C. The average temperature of inflow and outflow water was 10,2 °C.

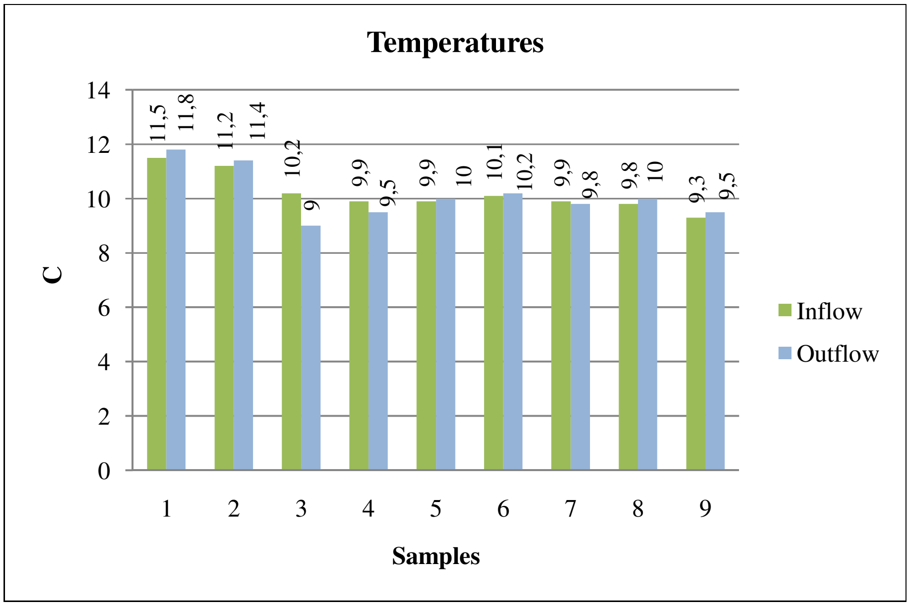

FIGURE 23 *Temperature of the incoming and outgoing wastewater.*

10.2 Operation after the shutdown period

The following results are from the samples taken after a shutdown period of three months. First samples were taken on the same day of the reactor start-up (Table 6). The wastewater load was 1200 l/d during the sampling period.

TABLE 6 *Sampling period after shutdown period of 3months.*

Sample no.	Sampling date	Days from start-up
1	14.6.10	0
2	15.6.10	1
3	16.6.10	2
4	17.6.10	3
5	21.6.10	7
6	22.6.10	8
7	23.6.10	9
8	29.6.10	15
9	30.6.10	16

10.2.1 Reduction of organic matter (COD_{Cr}, BOD_7)

The COD_{Cr} reduction of the first four samples taken after shutdown period were between 55 and 86 %. During the sampling the Clewer process reached 95 % of COD_{Cr} reduction in seven days (Figure 24). After seven days the process ran normally. Between the days seven and 16 the average COD_{Cr} concentration was 95,6 %.

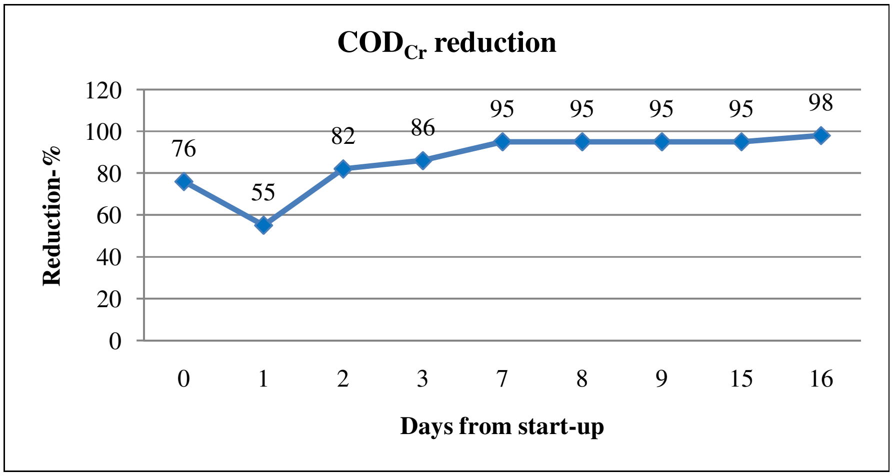

FIGURE 24 *COD_{Cr} reduction percentage after shutdown period.*

Figure 25 shows that after two days of the shutdown period the Clewer process reached 90 % of BOD_7 reduction and fulfilled the requirements in the decree 542/2003. The average BOD_7 reduction between the days two and 16 was 95,7 %.

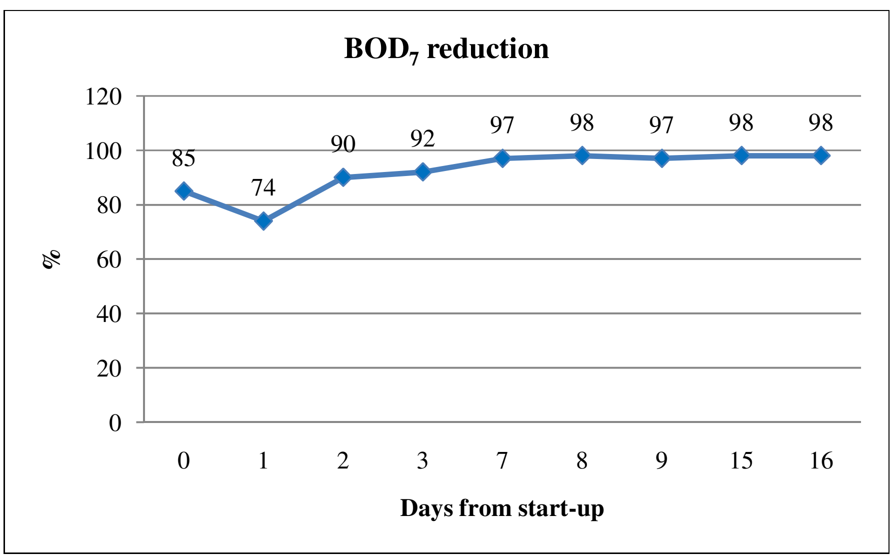

FIGURE 25 *BOD_7 reduction percentage after shutdown period.*

10.2.2 Total nitrogen reduction

The reduction of total nitrogen in Clewer Always Ready process reached the purification requirements (40 %) of the decree 542/2003 immediately after the shutdown period (Figure 26). A warmer temperature of wastewater affected the nitrification positively; it reached quickly the reduction level that it was before shutdown period.

