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Industrial wastewater management in Chile – Currently applied methods and suggestions for new techniques

Industriell avloppsvattenhantering i Chile- nuvarande metoder och förslag till nya tekniker

Lise Toll

Abstract

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The purpose of this thesis is to examine the current situation in Chile with regard to the treatment of industrial wastewater, with the aim of identifying the potential for the implementation of separation technologies.

The analysis is based on four case studies carried out in the Santiago region to determine existing approaches used in dealing with wastewater across a range of industries. The case studies are developed from site visits and interviews conducted with the local industries.

Moreover, a literature review, an examination of the relevant legal framework and interviews with local industries and regulators has been performed. This has enabled the situation in the Santiago region, as demonstrated by the case studies, to be described within the wider environmental and legal context in Chile.

Earlier investigations considering the management of industrial wastewater in Chile was performed by Anna Risberg in 2005. The development of legal provisions applicable to regulation of wastewater management has been investigated by comparing the present situation with her study.

On the basis of this analysis, suggestions are made as to the potential for implementation of more advanced separation technologies in Chile to enable the achievement of better outcomes for water economy throughout the country as well as for a decreased volume of hazardous waste produced in the industry. In conjunction with these technical conclusions, a short review of the investment environment has been made, with a focus on the possibility for Swedish companies to supply such advanced separation technologies.

Keywords: industrial wastewater technologies, membrane technologies, sustainable development, Chile, Santiago

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Referat

Industriell avloppsvattenhantering i Chile – nuvarande metoder och förslag till nya tekniker *Lise Toll*

Syftet med detta examensarbete är att undersöka den nuvarande situationen i Chile angående vattenreningsteknik för industriellt avloppsvatten. Vidare är avsikten att identifiera möjligheten för att tillämpa separationsmetoder, såsom membrantekniker, jonbyte och avdunstning, integrerat i produktionsprocesserna.

Undersökningen är baserad på fyra fallstudier där de nuvarande tillvägagångssätten för att hantera industriellt avloppsvatten har granskats vid olika slag av industriella verksamheter. Fallstudierna grundas på information som insamlats genom besök vid industrier samt intervjuer av anställda vid respektive företag.

För att identifiera möjligheterna för tillämpning av ny teknik inom vattenreningsteknik för industriellt avloppsvatten har även en litteraturstudie angående miljösituationen och i Chile och relaterade lagar genomförts.

Baserat på denna undersökning ges förslag angående tillämpningsmöjligheterna för separationstekniker vid industrierna i Chile. Vidare diskuteras förbättringar angående vattenkvalité och vattenanvändning i Chile som tillämpningen kan bidra till. Tillsammans med de tekniska slutsatserna ges även en kortare översikt av affärsklimatet i Chile med fokus på hur svenska företag kan tillgodose Chilenska industrier med separationstekniker.

Nyckelord: Industriella avloppsvatten, vattenreningsteknik, membrantekniker, hållbar utveckling, Chile, Santiago

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Preface

This master thesis was written for Mercatus Engineering and Vilokan. It is part of the M.Sc. Education in Aquatic and Environmental Engineering at Uppsala University. It covers 30 academic credits. Irena Butaité at Mercatus Engineering has been the supervisor and the subject reviewer was Professor Bengt Carlsson at the Department of Information Technology at Uppsala University.

First I would like to thank SET – Swedish Environmental Technology for making this interesting and rewarding project possible. More over, I would like to thank a number of people who helped me during my time in Chile. Especially Arturo Arias, Martine Oddou, Consuelo Vargas, Marcelo Rocca Salinas, Mauricio Chacón, Guillermo Escobar and everyone else I met when I visited industries in the Santiago region.

I am grateful for having Karen Teran as my Spanish teacher at the language school Sur Pacifico situated in Manta, Ecuador. Without your professional help and motivating classes I would not have been capable to perform my work in Chile.

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Populärvetenskaplig sammanfattning

Industriell avloppsvattenhantering i Chile – nuvarande metoder och förslag till nya tekniker *Lise Toll*

Chile hade under 80- och 90-talet en stark ekonomisk tillväxt, huvudsakligen tack vare en ökad export av naturresurser så som mineraler, skog, jordbruksprodukter och fisk. Den ökade produktionen skedde på bekostnad av miljön och idag tampas Chile med utmaningar som luftförorenade städer, avfallshantering och förorenade vattendrag.

Tecken visar att intresset för miljön har på senare år ökat hos folket i Chile. Dessutom ses en miljömässig hållbar produktion som ett måste för en fortsatt framgångsrik export till omvärlden.

