The possibilities of recycling wash water at Vidinge

by

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Master Thesis number: 2019-08

Water and Environmental Engineering
Department of Chemical Engineering
Lund University

January 2020

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Picture on front page: Salad in bath. Photo by Julia Mauritzon.

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Preface

This report is the outcome of my master thesis and the final part of Master of Science in Environmental Engineering at Lund's University. The project has been a collaboration with Vidinge AB and the Department of Chemical Engineering.

The outcome of the work will hopefully be used at Vidinge to in a larger extent have an understanding and strategy of planning future investments. I want to start to thank the employees at Vidinge for taking care of me and answering my questions.

A special thanks to Michael Cimbritz and Gertrud Persson for many good advices during the work.

Lastly, thanks My Bejmar for your review of the report.

Julia Mauritzon

December 2019, Lund

Summary

Water is a resource of importance and with drier weather around the world, including Sweden, there is a risk of too low levels of water to satisfy for instance households, animals and industries in the future. Fresh-cut fruit and vegetable industries are water intense and almost all process water is used in the washing process. To decrease the water consumption recirculation of wastewater has been proposed. Investigations in possibilities of recirculation in one of the largest processing and packaging industries of salad in Scandinavia, Vidinge, has been done.

The washing lines at Vidinge consist of several steps, including baths and sprinklers, and water is the only disinfectant used at the salad. The water flows in opposite direction to the salad to decrease both water consumption and risk of cross-contamination. Pathogens in the ready-to-eat food is a severe risk to human health and it is of importance to continuously decrease the risk of cross-contamination. Therefore, a disinfection method for removal of microorganisms before the water is recirculated back into the process is required. Today tap water from the municipal water supply is used as process water at Vidinge and in the future a recirculation system of water with drinking quality is required to be used at the last step in the washing line. However, in initial washing steps only treated water is required.

Today Vidinge uses a biological treatment applied during summertime for reduction of impurities in the wastewater. Some of the wastewater is after being treated and disinfected by UV-C reused for irrigation on nearby fields. These treatment methods have shown good potential. However, as wastewater is produced during the whole year a more sustainable treatment system is required.

Measurements of the wastewater have shown too high concentrations of pesticides, chemical characteristics as nutrients, BOD and COD, physical characteristics as turbidity and TS and microorganisms for the water to be recirculated. In a future treatment plant biodegradation is proposed as a secondary treatment step for nutrient removal and reduction of BOD, COD and TOC after the mechanical filtration already applied at Vidinge. For reduction of metals, TSS/TS and chlorinated compounds different filtration techniques as membrane filtration and sand filtration have been investigated. With membrane filtration with low pore sizes (as RO) removal of pesticides and chlorinated compounds are achieved. Adsorption methods (as GAC) have also been reported to be effective.

Disinfection methods as UV-C, US (ultrasound) and AOP (advanced oxidation processes as an energy source (UV) in combination with an oxidant and/or a catalyst) have been investigated in several studies to remove microorganisms in wash water from salad. Both UV-C and AOP have shown great potential to be used in industries. Treatment of UV-C is also a relatively cheap method.

In conclusion, a multifunctional WWTP is required for the water to be sufficiently treated for recirculation and the most important step is disinfection of microorganisms. However, trial in pilot scale of the wastewater at Vidinge and a more accurate costal estimation are required before application.

Sammanfattning

Vatten är en ständigt viktig resurs och med torrare väder runt om i världen, även i Sverige, finns en risk att för låga vattennivåer för att tillfredsställa behoven för bland annat hushåll, djur och industrier i framtiden. Industrier som producerar färsk frukt och grönsaker har hög vattenförbrukning och nästan allt processvatten används i sköljningsprocessen. För att minska vattenförbrukningen har recirkulation av avloppsvattnet blivit förslaget. Undersökningar av möjligheterna för recirkulation av vatten i en av de största process- och förpackningsindustrierna i Skandinavien, Vidinge, har gjorts.

Sköljlinjerna på Vidinge består av flertalet steg, där både bad och sprinklers ingår, och vatten är det enda desinfektionsmedlet som används på salladen. Vattnet rinner i motsatt riktning till salladen för att minska vattenkonsumtionen och risken för korskontaminering. Patogena organismer från färdigmat är en av de mest allvarliga riskerna för människans hälsa och det är viktigt att kontinuerligt förebygga risken för kontaminering. Därför är en desinfektionsmetod för att ta bort mikroorganismer från vattnet innan det recirkuleras tillbaka till processen nödvändigt. Idag används endast kommunalt dricksvatten som processvatten på Vidinge. I ett framtida recirkulationssystem behövs vatten med dricksvattenkvalitet på sista steget i sköljlinjen, medan endast renat vatten är nödvändigt på stegen innan.

Idag använder Vidinge biologisk rening under sommartid för att rena vattnet. En del av avloppsvattnet återanvänds sedan till bevattning genom att först renas och desinficeras med UV-ljus. Dessa reningsmetoder har visat en god reningspotential, men eftersom avloppsvatten produceras under hela året behövs en mer hållbar reningsmetod.

Analyser av avloppsvattnet har visat för höga koncentrationer av pesticider, kemiska egenskaper som näringsämnen, BOD och COD, fysikaliska egenskaper som grumlighet och suspenderande ämnen och mikroorganismer för att vattnet ska kunna recirkuleras.

I ett framtida reningsverk är biologisk nedbrytning förslagen för nedbrytning av näringsämnen och minskning av BOD, COD och TOC efter det mekaniska filtret som redan är installerat på Vidinge. För att reducera metaller, suspenderat material och klorerade föreningar har undersökningar av olika filtreringstekniker, som membran och sand, gjorts. Membranfilter med små porstorlekar (omvänd osmos) har även kapacitet att ta bort pesticider, vilket även gäller för aktivt kol.

För att ta bort mikroorganismer i tvättvatten från sallad har desinfektionsmetoder som UV-ljus, ultraljud och avancerade oxidationsprocesser (AOP, som en energikälla (ex. UV) i kombination med ett oxidationsmedel och/eller en katalysator) undersökts i flertalet studier. Både UV-ljus och AOP har visat mycket god potential för att användas i industriell skala och UV-ljus är dessutom en relativt billig metod.

Sammanfattningsvis behövs ett multifunktionellt reningsverk för att avloppsvattnet ska bli tillräckligt rent för att kunna recirkuleras i processen och desinfektionssteget är viktigast. Innan ett nytt reningsverk tillämpas krävs ett försök i pilot-skala och då kan även en mer exakt kostnadsberäkning göras.

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List of abbreviations

Word	Explanation
AOP	Advanced Oxidation Process
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DBP	Disinfection Byproducts
GAC	Granular Activated Carbon
IE	Intestinal enterococci
NF	Nano filtration
RO	Reverse Osmosis
SGB	Slow Growing Bacteria
TOC	Total Organic Carbon
TS	Total Solids (dissolved, suspended and settleable)
TSS	Total Suspended Solids
UF	Ultra filtration
US	Ultrasound
UV-C	Ultraviolet light
WWTP	Wastewater Treatment Plant

1 Introduction

High water consumption and wastewater formation are the main problems in the food industry and particularly the fresh cutting industry of today (Millan-Sango *et al.*, 2017). It is approximately between 8 and 15% of the industry water that occur by the food industry, and the fresh-cut sector is one of the most water intensive food industries (Ölmez, 2013). In fresh cut industry, the process water is mainly used for washing and sanitation operations. Most of the fruits and vegetables that enter the washing step has not been treated, which implies that a large amount of water is needed to remove hazardous microorganisms, sand and other impurities (Ignat *et al.*, 2015). Investigations have shown that almost 70% of total water intake of a fresh-cut industry is used for washing operations (Millan-Sango *et al.*, 2017). Water consumption together with wastewater volumes range between 2-11 m^3/ton and 11-23 m^3/ton product respectively (Manzocco *et al.*, 2015a). The ranges are dependent on efficiency of machines, process design and size of the plant. The numbers are not only implicating a tremendous waste of water, but also energy since most of the water is used at refrigeration temperature to accomplish good quality of the fresh-cut produced vegetables or fruits (Manzocco *et al.*, 2015a; Grudén *et al.*, 2016).

A worldwide known problem of today is the climate change and the increasing temperature of earth (National Climate Assessment, 2019). The climate change may lead to more extreme weather, and sometimes even drier climates with higher temperatures in periods even in Sweden. The summer of 2018 was characterized by extremely high temperatures without rain, which led to very low groundwater and lake levels in many places in Sweden. This was not only affecting the households and animals, but also industries that are using water in their processes.

Different treatment methods, as chemical and physical, are used in the food industry. The most commonly applied disinfectants are based on chlorine, either as gaseous chlorine or hypochlorite ion (Hägele *et al.*, 2016; Millan-Sango *et al.*, 2016; Smith, 2016). Chlorine is popular mostly due to its low cost, easy use and strong antibacterial activity. However, chlorinated wastewater has a great environmental impact and the chlorinated byproducts that potentially are formed have a negative impact on human health (Anese *et al.*, 2015; Hägele *et al.*, 2016). Alternative methods of disinfection are biological, physical and chemical, stand alone or in combinations (Meireles *et al.*, 2016).

The large consumption of water in the fresh-cut industry in combination with increasing consumption of fresh produce vegetables and the increase of foodborne diseases imply that the problem not only is environmental but also a forthcoming health issue (Mogren *et al.*, 2018). One of the main contamination sources in the fresh-cut industry is cross-contamination (Gómez-López *et al.*, 2014; Anese *et al.*, 2015). This implies that the wash-water may distribute disease-causing pathogens, dirt, organic matter and microorganisms when accumulating due to recycling of water. To be able to recirculate water, it is of high importance not to accumulate impurities.

North of Lund, in Teckomatorp, is one of the largest fresh-cut industry in Scandinavia located: Vidinge Grönt AB (Vidinge) (Vidinge, 2019). Every hour between 6 am and 10 pm 600 kg of washed and precut ready-to-eat salads are produced, packaged and delivered to customers around Scandinavia (Grudén *et al.*, 2016). Every day 200 m^3 wastewater is also produced, all year round.

The wastewater produced at Vidinge and their washing process have been investigated to evaluate methods of decreasing their consumption of water. Today Vidinge is in process of expanding their industry which implicates that several different actors are interested in their processes, consumption and emissions. Some water is recycled in the machines during the washing process and some of the wastewater is reused for irrigation. However, reuse of wastewater in terms of irrigation is not a sustainable solution during all time of the year since farming during wintertime is not possible due to the climate in Sweden. Wastewater treatment should result in a sustainable water treatment all year around, and not only in the summer. The proposed method to decrease the water consumption at Vidinge is by finding recycling water systems so that some of the wastewater can be recycled back into the washing process. This would not only lead to a lower discharge of wastewater and emissions, but also to a lower water consumption of the municipal water system.

1.1 Aim

A recirculated water system is proposed to decrease water consumption, emissions and wastewater discharge at Vidinge. However, it is not known if it is possible to recirculate water in a fresh-cut industry in Sweden. The cleaned water can not contain any unhealthy compounds or microorganisms since the company are producing ready-to-eat food. Therefore, different treatment-methods will be investigated to ensure that no cross-contamination occur and laws and regulations are fulfilled.

The objective with this master thesis is to find suitable method(s) of recirculation of wastewater on a fresh cut-industry and to find the possibilities of recirculation. This is achieved by answering the research question presented below.

1. Is it possible to recycle process water from a fresh cut-industry?
2. What methods are used in fresh cut-industries for wastewater treatment?
3. What regulations and limitations of the process water in the washing process exists and if those are reasonable?

1.2 Scope and limitations

The audience of this report is expected to be Vidinge management, industrial researchers, academics and students with a similar education.

The following limitations of the project scope was identified:

- Wastewater after mechanical filtration at the site was studied for the possibilities.
- Economically, no contribution of money was put on the project including no experimental performance could be performed. This also meant that only analysis done as a routine at the company was investigated to find a reliable method to treat the water.

2 Materials and methods

This master thesis is a project initiated by Vidinge to investigate the possibilities, limitations and solutions of reusing their wastewater. To be able to fulfill the aim within the limitations of the thesis different methods have been used. Firstly, research in literature has been made to evaluate different processes and the possibilities of recirculation. Relevant techniques and regulations were based on the type of industry; a fresh-washing process that delivers ready-to-eat salad. With this information regulations for effluent water from a wastewater treatment plant (WWTP) or influent water to the wash process achieved. Secondly, analyses at Vidinge have been investigated to find the concentration that will go into the treatment plant. Results of UV-C treatment for irrigation were also studied to evaluate the efficiency of such a treatment method. During the work, discussions with different employees at Vidinge and experts in the area have been done to get more inside information, both about the plant and the design but also possible methods of application. The different methods were applied continuously through the writing to have a good communication as different treatment methods, regulations and other information were investigated.

2.1 Literature research

Laws and regulations of water quality in the process, recirculation of water and water emission have been investigated, including regulations of Swedish Food Agency (Livsmedelsverket), EU, German standard (DIN 19650) and Canadian standard (BC; Water Quality Criteria for Microbial Indicators) of irrigation and Swedish Environmental Code (Miljöbalken) (Miljöbalk (1998:808), 2019).

Possible disinfection techniques of recirculation have been studied with different search engines at internet as google scholar and lubsearch (search tool through Lund University). Keywords that have been used include “water”, “reuse”, “recycle”, “fresh-cut”, “salad”, “treatment” and specific treatment methods as “UV”, “US”, “AOP”, “filtration” etc.

2.2 Interviews

Interviews were made with persons at different positions at Vidinge to get an overview of their processes. Interview has also been made with Beatrix Alsanius (Professor in horticulture, SLU Alnarp) who has expertise in the area and been researching at Vidinge. To evaluate the water treatment needed for discharge to the recipient, there have been meetings and discussions with experts from Malmberg and SWECO during the autumn.

2.3 Analysis at Vidinge

Investigations of analysed parameters of process water and wastewater have been performed to evaluate characteristics and efficiency of filtration, biological treatment and UV-C disinfection. Water samples have been taken out by responsible staff at Vidinge, who also measures pH and temperature. The samples are sent to SYNLAB for analysis. Results of analysis are compiled in an excel file by responsible staff at Vidinge.

The type of analyses are dependent on time of the year and on regulations. Microorganisms of the washing line are controlled once a year and of irrigated water once or twice every summer (as it is in use). In connection to an ongoing expansion of the industry measurements of the wastewater have been made. The analysed parameters of the wastewater are chosen based on recommendations from the County Board (Länsstyrelsen) and SYNLAB. The analyses include both chemical and physical characteristics, and some examples are presented below:

- Microorganisms measured in different water includes *Escherichia Coli*, Intestinal Enterococci, Cultivable microorganisms, slow growing bacteria and total Coliform bacteria.
- Physical characteristics of water includes turbidity and TSS/TS.
- Chemical characteristics includes COD, BOD and measurements of nutrients.
- Analyses have also been made of pesticides in the water.