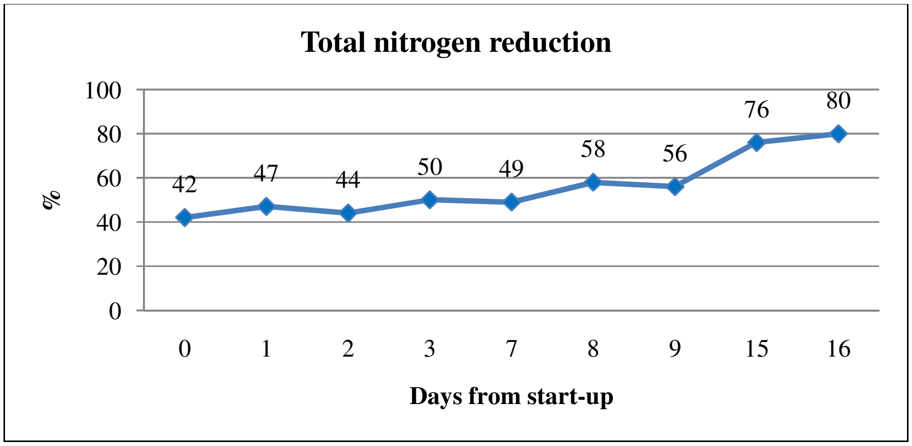

FIGURE 26 *Total nitrogen reductions after shutdown period.*

10.2.3 Total phosphorus reduction

The reduction of total phosphorus (Figure 27) reached the requirements of the decree 542/2003 in one day. The average reduction of total phosphorus was 92 % in samples no. 2–9. These reduction results are higher than the 85 % required in the decree 542/2003.

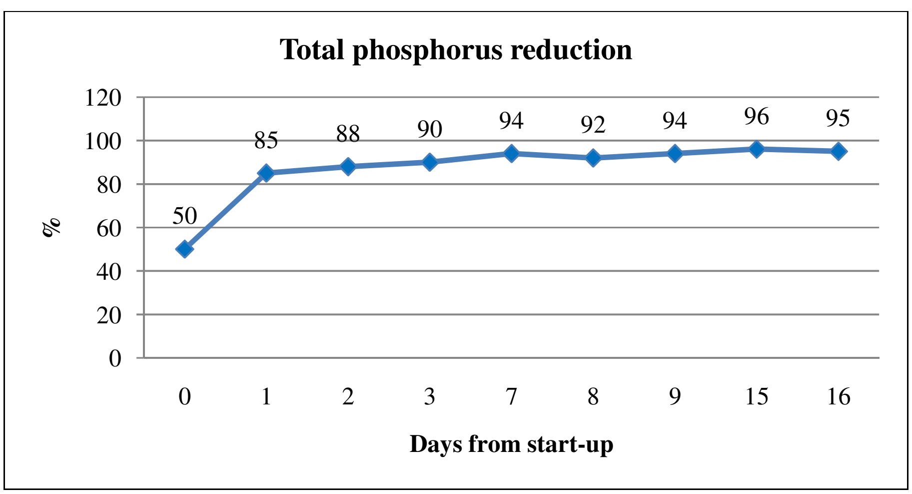

FIGURE 27 *Total phosphorus reductions after shutdown period.*

10.2.4 Reduction of NH_4-N and concentration of NO_3-N

NH_4-N reductions is seen in Figure 28. The process ran normally after seven days from the shutdown period. The sample taken at the end of the follow-up period shows that the reduction had reached 95 % in 16 days.

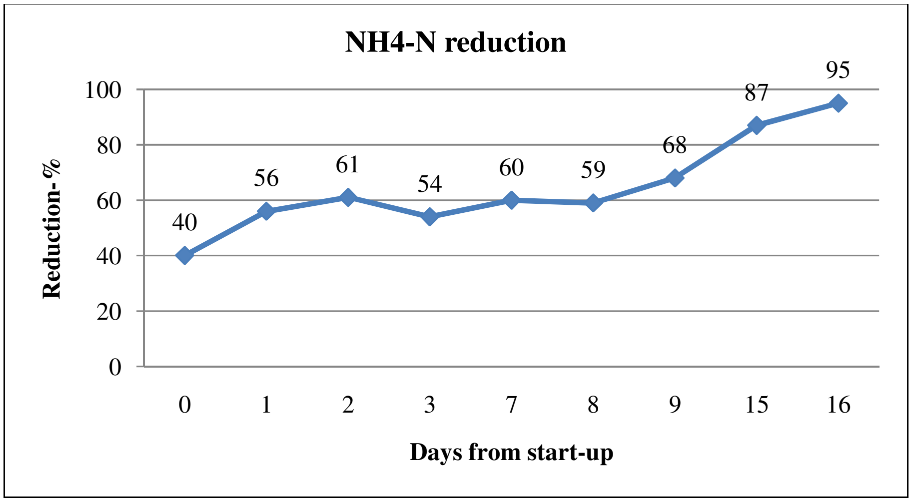

FIGURE 28 *Ammonia nitrogen reduction percentage after shutdown period.*

The amount of nitrate nitrogen in purified water grew during the sampling weeks (Figure 29). In practice, during the normal wastewater purification process, all ammonia acting with wastewater is oxidized to nitrate. Parts of the nitrates are reduced into gaseous nitrogen. Full reduction of nitrates does mainly not occur, because of lack of organic matter in wastewater.

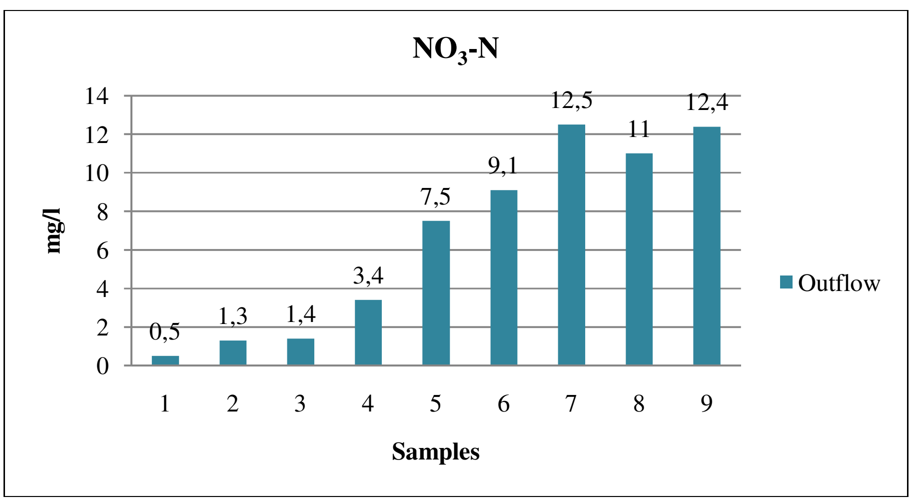

FIGURE 29 *Nitrate nitrogen concentration after shutdown period.*

Figure 30 shows the comparison of concentrations of ammonia nitrogen and total nitrogen from inflow wastewater, after shutdown period. In these nine samples average 71 % of nitrogen is in the form of ammonia nitrogen. The ammonia nitrogen concentrations are similar to concentrations before shutdown period.