Även regeringen verkar för att förbättra miljösituationen. Den första miljölagen i Chile kom 1994 och regeringen har sedan dess fortsatt att utveckla rättsnormer inom detta område. Den tredje september 2006 var en viktig milstolpe i landets arbete för att förbättra vattenkvalitén i sjöar och vattendrag. Från och med detta datum är alla industrier som släpper ut sitt avloppsvatten till vattendrag skyldiga att rapportera avloppsvattnets sammansättning varje månad till en statlig kontrollmyndighet. Antalet industrier som månadsvis rapporterar sina värden har därmed ökat med 80 % under de senaste sju åren. Detta har inneburit att många industrier har fått se över sin produktion och avloppsvattenrening för att inte överskrida de rådande normerna.

På grund av Chiles geografiska utbredning är nederbördsfördelningen i Chile är mycket ojämn. Vattentillgångarna är stora i söder men inte i de norra och centrala delarna av Chile där efterfrågan på vatten är som störst. Hushåll, gruvverksamhet, jordbruk, vattenkraft och industrier måste därför samsas om vattentillgångarna. Efterfrågan på vatten hos dessa intressenter tros öka till det dubbla inom 40 år. Samtidigt finns en oro att nederbördsmängden i landet kommer att minska.

Företag som släpper ut industriells avloppsvatten låter vanligen ett externt företag ta hand om vätskor och processbad innehållande höga halter av farliga ämnen för att inte överskrida gränsvärden gällande föroreningar. Detta är ett steg i rätt riktning för att förbättra vattenkvalitén i landets vattendrag, men detta innebär att volymen farligt avfall som industrin genererar är stor. Dessutom effektiviserar inte denna lösning vattenhushållningen i Chile. För en långsiktigt hållbar lösning bör istället tekniker som möjliggör återvinning av kemikalier och recirkulering av vatten tillämpas.

Separationstekniker är ett samlingsnamn för en rad tekniker som, till skillnad från ett traditionellt reningsverk, ofta är integrerat i produktionsprocessarna för att separera specifika föroreningar. På så sätt kan dessa föroreningar koncentreras och vatten kan återanvändas i produktionen. Separationstekniker är därför viktiga redskap för att minska volymen producerat farligt avfall och minska vattenförbrukningen hos industriella processer.

Tre av de fyra besökta Chilenska industrierna har idag ett separat reningsverk för att rena avloppsvattnet från produktionen innan det når recipienten. En av industrierna har tillämpat metoder som spar- och motströmssköljning för att minska vattenförbrukningen. Ingen av de besökta industrierna tillämpar idag separationstekniker såsom membrantekniker eller jonbyte. Tre av industrierna är intresserade av tekniker för att förminska vattenförbrukningen och två industrier vill minska sin produktion av farligt avfall. Genom att tillämpa mer avancerade separationstekniker såsom membrantekniker, jonbyte och avdunstning kan detta möjliggöras. Förutom de besökta industrierna finns tillämpningsmöjligheter för separationstekniker vid papper och pappersmassaindustrin samt inom gruvsektorn, två av Chiles största företagsamheter.

Om vatten framöver uppfattas som en begränsad tillgång så kommer industrier att behöva tillämpa effektivare strategier angående vattenkonsumtionen. Detta innebär i sin tur att de befintliga vattenresurserna har större chans att möta efterfrågan från samtliga intressenter inklusive jordbruksektorn och hushållen.

Table of content

1 Introduction

The application of treatment technologies for domestic wastewater as well as industrial wastewater varies exceedingly in different parts of the world. Factors like existing infrastructure, economy and the social attitude towards environmental issues contribute to the application of wastewater treatment technologies. Laws and regulations put pressure on industries to employ strategies and technologies to improve the quality of their wastewater. Consequently, industries situated in countries where stricter regulations are applied will need to consider methods more carefully in order to meet the national standards.

The traditional wastewater treatment technologies are applied at the end of the process and are therefore referred to as “end–of–pipe treatment technologies”. In this approach, all flows of contaminated water are gathered and cleaned to prevent environmental impacts on the recipient. Often the by-product from this treatment is sewage sludge and, depending on industry, this might contain a high level of various hazardous contaminants (Ford, 1992).

A more sustainable option or complement to the end-of-pipe-treatment can be achieved by focusing on the recycling of water and materials. This can be achieved by employing separation technologies integrated in the production processes. They enable water to be re-used in the process and captured chemicals and metal ions can be returned to the source (Mercatus, 2008). These are important benefits in order to achieve a more sustainable industrial production.