3 Quality requirements of water

It is of importance to maintain a high quality to ensure that no cross contamination occur or that the salad gets negatively affected by the water. Outbreaks of diseases that can be linked to fruit, berries and salad have increased the last decades and in 1996-2006 45 cases were reported (Alsanius, Kristensen and Gustafsson, 2010; Mogren *et al.*, 2018). The pathogens mainly linked to the outbreaks are shiga toxin produced by *Escherichia Coli (E. Coli), Salmonella Yersinia* and *Listeria Monocytogenes* (Mogren *et al.*, 2018).

European and Swedish regulations have been investigated to find limitations of the wash water in fresh-cut processes. Vidinge is today using tap water from the municipal water supply in their fresh-cut process. Regulations of tap water quality is controlled by the Swedish food Agency (Livsmedelsverket) and their definition and limits are presented in chapter 3.1.

At Vidinge some of the water is reused for irrigation with disinfection by UV-C (chapter 7). Last year European Council (Europeiska Kommissionen, 2018) presented a general guideline of irrigation water quality. Other regulations, both German and Canadian standards, of irrigation water have been studied by Alsanius, Kristensen and Gustafsson (2010). The regulations are used to quantify the needs of treatment of the wastewater to be reused.

3.1 Regulations of water in fresh-cut industry

If fresh fruit and vegetables undergo post-harvest washing treatment prior to packing, potable water must be used for final wash of ready-to-eat fresh fruit and vegetables (European Union, 2004). Cleaned non-potable water may be used for initial washing steps (all washing steps before the last step). However, the water should not compromise food safety in the circumstances of its use. Cleaned water should have a separate system to tap water, be clearly identified and not be connected into portable systems.

3.2 Regulations of tap water

The regulations and limit values of tap water of the Swedish Food Agency (Livsmedelsverket, 2015) have been investigated.

The definition of drinking water is:

a) *"all water that is used, either in its original state or after preparation that is intended for (...) food preparation, regardless of origin (...)"* (SLVFS 2001:30, 1§).
b) *"all water that is used in an food producing company for manufacturing, processing, preservation or marketing of goods (...), if not the company can proof the inspection that the quality of the water can not affect the health of finished food"* (SLVFS 2001:30, 1§)
c) *(...)*

The water fulfills the quality regulations regarding cleanness and healthiness of drinking water if it is:

- *“Not containing any microorganisms, parasites or substances in quantity or levels that can represent a danger for human health, and*
- *Fulfills the limits that is presented (...)”* (LIVSFS 2015:3, 7§)

The quality regulations should be observed:

” (...) for drinking water that is used in a food producing company, in the point inside the company where it is used (...)” (LIVSFS 2015:3 8§)

In Table 3.1 limit values of different microorganisms of drinking water quality (Livsmedelsverket, 2015) are presented: Actinomycetes, Cultivable microorganisms in 22°C in 3 days (Cult. Microorg.), Clostridium perfringens, *E. Coli*, Intestinal enterococci (IE), Coliform Bacteria, Micro Sponge and Slow growing bacteria (SGB).

Table 3.1. Microbial limitations of drinking water quality (Livsmedelsverket, 2015).

Parameter	**Limit value for unprofitable at sampling point**	**Limit value for profitable with a mark at sampling point**
Actinomycetes		100 CFU/100ml
Cult. Microorg.		100 CFU/100ml
Clostridium perfringens		Detected (in 100 ml)
E. Coli	Detected (in 100 ml)	
IE	Detected (in 100 ml)	
Coliform bacteria	10 CFU/100ml	Detected (in 100 ml)
Micro sponge		100 CFU/100ml
SGB		5000 CFU/100ml

Regulations and limitations of for instance chemicals and fertilizers of drinking water quality are presented in Table 3.2. Limit values are presented differently depending on whether the water is still profitable (but with a mark) or if it is not profitable for drinking water. Some parameters have both limitations, and some only one of them.

Table 3.2. Limit values of parameter to fulfill drinking quality, exceeded limit values in the wastewater are marked with italic (Livsmedelsverket, 2015).

Parameter	Limit value for unprofitable at sampling point	Limit value for profitable with a mark at sampling point
1,2-dichloroethane	3 µq/l	
Acrylamide	0.10 µq/l	
Aluminum		0.1 mg/l
Ammonium		0.5 mg/l
Antimony	5.0 µq/l	
Arsenic	10 µq/l	
B(a)p	0.01 µq/l	
Benzene	1 µq/l	
Boron	1.0 mg/l	
Bromate	10 µq/l	
Cadmium	5 µq/l	
Calcium		100 mg/l
Chloride		100 mg/l
Chromium	50 µq/l	
Color		30 mg/l
Conductivity		250 mS/m
Cupper	2 mg/l	0.2 mg/l
Cyanide	50 µq/l	
Epichlorohydrin, calculated	0,1 µq/l	
Fertilizers - individual	0.1 µq/l	
Fertilizers -total	0.50 µq/l	
Fluoride	1.5 mg/l	
Iron		0.2 mg/l
Lead	10 µq/l	
Magnesium		30 mg/l
Mangan		0.05 mg/l
Mercury	1 µq/l	
Nickel	20 µq/l	
Nitrate	50 mg/l	
Nitrite	0.5 µq/l	
Oxidizable		4 mg/l
PAH	0.1 µq/l	
pH	10.5	<7.5 >9.0
Radon	>1000 Bq/l	>100 Bq/l
Selenium	10 µq/l	
Smell	Distinct or very distinct	Weak
Sodium		100 mg/l
Sulphate		100 mg/l
Taste	Distinct or very distinct	Weak
Tetrachloroethene and trichloroethene	10 µq/l	

TOC		Determined by inspection authority
Trihalomethanes (THM) - total	100 µq/l	50 µq/l
Turbidity		1.5 (FNU, NTU)
Vinyl chloride, calculated	0.5 µq/l	

3.3 General guideline of irrigation water

Alsanius, Kristensen and Gustafsson (2010) studied German (DIN 19650) and Canadian (BC; Water Quality Criteria for Microbial Indicators) standards of irrigation water, presented in Table 3.4. The large difference between the limits depends on the difference in calculations of the standards. Broadly, DIN-standard is based on one sample, but the BC-standard is based on a geometric mean of 5 samples during a period of 30 days. This would indicate that BC-standard is a more forgiving method when large outbreaks occur, however, the concentration limits of DIN is much greater than the ones of BC.

Table 3.3. Limit values by German (DIN 19650) and Canadian (BC; Water Quality Criteria for Microbial Indicators) standard.

	Limit values by DIN 19650	**Limit values by BC-standard**
E. Coli	200 CFU/100 ml	77 CFU/100 ml
IE	100 CFU/100 ml	20 CFU/100 ml
Coliform bacteria		100 CFU/100 ml
Salmonella	Detected	

2018 a new general guideline of recirculated irrigation water was presented by the European council (Europeiska Kommissionen, 2018). The lowest quality for irrigation of crops that are consumed raw and, in that way, have contact with the water are presented in Table 3.3. The limit values of *E. coli* and *legionella* should be achieved in at least 90% of the samples and none of the samples should override the limit with 1 log-unit to be profitable for consumption. The limit values of BOD_5, TSS and turbidity should be satisfied in at least 90% of the samples.

Table 3.4. Limit values of recirculated water for irrigation (Europeiska Kommissionen, 2018).

Parameter	**Limit value**
E. Coli	10 CFU/100 ml or below detection
BOD_5	10 mg/l
TSS	10 mg/l
Turbidity	5 NTU

Legionella	1000 CFU/l if it is risk of aerosolization in greenhouse

3.4 Classification of recirculated water

To evaluate the regulations and the difference between discharging wastewater or having a WWTP to make the water clean enough to be reused, the Swedish Environmental Code (Miljöbalk (1998:808), 2019) has been studied to investigate if other terms and conditions should be met. In 15 Ch. 1§ in Swedish Environmental Code the classifications of waste and by-product are defined:

1. "Waste is considered an object or substance that the holder gets rid of or is intended or obliged to get rid of."
2. "An object or substance should be considered a by-product instead of waste if the object or substance:
    1. Has emerged in a process where the main purpose is not to produce the object or substance.
    2. Can be used instantly, without any further treatment than the processing which is normal in industrial practice.
    3. Will continue to be used in a health-wise and environmentally acceptable way and which not is in conflict with law or other constitution." (Miljöbalk (1998:808), 2019; Naturvårdsverket, 2019)

Conditions of waste to cease being waste is presented in the directive by European Union (Europeiska Unionen, 2008), Article 6. This is fulfilled when waste has undergone a recirculating procedure and the following cumulative conditions are met:

1. "The substance or object should commonly be used for specific purpose.
2. There is an existing market or demand of substance or object.
3. Substance or object should fulfill the technical requirements of the specific substance or object and existing laws and standards of products.
4. Application of the substance or object will not implicate in negative consequences of environment and human health." (Europeiska Unionen, 2008)

3.5 Guidelines of water to recipient

If the water is to be discharged to the environment instead of recirculated in the process after treatment depends upon several different parameters that needs to be controlled. Some important parameters that should be controlled are: BOD, COD, nutrients as nitrogen and phosphorous. The concentrations in discharged water are most often varying dependent on industry and can be formulated in different ways, both monthly and yearly. The limitations of wastewater from Vidinge to the recipient is under investigation by the Country Board (Johansson, 2019). In discussion with SWECO (Andersson and Levin, 2019) some criteria of emissions to recipient with respect to the industry and the environment were proposed.

- Total phosphorus emissions: 0.045 mg/l
- Total nitrogen emissions of 8 mg/l
- Total BOD_7 of 8 mg/l

However, these limit concentrations are speculations and should only be used as guidelines before the real concentrations are determined by the Country Board.

Effluent requirements on metals were lacking in the regulations of the Swedish Food Agency and therefore classifications of different metals in wastewater to the recipient (Table 3.5) are studied. Very low levels implies no or very small risks of biological effects, seen to the left in the table (Ekologigruppen Eko AB, 2019). The risks are increasing to right where very high levels imply that the metals will affect the survival of the organisms in the water after a short exposure time.

Table 3.5. Classifications of different metals in water (Ekologigruppen Eko AB, 2019).

Classification	Very low levels (µg/l)	Low levels (µg/l)	Moderate levels (µg/l)	High levels (µg/l)	Very high levels (µg/l)
Cadmium	<0.01	0.01-0.1	0.1-0.3	0.3-1.5	>1.5
Lead	<0.2	0.2-1	1-3	3-15	>15
Chrome	<0.3	0.3-5	5-15	15-75	>75
Arsenic	<0.4	0.4-5	5-15	15-75	>75
Cupper	<0.5	0.5-3	3-9	9-45	>45
Nickel	<0.7	0.7-15	15-45	45-225	>225
Zink	<5	5-20	20-60	60-300	>300

4 Quality of salad

Plants, as salad, are naturally colonized by different microorganisms (Alsanius, 2014). The relationship of the colonies is depending on the physical, chemical and biological characteristics of the surface of the salad and the environment. Contamination of fresh produced products may be during the whole production chain, from cultivation, through the washing process to storage and consumption. Temperature, content of organic material and turbidity are examples of important characteristics for the survival and presence of different contaminating microorganisms in water. In a washing process the placement of the washing has an important part, since higher quality of water (drinking water) is required closest to the consumer to reduce the risk of contamination (Alsanius, 2014).

During processing steps as washing and cutting the natural protective barrier of leafy vegetable cells is damaged, implicating that intracellular nutrients are released from the leaf, which may facilitate bacterial growth (Söderqvist *et al.*, 2019). In a study of Grudén *et al.* (2016) samples of salad were taken out in a fresh-cutting process at different events during the washing process. None of the samples showed populations of *Salmonella* spp. or *Campylobacter* spp. Population of total coliforms and *E. Coli* was below 1 CFU/g. IE was above detection limit in 50% of the samples of unwashed salad and in 30% of washed salad. However, it is known that washing without additives has failed eliminating IE. In the report it was also concluded (Grudén *et al.*, 2016) that the microbial load increased when reclaimed washing water was reused and also in the end of the work shift, after 4.5 h.

4.1 Washing water

The quality of salad dependent on quality of water have been discussed with Beatrix Alsanius, SLU Alnarp (Autumn 2019). Alsanius advocates good water quality, equivalent with the quality of drinking water in the last step of the washing line, especially in the sense of decreasing population of microorganisms. This is in line with regulations of washing water quality from the European Union presented in 3.1 (European Union, 2004).

The process design of washing water at fresh-cut salad has been reported to decrease microorganisms on salad by 0.1 to 1 log units, i.e., at most 90% (Söderqvist *et al.*, 2019). However, the washing water will at operation rapidly become contaminated, reaching microbial counts in the same order of magnitude as in the unwashed salad (Manzocco *et al.*, 2015a). The washing water should thus continuously be renewed to decrease risk of microbial growth and vegetable cross-contamination.

For an efficient water usage it is recommended to let the water flow in opposite direction to product (Manzocco *et al.*, 2015b). Application of such solutions can contribute to reduce water needs with more than 30%. Sufficient online monitoring of water characteristics is proposed to control the washing efficiency.

5 Wastewater treatment for recirculation

Wastewater treatment processes can be classified as primary (pretreatment), secondary (biological) or tertiary (biological or disinfection) treatment steps, depending on used method and what type of contamination that should be decreased (Smith, 2016). The treatment steps may also be used differently depending on water. Mechanical filtration and sand trap are practiced at Vidinge throughout the whole year (Matvyeyev, 2019) and will therefore act as primary treatment step in a future WWTP. Thus, the focus will be at secondary and tertiary treatments.

In the research the objective has been to find environmentally friendly water treatment techniques that can be used for recirculation of washing water at Vidinge. Even though chlorine is the most well-used technique for disinfection and recirculation of wastewater today, it is an instable chemical and byproduct formation of trihalomethanes (THMs) and other carcinogenic disinfection byproducts (DBPs) in the presence of organic carbon may occur (Selma *et al.*, 2008; Ölmez, 2013; Gómez-López *et al.*, 2015; Hägele *et al.*, 2016). The byproducts are not only harmful for the environment but also to human health, which is of high importance for a food company as the salad are delivered as ready-to-eat food. However, the use of chlorine as a disinfection method has been decreased in recent years, which can be seen as an increasing awareness of its negative effects (Uslu *et al.*, 2016). To meet the vision of healthiness and a more environmentally friendly image at Vidinge, the focus has been on technologies without chemical input.