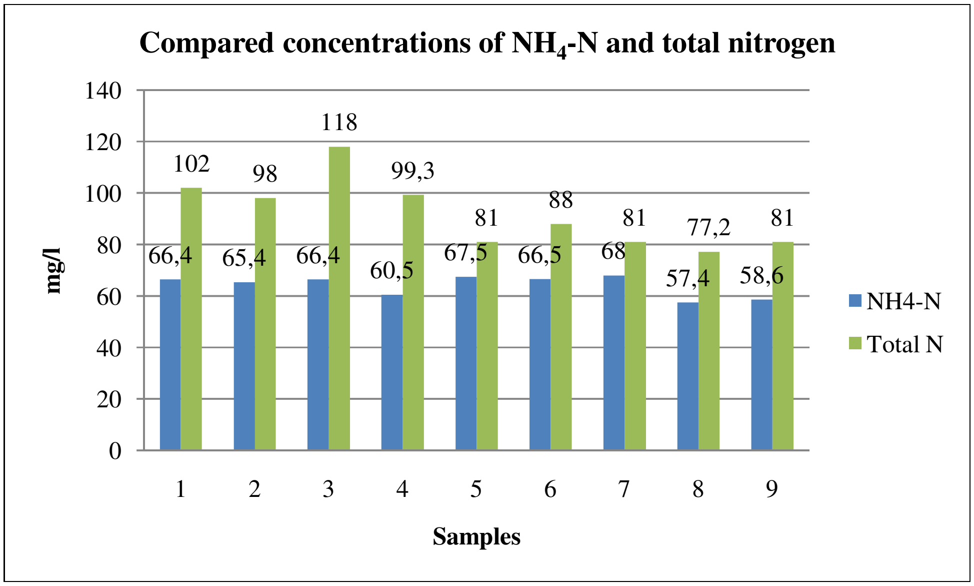

FIGURE 30 *Comparison of ammonia nitrogen and total nitrogen concentrations before the shutdown period of 3 months.*

10.2.5 pH and temperature

pH of incoming and outgoing water did not vary much after the shutdown period (Figure 31). The averages were 7,4 (inflow) and 7,1 (outflow). The average pH was the same as before shutting the reactor. pH level should be over 7, otherwise it can cause a reduction in nitrification activity in the process.

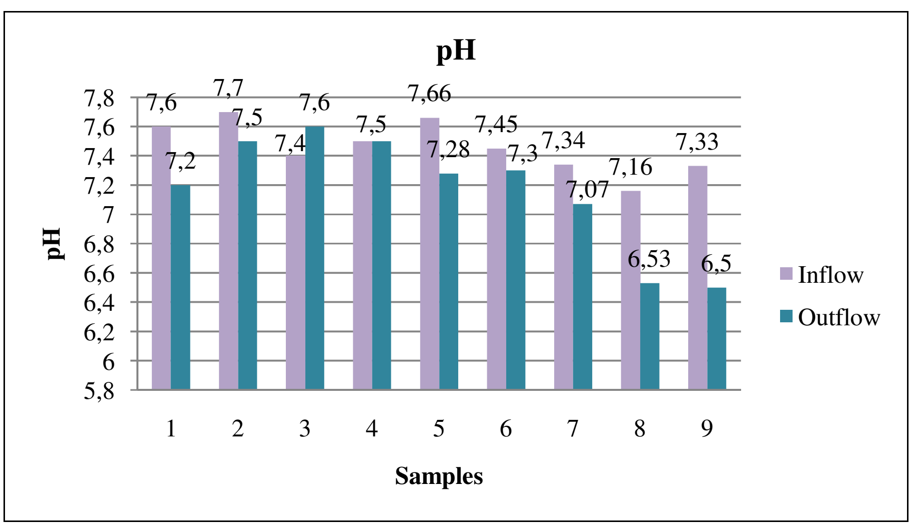

FIGURE 31 *pH of wastewater and purified water after shutdown period.*

The temperatures were notably higher than before shutdown period (Figure 32). The warming up temperature outdoors was affecting the process temperature, however it stayed stable during the sampling. The average temperatures were 12,9 °C (inflow) and 16,9 °C (outflow).

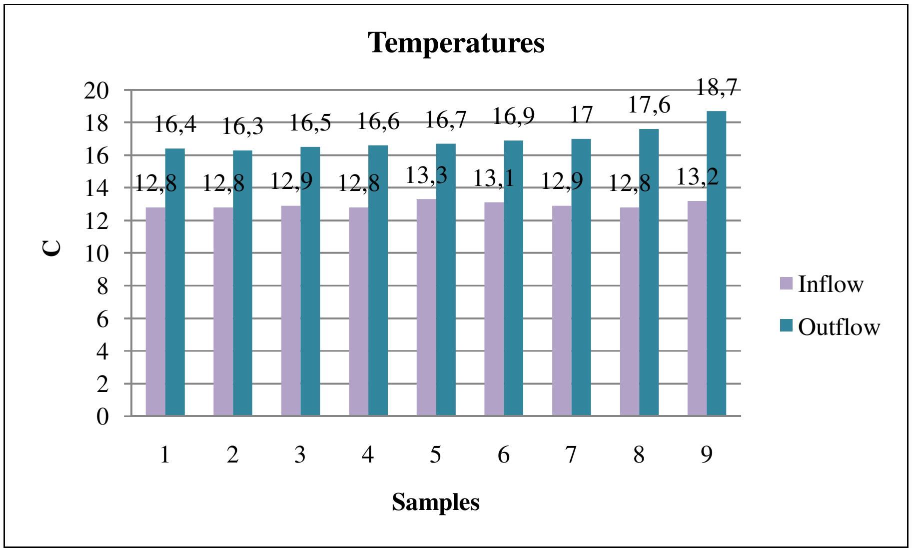

FIGURE 32 *Temperatures of samples after shutdown period.*

The temperature of outgoing purified water in Clewer Always Ready process increased a little after shutdown period at the same time with the outside temperature. The removal effiency of nitrogen is conditional to process temperature and sludge age. Thus, in summer time the removal is much easier than in winter.

The following Table 7 shows the result ranges between the samples.

TABLE 7 *Range of analysis results before and after shutdown period.*

	BEFORE		**AFTER**	
	Inflow	Outflow	Inflow	Outflow
	mg/l	mg/l	mg/l	mg/l
COD_{Cr}	417–1020	28–46	517–1240	29–148
BOD_7	210–430	8–15	230–360	5–60
Tot. nitrogen	60–118	20–51	77,2–118	16–66
NH_4-N	49,5–68,5	5,2–14,4	57,4–68	2,9–39,5
NO_3-N	No sampling	18–26,6	No sampling	0,5–12,5
Tot. phosphorus	8,1–13,3	0,5–1,1	10–12,7	0,5–5,3
pH	7,6–7,9	5–7,1	7,16–7,7	6,5–7,6
Temperature	9,3–11,5	9–11,8	12,8–13,3	16,3–18,7

Table 8 shows the time that was required for Clewer Always Ready 800 process to reach the requirements of the decree 542/2003 and table 9 shows the required time for Clewer process to reach full recover and normal operation level.

TABLE 8 *The time required for Clewer Always Ready process to reach requirements of the decree 542/2003 after shutdown period of three months.*

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Parameter	After shutdown		Requirement of the decree 542/2003
	Days	Reduction, %	Reduction, %
BOD_7	2	90	90
Total N	Immediately	42	40
Total P	1	85	85

TABLE 9 *The time required for full recover of Clewer Always Ready process after shutdown period of three months.*

Parameter	After shutdown		Normal operation
	Days	Reduction, %	Reduction, %
BOD_7	8	97	96
Total N	8	58	60
Total P	7	94	93

10.3 Comparison of reduction results

Although the COD_{Cr} reduction immediately after the shutdown period was low, seven days it reached the level in, where it was before the reactor was stopped. The reduction of BOD_7 reached the level where it was before shutdown period also in seven days. The compared COD_{Cr} reductions are seen on Figure 33 and BOD_7 reductions in Figure 34.