1.1 Aim

The aim of this master thesis is to

(1) Investigate the possibilities for certain wastewater technologies, referred to as separation technologies, to be applied by industries in Chile.

(2) Investigate the development of legal provisions applicable to regulation of wastewater management and its effects on the management of industrial wastewater by comparing the present situation with a study that was performed by Anna Risberg in 2005.

(3) Illustrate how separation technologies could be applied at four visited industries in the Santiago region.

(4) Give a short review of the investment environment in Chile, with a focus on the possibility for Swedish companies to supply separation technologies.

Limitations
The project focuses on the situation in Santiago de Chile and its surroundings. However, other parts of Chile are taken into account in some aspects. At the four visited industries general suggestions and possible results from the employment of new technology, including separation technologies are given. This is because the amount of relevant data has not been sufficient to calculate legitimate empirical results.

2 Methods

In order to investigate how separation technologies could be applied at industries in Chile, a number of topics have been investigated.

Environmental situation
A short overview of the environmental situation, including the water economy and the handling of hazardous waste in the country illustrates the conditions and necessitate for the employment of separation technologies in the country. This investigation is based on interviews with employees at the National Commission of the Environment (CONAMA), employee at the company Hidronor and on a literature study of relevant material.

Development of related laws
Investigations considering industrial wastewater management in Chile were performed by Anna Risberg in 2005 and the intention has been to compare the results in order to investigate the legal and environmental development during the past years. Risberg wrote that from 2006 Chilean law forced all concerned industries to report their effluent values to the government on a monthly basis (Risberg, 2005). Therefore the legal development since 2005 until today has been investigated and whether this has increased the interest of Chilean companies for investment in environmental technologies. The understanding of related laws and their impact on the development of industrial wastewater treatment have been obtained from interviews with employees at the Superintendence of Health Service (SISS) in Chile and from a literature study of the related laws and annual progress reports from SISS.

Case studies – wastewater handling at four Chilean industries
When four industries for the analysis were to be found, the focus was to distinguish industries that would benefit from the employment of separation technologies. These are mainly production industries and in particular those dealing with metals, surface treatments and cutting fluids but also other types of industries with the aim to recycle water in their production. Furthermore it was of interest to find companies that were interested in developing the currently applied methods for the treatment of their industrial wastewater.

The companies were identified by:

(1) Contacting companies with suitable industrial activities that did not comply with related regulations and were therefore listed on the webpage of SISS.
(2) Attending events within the field of industrial activities or water use which were organized by companies or governmental organizations.
(3) Cooperating with local environmental consultancy firms.

An essential part of the timeframe for this project was assigned for the search for suitable industries and study visits to Chilean companies with an industrial production. Although only four of the ten visited industries are explained in detail, the remaining company contacts and study visits have contributed to a better understanding of the general situation considering management of industrial wastewater in the country.

At each visited company, the existing wastewater treatment technologies are analyzed to evaluate the methods used. The analyses are derived from study visits and interviews with employees at each company. Since the purpose is to give a general picture of the handling of industrial wastewater, the identities of the companies and interviewed employees are not revealed.

A literature study of relevant separation technologies and industrial processes was performed in order to study the possibilities for applying separation technologies at the visited industries. Moreover the industrial processes and wastewater treatment technologies at the visited industries in Chile have been compared with those at Swedish companies with similar industrial activities.

Business opportunities Chile-Sweden
The possibility for Swedish companies to supply separation technologies to the Chilean industry has been investigated by reading material printed by the Swedish Embassy in Chile and by interviewing representatives from related organizations.

3 Information about Chile

Chile is situated along the west coast of South America. With an area of 756,626km2, it is the seventh largest country in South America. Chile is a long and narrow country. From the border with Peru in the north down to Kap Horn in the south, the distance is 4,200km, and therefore the climate varies immensely throughout the country (The Swedish Embassy, 2007). While the north has a desert climate, the central parts have a Mediterranean climate. The south regions have a tundra climate including colder temperatures in the mountain regions (Nearyl & Garcia-Cheveisich, 2008). Most of Chile's 16 million people live in the central parts of the country. Approximately 7 million people live in the capital, Santiago de Chile, and its surroundings. This region is referred to as Region Metropolitana (RM). It is located in the central parts of the country, near the coast and surrounded by mountain peaks which are part of the Andes (The Swedish Embassy, 2007).