The main object of the treatment design is therefore to find safe methods of recirculating the process water and techniques not forming dangerous byproducts (Millan-Sango *et al.*, 2017). Further focus in this study has been on disinfection of microorganisms in the water, due to regulations presented above and the importance of those to not cause harm at the supplier.

A summarized table of the different wastewater treatment steps and methods together with removal parameters are presented in the end, chapter 5.6.

5.1 Characteristics of water

Different analytical methods are used for characterization of wastewaters and sludge (Andersson *et al.*, 2011). Many of the methods have been developed for WWTP and some of the most important will be described.

5.1.1 Chemical

Chemical characteristics are for instance concentration of ionized hydrogen, pH and oxygen demand, which can be measured as chemical oxygen demand (COD) or biochemical oxygen demand (BOD) (Andersson *et al.*, 2011). COD is an indicative measure of the amount of oxygen that can be consumed by reactions in a specific solution. This is for instance applied to quantify the amount of oxidizable pollutants found in surface water or wastewater. BOD is the amount of dissolved oxygen needed by aerobic organisms to break down organic matter for a specific time period (5 or 7 days). Calculations of BOD started in England in the beginning of the last century to measure the amount oxygen in the river that could be used by the wastewater

(Balmér, 2015). Since it took 5 days for the emissions from London to meet the ocean by the river Thames, 5 days of oxygen consumption was used. In Sweden and some other countries BOD_7 is the most common method to calculate BOD today, this only because of the inconvenience of waiting 5 days (implying working on weekends). The ratio of BOD_5 and BOD_7 is dependent on the nature of water but can be set to approximately 1.15-1.18. A mean value of 1.165 was used in this report to be able to compare values (equation 1).

$$BOD_7 = 1.165 \times BOD_5 \quad (1)$$

Nutrients as nitrogen and phosphorous are important for both animal and plant growth, but in too high concentrations these can cause eutrophication (Smith, 2016). An increase in concentration can also lead to enhanced growth of vegetation or phytoplankton and algal blooms, which is disrupting the ecosystem and causing a variety of problems.

Measurements of chlorine (as chlorine residual) would estimate the efficiency of the disinfection or demonstrate the safety of discharge to aquatic systems.

5.1.2 Physical

A physical measurement is for instance total suspended solids (TSS), which is the mass of dried solids remaining on a filter (Andersson *et al.*, 2011). In the measurements total solids (TS) may also be analyzed, this indicates the number of solids, both dissolved and suspended, in water. Physical characteristics also includes metals and temperature.

Another measurement, turbidity, can be done in different ways, which also results in different units including NTU (Nephelometric Turbidity Unit) and FNU (Formazin Nephelometric Unit). Both methods uses light and takes the angle into consideration, however with NTU the light is coming from a tungsten lamp at an angle of 90±30° and with FNU from a NIR with wavelength 860±60 nm at an angle of 90±2.5° (Andersson, 2011). The measurement units relate as: NTU=FNU. In this report both is used due to different regulations and analyses.

5.2 Secondary treatment - biodegradation

The focus at the secondary treatment step is removal of nutrients and other oxidants (Andersson *et al.*, 2011). The treatment step often includes using of a concentrated mass of microorganisms that breaks down organic matter, therefore this step is called biological treatment step.

To decrease the concentration of organic matter and nutrients in wastewater, biodegradation may be used, i.e. a mass of microorganisms to break down organic matter (Smith, 2016). For efficient biodegradation sufficient amount of nutrients such as nitrogen (N), phosphorus (P) and trace elements are needed (Andersson *et al.*, 2011). As the microorganisms multiply in the treatment process a semi-solid slurry called sludge is formed. An excess of sludge is formed continuously, implicating that some must be removed. Biodegradation can be made both aerobic and anaerobic. To estimate the most suitable treatment the "role of thumb" can be followed. This method state that a weight ratio between COD:N:P of 100:5:1 is implicating that an aerobic process is most profitable and a minimum of 250:5:1 is required for an anaerobic.

Smith (2016) is implying that the inlet concentration of BOD_5 is restricted to around 1 kg/m^3 or COD of maximum 3.5 kg/m^3 and the BOD_5 level tend to exceed 1 kg/m^3 in anaerobic processes (presented in Table 5.1). The processes are also different in their treatment result since an aerobic can remove up to 95% BOD but an anaerobic 75-85%. The aerobic process has stable end products (CO_2, H_2O, etc.) but has a high sludge formation, in comparison with anaerobic treatment that is low in sludge formation but forms unstable end products (CH_4, H_2S, etc.).

Table 5.1. Comparison of aerobic and anaerobic water treatment (Andersson et al., 2011; Smith, 2016).

Aerobic	**Anaerobic**
$BOD_5 < 1$ kg/m^3	$BOD_5 > 1$ kg/m^3
Stable end products (CO_2, H_2O, etc.)	Unstable end products (CH_4, H_2S, etc.)
BOD_5 removal up to 95%	BOD_5 removal 75-85%
High sludge formation	Low sludge formation
COD:N:P ratio 100:5:1	COD:N:P ratio 250:5:1

For mixed culture system in aerobic processes mesophilic temperatures (10-40 °C) are most common (Andersson *et al.*, 2011). This since it takes a long time for the microorganisms to be adapted to higher or lower temperatures, even longer than adapting to toxic substances. For anaerobic degradation processes mesophilic (10-40 °C) or thermophilic (>45 °C) temperatures are normally used. However, the temperature ranges used are depending on the incoming water temperature, and the location of the process (climate).

5.2.1 Process

For optimization of nutrient removal often both aerobic and anaerobic stages are used in combination in the WWTP (Andersson *et al.*, 2011). The stages can be designed in different ways depending on the characteristics of the water.

5.3 Tertiary treatment - microorganisms

A risk that will develop as recycled wastewater re-enter the process is microbial contamination. The microbial activity is also seen as one of the main goals to decrease before the water is recirculated back to the washing process at Vidinge. The treatment step in which the focus is removal of microorganisms is called tertiary treatment step. Different disinfection technologies exist based on the exploitation of physical or chemical stresses, applied alone or in combination (Manzocco *et al.*, 2015). However, only a limited amount of the technologies has shown to be applicable and have enough removal efficiency to be implemented in a re-circulating wastewater system in a fresh-cut process.

5.3.1 Filtration

For filtration of microorganisms membrane filters classified as microfiltration (0.05-10 µm), ultrafiltration (UF, 0.001 – 0.1 µm), nanofiltration (NF, 0.0005 – 0.002 µm) and reverse osmosis (RO) (<0.0005 µm) can be used (Allende and Monaghan, 2015). A simplified overview of; pore sizes, required pressures, size ratio of substances to be separated and separation process is presented in Table 5.2. As visualized in the table higher pressures are required when there is smaller pore sizes in the filter (Smith, 2016). The filtration techniques can be effective in means of disinfection by size exclusion. Different configurations including tubes, plate-and-frame arrangements and spiral wound modules is used depending on particle size. In experiments it has been proven that UF after biological treatment can, due to the removal of biomass, in many circumstances remove virtually all BOD (Smith, 2016). However, filtration methods are sensitive to extreme pH. Filters with larger pore sizes than presented in the table are mainly used to reduce soil and plant material before membrane filters to decrease the risk of clogging (Allende and Monaghan, 2015).

Table 5.2. Approximate overview of particle size and membrane separation processes (Smith, 2016; Moran, 2018b).

<table>
<tr><td>Pore size, log scaled</td><td></td><td colspan="2">0.001 µm</td><td colspan="2">0.01 µm</td><td colspan="2">0.1 µm</td><td>1 µm</td><td colspan="2">10 µm</td><td colspan="2">100 µm</td><td>1000 µm</td></tr>
<tr><td>Pressure</td><td colspan="2">10-50 bar</td><td colspan="2">5-20 bar</td><td colspan="2">1.5-10 bar</td><td colspan="3">< 4 bar</td><td colspan="4"></td></tr>
<tr><td rowspan="2">Size ratio of substances to be separated</td><td colspan="2">Solved salts</td><td></td><td colspan="3">Viruses</td><td colspan="2">Bacteria</td><td></td><td>Yeast</td><td></td><td colspan="2">Sand</td></tr>
<tr><td colspan="2"></td><td>Sugar</td><td colspan="2">Pyrogens</td><td colspan="4"></td><td colspan="2">Pollen</td><td colspan="2"></td></tr>
<tr><td>Separation process</td><td colspan="2">RO</td><td colspan="2">NF</td><td colspan="2">UF</td><td colspan="3">Microfiltration</td><td colspan="4">Particle filtration</td></tr>
</table>

A trial run with drum filtration with different pore sizes has been made at another salad washing company by using wash water from production of provencal and chopped iceberg (AR and Hydrotech, 2008). In the experiment concentrations of different impurities in water dependent on filters with pore sizes of 10, 20, 30 and 40 µm were measured and compared with non-filtered water. In both water from provencal and chopped iceberg TSS was halved when filtrated with 20 µm. With the filter of 10 µm the turbidity was halved and TSS decreased with approximately 2/3 for both cases. The experiment also showed that wash water of provencal lettuce contains larger particles than water of chopped iceberg and a decrease in microbial load could only be registered when iceberg lettuce was processed, in other cases could an increase be noticed.

Reverse osmosis (RO) is applied in many recirculating systems for drinking water quality (Guo, Englehardt and Wu, 2014) and to achieve a tolerably smooth treatment while in operate pretreatment including sedimentation or filtration is required.

Sand filtration
Other filtration methods include rapid and slow sand filtration. Sand filtration is the most common method of solids removal in wastewater treatment (Moran, 2018a). Rapid sand filtration is consisting of many different solid removal mechanisms, of which the key is impingement; particles stick to the sand and get stuck to them. However, the filter must be taken offline for backwashing frequently.

Slow sand filter can be fed with pretreated urban wastewater and has the ability of reducing turbidity to <1 NTU and TOC by 10% (Allende and Monaghan, 2015; Moran, 2018b). The technique can improve color, smell and taste of the wastewater and also reduce concentrations of ammonia and manganese. Slow sand filters are simple and cheap to build and run, however, they take up a lot of land. A solution of optimizing the land covered by slow sand filtration is to install a bed of granular activated carbon (GAC) below. In this way is a combination of solids and dissolved organics removal achieved (more about GAC in 5.4.2). The microbial removal in a slow sand filtration is carried out by a complex layer of organisms as bacteria, fungi and algae located in the upper layer on the sand bed called *schmutzdecke* (German for "dirty skin") (Allende and Monaghan, 2015; Moran, 2018a). The sand in the sand filter is only acting as a supporting medium to the *schmutzdecke* which is also physically entrapping the microorganisms and debris. It has been reported to have the ability to remove 95% of coliform bacteria in wastewater from washing of leaves (Moran, 2018b) and have been successful in eliminating protozoan pathogens (Alsanius *et al.*, 2011).

5.3.2 UV-C

UV-C light has been applied as disinfectant of wastewater at food industries for water recirculation (Millan-Sango *et al.*, 2017). UV-C is an antimicrobial technology based on chemical stress that has shown promising result due to the ability to damage microbial DNA, blocking DNA transcription and replication therefore harming the cellular functions which implicate cell death (Manzocco *et al.*, 2015b). The method is also favorable since it is easy to operate, not having any toxic effects and is not forming residues nor halogenated DBP (Ölmez, 2013; Manzocco *et al.*, 2015a). UV is highly dependent on the turbidity due to its limited penetration ability (Gil *et al.*, 2009). For UV to act as a disinfection method of washing water it would it be necessary with filtration to remove suspended solids. The technology is still under investigation and have continuously been improved since the first application of tap water disinfection in 1910 (Manzocco *et al.*, 2015a).

UV-C has been proven to be less effective against some viruses and spores and it also requires a low concentration of particles to provide a good treatment, presented in Table 5.3 (Ölmez, 2013; Allende and Monaghan, 2015; Moran, 2018a). If a minimum dose of 25 mWs/cm^2 is applied, may an 99.999% inactivation of *E. Coli* be provided (Moran, 2018b). It is also required to have an even lower turbidity (< 1 NTU) in the ingoing wastewater than presented in Table 5.3 for drinking water by the United Kingdom's DWI guidelines. The usage of UV-C may affect the environment in a life cycle perspective since the lamp cause mercury waste in the end of usage (Manzocco *et al.*, 2015a). However, new lamps without mercury are under research.

Table 5.3. Maximum contamination for effective UV disinfection (Moran, 2018b).

Description	**Max Contamination**
Transmittance (254 nm, 5 cm)	80%
Turbidity	15 NTU
Color	10 mg/l Pt
Iron	5 mg/l
Manganese	8 mg/l
Calcium	110 mg/l
TOC	4 mg/l

Selma *et al.* (2008) investigated the effect of UV-C treatment (15 W fluence and 253.7 nm wavelength) with filtered wash water of onion and escarole for recirculation purpose. The technique reduced the kinetics of total mesophilic bacteria in onion wash water with 0.6 log CFU/ml after 20 min and 3.0 log CFU/ml after 60 min. Coliform bacteria was reduced with 1.6 log CFU/ml after 20 min and 2.4 log CFU/ml after 60 min. Reduction of yeasts in onion wash water was at the most after 60 min, and had then been reduced with 1 log CFU/ml. In escarole wash water the concentration of mesophilic bacteria, total coliforms and molds were almost stable after 20 min, which had reduced the populations with 3.5, 2.8 and 1 log CFU/ml respectively. However, UV-C treatment was not effective at decreasing neither COD nor turbidity in water.

It has been reported that lower thickness of the wastewater layer exposed to UV-C light will obtain a higher decontamination level (Selma *et al.*, 2008; Ignat *et al.*, 2015). In an experiment wash water from mâché was exposed to UV-C by increasing time, up to 60s (Ignat *et al.*, 2015). The fluence of the sample was equal to 0.1, 0.2, 0.4, 0.6 and 1.2 kJ/m^2. In the lowest fluence *S. enterica* and *Salmonella* where completely inactivated (>5 log reductions) and *L. monocytogenes* was decreased below the detection limit (10 CFU/ml). Doses equal to 0.6 and 1.2 kJ/m^2 were required to decrease *E. Coli* with more than 5 log CFU/ml.