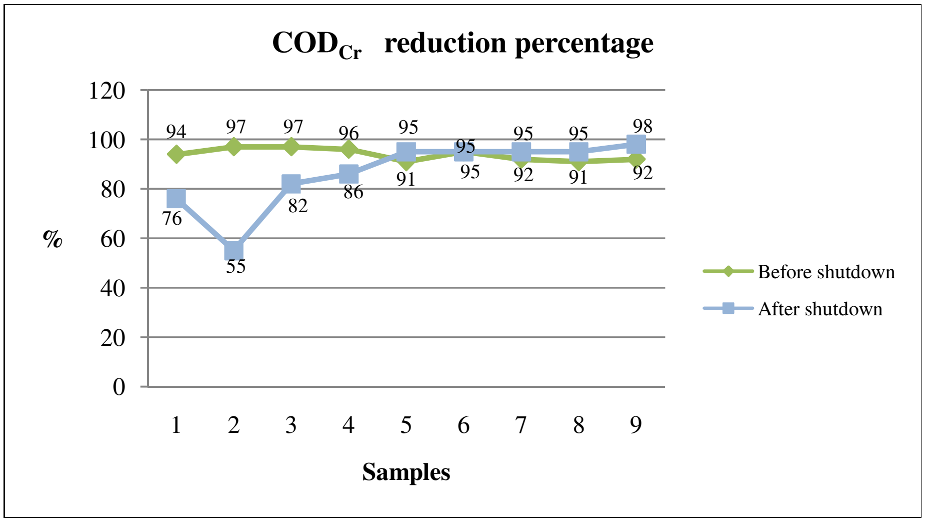

FIGURE 33 *Comparison of COD_{Cr} reductions before and after the process shutdown of 3 months.*

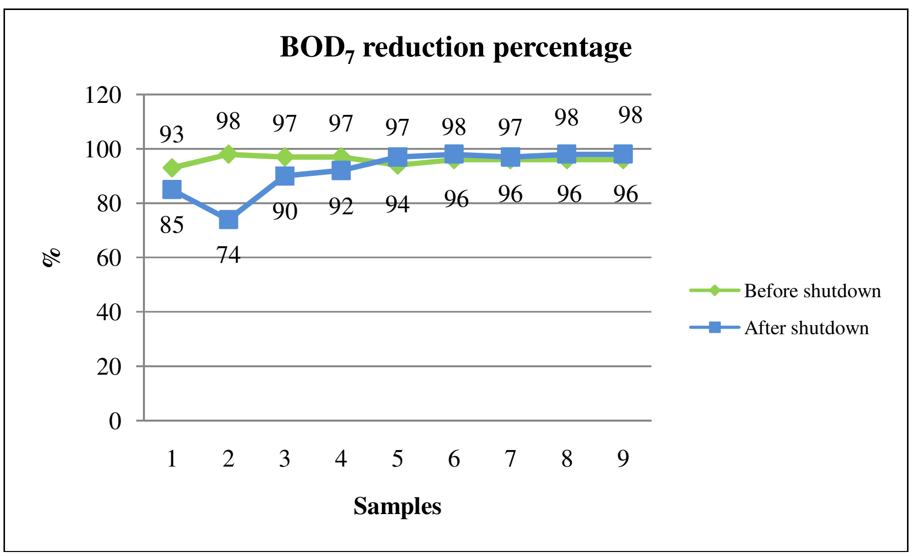

FIGURE 34 *Comparison of BOD_7 reductions before and after the process shutdown of 3 months.*

The reduction in ammonia nitrogen seen on Figure 35 shows that after the shutdown period the reduction percentage slowly increased in 16 days to over 90 %. Reduction percentage was notably higher than before shutdown period. This was presumably result of warming outdoors temperature.

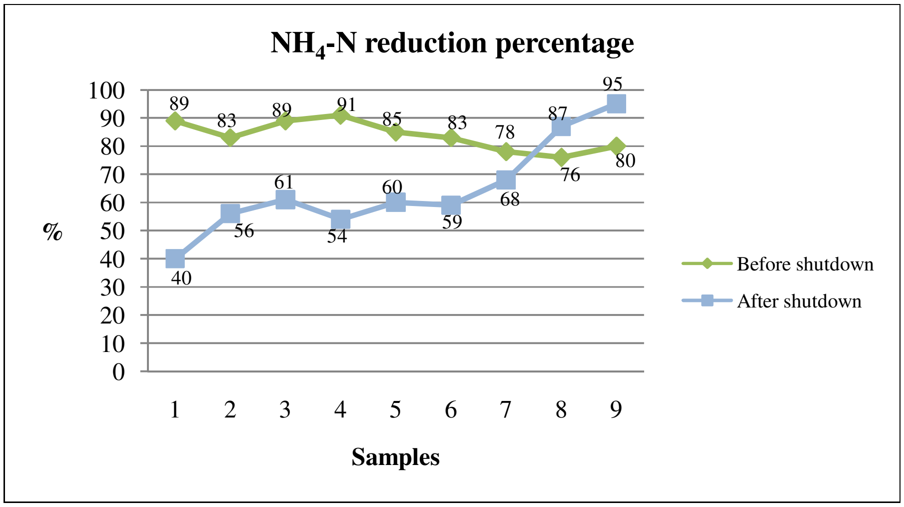

FIGURE 35 *Comparison of ammonia reductions before and after the process shutdown of 3 months.*

Concentrations of nitrate nitrogen after shutdown period were close to zero and stayed quite low comparing to results before shutdown period (Figure 36). The biofilm treatment process had been running over a year before shutdown period so the NO_3-N concentrations were higher.

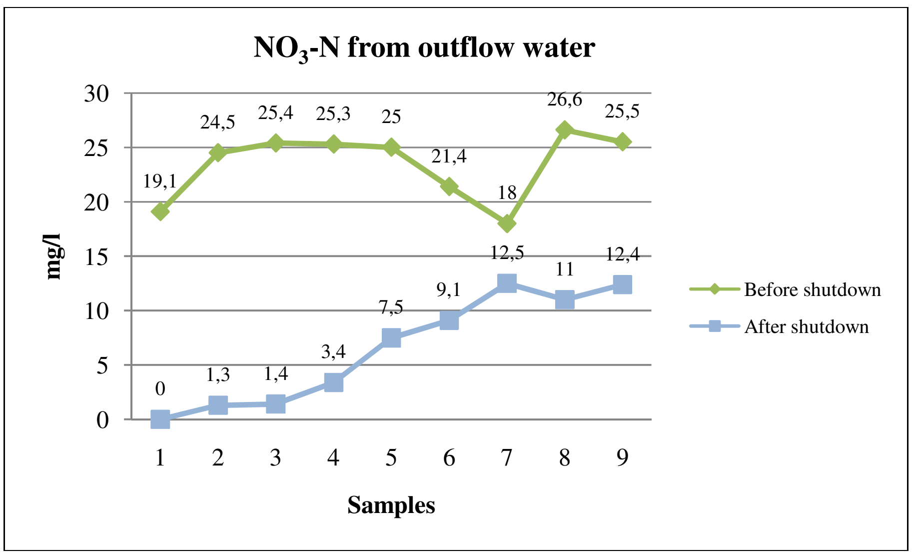

FIGURE 36 *Comparison of nitrate nitrogen reductions before and after the process shutdown of 3 months.*

The reduction of total nitrogen decreased percentually to 40 % before the shutdown period. When starting the process after the shutdown, the reduction was 42 % and increased to 80 % (Figure 37), so after eight days the Clewer Always Ready process reached its normal operation.