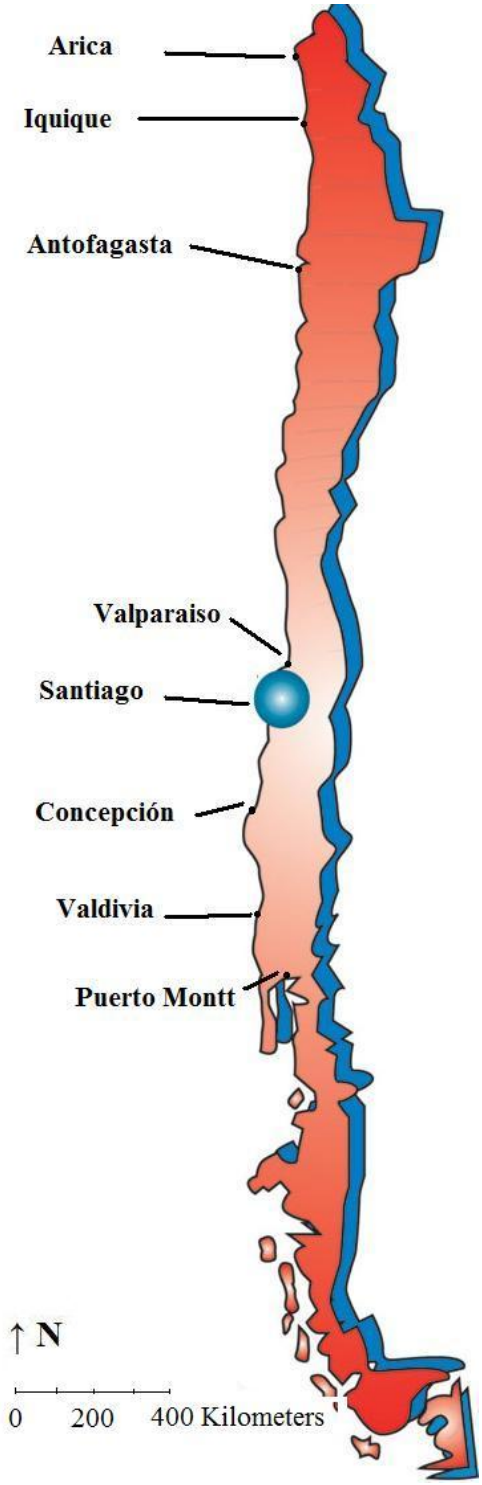


Figure 1. Map of Chile

3.1 Meteorological- and hydrological conditions

The abundance of water differs dramatically between the arid northern and the wet southern parts of Chile. See Table 1 for the average annual precipitation in some locations in the country.

Table 1. Precipitation in different cities in Chile
Source: Nearyl, Garcia-Cheveisich, 2008

City	Average annual precipitation (mm)	Location	Region
Arica	<1	North	Arica
Copiapó	21	North	Atacama
Santiago	330	Central	Santiago
Concepción	1320	Central	Bio-Bio
Valdivia	2535	South	Los Ríos
Puerto Aisén	2973	South	Aisén
Chiloé National Park	>4000	South	Los Lagos

Santiago RM is situated in the basin of Río Maipo and its tributaries Río Mapocho, Río Angostura, Estero Puangue y Estero Popeta. The climate in the region is defined as temperate Mediterranean with a longer dry season and clearly marked winters. The annual average temperature in the Santiago area is 14.5º C, but temperature can in extreme cases drop to zero degrees Celsius during the winter period and reach over 30º C during the summer days. The measured precipitation varies between 300mm/year and 500mm/year depending on distance to the coast and altitude. The regions which are situated in the Andes mountain chain above 3000m have a colder climate. This climate is characterized by lower temperatures and snowfall. The main precipitation in the Santiago region occurs during the winter months May, June, July and August. The melting of snow and ice from higher regions in the Andes contributes significantly to the torrent in Río Maipo and its tributaries during the dryer season, October to March (Cade Idpe, 2004).

El Niño-Southern Oscillation (ENSO)
ENSO is an ocean-atmosphere phenomenon that has an affect on the abundance of water in Chile. During normal circumstances, the trade winds and the warm ocean currents around the equator flow in the west direction over the Pacific Ocean towards Indonesia and Australia. The warm surface water give rise to low pressure systems including intensive rain showers over Indonesia and north east Australia. On the other side of the Pacific Ocean, cooler water from the Humboldt Current flows north-westward along the west coast of South America from the southern tip of Chile to northern Peru. The air pressure is normally high making Peru and northern Chile among the driest places on earth.