Pulsating light has been tried as a treatment method for recirculation of fresh-cut washing water in even higher fluence (Manzocco *et al.*, 2015a). With 11.0 kJ/m^2 the water was recirculated for up to 5 washing cycles in an artificial, lab-scaled fresh-cut washing process. In the experiment lamb's lettuce was washed in tap water at 8 °C for 2 min with 1:10 (w/v) salad/water ratio and in each cycle a new batch of lettuce was washed with treated water to simulate industrial processing. The fluence reduced native microflora (total viable count, *Pseudomonas* spp., Enterobacteriaceae and total coliforms) and inoculated pathogens (*S. enterica, L. monocytogenes* and *E. Coli)* with 5 and 6 log reductions respectively. The result implicated that the microbial load and log reduction were independent of the number of wash-cycles and corresponding to the salad washed with tap water. However, research has also shown that penetration depth is decreased with increasing number of washing cycles (Ignat *et al.*, 2015). In the 5^{th} washing cycle 63% of the UV-C light was able to reach any particle at less than 0.95 cm water depth. Therefore the thickness during the experiment by Manzocco *et al.* (2015a) was maintained to

0.4 cm. To achieve a reliable reduction of microbial activity, pulsed light treatment should be applied on thin wastewater layer.

5.3.3 Ultrasound (US)

Another disinfection technology investigated for usage within fresh-cut industry is US (ultrasound or ultrasonic) (Elizaquível *et al.*, 2012). US is defined as soundwaves having higher frequency than the human ear can comprehend, around 20 kHz (Jambrak, 2012). High-power ultrasound (HPU) also have been investigated to disinfect process water (Gómez-López *et al.*, 2009, 2014, 2015; Anese *et al.*, 2015). The difference of HPU compared to US is that the former operates at higher frequencies, 20-500 kHz and has higher intensity than 1 W/cm^2. US frequencies at these high frequencies (20 kHz and above) are not toxic and considered safe for both environment and human health (Anese *et al.*, 2015; Gómez-López *et al.*, 2015; Manzocco *et al.*, 2015a). The technologies have not only been investigated for disinfection, but also in recirculating systems (Elizaquível *et al.*, 2012; Anese *et al.*, 2015). The HPU and US-technologies are alone or in combination with other technologies used as disinfection techniques at industrial scale today (Gómez-López *et al.*, 2014).

When disinfecting with US or HPU, two main mechanisms occur causing antimicrobial effects: caviation and sonolysis (Farshbaf Dadjour *et al.*, 2006; Anese *et al.*, 2015; Gómez-López *et al.*, 2015; Millan-Sango *et al.*, 2016). The sonic waves forms caviation bubbles, which when collapsing form local hotspots of pressure (100 – 5 000 bar) and temperature (700 – 4 700 °C) which leads to formation of small vapor-filled cavities. In turn, free radicals, as hydroxyl radicals (·OH), and hydrogen peroxide are formed, which is a result of sonolysis. The permeability of the cell membranes is increased by the produced energy (Meireles, Giaouris and Simões, 2016). This technology can both in combination with other methods and on its own inactivate microbial load, including algae. Unlike UV-C treatment US has other reported advantages including thermolysis, shear degradation, oxidation and enhanced mass transfer (Allende and Monaghan, 2015).

The effectiveness of US is increasing with power input and exposure time (Anese *et al.*, 2015). Investigations have also shown that the efficiency increases even further when a combination with other biocidal treatments such as chlorination, organic acids and UV-C (Ayyildiz *et al.*, 2011; Anese *et al.*, 2015) is used. A study made by Gómez-López *et al.* (2014) indicated that the removal efficiency with US of inoculated *E. coli* O157:H7 in the water from fresh-cut lettuce is increased when combining with heat. The result was strengthened with another study (Anese *et al.*, 2015) where the reduction of total microbial count *of L. monocytogenes*, *E. coli* and *S. enterica* were lowered considerably. As the US-treatment was performed under controlled temperature, it did not exceed 35 °C (Anese *et al.*, 2015). However, as uncontrolled temperature was applied, it increased to 90 °C with continuous US and 65 °C with pulses of US (0.5 sec on and 0.5 sec off). As temperature control was applied, a reduction of total microbial count of 2.8 log CFU/ml was achieved. With uncontrolled temperatures reductions of 2.4 log CFU/ml and 3.2 log CFU/ml for pulses respectively continuously US were achieved. This implies that instead of increasing the US power input and getting the generated heat dissipated, the generated heat can be used in the process to increase the reduction of microorganisms. Gómez-López *et al.* (2014, 2015) demonstrated in their experiments that COD levels does not have any influence of HPU efficiency.

5.3.4 AOP

Advanced oxidation processes (AOP) are in a broad sense when two oxidants or more are used simultaneously (Selma *et al.*, 2008; Gil *et al.*, 2009). The technologies are in-situ generated processes of highly reactive radical intermediates, especially the most powerful oxidant known: hydroxyl radicals (·OH) (Matilainen and Sillanpää, 2010). These radicals can be formed with an energy source (UV-C, US etc.) and primary oxidants (O_2, O_3, H_2O_2 etc.) or catalysts (TiO_2). The radical attacks the target molecules and breaks them to fragments until ultimate mineralization or complete oxidation. To obtain maximum ·OH yield pre-programmed dosages, sequences and combinations of reagents are used. If applied at high dosages, AOP may reduce contaminations and significantly decrease both COD and TOC. The method is sometimes even useful in decreasing biologically toxic or non-degradable toxics such as pesticides.

Due to the combinations of reagents, the focus in further investigations of AOP has been in methods that have been investigated or is used in fresh-cut processes or similar processes for removal of microorganisms.

UV-C and H_2O_2

One of the most common processes to generate ·OH is through UV-C and hydrogen peroxide (H_2O_2) (Selma *et al.*, 2008). Van Os *et al.* (2012) have studied possible methods to enable sustainable recirculation water in the Dutch greenhouse industry. In one study H_2O_2 followed by UV-C was used in a rose cultivation. The result showed that all microorganisms were eliminated, and no pathogens could be found after treatment. The studies by Van Os *et al.* (2012) and other studies have shown no substantial difference of nutrients when greenhouse water was treated with H_2O_2 followed by UV-C. However, iron has been shown to decrease linearly with increasing UV-C dosage.

In another study the combination of UV-C and H_2O_2 was investigated for recirculation of spent lettuce wash water (Alharbi, 2016). It was shown that the UV-C dosage needed to inactivate spores and result in reduction higher than 5 logs was significantly lower when H_2O_2 was used together with UV-C. For example, an UV-C dosage of 10.3 kJ/m^3 had same removal effect on *L. monocytogenes* as UV-C dosage of 1.7 kJ/m^3 combined with 1% H_2O_2. In a similar way the microbial activity was decreased with the combination of UV-C and H_2O_2. The population of *E. Coli* P36 was not detected when usage of UV-C fluence of 10.35 kJ/m^3,1.9 kJ/m^3 and 1% H_2O_2 or 0.69 kJ/m^3 and 2% H_2O_2. A greater reduction was achieved for *Salmonella* as well, fluence of 43.8 kJ/m^3 was needed for non-detection of *Salmonella* without H_2O_2, but when a concentration of 1% was used, 10.35 kJ/m^3 fluence was needed and with 2% only 5.2 kJ/m^3 was needed for the *Salmonella* to be inactivated.

UV-C and O_3

A very common process of producing ·OH is by combining UV-C and ozone (O_3) (Selma *et al.*, 2008). This combination will provide the maximum yield of ·OH per oxidant. In an experiment by Selma *et al.* (2008) the method was tried on filtered wash-water from cut onion and escarole separately. In the experiment an UV-C lamp (253.7 nm wavelength and 15 W fluence) and O_3 with a treatment column, a flow of 80 mg/min was used. After 60 min of treatment of escarole water with O_3 and UV-C, reduction of mesophilic bacteria, total coliforms and molds were 6.6, 4.2 and 1.5 log CFU/ml respectively. Already after 20 min the reductions were 5.5, 4.2 and 1.5 log CFU/ml respectively. With onion water the log reduction of mesophilic bacteria and total coliforms were 3.2 CFU/ml and 4.0 CFU/ml respectively after 20 min and after 60 min 4.0 respectively 5.0 CFU/ml. No yeasts were observed after 20 min treatment of the onion water. In this trial COD and turbidity of onion wash water were reduced 12-13% and 81% respectively after 60 min. The result can be compared to the result of disinfection with UV-C alone, presented above.

US and UV-C

It has been reported that a combination of US with other oxidation methods results in higher rates of oxidation and mineralization of organic matter (Matilainen and Sillanpää, 2010). David Millan-Sango *et al.* (2017) investigated the effect of treating fresh-cut water by US, UV-C and a combination of US/UV-C. The efficiency was determined in terms of inactivation of microbes, reduction of TSS, color and COD. The water was recirculated in a closed loop-system which consisted of an US device (26 kHz) and a UV-C light system (1.64 kJ/m^2) for 30 min. The result showed that the efficiency increased when the technologies were combined in terms of microbes (reduction up to 3.58 ± 0.39 log CFU/ml), TSS (reduction up to 30%) and COD (reduction up to 79%). However, for color reduction the numbers where similar of US and US/UV-C (reduction of approximately 43%).

US and TiO_2

In further studies the addition of titanium dioxide (TiO_2) to US-treatment has been investigated (Gómez-López *et al.*, 2015). Addition of TiO_2 did not significantly improve the inactivation of *E. Coli* in the result presented by Gómez-López *et al.*, (2015). However, other experiments made by Farshbaf Dadjour *et al.* (2006) indicates the opposite, that the addition of TiO_2 increases the efficiency of US. The studies differ due to concentration and particle size of TiO_2, in Farshbaf Dadjour *et al.* (2006) study 2 000 g/l respectively 2 mm in diameter was used compared to the study by Gómez-López *et al.* (2015) where 5 g/l respectively 20-40 nm in diameter was used.

5.4 Tertiary treatment - pesticides

Pesticides have been used over the last 50 years to control weed (herbicides), insects (insecticides), fungus (fungicide) etc. Residues of pesticides in water has been proven to have negative health effects in very small concentrations (pg/l or ng/l) (Plakas and Karabelas, 2012). Those may lead to cancer, genetic malformations, neuro-developmental disorders and damage of immune system. For water to reach the quality of drinking water set by Swedish Food Agency (Livsmedelsverket, 2015) limits of 0.1 µg/l for individual pesticides and 0.5 µg/l for the sum of all detected pesticides should be met (presented in Table 3.2). In contrast to the Swedish Food Agency, the residue limits of pesticide set by WHO (World Health Organization) and USEPA (U.S. Environmental Protection Agency) are dependent of the toxicity of the pesticide and the limits for different residues are individual (Plakas and Karabelas, 2012).

5.4.1 Filtration

RO has been proven an excellent performance in removing pesticides, including chlorinated organophosphorus and hydrocarbons (Plakas and Karabelas, 2012).

5.4.2 Adsorption

Adsorption may be used as a primary or tertiary treatment step for removal of organic compounds, metals, color, taste and/or odor (Smith, 2016; Moran, 2018b). The most common used absorbent is GAC, although synthetic resins are also used. As described earlier GAC can be integrated with slow sand filtration to obtain a combined filtration and adsorption medium and to optimize the land used for the treatment. The removal of organics by GAC may also, in some sense, be biological(BAC) (Moran, 2018a). However, regeneration of saturated adsorbents may cause carbon losses of approximately 5-10% (Smith, 2016).

GAC is an effective method of removal of pesticides, were pollutions are adsorbed to the medium water (Ormad *et al.*, 2008). This implies that the pesticides are not destructed, only removed to another medium, introducing a new problem of pollution (Plakas and Karabelas, 2012).

In an experiment (Ormad *et al.*, 2008) effectiveness of GAC was investigated. The study showed GAC to be very effective and was obtaining an overall average removal percentage of 75% by means of pesticides. In practically all cases removal percentage of 60% or above was obtained. TOC was reduced with 19%. In a combination of peroxidation by ozone and GAC a removal percentage of 90% has been achieved (Ormad *et al.*, 2008), were above 60% removal of pesticides was achieved in all cases and TOC removal was 27%.

5.4.3 AOP

Degradation of pesticides has successfully been achieved with AOP methods as H_2O_2 followed by UV-C at rose cultivation (Van Os *et al.*, 2012). The result differed depending on different pesticides and with different UV-C and H_2O_2 dosages. A few pesticides were removed (or transformed) completely, other decreased in concentration. As for example it was reported that imidacloprid (insecticide) mainly was decreased by UV-C and cyprodinil (fungicide) mainly by H_2O_2.

5.5 Tertiary treatment – chlorinated compounds

A treatment method for byproducts of chlorine may be required for recirculation of wastewater. Technologies that has shown at least partially effective results includes GAC, ozonation, biofiltration and membranes (especially RO and NF) (Jiang and Adams, 2006). Methods of GAC and membranes have, for example, been reported to be effective in drinking water plants for removal of chloro-s-triazines.

5.6 Summary of treatment methods

Previously discussed methods for water treatment and recirculation are summarized and presented in Table 5.4. If the chosen method has capacity to remove a specific impurity this is marked with “X”. Notice that the efficiency of the removal is not considered, only if the method has a capacity of removal, investigated in this chapter.

Table 5.4. Summary of treatment methods and removal potentially presented in chapter 5.2-5.5.

Removal/ Method	**Nutrients**	**TSS/ TS**	**COD**	**BOD**	**TOC**	**Metals**	**Pesticides**	**Chlorinated comp.**	**Microorg.**
Biodegradation	X		X	X	X				
Filtration > 1 µm		X							
UF		X		X		X			X
NF		X		X		X	X	X	X
RO		X		X		X	X	X	X
Rapid sand filtration		X			X	X		X	X
Slow sand filtration		X			X	X		X	X
Adsorption		X			X		X	X	
UV							X		X
US									X
UV + O_3			X						X
UV + H_2O_2							X		X
UV + US		X	X						X
US + TiO_2									X

It can be seen in Table 5.4 that biodegradation is the only method discussed that has capacity of nutrient removal. TSS/TS is removed by different methods and especially different filtration methods. However, the efficiency depends on the size of filtration if no coagulation agent is used. Usage of filtration is necessary to remove metals, pesticides and chlorinated compounds. Adsorption with for instance GAC has been proven to be effective of removal of pesticides, and with this method will some of TSS/TS, TOC and chlorinated compounds also be decreased.

The most critical impurity to be removed, microorganisms, can be decreased with several different methods (Table 5.4). It is of importance to find a disinfection method, as UV, US, RO and different AOPs, to remove the microorganisms and/or get drinking quality water. Even though some other methods have been proven to remove microorganisms, they are not used as disinfection methods for the water to be recirculated.