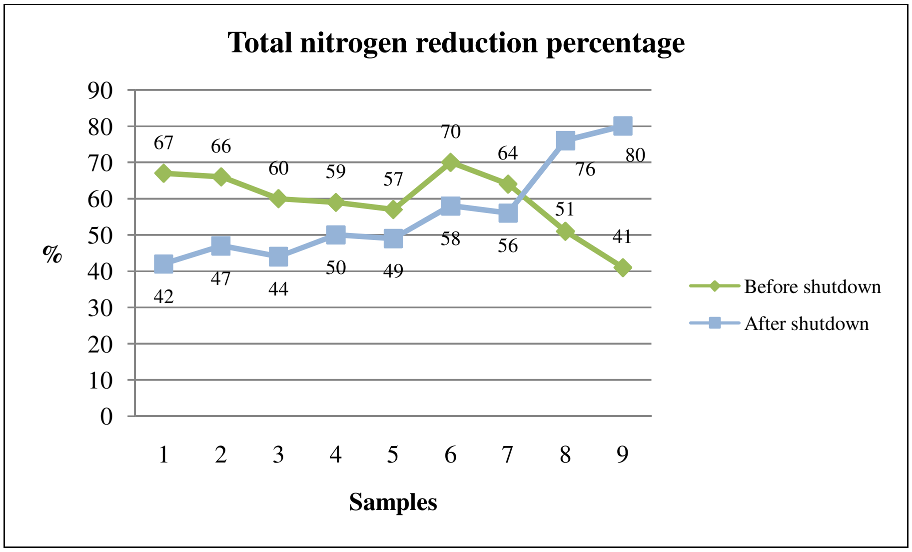

FIGURE 37 *Comparison of total nitrogen reductions before and after the process shutdown of 3 months.*

The reduction of total phosphorus samples was over 90 % before shutdown. After the shutdown period the reduction percentage increased rapidly back to 90 % (Figure 38). After seven days the Clewer Always Ready process reached its normal operation in total phosphorus reduction of 94 %.

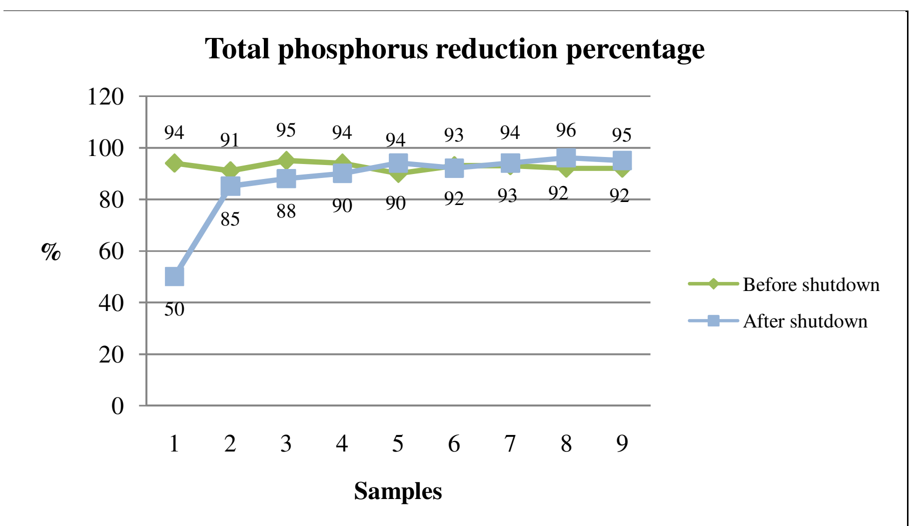

FIGURE 38 *Comparison of total phosphorus reduction after the process shutdown of 3 months..*

Figure 39 shows the compared results of nitrogen compounds before the reactor was shut down. Ammonia nitrogen and nitrate nitrogen results are compared to total nitrogen results. These two columns have rather similar concentrations, which is a result from the stable process.

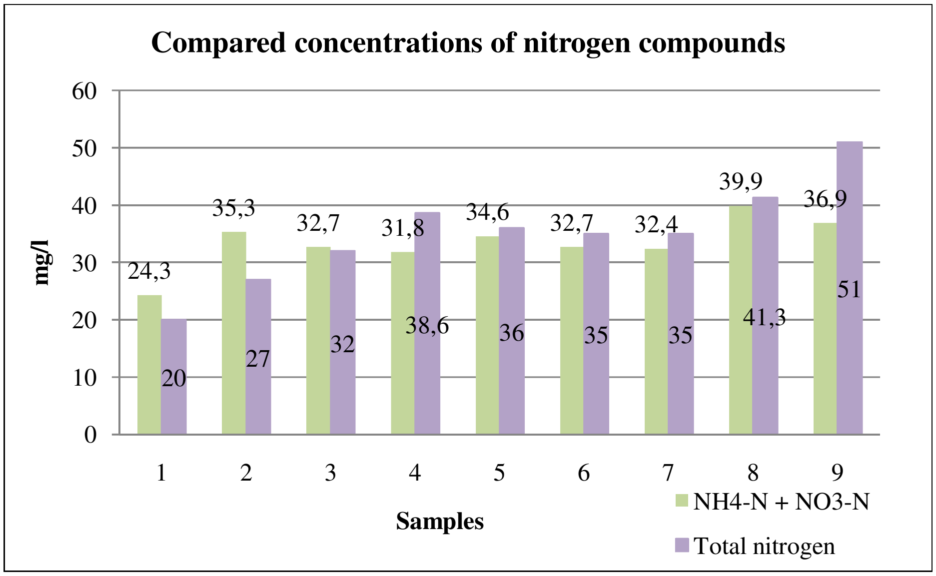

FIGURE 39 *Comparison of nitrogen compounds, before shutdown period.*

Results seen in Figure 40 are compared nitrogen compound results after the shutdown period. At the beginning of the sampling period the concentration differences between ammonia nitrogen/nitrate nitrogen and total nitrogen are higher than before shutdown period. After 7 days from start-up the concentration differences become more even.

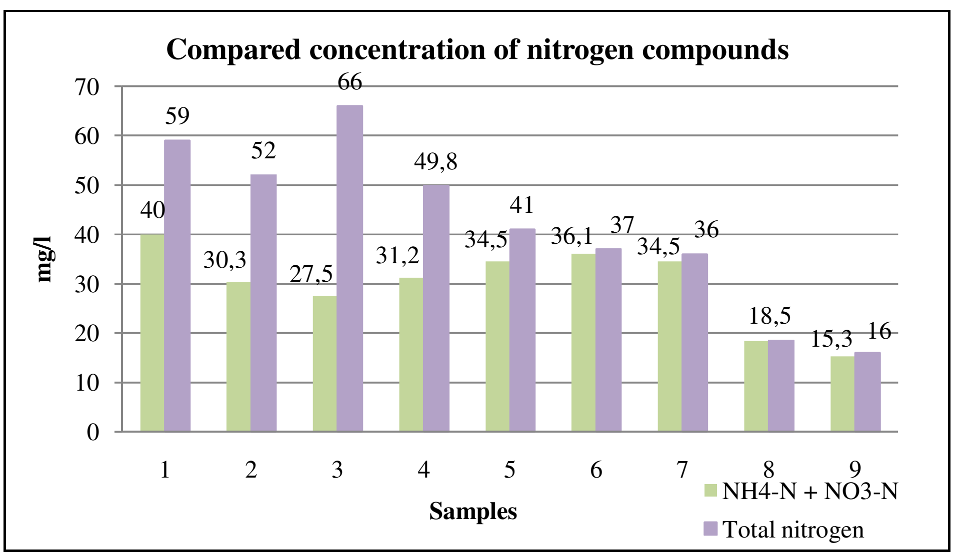

FIGURE 40 *Comparison of nitrogen compounds, after shutdown period.*

11 CONCLUSIONS

Microbial activity in a small scale wastewater treatment plant is normally assumed to start working properly in about three weeks after the shutdown period. If the nitrification and other microbial activity does not begin the microbes in the process might have died or the environment for microbes is not favourable. In any case the process needs a dissection and follow-up period done with sampling.