During year when the weather phenomena El Niño appears, the pressure conditions in the atmosphere changes which in its turn changes the directions of the Trade winds. The warm surface water stays outside the coast of South America and this region is hit by heavy rains and extreme flooding events. On the contrary, Indonesia and Australia are during the periods of El Niño hit by dryer conditions that affects agricultural activities and causes severe bush fires.

La Niña is the name of the phenomena that follows the El Niño period. During La Niña periods, the opposite extreme to El Niño appears. The ocean water in the eastern and central parts of the Pacific Ocean is cooler than during normal conditions while the water outside Indonesia and Australia is warmer than normal. On land the pressure is low and heavy rain falls in Indonesia and North East Australia. A higher air pressure over the coast of Peru and Chile gives very dry conditions during La Niña conditions in parts of South America.

The latest El Niño occurred in 2006 and lasted until 2007. This was followed by a La Niña event which lasted until June 2008 with some signs of redevelopment in December the same year (World Meteorological Organization, 2009). During the last La Niña event, the water deficit was observed to be larger than the average during these conditions (Vargas et al, 2008).

3.2 Land use

The catchment of Rio Maipo covers the region of Santiago RM as well as parts of neighbor regions. With a total catchment area of 15,304km^2 and a length of about 250km, it is the main source for fresh water in Santiago RM. It accounts for about 70% of the demand for domestic water and close to 90% of the water used for irrigation purposes in the area. Further more, the river system is an important source for energy supply by hydroelectric power plants. Since Santiago RM takes up a significant part of the catchment area to this river system, human and industrial activities have a mayor impact on the availability and condition of water in the basin.

Table 2. Land use in the run of area of Río Maipu
Source: Cade Idpe, 2004

Basin of Río Maipo (km^2)	Land Use	Land surface (km^2)	Part of the basin used for this purpose. (%)
15,304	Meadow	647	4.2
	Agricultural land	2464	16.1
	Forestry plantations	96	0.6
	Urban and industrial areas	582	4
	Mining activities	20	0.1
	Native or mixed forest	732	4.8
	Other uses	6340	41.4
	Areas without vegetation	4424	28.9

3.3 Environmental situation

Chile's economy grew quickly in the 1980s and 1990s, largely as a result of the increased export of natural resources - primarily minerals, forest, agriculture and fish. Whilst providing obvious economic benefits, this has had undesirable consequences for the environmental situation in the country. The principal environmental challenges are air pollutions in many cities, garbage management and water quality. However, as an exporting country, it is of high importance to meet the growing demands of environmental awareness from the surrounding world. This has contributed to an increasing interest in environmental issues during recent years. The first environmental law was introduced in 1994 and since then, further regulations have been put in place, and government institutions created to oversee the implementation and enforcement of the new laws (The Swedish Embassy, 2007). More information about the related institutions and regulations is given in Chapter 4.

3.4 Water quality

Chile does not have enough wastewater treatment plants to deal with the volume of sewage water that it produces, and therefore contaminated water is a general problem in the country. To combat this, an investment program with the aim to improve the water quality has been put into action. The percentage of domestic wastewater that is treated in a treatment plant reached 30% in 2003 and has today passed 70%. The national goal is a treatment of 95% of the domestic wastewater by the year 2010 (The Swedish Embassy, 2007). In addition, the water quality in the northern regions is affected by the mining and fishing industries. In the central part of Chile, contamination of water supplies is mostly caused by the emissions of untreated domestic and industrial wastewater, including water from the fishing industry and the production of pulp (The Swedish Embassy, 2007).

Studies have shown that the water quality in the Santiago region is characterized as "poor", "very poor" or "extremely poor". Water categorized as "poor" can be used for controlled irrigation purposes whereas water of "very poor" and "extremely poor" quality should neither be used for irrigation nor as a drinking water source. The main contamination problems are organic substances like suspended solids and increased values of BOD5 (CONAMA, 2008). The contamination of metals in the river system in the Santiago region is very low and not a key problem (Rocco, 2008 pers. comm.).