5.7 Disinfection methods of salad

In other studies, the reduction of water usage has been investigated with usage of e.g. UV-C disinfection of the salad instead of water alone (Chun, Kim and Song, 2010). The result of UV-C treated ready-to-eat salad has shown that *E. Coli* in salad treated with dosage of 8 kJ/m^2 was decreased to 2.39 log CFU/g, compared to the untreated 4.55 log CFU/g. The treatment yields a reduction of 2.16 log (Chun, Kim and Song, 2010), compared to 1-2 log reductions with water disinfection (Söderqvist *et al.*, 2019). Irradiation of UV-C was also affecting the storage time of the ready-to-eat salad since the microbial growth during storage time was decreased (Chun, Kim and Song, 2010). It also has been reported that the disinfection by UV-C is more effective in reducing total aerobic bacteria at watermelons than usage of chlorine or ozone. Other sources (Gil *et al.*, 2009) claim that UV-C has no effect on surfaces, neither on machinery nor on leaves.

It has been reported that the total bacteria counts are similar when the produced salad are washed with tap water as when another sanitization method is used (Gil *et al.*, 2009). It was also observed (Gil *et al.*, 2009) that the quality of the process water impacted the effectiveness of washing and that the risk of cross-contamination not is eliminated by using large quantities of water. In the washing process the inoculation is important; dip inoculation has been observed to be the best method, followed by spot and spray inoculation for different treatments.

Disinfection methods such as ozone, chlorine, electrolyzed water and H_2O_2 at fresh fruit and vegetables are not permitted under Swedish legislation (Grudén, Mogren and Alsanius, 2016). Today therefore only tap water is used in the green-wash industries in Sweden.

5.8 Costs

WWTPs are an investment for the company and will cost money. The total cost is highly dependent on treatment method chosen, size and placement. Different factors contribute to the costal estimation of a wastewater treatment and recirculation system (Kumar, Groth and Vlacic, 2015). There are not only specific costs for different methods, but also pipes, pumps, location and energy consumption to take into consideration. To calculate the costsbot capital costs and operational costs should be estimated.

5.8.1 Capital cost

Capital cost includes all cost items that is directly related to the establishment and upgrading of the plant (Kumar, Groth and Vlacic, 2015).

1. **Costs of land and building** - Land is necessary to build a plant, as well as a building to house auxiliary processes, control center and other objects of the treatment plant.
2. **Water intake and distribution system -** How far the treatment plant will be from the discharge and from the fresh cut as well as from where the recirculated cleaned water will be connected to the washing process again. Depending on distance different pumps and pipes are needed. Amount of water to be treated is also determine the size of the plant.
3. **Energy Consumption** - Electrical and process control systems can be kept simple or made intelligent dependent on the plant requirement.
4. **Material depending on treatment method** – This includes membranes if filtration is chosen, lamps in UV-C treatment, etc.

5.8.2 Operational cost

Operational cost consists of costs incurred when the construction and development of the plant is finished (Kumar, Groth and Vlacic, 2015). This includes ongoing costs which are frequently transacted but not capital cost. The operational cost is often calculated annually and may vary and change with time.

1. **Energy –** Almost all processes, from feed to discharge and pumps are directly or indirectly reliant on energy.
2. **Chemicals –** Chemicals can be used for various techniques for example coagulation or sanitation. This is depending of incoming and outgoing quality of water and strategy of plant.
3. **Maintenance -** Including costs of maintenance and reparation to improve integrity.
4. **Labor –** To ensure quality uptime, reliability and regulatory compliance standards are maintained to operate the plant.
5. **Waste disposal –** Waste is generated independent of treatment techniques. The waste must be treated and discharged in compliance with environmental regulations.
6. **Facility management costs –** Including building maintenance, utilities and on-going cost to maintain safe and orderly facility.

5.8.3 Application

An approximate calculation of costs of a new treatment plant is, as mentioned, affected by many different components. For the application at Vidinge is for example the size of the plant, amount of water to be treated, required quality of the recirculated water, inflow quality, maintenance and (perhaps) extra personnel factors to take into consideration to get an overview of the total price.

Treatment methods
From studies (Guo, Englehardt and Wu, 2014; Plumlee *et al.*, 2014) the order of costs of treatment methods have been investigated. These showed that the capital costs of RO or NF almost is twice as expensive as microfiltration or UF. The capital cost of disinfection by UV-C was in turn 10 times less than microfiltration or UF and very low in comparison with RO, NF, microfiltration and UF. Adsorption processes as GAC and BAC have been shown to be in a price range between RO/NF and microfiltration/UF. However operational costs are lower.

Energy consumption
The energy consumption of discussed methods is also different. In an example presented by Millan-Sango *et al.* (2017) the energy requirement was calculated to compare three different methods: US, UV-C and US/UV-C (Table 5.5). The cost is calculated with numbers from Kundkraft (2019), approximating 0.693 SEK/kWh, to get an updated approximation of electrical cost in Swedish SEK. The authors (Millan-Sango *et al.*, 2017) considered the operational costs of all methods as low even though the cost of using US is more than twice as large as UV-C alone. Although, the cost should be investigated further and in larger scale before it can be considered by the industry.

Table 5.5 Energy requirement and costs for UV-C, US and microfiltration (assuming 0.693 SEK/kWh) (Millan-Sango *et al.*, 2017; Kundkraft, 2019).

Technology	**Electrical consumption (kW/h)**	**Cost (SEK/h)**
US	0.107	0.074
UV-C	0.040	0.028
US/UV-C	0.114	0.079

In a study by Plappally and Lienhard V (2012) energy consumption of different disinfection methods in conventional surface water treatment plant were investigated. They calculated the energy range of UV- C to 0.01-0.05 kW/h, which is in line with the result of Millan-Sango *et al.* (2017). The electrical consumption of microfiltration or UF was proposed to be 0.18 kW/h, which together with the approximation from Kundkraft (2019) is calculated to 0.125 SEK/h. The electrical energy consumption of RO in Brackish water has been reported to be 1.0-2.5 kW/h 2010 (Plappally and Lienhard V, 2012).

6 Process water at Vidinge

The water supply of Vidinge is tap water from the municipal water authority. At the industry area the water is divided into two applications: domestic water and process water. The pipe systems are divided as well, and the domestic water is after usage lead to a municipal treatment plant, unlike the process water that is treated at Vidinge. The process water is mainly used for washing the salad and some for cleaning of facilities and machines. In the washing process of Vidinge water only (no chemicals) is used to reduce the bacterial load.

6.1 Washing process

The washing process at Vidinge consist of different steps depending on the kind of salad processed. The two lines that was studied for possible water recirculation are *Baby leaf line* and *Big cutting line*. The *Baby leaf line* handles and washes the salad that does not need to be chopped, including baby leaf, mâché, rucola and mangold. The *Big cutting line* handles and washes the salad that needs to be chopped including iceberg lettuce, romaine and kale. Both lines include the washing steps presented in Figure 6.1. The untreated salad is first washed in Bath 1 with recycled water from Bath 2. In Bath 2 the water is washed by tap water through 7 sprinklers. The sprinklers are spraying water on the salad in approximately 3 l/min in total. It also exists sprinklers at the first baths, to be used when the raw material is extremely earthy. The system is filled up with water automatically to keep the set volume, so the flow of water through the baths is not knowable. To keep the quality of salad during the washing steps water temperatures of 2-4 °C are used.

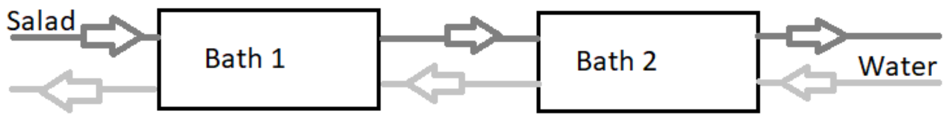

Figure 6.1. Schematic picture of washing lines at Vidinge.

Baby leaf line consists of a third step (Figure 6.2) where the salad is sprayed with water a second time. The third bath is a closed loop system where water from bath 3 is mixed with tap water. The leafy vegetables are then drained and dried before packaging and finally stored and delivered to the customer.

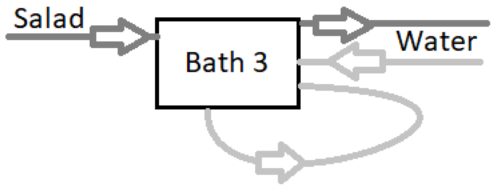

Figure 6.2. In the "Baby leaf line", one third step exists. In this step water is sprayed on the salad. The salad is going on a ramp which the water flow through and into bath 3. This is a closed water system and the water is recirculated within it.

The washing lines are run in teams by 2 shift a day. In both lines the machine systems are drained and filled up with fresh water every 4.5 h during production (Figure 6.3). However, the sort of salad is not only switched at these events, implicating that salad of different sort or origin can use the same wash water. Both lines are cleaned once, by the end of the day (Figure 6.3).

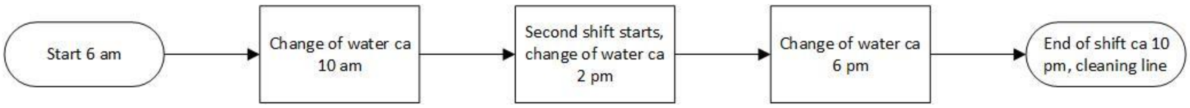

Figure 6.3. Schedule of the water and personnel shift in both lines at Vidinge.

Vidinge is expanding their activity and parts of the company will in a close future move to new facilities (including *Baby leaf line* and *Big cutting line*). The wastewater treatment will be improved and many of the machines will be replaced with more effective ones that are more automatic and lower in water consumption per weight mass of salad. Nevertheless, the total requirement of water will increase since an increased demand can be seen in the future. The company expect an increase to around 400 m^3/day from todays 200 m^2/day in a couple of years (Tomas Johansson, 2019).

6.2 Measurements of microorganisms in process water

Transmission of foodborne pathogens to the consumer cannot be totally avoided (Grudén, Mogren and Alsanius, 2016). During the washing step macroscopic contaminations as soil and bird droppings are removed. Moreover, the washing process will also reduce the leaf-associated microbiota and eliminate foodborne pathogens.

Analyses have been made in the baths that should contain the cleanest wash water (Bath 2 in Figure 6.1 and 3 in Figure 6.2) after 4.5 h to evaluate how much impurities that is recirculated to the next bath in the wash watering system. Analyzed microorganisms in the baths from year 2016 – 2019 are presented in Table 6.1.

Table 6.1. Microorganisms in process water in the lines after 4.5 h of washing without switching water in the machines.

Date	Product line	Bath	Cultivable micro-org. (CFU/ml)	SGB (CFU/ml)	Coliform bacteria (CFU/ml)
2016-01-13	Baby leaf	3	>300 000	>5 000	260
	Cutting	2	>300 000	>5 000	>10 000
2016-08-03	Baby leaf	3	23 000	>5 000	5 700
	Cutting	2	20 000	>5 000	5 100
2017-01-30	Baby leaf	3	>300 000		36
	Cutting	2	58 000	>5 000	640
2017-08-02	Baby leaf	3	220 000	>5 000	330
	Cutting	2	100 000	>5 000	>10 000
2017-12-22	Baby leaf	2	>5 000	>300 000	330
	Baby leaf	3	>5 000	190 000	9
2018-01-04	Baby leaf	3	260 000	>5 000	710
	Cutting	2	14 000	>5 000	670
Ranges	***Baby leaf***	***3***	***23 000 – >300 000***	***>5 000 – 190 000***	***9 – 5 700***
	Baby leaf	***2***	***>5 000***[1]	***>300 000***[1]	***330***[1]
	Cutting	***2***	***14 000 – >300 000***	***>5 000***[1]	***670 – >10 000***

Measurements in Table 6.1 were made with consideration to some indicator organisms, namely Cult. Microorg., SGB and total coliform bacteria. Measurements have been done at in total 6 different occasions at the lines. Samples have been taken 6 times from bath 3 in *Baby leaf line*, 5 times from Bath 2 in *Cutting line* and 1 time from Bath 2 in *Baby leaf line*. Ranges of the analyses are presented in bold italic at the end of the table. In many cases the detection limit of the analyzing method is overridden. It can be concluded that populations of microorganisms exist in the cleanest baths, which implies that microorganisms will be transferred to the first bath in the washing process.

The increased population of microorganisms in water is well known by employees, however, it is not seen as a problem since the populations are decreased to a profitable amount at the salad. It is not all measured microorganisms that may pose threats to the health, for instance presence of *E. Coli* or *Salmonella* are most problematic. The measurements of the salad are made more often than the measurements of the water.

The populations of different microorganisms are also controlled after cleaning of machines and facilities. Directly after cleaning and before the process starts the water should be at drinking quality.

No measurements of microorganisms transferred by the leaves from Bath 1 to Bath 2 have been made. Neither has it been investigated in accumulated microorganisms in Bath 1.

[1] Where no range of values is showed, too few analyses have been made for a range to be calculated.

7 Wastewater treatment at Vidinge

In the WWTP at Vidinge today, mechanical treatment with screens of 5 mm in diameter are used to separate larger particles as soil and leaves from the water (Figure 7.1). The water is then flowing to a pond where it settles before it is sprinkled out on a specific area where, since spring 2019, biological treatment occur (Tomas Johansson 2019). The object with the biological treatment is reduction of BOD and nutrients (especially nitrogen (N)). These are brought up by for example clover and willow at the field or settling in the earth/ground (Persson, 2019). The ground under the field is drained and the wastewater after biological treatment is lead to a second pond where the water may settle even further. In summertime the water is used for irrigation on nearby fields where for instance salad is grown. UV-C treatment is applied at the wastewater to decrease microbiological activity before irrigation (Denys Matvyeyev 2019). Some water is flowing by overflow from Pond 2 to Väla stream. With applied biological treatment the flow in Väla stream also is better preserved during summer due to less pumping of ground water than before (Persson, 2019).

Another positive effect of biological treatment is that infectious agents from the process water will be biologically purified (Persson, 2019). The concentration of infection agents is expected to be reduced by at least 2 log (99%) and the purification effect of biological treatment has been documented in several studies.