The sampling periods of this work were done during winter 2009 and spring/summer 2010. The first sampling period lasted from November 2009 until March 2010, approximately five months. During this time the outside temperature in Suomenoja ranged approximately between -15 and 10 degrees. The shutdown period lasted three months, from March until June 2010. After the shutdown during the second sampling period, the outside temperature was already over 15 degrees.

Before shutdown, in normal operation the reduction percentages of Clewer Always Ready biofilm process were higher than the requirements in the decree 542/2003. (BOD_7 96 %, total nitrogen 60 % and total phosphorus 93 %). Purification effectiveness and reduction values of Clewer process corresponded very quickly to the requirements set in the government decree 542/2003 after shutdown period.

After shutdown period the BOD_7 reduction reached the required purification effectiveness of the decree 542/2003 in two days and COD_{Cr} recovered to its normal operation in seven days. Total nitrogen reduction was 42 % immediately after start-up, so Clewer process reached the requirements in the decree 542/2003 on the first day of sampling after shutdown period. Total phosphorus reduction reached the required purification effectiveness of the decree in one day after the sampling was started. The recovery of nitrification and removal of phosphorus, BOD_7 and COD_{Cr} from the wastewater succeeded and the concentrations returned to what they were before the three months` shutdown period. The BOD_7 reduction recovered to its normal operation in eight days. Total phosphorus recoved to its normal operation in seven days and total nitrogen in eight days (Table 8 and 9).

Shutdown periods done to small scale treatments plants are still few and far between. No results of this kind of three months` (or longer) experiments came up during the implementation of this work. Results are available only from two weeks` shutdown/holiday periods, but they are not quite comparable to the results in this work. This experimental work gave good information about the recovery of microbial activity and purification effectiveness of Clewer Always Ready process, during the normal operation and during the shutdown period. The results can be used as a part of the marketing of Clewer Always Ready process.

For the moment there are only a few research results at hand concerning the purification effectiveness and functionality testing of the small scale treatment plants on the market. It is probable that the manufacturers of small scale treatment plants will implement more of these kinds of experiments before the government decree comes into effect in January 2014.

SOURCES

Alander Timo, 2007. Koskisen Oy.n jätevesien puhdistamisen tehostaminen (tutkintotyö).
https://oa.doria.fi/bitstream/handle/10024/19216/Alander.Timo.pdf?sequence=1
Reference 05.11.2009

Ayoub George, 2000. Wastewater treatment technologies, Medaware. (Power Point presentation) Faculty of Engineering and Architecture, American University of Beirut.
Reference 7.4.2010

Bioclere homepage, 2010
http://www.bioclere.co.uk/bioclere.php
Reference 7.4.2010

Clewer homepage, 2009. Clewer Ltd.
http://www.clewer.com/home.php
Reference 18.1.2010

Finlex, 2010. Valtioneuvoston asetus talousjätevesien käsittelystä vesihuoltolaitosten viemäriverkostojen ulkopuolisilla alueilla, 542/2003.
http://www.finlex.fi/fi/laki/alkup/2003/20030542
Reference 18.3.2010

Fortuny Aqua homepage 2009. RBBR Technology.
http://www.fortunyagua.com/
Reference 24.4.2010

Harald Pleym y.m., 1991. Ympäristötekniikka, p. 223–224. Tammertekniikka, Jyväskylä.
Reference 4.11.2009

Harrison John A., 2003. The nitrogen cycle of microbes and men.
http://www.visionlearning.com/library/module_viewer.php?mid=98
Reference 4.11.2009

Hostikka Salla ja Rantanen Pirjo, 2003. Nitrifioiva kantoaineprosessi. Vesitalous – lehti.
http://www.mvtt.fi/Vesitalous/arkisto/2003/062003/sallhost.pdf
Reference 21.4.2010

Huhtamäki Markku, 2007. Biofilmi- ja aktiivilieteprosessin yhdistelmä ravinteiden poistossa. Käytännön kokemuksia ja suuntaviivoja laitosten suunnittelulle ja käytölle (Ripesca-projekti).
http://www.raisio.fi/ripesca/Manuals%20for%20www%20page/manual%2001fi%20%20Biofilmiaktiivilieteprosesit%20suunnittelu%20ja%20k%C3%A4.pdf
Reference 4.11.2009

Järvinen Ari, 2003. Ravinteiden poistaminen jätevesitutkimuksen polttopisteessä. TKK Vesihuoltotekniikan laboratorio.
http://www.tkk.fi/Yksikot/Rakennus/Vesihuolto/Tutkimus/tproj_ravin.html
Reference 16.7.2010

Klargester homepage
http://www.klargester.ie/
Reference 24.6.2010

Koskinen Anna, 2008. Selvitys haja-asutuksen jätevesiasetuksen huomioon ottamisesta kuntien ympäristönsuojelumääräyksissä. Suomen ympäristökeskus.
http://www.ymparisto.fi/default.asp?node=22331&lan=fi
Reference 30.6.2010

Kujala-Räty Katriina, Mattila Harri ja Santala Erkki (toim.), 2008. Haja-asutusalueiden vesihuolto, p.83. Hämeen ammattikorkeakoulu ja Suomen ympäristökeskus, Hämeenlinna.
Reference 10.12.2009

Kujala-Räty Katriina 2005, Haja-asutuksen jätevedenpuhdistuksen peruskäsitteitä (luonnos), Suomen ympäristökeskus.
Reference 5.11.2009

Kuokkanen Anna, 2008. Jäteveden ja jätevesilietteen käsittely. Aalto-yliopiston teknillinen korkeakoulu.
http://www.water.tkk.fi/wr/kurssit/Yhd-12.1020/Luento11a_2008.pdf
Reference 06.11.2009

McGraw-Hill Professional Publishing, 2005. Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants, p 8-9.
Water Environment Federation.
http://site.ebrary.com/lib/hamk/Doc?id=10196940&ppg=54
Reference 7.4.2010

Niemi Juha ja Myllyvirta Tero, 2007.
Selvitys haja-asutusalueen jätevesien pienpuhdistamoiden toimivuudesta, Itä-Uudenmaan ja Porvoonjoen vesien- ja ilmansuojeluyhdistys ry.
http://www.vesi-ilma.fi/Jatevesiraportti3.pdf
Reference 7.4.2010

Nurmijärven kunta – Ympäristökeskus, 2009. Pienpuhdistamot,
http://www.nurmijarvi.fi/palvelut/ymparisto/jatevesi/fi_FI/pienpuhdistamo/
Reference 4.11.2009

Pohjois-Pohjanmaan Ympäristökeskus, 2007. Jätevesiopas.
http://www.ymparisto.fi/download.asp?contentid=46937
Reference 1.7.2010

Rantanen Pirjo, 2008. Typenpoisto, alkaliteetti ja fosforinpoisto – kolmiodraaman ainekset? Haja-asutuksen vesihuollon teemapäivä (Power Point presentation). Suomen Ympäristökeskus.
http://www.ymparisto.fi/download.asp?contentid=84928
Reference 22.5.2010

Santala Erkki, 2009. Miten hajajätevesiasetuksen toimeenpano edistyy. (Power Point presentation). Suomen Ympäristökeskus.
http://www.ymparisto.fi/download.asp?contentid=79837
Reference 4.1.2010

Saralehto Kai, 2004. Kiinteistökohtainen jätevedenkäsittely. Menetelmän valinta, suunnittelu ja asiakirjat.
http://www.rakentaja.fi/pdf/hajahanke/Kiinteistokohtainen_jatevesien_kasittely_kai_saralehto.pdf
Reference 22.4.2010

Srinivas T., 2008. Environmental Biotechnology.
http://site.ebrary.com/lib/hamk/Doc?id=10318681&ppg=70
Reference 7.4.2010

Suomen Sakokaivo homepage 2007.
http://www.sakokaivo.fi/303.htm
Reference 21.4.2010

Suomen Ympäristökeskuksen puhdistamosivusto 2009.
http://www.ymparisto.fi/default.asp?contentid=274016&lan=fi&clan=fi
Reference 22.4.2010

Suomen Ympäristökeskus, 2009. Pienpuhdistamoiden testaus.
http://www.ymparisto.fi/default.asp?contentid=327177&lan=FI
Reference 10.12.2009

Vilpas Riikka, 2004. Pienpuhdistamoiden ja saostussäiliöiden CE-merkintä ja laitetestaus. Ympäristö ja terveys 5/2004, Suomen ympäristökeskus.
http://www.ymparisto.fi/download.asp?contentid=25037
Reference 21.4.2010

Vilpas Riikka, 2010. Collected results of EN testing (Based on the test report of 26 April 2010, SYKE-2004-A-3-A4/37) Suomen Ympäristökeskus.
http://www.clewer.com/en/liiteet/ClewerKootuttuloksetEN270410.pdf
Reference 10.6.2010

Wang Lawrence K., Hung Yung-Tse and Shammas Nazih K., 2009. Handbook of environmental engineering, Advanced Biological Treatment Processes, p. 632-633.
Reference 7.4.20

Appendix 1/1

ANALYSIS RESULTS, CLEWER ALWAYS READY 800 PROCESS

Results before shutdown period:

Sample no.	Date	Waste water	CODcr			BOD_7			Total nitrogen			Total phosphorus		
			Inflow	Outflow	Reduction	Inflow	Outflow	Reduction	Inflow	Outflow	Reduction	Inflow	Outflow	Reduction
		l/d	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
1	10.11.2009	1600	490	31	94	210	14	93	60	20	67	8,1	0,5	94
2	7.12.2009	1200	860	28	97	350	8	98	80	27	66	10,5	0,9	91
3	11.1.2010	600	1020	35	97	430	12	97	81	32	60	13,1	0,69	95
4	18.1.2010	1200	947	35	96	400	11	97	93,8	38,6	59	12,8	0,73	94
5	8.2.2010	1200	525	46	91	270	15	94	83	36	57	10,9	1,1	90
6	15.2.2010	1200	902	45	95	340	12	96	118	35	70	13,3	0,99	93
7	22.2.2010	1200	557	44	92	260	11	96	96	35	64	11	0,81	93
8	17.3.2010	1200	417	39	91	300	11	96	84,6	41,3	51	9,7	0,79	92
9	22.3.2010	1200	468	38	92	250	10	96	86	51	41	10,9	0,89	92
	Average		687,33	37,89	93,8	312,22	11,56	95,89	86,93	35,1	59,41	11,14	0,82	92,56
	Std deviation		225,45	5,93	2,33	68,92	1,95	1,45	14,62	8,22	8,58	1,6	0,17	1,44
	Average+StdDev		912,78	43,82	96,09	381,15	13,51	97,34	101,56	43,32	67,99	12,75	0,99	94
	Average-StdDev		461,88	31,96	91,51	243,30	9,61	94,44	72,31	26,88	50,82	9,54	0,66	91,12

Sample no.	Date	Waste water	pH		Temperature		NH_4-N			NO_3-N
			Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Reduction	Outflow
		l/d			°C	°C	mg/l	mg/l	%	mg/l
1	10.11.2009	1600	7,7	6,2	11,5	11,8	49,5	5,2	89	19,1
2	7.12.2009	1200	7,7	6,6	11,2	11,4	65	10,8	83	24,5
3	11.1.2010	600	7,9	5,1	10,2	9	66,5	7,3	89	25,4
4	18.1.2010	1200	7,8	5	9,9	9,5	68,5	6,5	91	25,3
5	8.2.2010	1200	7,8	6,5	9,9	10	63,5	9,6	85	25
6	15.2.2010	1200	7,8	6,8	10,1	10,2	67,1	11,3	83	21,4
7	22.2.2010	1200	7,6	7,1	9,9	9,8	64,3	14,4	78	18
8	17.3.2010	1200	7,8	6,1	9,8	10	55,5	13,3	76	26,6
9	22.3.2010	1200	7,6	6,3	9,3	9,5	57,4	11,4	80	25,5
	Average		7,74	6,19	10,2	10,13	61,92	9,98	83,8	23,42
	Std deviation		0,1	0,67	0,66	0,86	6,01	2,93	4,93	2,94
	Average+StdDev		7,84	6,86	10,86	10,99	67,93	12,91	88,73	26,36
	Average-StdDev		7,65	5,51	9,54	9,28	55,92	7,05	78,88	20,48

Appendix 1/2

ANALYSIS RESULTS, CLEWER ALWAYS READY 800 PROCESS

Results after shutdown period:

Sample no.	Date	Waste water	COD_{Cr}			BOD_7			Total nitrogen			Total phosphorus		
			Inflow	Outflow	Reduction	Inflow	Outflow	Reduction	Inflow	Outflow	Reduction	Inflow	Outflow	Reduction
		l/d	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
1	14.6.2010	1200	611	148	76	260	40	85	102	59	42	10,7	5,3	50
2	15.6.2010	1200	517	230	56	230	60	74	98	52	47	10	1,5	85
3	16.6.2010	1200	685	123	82	300	30	90	118	66	44	12,5	1,45	88
4	17.6.2010	1200	709	101	86	320	25	92	99,3	49,8	50	11,2	1,1	90
5	21.6.2010	1200	780	35	96	340	8	97	81	41	49	11,2	0,7	94
6	22.6.2010	1200	809	41	95	350	7	98	88	37	58	11,7	0,9	92
7	23.6.2010	1200	696	35	95	310	8	97	81	36	56	11,8	0,75	94
8	29.6.2010	1200	692	33	95	310	5	98	77,2	18,5	76	11,7	0,5	96
9	30.6.2010	1200	1240	29	98	360	7	98	81	16	80	12,7	0,6	95
	Average*)													
	Std deviation*)													
	Average+StdDev*)													
	Average-StdDev*)													