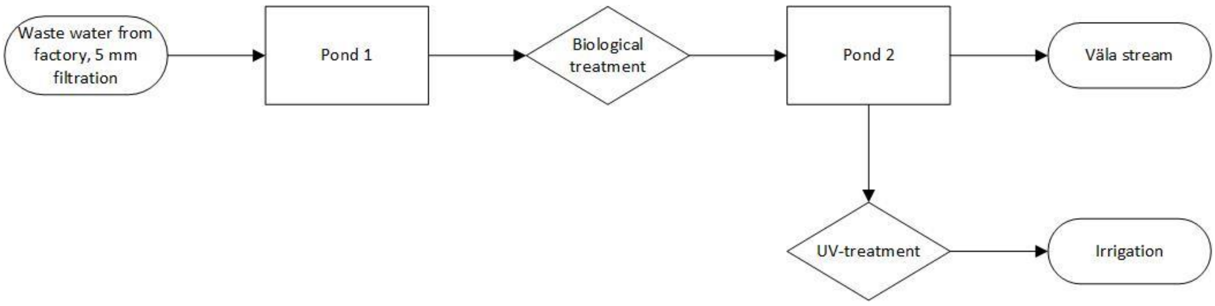

Figure 7.1. Simplified flow chart of WWTP at Vidinge today.

In the new WWTP (Figure 7.2) the mechanical treatment will be improved and screening/filtration in 2 steps: 0.75 mm and 0.25 mm will occur. In between the filtration steps the treatment will also contain a sand trap, where solids are separated from the water. Water will then be collected in a buffer tank where a controlled waterflow to the pond is applied. It is from this point of the treatment further technologies are required to get an even more purified water. The objective is also to recirculate parts of the water to be used in the washing process. In summertime biological treatment will still be operative before water flows to the second pond to be used for irrigation or by overflow to Väla stream.

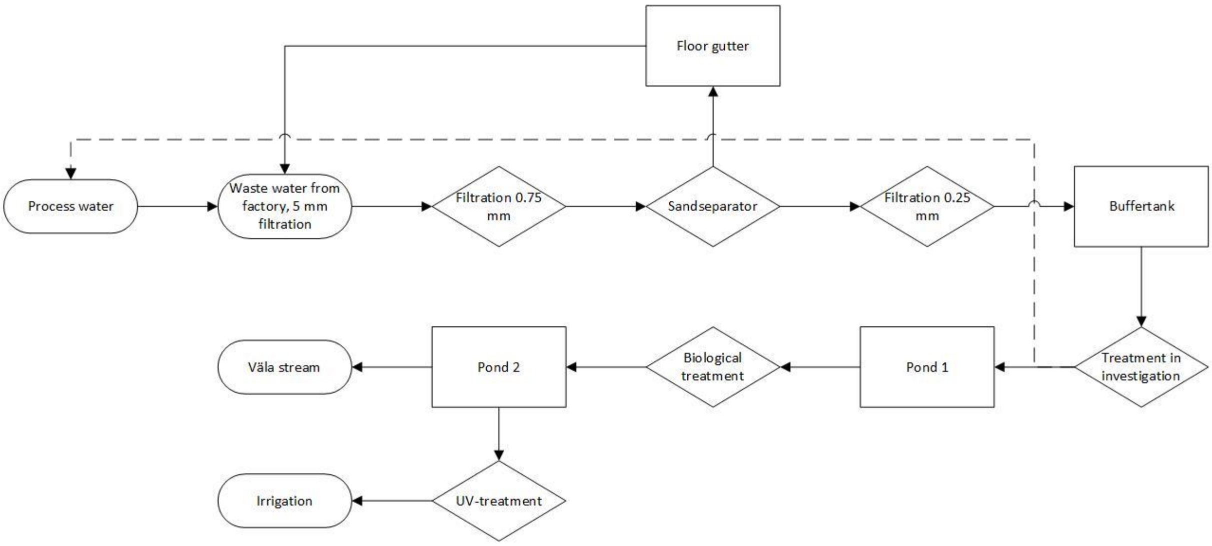

Figure 7.2. Simplified flow chart of future WWTP at Vidinge.

Some of the water from the sand trap step will be led to floor gutter (Figure 7.2). A low flow of water will be applied in the floor gutter during the whole process day and residues that falls to the floor (as plastics and salad) will be transported in this.

Even though a large part of the wastewater is used for irrigation there is interest from the management to lower the water consumption and increase exploitation of water within the plant by recirculation (dashed arrow in Figure 7.2). It is important to keep in mind that the irrigation and the biological treatment only is applicable half of the year, but the washing process of different salad is all year. For that reason and to increase the sustainability of the company by recirculating water, different treatment techniques are investigated.

7.1 Measurements of wastewater at Vidinge

During the last years analyses of chemicals, nutrients, pesticides and other impurities have been made in wastewater of the washing process at Vidinge. In the following paragraph mean values of these are presented to get an overview of impurities. The results can be compared with Table 5.2 where different substances are presented with pore sizes of filtration. However, the filtration applied at Vidinge is larger than the largest pore size presented in the table.

7.1.1 Characteristics of wastewater

In Table 7.1 some important parameters of wastewater quality indicators to asses suitability of wastewater for disposal, treatment or reuse are presented. The values are means of measurements made twice a week March – August 2019. Indicators are both chemical and physical characteristics of the water. The mean values are compared with the limitations of drinking water set by the Swedish Food Agency (Table 3.2), and the values that overrides the limitations are marked in *Italic*.

Table 7.1. Measured mean values March – August 2019 in WW before Pond 1 (untreated) and before Pond 2 (after biological treatment). The values marked in italic is overriding the limitations of drinking water set by the Swedish Food Agency.

Chemical	Mean in WW before Pond 1 2019	Mean in WW before Pond 2 2019
Aluminum	*0.29 mg/l*	0.095 mg/l
Ammonium	*4.4 mg/l*	0.42 mg/l
Ammonium nitrogen	2.2 mg/l	0.51 mg/l
Arsenic	0.6 µg/l	0.017 µg/l
Barium	27 µg/l	72.1 µg/l
BOD7	364 mg/l	5.8[2] mg/l
Cadmium	0.2 µg/l	0.09 µg/l
Calcium	27 mg/l	92.4 mg/l
Chloride	40.3 mg/l	44.8 mg/l
Chromium	12 µq/l	1.0 µg/l
Cobalt	0.3 µq/l	3.05 µg/l
COD	644 mg/l	84.1 mg/l
Color	*72 mg/l Pt*	*227.5* mg/l Pt
Conductivity 25 °C	36 mS/m	65 mS/m
Cupper	110 µg/l	4.35 µg/l
DOC	200 mg/l	29.4 mg/l
Fertilizers - individual	Max *1.44* µq/l in WW (Table 5.3)	Not measured
Fertilizers -total	*Compare individual*	Not measured
Fluoride	*14 mg/l*	0.7 mg/l
Phosphate phosphorus	972 µg/l	189 µg/l
Iron	*0.4 mg/l*	*5.1* mg/l
Lead	1.5 µq/l	1.1 µg/l
Magnesium	2.9 mg/l	4.6 mg/l
Mangan	0.04 mg/l	0.8 mg/l
Mercury	<0.1 at al samples	<0.1 at al samples
Nickel	5 µq/l	10.6 µg/l
Nitrate	1.5 mg/l	8.4 mg/l
Nitrate + Nitrite-nitrogen	2 mg/l	0.28[3] mg/l
Nitrite	*4.7 mg/l*	0.053 mg/l
pH	7	7.1
Sodium	22 mg/l	31.5 mg/l
Strontium	55 mg/l	0.23 mg/l
Sulphate	12 mg/l	36 mg/l
Total - N	15 mg/l	2.9 mg/l
TOC	240 mg/l	30.3 mg/l
Total - P	3.0 mg/l	0.51 mg/l
TSS	80 mg/l	12.9 mg/l
Turbidity	53.5 FNU	9.5 FNU
Zinc	100 µq/l	100 µq/l

[2] Values measured below detection limit (<3) calculated as 1.5 to get mean value.
[3] Values measured below detection limit (<10) calculated as 5 to get mean value.

7.1.2 Microorganisms in wastewater

Measurements of *E. Coli*, Coliform bacteria and IE in wastewater have been made June – August 2019. In total 17 measurements have been done, and the results are summarized in Table 7.2 with ranges and mean values. The ranges are large for all measured microorganisms. It can be concluded that the highest concentration is of Coliform Bacteria.

Table 7.2. Ranges and mean values of presence of E. Coli, Coliform Bacteria and IE in wastewater.

	E. Coli **(CFU/100 ml)**	**Coliform Bacteria (CFU/100 ml)**	**IE (CFU/100 ml)**
Range	<10 – 7 500	12 000 – 51 000	140 – 45 000
Mean	2 831	32 000	9 214

7.1.3 Pesticides in wastewater

Another impurity present in the wastewater are pesticides that comes from the wash off from the salad. Analyses of pesticides in the water have been made both in the pipe and in pond 1. The pond is acting as a buffer, where all wastewater is collected before further treatment. Measurements of the wastewater (from pipe) have been made May 2019 – August 2019 and of pond 1 October 2018 - April 2019. Analysis of samples from the different places have never been made at the same time. During the year there are some differences within the production. In summertime is the largest quantity of salad from Sweden and the production is very large and in wintertime basically no salad is from Sweden and the production is much lower.

The substances with concentrations above the detection limit 0.05 µg/l in the wastewater or the pond, are represented below in table 7.3. To calculate mean concentrations of pesticides, 0.025 µg/l was used for all measurements below the detection limit.

Table 7.3. Pesticides were a concentration above detection limit for drinking water (0.05 µg/l) were detective in both wastewater in pipe and in Pond 1. Measurements are made in pipe May – August 2019 and pond October – April 2019.

Substance	Max WW (µg/l)	Max Pond 1 (µg/l)	Mean WW (µg/l)	Mean Pond 1 (µg/l)	Guide values (µg/l)
Acetamiprid (insecticide)	1.17	0.076	0.099	0.038	
Azoxystrobin (fungicide)	0.169	0.253	0.037	0.098	0.9
BAM (2,6-dichorben-samide) (herbicide)	0.129	<0.05	0.039	0.025	
Boscalid (fungicide)	0.328	<0.05	0.060	0.025	
Chloridazon desphenyl (herbicide)	1.44	4.26	0.32	2.033	10
Cyprodinil (fungicide)	<0.05	0.055	0.025	0.029	0.2
Difenoconazole (fungicide)	<0.05	0.054	0.025	0.029	0.02
Dimethomorph (fungicide)	<0.05	0.178	0.025	0.058	2
Diuron (herbicide)	0.073	<0.05	0.028	0.025	
Fenhexamid (fungicide)	0.072	0.115	0.028	0.052	10
Fenpropimorph (fungicide)	0.149	<0.05	0.033	0.025	0.2
Fluaxifop (herbicide)	0.128	<0.05	0.031	0.025	
Imidacloprid (insecticide)	0.098	<0.05	0.030	0.025	
Mandipropamid (fun-gicide)	1.23	3.34	0.15	1.225	
Metamitron (herbicide)	0.105	<0.05	0.030	0.025	10
Propamocarb (fungicide)	0.621	1.57	0.106	0.342	90
Propiconazole (fungicide)	0.94	<0.05	0.082	0.025	7

Propyzamide (herbicide)	0.10	<0.05	0.030	0.025	10
Pyrimethanil (fungicide)	0.073	<0.05	0.028	0.025	30
Tebuconazole (fungicide)	0.054	<0.05	0.027	0.025	
Terbuthylazine Desethyl (DETA) (herbicide)	0.152	<0.05	0.033	0.025	0.02

The majority of the pesticides are metabolites of other substances and the type of pesticideis presented in parenthesis in Table 7.3. Investigations have shown that some of the pesticides that has concentrations above the detection limit are degradation products of pesticides banned in Sweden. For example BAM is a degradation product of dichobunid (herbicide) that is forbidden in Sweden since 1990 (Czulowska, 2011). Terbuthylazine Desethyl is a degradation product of Terbuthylazine which has been forbidden in Sweden since 2003. However, both degradation products were found in streams in Skåne in investigations made by Czulowska (2011). Pyrimethanil also is a forbidden pesticide, which created headlines when it was found in Swedish raspberries 2017 (Lindhe, 2017).

In Table 7.3 especially one fungicide, Mandipropamid, and one herbicide, Chloridazon desphenyl, has been detected and quantified in high concentrations compared to other pesticides. The mean of both pesticides in the pond is above 1 µg/l.

A column with guide values of pesticides in surface water by Swedish Inspection of Chemicals (Kemikalieinspektionen, 2016) are summarized in Table 7.3. As can be seen in the table it is only two pesticides that are overriding the limit values at any time: Difenoconazole and Terbuthylazine Desethyl. However, the result of these cannot be totally trustful since the detection limit is higher than the guide values. These limits are also the lowest presented and marked as "preliminary" at the webpage of Swedish Inspection of Chemicals. Recommendations of priority substances in Sweden is compiled in the guidance "Monitoring of priority environmental hazardous substances listed in the Water Framework Directive" (Naturvårdsverket, 2008).

7.1.4 Residues of cleaning water

In the end of each production day (at ca 10 pm) the machines and facilities are cleaned. Different sanitation products are used, including products containing chlorine. Around 8 m^3 of wastewater is produced during cleaning. After this water is led to the same pipes as the wastewater produced during washing of the salad, which implicates that it also will be treated in the same way. However, no analysis of wastewater is taken at this time and no analysis of residues of chlorine have been done.

7.2 UV-treatment at Vidinge

At the fields nearby Vidinge irrigation is conducted using wastewater from pond 2. The wastewater is treated with UV-C technology before it is reused for irrigation. The UV-C treatment consist of 4 lamps, with an effect of 150 W at the wavelength 254 nm and a fluence of 0.4 kJ/m^2 (WEDECO, 2007). The selectivity of the UV-C sensor is specified to be > 90%.

7.2.1 Characteristics of water before treatment

In October some physical and chemical characteristics of water in pond 2, that later is used for irrigation, has been comprised. The mean values of 4 independent analyses made are presented in Table 7.4. All measurements of BOD_5 was below detection limit, <3 mg/l. The characteristics is studied due to the importance and effectiveness of the disinfection treatment. Turbidity of water in pond 2 was measured to be low at all occasions (turbidity < 11 FNU at all samples).

Table 7.4. Characteristics of the water in pond 2.

Parameter	Mean value
BOD_5 (mg/l)	<3
Turbidity (FNU)	5.88
TS (mg/l)	457.5

7.2.2 Microorganisms in water after treatment

Concentrations of three different microorganisms: Cult. Microorg., *E. Coli* and IE have been measured in the water before and after the biological treatment since 2016. The concentrations of the microorganisms after UV-C treatment can be seen in Table 7.5. The concentrations of both *E. Coli* and IE are around 10 at all measurements, but the concentration of Cultivable Microorganisms is always at least 10 times higher.

Table 7.5. Concentration of measured organisms in irrigation water. The irrigation water is reused water from wastewater of wash-of process by UV-C treatment.