Sample no.	Date	Waste water	pH		Temperature		NH_4-N			NO_3-N
			Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Reduction	Outflow
		l/d			ºC	ºC	mg/l	mg/l	%	mg/l
1	14.6.2010	1200	7,6	7,2	12,8	16,4	66,4	39,5	41	0.5
2	15.6.2010	1200	7,7	7,5	12,8	16,3	65,4	29	56	1,3
3	16.6.2010	1200	7,4	7,6	12,9	16,5	66,4	26,1	61	1,4
4	17.6.2010	1200	7,5	7,5	12,8	16,6	60,5	27,8	54	3,4
5	21.6.2010	1200	7,66	7,28	13,3	16,7	67,5	27	60	7,5
6	22.6.2010	1200	7,45	7,3	13,1	16,9	66,5	27	59	9,1
7	23.6.2010	1200	7,34	7,07	12,9	17	68	22	68	12,5
8	29.6.2010	1200	7,16	6,53	12,8	17,6	57,4	7,4	87	11
9	30.6.2010	1200	7,33	6,5	13,2	18,7	58,6	2,9	95	12,4
	Average*)									
	Std deviation*)									
	Average+StdDev*)									
	Average-StdDev*)									

*) The average values are not expressed due to the transient conditions of the process after a shutdown period.

Appendix 2/1

FINNISH ENVIRONMENT INSTITUTE
Suomenoja Research Station

SYKE

NB 1762
EN 12566-3:2005/A1:2009; Annexes A and B

27 April 2010

COLLECTED RESULTS OF EN TESTING

(Based on the test report of 26 April 2010, SYKE-2004-A-3-A4/37)

Clewer septic tank 5m^3 + Clewer 800 S (= Clewer* wastewater treatment plant)
Clewer Oy

The Finnish Environment Institute (SYKE) has carried out initial type testing of the Clewer wastewater treatment plant in accordance with the standard EN 12566-3:2005/A1:2009 (CEN), including tests in accordance with Annexes A (watertightness) and B (treatment efficiency). This report includes the collated results of treatment efficiency testing. Testing was performed at SYKE's Suomenoja Research Station at Hyljeluodontie 5, FI-02270 Espoo, Finland. The watertightness test was performed and approved in March 2008.

SYKE has been found to fulfil the requirements of reliability and independence, as well as other general requirements set by the Act on the Approval of Construction Products (230/2003) for a body involved in assessing the conformity of products for CE marking, including the competence to carry out initial type testing of equipment for the treatment of domestic wastewater.

Clewer* wastewater treatment plant is a biological-chemical continuous treatment plant made of polyethylene that is designed to treat all domestic wastewater. According to the manufacturer, the nominal hydraulic daily flow of the treatment plant is 1.2 m^3/d and the nominal organic load 350 g BOD_7/d.

NOTE! In addition to Clewer 800 S, the biological part shown in the picture, the treatment plant includes a septic tank (5m^3).

Test schedules

Sequence	Flow l/d	Duration weeks	Samples
1 Biomass establishment	1200	x	x
2 Nominal 100 %	1200	6	4
3 Underloading 50 %	600	2	2
4 Nominal 100 % + power breakdown 24h	1200	6	5
5 Low occupation stress 0 %	0	2	-
6 Nominal 100 %	1200	6	3
7 Overloading 150 % *	1800* / 1200	2	2
8 Nominal 100 % + power breakdown 24h	1200	6	5
9 Underloading 50 %	600	2	2
10 Nominal 100 %	1200	6	3
* 150% overload is organised for a duration of 48 h at the beginning of the sequence		38+X	26

Treatment efficiency during nominal loading, underloading, and overloading

Parameter	Nominal* 1200 l/d	Underloading** 600 l/d				Overloading*** 1800 l/d	
Total chemical oxygen demand COD (%)	92	93	94	94	95	92	88
Total biological oxygen demand BOD (%)	95	96	98	96	97	88	91
Suspended solids SS (%)	93	95	96	94	96	92	87
Total nitrogen N_{tot} (%)	65	83	87	58	55	55	60
Total phosphorus P_{tot} (%)	89	85	88	92	93	83	86

* the mean value of 20 samples
** 4 composite samples
*** 2 composite samples

Appendix 2/2

S Y K E FINNISH ENVIRONMENT INSTITUTE
Suomenoja Research Station

NB 1762
EN 12566-3:2005/A1:2009; Annexes A and B

27 April 2010

The mean values for influent and effluent loads as well as influent and effluent concentrations
(During nominal sequences 2, 4, 6, 8 and 10)

Parameter	BOD_7	COD_{Cr}	SS	P_{tot}	N_{tot}	NH_4-N	pH	Wastewater temperature °C
The mean value of the influent load (g/d)	364	887	444	12,0	77	65	-	-
The range of variation (g/d)	240 - 468	588 - 1200	312 - 588	7,8 - 16,8	46 - 101	35 - 89	-	-
The mean value of the influent concentration (mg/l)	303	739	370	10,0	64	54	7,6	13,0
The range of variation (mg/l)	200 - 390	490 - 1000	260 - 490	6,5 - 14,0	38 - 84	29 - 74	7,3 - 7,8	9,0 - 16,1
The mean value of the effluent load (g/d)	18,1	66	29	1,3	27	7	-	-
The range of variation (g/d)	3,6 - 30,0	36 - 102	10 - 64	0,3 - 2,8	11 - 48	0,3 - 18	-	-
The mean value of the effluent concentration (mg/l)	15,1	55	24	1,1	22	6	6,4	14,6
The range of variation (mg/l)	3,0 - 25,0	30 - 85	8 - 53	0,26 - 2,3	10 - 40	0,3 - 15	6,3 - 7,1	8,1 - 18,0

The use and maintenance of the Clewer* wastewater treatment plant and observations during testing

The operation of the Clewer* wastewater treatment plant was monitored regularly and it was used and maintained in accordance with the manufacturer's instructions. The normal use and maintenance operations of the Clewer* wastewater treatment plant are the removal of sludge, the addition of a precipitating chemical, and regular monitoring of the plant's operations by observing the control station monitor, indicator lights, and pumps. The treatment plant includes a 30-litre tank for the precipitating chemical, which with the test loading needs to be filled every 4 months. During the testing, the average consumption of the chemical was 0.181 l/m^3. The septic tank was emptied once during the test, roughly 8 months after the test began.

The electrical equipment of the Clewer* wastewater treatment plant include the fans (2) and the recycling, extraction, surface sludge, and chemical pumps. With the test flow, the treatment plant used 3.77 kWh/day on average, which means that the annual electricity consumption is 1 376 kWh.

The treatment plant started normally after power breakdowns that were part of the testing programme (sepuences 4 and 8). No overflows were observed during the weekly peak flow discharges (= 400 l of wastewater during 6 minutes) that were conducted during normal loading. Operations started normally after a two-week low occupation stress (sequence 5), and no significant weakening was observed in treatment efficiency.

A final inspection was conducted on the plant once the testing was completed, in which the condition of the tanks, connections, and equipment was checked. The treatment plant was found to be in good order, with no deviations or weakening of condition.

Verified:

27 April 2010 Helsinki

Date and time

[redacted]

Responsible manager of the testing, research engineer Riikka Vilpas, SYKE

SUOMEN YMPÄRISTÖKESKUS S Y K E FINNISH ENVIRONMENT INSTITUTE