Time	Cult. Microorg. (CFU/100 ml)	*E. Coli* (CFU/100 ml)	IE (CFU/100 ml)
Jun -16	4 365	10	10
Aug -16	1 750	10	10
Jun -17	340	9.5	10
Jun -18	580	10	10
Aug -18	1 400	10	10
Jul -19	100	10	10

For calculation of removal efficiency of microorganisms presented in Table 7.6 and Figure 7.3, equation 2 and 3 were used.. In both equations is "A" representing the number of microorganisms before disinfection and "B" the number of microorganisms after.

$$Removal\ efficiency\ (\%) = \frac{(A-B)}{A} \times 100 \tag{2}$$

$$Log\ reduction = \log_{10} \frac{A}{B} \tag{3}$$

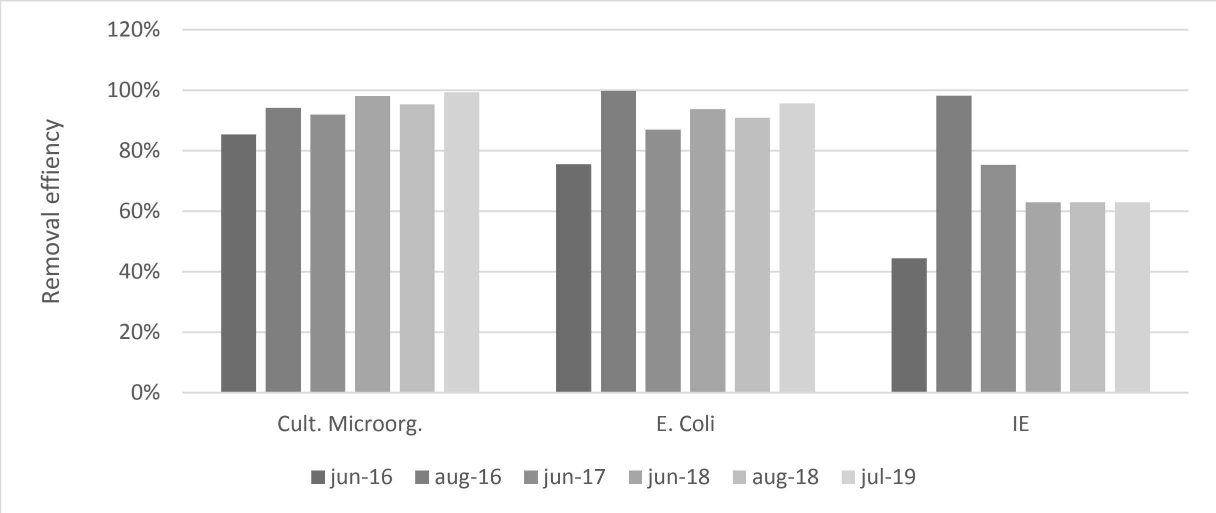

Figure 7.3. Removal efficiency of measured microorganisms in irrigation water, that is reused from the wastewater by UV-C treatment.

In Figure 7.3 the removal efficiency of microorganisms by UV-C treatment of the wastewater is presented, calculated with equation 2. Table 7.6 shows the log removal of microorganisms, calculated with equation 3. The result shows a removal efficiency of 80 - 100% of cultivable microorganisms and *E. Coli*, or $\log_{mean}$ reduction of 1.3 and 1.4 log reductions respectively. However, a lower removal efficiency 40-100% or 0.7 log reductions of IE was calculated. The removal efficiency through 2016 to 2019 shows an increased trend for cultivable microorganisms and *E. Coli* but does not show the same pattern in the removal of IE.

Table 7.6. Log reduction of microorganisms in irrigation water with UV treatment at Vidinge.

	Cult. Microorg.	***E. Coli***	**IE**
Log_{MIN}	0.8	0.6	0.3
$LogG_{MAX}$	2.2	2.7	1.7
Log_{MEAN}	1.4	1.3	0.7

8 Discussion

8.1 Wash water

The quality of wash water is of high importance for the washed vegetables. With water containing impurities the risk of cross-contamination is high, which would contribute to a higher population of microorganisms in the ready-to-eat fresh vegetable and affecting the best before date and the consumer in a negative way. The washing process at Vidinge is designed so that water flows in the opposite direction of the salad. This way of washing contributes to a decreased risk of cross-contamination and a low consumption of water (Manzocco *et al.*, 2015a).

Table 6.1 showed the result of analyzed microbial activity of the cleanest baths in the washing process. Since the concentrations are high already in the cleanest baths, microorganisms will be transferred to the first bath in the washing process. Microorganisms will probably accumulate there until the bath is emptied after 4.5 h. During the washing process, salad is transferred from bath 1 to bath 2, which implicates that it also exists a risk of contamination from bath 1 to bath 2. This fact fortifies the importance of adequate treatment and disinfection of incoming water to the process.

Parameters measured in wastewater presented in Table 7.1 are compared with the limitations from Swedish Food Agency (Table 3.1), where values overriding the substance is marked in *italic* in Table 7.1. Chemicals that exceeds the limitations and thereby need to be decreased for recirculation where tap water quality is required are aluminum (Al), ammonium (NH_4^+), fluoride (F^-), iron (Fe), nitrate (NO_3^-) and color. For removal of ammonium and nitrate have biodegradation shown potential and for removal of metals different filtration methods have been presented, including sand filtration, NF, UF and RO. Color has been removed with sand filtration, adsorption (GAC) and with US in combination with UV. However, it is only nitrate and fluoride that are exceeding the limitations marked “unprofitable”. The other impurities are overriding the limitation values marked “profitable with a mark”. It is worth noting that not all substances measured in the wastewater are included in the regulations of Swedish Food Agency.

By comparing Table 7.2 with 6.1 it can be concluded that the concentrations of coliform bacteria are increased from the cleanest baths of tap water intake to the wastewater. However, *E. Coli* and IE are not analyzed in the baths and SGB and Cultivable microorganisms are not analyzed in the wastewater.

8.2 Wastewater treatment today

The wastewater treatment at Vidinge today is a functional system to discharge water to Väla stream during summertime and is then removing organic compounds, nutrients and many other impurities from the water. However, this method is not applicable during wintertime due to the climate in Sweden, where the field will be saturated and/or frost, ice and snow will make it impossible.

The effectivity of biological treatment during summertime can also be concluded by the guide values gained from SWECO. As mentioned before SWECO is not determine the discharge values to recipient, it is the Country Board that will be determine those. Since the values are not decided, guide values gained from SWECO were used to evaluate the wastewater. Measured concentrations of BOD_7, nitrogen and phosphorus were below the proposed limit values during summertime. However, the concentrations are required to be decreased to comparable values during wintertime.

The substances measured in wastewater before and after biological treatment (Table 7.1) were in some cases increased after biological treatment and in other decreased. This may be due to effects as settling and dilution as well as biological treatment before pond 2. Measured values of Al, NH_4^+, F^- and NO_3^- decreased to a limit lower than the one set by the Swedish Food Agency after biological treatment. However, iron and color increased remarkably and exceeded limit of drinking water quality in the pipe to pond 2.

Some metals are not included in the regulations by the Swedish Food Agency and to compare the measured values discharge classifications were used (Ekologigruppen Eko AB, 2019). Comparing concentrations in Table 7.1 with the guidance for discharge of water, Table 3.3, it was concluded that all metals in the wastewater of Vidinge, except zinc, were classified at moderate level or lower. Zinc is however classified as being on high level due to the concentration of 100 µg/l. The substance is not included in the regulations of drinking water quality (Livsmedelsverket, 2015).

Even if recirculation of water is not possible, the wastewater needs to be treated further to meet regulations of discharge.

8.2.1 Irrigation

Maximum 2.7 log reductions of microorganisms (*E. Coli*) has been achieved by the UV-C treatment of irrigation at Vidinge. The concentration of *E. Coli* has never overridden the limitations (set by either BC, DIN or EU) and the reduction is therefore effective for the water for irrigation. Even though the removal of microorganisms is approved in the irrigation system, further treatment and higher removal would be required for the water to be recirculated back into the washing process.

Efficiency of UV-C treatment

The efficiency of removal and penetration in water of UV-C treatment for irrigation may be affected due to several parameters (Moran, 2018b). An evaluation of parameters affecting the UV-C capacity is hard due to the few analyses during the periods where UV-C treatment of irrigation water is used. However, a few samples of water in Pond 2 where analyzed in October 2019. In these samples the proposed limit (Moran, 2018b) for effectivity of UV-C by turbidity was not overridden (15 NTU).

In conjunction with turbidity, TS was analyses. Contrary to the turbidity, the result was showing a high concentration of TS. An explanation to this may be due to large but relatively fewer particles in the water. More measurements at different times and different places by the pond is needed to determine the reason. The other parameters indicating penetration efficiency of UV-C have not been analyzed in Pond 2.

In the wastewater in the pipe leading from biological treatment to pond 2, analyses have shown high concentrations of TOC. If compared with the limitations for an effective UV-C treatment the mean is 7.5 times higher than the proposed limit. Iron in wastewater after biological treatment was approximately at the value presented by Moran (2018b) (5 mg/l). Both manganese and calcium had concentrations below the values. Due to diluting and settling effects the values are probably lower in the pond than in the pipe leading to it. The reduction of microorganisms is therefore probably mostly dependent of the fluence (0.4 kJ/m^2). An increased fluence would probably lead to an increased reduction of microorganisms.

Regulations of irrigation

In order to fulfill the proposed directive of irrigation water by EU (Europeiska Kommissionen, 2018) the analyses proposed by EU (Table 3.2) should be performed regularly. With the analysis done today it is not known whether the conditions of irrigation are fulfilled. In the analysis both IE and *E. Coli* do have limit values presented in German (DIN 19650) and Canadian (BC; Water Quality Criteria for Microbial Indicators) standards (Alsanius, Kristensen and Gustafsson, 2010). The conditions of both microorganisms have always been fulfilled during the years due to the low concentrations of both *E. Coli* and IE at all measurements. However, even though cultivable microorganisms in 22 °C is a good indicator of microbial load in water, it does not exist any limit of the population in irrigation water and it cannot be sure whether the conditions of DIN and BC are met.

Results of analysis made in pond 2 in October are presented in Table 5.4. The results imply that mean turbidity of the water before UV-C treatment was too high due to the limit of 5 NTU in irrigation water (Europeiska Kommissionen, 2018). Though, due to that measurements are lacking, and no analysis of turbidity are made after the UV-C treatment, the turbidity after the treatment is not known. In October the concentration of TS was measured too, however, this is not the same as TSS that is requested by the EU. Even though TSS is a part of TS, the quotient between them are varying. This means that the measured TS cannot be compared with TSS. Samples of *E. Coli* in irrigation water has been taken all years that UV-C treatment and irrigation have been applied. The results have always been below the limit (DIN, BC and directive by EU) after treatment. *Salmonella* is not measured at any time neither in the process line nor in the wastewater.

To meet the recommendations of the directive by EU (Europeiska Kommissionen, 2018) and to ensure that the wastewater has good enough quality of being irrigated, BOD_5, turbidity, *E. Coli* and TSS and *Salmonella* should be measured in the future.

8.2.2 Possible reuse

Another possible solution for optimizing the water usage is to reuse water for irrigation to a higher extent than today. Most of the wastewater produced could be collected in larger ponds/buffer zones and more water could be reused in terms of irrigation. However, the problem during wintertime, with no irrigation and limited or none effect of biological treatment is still there.

8.3 Wastewater - characteristics

Due to the limited effects of wastewater treatment during wintertime measurements of wastewater before the pond or in pond 1 (buffer) are evaluated for process solutions.

8.3.1 Microorganisms

Population of coliform bacteria was increased considerably in wastewater from the baths (Table 6.1 and 7.2). Even though no other parameter of microorganisms have been analysed in both baths and in the wastewater, it can be concluded that the population of microorganisms in the water are increasing during its usage and by time and that the content of microorganisms in wastewater is high. In discussion with an expert in the area (Carl-Johan Legetth, 2019) the population of microorganisms in wastewater of Vidinge was compared to correspond to populations of microorganisms in urban water.

8.3.2 Pesticides

The concentration of some pesticides is increasing over the pond and some concentrations are decreasing (Table 7.3). This may have several explanations:

1. **Degradation rate of different pesticides** - The pesticides that have a low degradation rate will increase in concentration over time.
2. **Herbicides attaches to soil particles** – As the pesticides are accumulating in the pond herbicides are forming strong bonds to soil particles. That would explain the decrease of herbicides and imply that sludge contaminated of pesticides is formed in the pond.
3. **Penetration from nearby fields -** The pesticides that are increasing in concentration in the pond is used at nearby fields, and since the pond is not completely dense the pesticides are penetrating into the pond.
4. **Origin of the salad -** Number 3 also implicates that the difference in concentration may be due to the origin of the salad, since it is mostly generated from nearby fields in Sweden summertime and only bought from other, warmer, countries during wintertime. This leads to suspicions that other pesticides may be used at salad that has not its origin from Sweden.
5. **Time difference in measurements** - The samples in pond 1 where taken during wintertime and in wastewater during summer. No sample has been taken during the same time period.

A combination of the presented explanations above would be likely for the pesticides in the ponds since different pesticides have different behaviors. With more analysis of pesticides in both salad and wastewater origin of pesticides could be evaluated. This would implicate that higher demands of the pesticides could be set and salad producers that are using pesticides forbidden in Sweden could be ignored.

Detection of some pesticides was made in both wastewater and Pond 1 (Table 7.3 and Figure 7.1). To determine the explanation of pesticides in wastewater it would be necessary to take more samples, at all times of the year. It was also noticed that some of the pesticides which the degradation products arise from are banned in Sweden since years ago. However, this is a widespread problem and concentrations of these pesticides have been found in several waters in

Skåne (Czulowska, 2011). For the concentration of pesticides to decrease higher requirements and awareness would be necessary. By comparing the measured concentrations of pesticides in wastewater (Table 7.3) with the limitations presented by the Swedish Food Agency (Table 3.2), a treatment method to reduce the concentration of pesticides is required to achieve drinking quality of the water.

8.4 Future wastewater treatment and recirculation

From Table 6.1 and 7.2 it can be concluded that the concentration of different microorganisms in water of fresh cut is very high. Already after a few hours of production the salad have contaminated the water, which fortify the importance of disinfected water for recirculation to eliminate the risk of impact of diseases at the consumer.

For the wastewater at Vidinge to be recirculated back and to keep it at the quality required, it is necessary for it to be treated for all discussed unwanted substances: nutrients, microorganisms, pesticides etc. The choice of process solution is depending on where the reused water will be added into the washing process. In any case, the fact that the water needs to be treated for several types of impurities implicates that not only one solution is sufficient, and a multifunctional treatment system is required for optimization of water quality. If the main goal of the WWTP is to reuse water at the last step of the washing processes drinking water quality is needed (Alsanius, 2014; European Union, 2004). This implies that a more profound, meticulous and more complex water treatment is necessary.

In literature a lot of different process solutions are presented, however only a small part of the techniques has been applied at fresh-cut processes for recirculation purposes. It is worth noting that in all experiments, including fresh cut vegetables and recirculation, the focus has been on decreasing microbial activity. Methods which seems to be the most studied today for recirculation at fresh cut industries includes US, UV-C and AOP.

In common for all process solutions is that a trial at pilot scale is preferred before the solution is being applied. The investigated research about disinfectants is done at laboratory scale, and these results are not necessarily directly transferable to large scale.

The already installed primary step of the treatment plant (mechanical filter of 5, 0.75 and 0.25 mm) will only remove larger particles of soil, salad, plastics and other larger residues. This means that even though a recirculation process is not applicable today, Vidinge does have to apply water treatment in a larger extent than installed now to decrease the content of impurities and fulfill the requirements of discharge of water to the environment.

The investment cost and appropriate method is also affected by the wastewater flow. Since Vidinge expands and expects to increase both their production of salad but also their consumption of water chosen size and method of wastewater treatment plant should be carefully made due to future water consumption. This will be affecting the price range as well.

8.4.1 Classification of recirculated water

Conditions presented by the directive of waste handling (Europeiska Unionen, 2008) should be fulfilled in order for the waste to become by-product. The conditions are met as:

1. The substance (water) will be used for a specific purpose.
2. Water is a valuable source and the demand is increasing, implicating that there is an existing market.
3. The technical requirements will be met in order to achieve the quality conditions of both water and salad.
4. The methods will be chosen so that it is no risk of negative consequences of environment or human health.

These four points implicates that the treated water that will be recirculated back to the process will be treated as a by-product and not as waste. To be able to recirculate water at the industry the water should be reclassified according to legislation. This is also implicating that the cleaned water may be sold to other customers

8.4.2 Secondary treatment step

Treatment of chemical characteristics in wastewater after biological treatment (summertime) would not be necessary since low concentrations of the substances are achieved (COD 84 mg/l, N 2.4 mg/l, phosphorus 0.5 mg/l and BOD_7 8.8 mg/l). Physically, both turbidity (9.5 NTU) and TSS (12.9) is low. This treatment is not sufficient during the whole year and a new WWTP is required.

For biodegradation either aerobic or anaerobic degradation can be applied. Since the ratio of COD is lower than 250:5:1 in the wastewater an aerobic process is most effective for a biodegradation process. For estimation by the other method BOD was evaluated. Mean BOD_7 of the wastewater during March – August 2019 has been calculated to 364 mg/l (Table 7.1). This may be recalculated to 0.312 kg/m^3 BOD_5 by equation 1. From the relationship presented by Smith (2016), an aerobic process is most suitable for biological treatment of wastewater at Vidinge.

Due to the relatively high temperature needed in an aerobic process compared to the temperature used in the washing lines (2-4 °C) heating of the water would be necessary. A solution may be to exchange the wastewater with the waste heat that is formed as the facilities and water are cooled down.

However, if a biologic step is introduced it is probably necessary to have a flow through the treatment all year around due to the risk of the microorganisms to die without a continuous flow.

8.4.3 Tertiary treatment step

A tertiary treatment step for removal of microbial activity, pesticides and probably residues of chlorine is needed. This is the most important step of the treatment for recirculation due to regulations and recommendations. However, the removal efficiency of the treatment step needed is depending on where in the washing process the cleaned water will be connected. If the water is to be connected at the final washing step drinking water quality is required.

For optimum effect of disinfection methods, including UV-C, it is necessary to reduce substances as TOC, TSS and turbidity (Moran, 2018b). One method of removal is filtration. However, filtration techniques should be introduced in steps to decrease the risk of clogging. Smaller pore sizes are not only more effective, but also more expensive due to higher investment costs, higher pressures needed and therefore resulting in higher operational costs in terms for example higher electricity consumption.

Further reduction of turbidity by slow sand filtration can be used in combination with membrane filtration. This will reduce both TOC and turbidity in water, making it harder for the microorganisms to hide behind particles in the water when treated with disinfection methods. The slow sand filter may be integrated with GAC to remove residues of pesticides and chlorine from the wastewater. However, since RO has shown potential in pesticide removal no further removal of these substances will be necessary if this is used.

Due to the unknown amount and sort of byproducts of chlorine resulting from cleaning of facilities and machines at Vidinge it is hard to evaluate if treatment methods to remove those are necessary. However, if GAC, NF or RO are used concentrations of chlorine-byproducts will probably decrease too.

When designing the process, the disinfection treatment step of microorganisms should be applied in the last stage of the WWTP. It is of importance to analyze the water before the disinfection step regularly. This is important due to mainly two factors.

1. The risk of decreased removal efficiency of microorganisms increases with high concentrations of TOC, TSS, turbidity etc. because microorganisms will hide in/behind the particles and will therefore not be affected of treatments as UV.
2. If filtration methods are used after disinfection methods a risk of growth of microorganisms is existing if not all organisms are eliminated.

As an option for disinfection, pulsating light of UV-C has been reported to be effective in fresh produce recirculating water (Manzocco *et al.*, 2015b). However, the fluence required was very high, 11 kJ/m^2. By addition of an oxidant, as O_3 and H_2O_2, for advanced oxidation combined with UV-C the fluence can be decreased. 1% of either O_3 or H_2O_2 has shown to reduce the required fluence remarkably. It is of importance to handle the chemicals with care, ozone is very dangerous for human health in low concentrations. If UV-C is chosen as treatment method light penetration is crucial layer to obtain good results.

US has not been shown to have as good results in removal of microorganisms as UV-C or AOP. UV-C alone has been reported to reduce different microorganisms with more than 5 log (Manzocco *et al.*, 2015b), while US only has achieved 3.2 log reduction as maximum (Anese *et al.*, 2015).

RO has shown high potential of removal of microorganisms (Table 5.2). However, it has not been studied as a disinfection method in wash water from fresh cut vegetables and/or fruit in the same extent as UV, US and AOP. The small particle sizes of the filter with the required high pressure would also implicate high costs.

8.4.4 Process design solutions

With information gained in this discussion and the summarized table of the different methods and removal capacities (Table 5.4) three different treatment solutions have been proposed. It is important to keep in mind that more combinations exist, and pilotscale experiments with the wastewater at Vidinge is recommended before application.

In Table 9.1 different process solutions (PS) are summarized with impurities to be removed. All process design solutions include biodegradation to remove nutrients.

Table 8.1 Process design solutions and removal capacity. PS 1: Biodegradation + UF/NF + UV (or AOP), PS 2: Biodegradation + Slow sand filtration + GAC + UV (or AOP) and PD3: Biodegradation + RO.

Re-moval	Nutri-ents	TSS/ TS	COD	BOD	TOC	Met-als	Pesti-cides	Chlorinated comp.	Micro-org.
PS 1	X	X	X	X	X	X	X	X	X
PS 2	X	X	X	X	X	X	X	X	X
PS 3	X	X	X	X	X	X	X	X	X

- **PS 1: Biodegradation + Filter + UF/NF + UV or AOP** – After the biological treatment a filtration step with larger particles is required. This since the wastewater will contain to many larger particles for the UF/NF. A filtration method as UF or NF has shown potential in removing impurities as TS/TSS and metals. However, for removal of chlorinated compounds and pesticides at least NF is required. By applying a disinfection method as UV or AOP in the last step the concentration of microorganisms can be controlled.
- **PS 2: Biodegradation + Slow sand filtration + GAC + UV or AOP –** Slow sand filtration in combination with adsorption as GAC have been shown to have good potential in removal of impurities as pesticides, chlorinated compounds, metals and TSS/TS. The method has also shown to remove 95% of coliform bacteria of wastewater from synthetic washing water. By applying a disinfection method as UV or AOP in the last step the concentration of microorganisms will be controlled.
- **PS 3: Biodegradation + Filter + RO** – A filtration step is required between biodegradation and RO for the RO to have optimum effect (5.3.1). No trials of RO have been found on wastewater from fresh-cut salad, implying that experiments are of importance to estimate removal capacities.

All three process options have good potential in removal of impurities and disinfection of microorganisms. However, since no information of RO of water from fresh cut of vegetables have been found this method needs to be further investigated. It has also been evaluated to be the most expensive treatment method, and filtration with larger pore sizes is probably required between biodegradation and RO. However, disinfection with UV and AOP has been reported to have great potential of washing water from salad.

Slow sand filtration has shown good potential in cleaning very dirty water. By combining this technology with an adsorption method as GAC will also pesticides and potential concentration of chlorinated compounds be removed from the water, and as UV/AOP is applied as a last step the remaining pesticides will be removed.

Even though not drinking quality is achieved, the recirculated water could be used to fill up the baths in the beginning of the shift or washing in Bath 2 at the baby leaf line. More investigations would be necessary for application in the industry.

8.5 Recirculation at washing lines

An additional process solution is to optimize the usage and decrease the risk of cross contamination already in the washing process. This may be done by continuously changing water in bath 1 and having a disinfection step (as RO, UV, US or AOP) before the water is recirculated back to the bath. By cleaning the water while in operate, both water usage and risk of contamination would decrease. If operated during running it also would be able to have an increased flow of vegetables, due to less stops for changing water.

An experiment like this has been done in lab-scale (Manzocco *et al.*, 2015a) and even though the result showed that the microorganisms were removed, it was concluded that the penetration depth of the water was decreased during the washing cycles. This would implicate that particles and organic substances are accumulated in the water.

A process design like this could reduce the risk of cross contamination among different sorts of salads or from detergents used while cleaning the facilities and machines. This method would however not decrease other impurities in water as TS/TSS, BOD, COD, TOC, nutrients or other impurities. Since the effect of many disinfection methods are highly affected by the concentration of these a treatment step before disinfection would be necessary. It may also be necessary to design the water treatment processes of the lines differently, due to the difference in size of particles (AR and Hydrotech, 2008) found in wash water of different salad (presented in 5.3.1).

9 Conclusion and recommendation

To tie together this thesis the questions asked to achieve the aim are answered:

1. It is possible to recycle water from a fresh-cut industry. One way of recycling is already performed at Vidinge, when water is used for irrigation. For the water to be recycled back into the process water treatment in multiple stages is necessary to ensure that all impurities are removed. However, for the water to be recycled back into the last stage/bath, water of drinking quality is required. This will lead to even more accurate methods of treatment. Of course, this is also a question of costs, since more advanced techniques will be more expensive for the company.
2. Methods for recycling water in fresh-cut industries are disinfection methods as UV, US and AOP including US+UV and UV+H_2O_2. Presence of TOC, TS/TSS and turbidity are decreasing the efficiency of disinfection methods.
3. Regulations of the quality of the washing water do exist. For the final washing step of ready-to-eat fresh-cut fruits and vegetables tap water is required and in initial steps the water should be clean enough (European Union, 2004). These qualities of washing water are reasonable due to discussions with different experts. For reusing water for irrigation the requirements presented in the guideline by EU should be followed (Europeiska Kommissionen, 2018). This may imply that the washing water before the last stage should at least have good enough quality to meet the quality of irrigation.

To meet the recommendations of the directive by EU (Europeiska Kommissionen, 2018) of recirculated water of irrigation and ensure good quality, BOD_5, turbidity, *E. Coli*, TSS and *Salmonella* should be measured after UV-C treatment during the months it is used. During the measurements, population of *E. Coli*, BOD_5, TSS and/or turbidity should also be measured in pond 2 to evaluate the efficiency of UV-C and how affected it may be of impurities in water.

A new water treatment plant is required at Vidinge to satisfy limits and regulations of effluent to the environment and/or Väla stream, since the applied wastewater treatment of today only is effective during summertime. The regulations of emissions to the recipient from the company has not been studied in detail in this thesis. However, it is required to decrease the concentration of many impurities in the wastewater during the wintertime. The WWTP may contain a secondary step to decrease the concentration of nutrients and BOD, preferably biodegradation. Depending on restrictions of emissions of pesticides, a treatment method to remove these is also required. By adding a disinfection method to remove microorganisms, it would be possible to get sufficiently clean water. It would however be necessary to study the impact of the water arising from cleaning of the facilities and machinery to evaluate if chlorinated compounds are present in the water.

For recirculation of water back into the washing line, treatment of the water to sufficient levels to be recirculated to the first bath (and second in *Baby leaf line*) is proposed. If the water is to be recirculated to the last step of the washing line drinking water quality is required (European Union, 2004). That quality would imply in a very complex and expensive treatment process, and the expenses would probably be too high in comparison to the costs of municipal water supply.

10 Future work

During the thesis work didnew questions arise, that was not be answered due to the limitations.

- How the wastewater of fresh-cut fruit and vegetables will be affected of biodegrading techniques.
- How large ratio of wastewater that can be treated and recirculated back into the washing process.
- How salad is affected of higher concentration of impurities as nutrients, metals and pesticides in the wash water.
- If it would be possible to pick out nutrients as nitrogen and phosphorus from the sludge for reuse purpose at fields, and if this would be applicable due to health and legislations.

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11.1 Interviews

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Andersson Klas and Levin Anne; SWECO. Autumn 2019.

Johansson, Tomas; Standard and Evaluation Manager, Vidinge Grönt AB. Autumn 2019.

Legetth, Carl-Johan; Chef of business at water treatment, Malmberg. Autumn 2019.

Matvyeyev, Denys; Project leader, Vidinge Grönt AB. Autumn 2019.

12 Appendices

12.1 Raw data measured values of wastewater

In Table 12.1 raw data of formal tests presented, summarized values were presented in Table 7.2.

Table 12.1. Formal test of different microorganisms in wastewater 2019.

Date	***E. Coli*** **(CFU/ml)**	Coliform Bacteria (CFU/ml)	IE (CFU/ml)
12-jun	7 500	>10 000	7 900
18-jun	940	>10 000	>10 000
19-jun	260	>10 000	>10 000
26-jun	4 000	>10 000	>10 000
27-jun	5 000	>10 000	>10 000
01-jul	1 100	>10 000	140
04-jul	-	>10 000	2 500
08-jul	<10	19 000	3 800
10-jul	1 200	16 000	3 100
15-jul	<10	12 000	330
17-jul	<10	48 000	45 000
24-jul	870	51 000	8 000
29-jul	4 400	36 000	1 900
31-jul	5 100	30 000	16 000
05-aug	1 600	48 000	16 000
07-aug	2 000	28 000	5 900