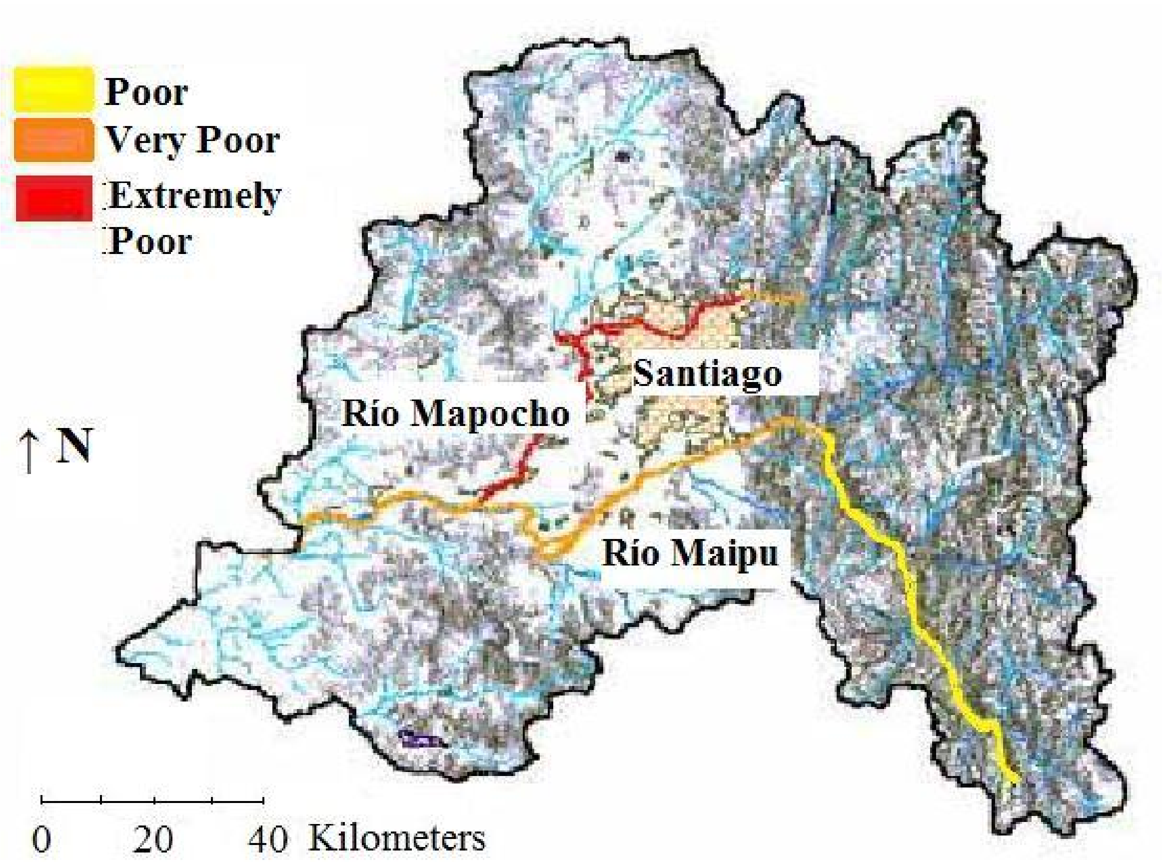


Figure 2. Water quality in the rivers in the Santiago area.
Source: CONAMA, 2008. Modified version.

3.5 Wastewater management in the Santiago region

The wastewater treatment in Santiago is operated by the private company Aguas Andinas. Their objective is to increase their facilities in order to treat 100% of the wastewater produced in Santiago RM before it is discharged in the local rivers. Today there are two principal treatment plants in Santiago; El Trebal and La Farfana. El Tribal is situated in the southern part of the city and has the capacity to treat wastewater from 1.7 million citizens. According to R.Torro at Aguas Andinas, this plant has the mayor load of industrial wastewater of the two treatment plants. La Farfana started operating in 2003 and treats approximately 50 % of the produced wastewater in Santiago RM which corresponds to the wastewater from 3,300,000 persons. Additionally, there are 13 smaller plants in use in the Santiago region. (Torro, 2008 pers. comm.).

3.6 Environmental awareness

Hazardous waste products from industries in Santiago RM are taken care of by the company Hidronor. They started this service in 1993, one year before the implementation of the first environmental law. According to R. Romero at Hidronor, the request for the service has increased remarkably since 1993 and has continued to do so after the amendment of law D.S. 90/2000 in 2006 (for more information see Chapter 4.2 and 7.1). He believes there has been a general rise in environmental awareness in Chile during the last years. However, he does not consider the amendment as the single reason for this. Instead he thinks that the publicity, from media and the general public, of incidents like CELCO's pollution have had a major impact (Romero, 2008 pers. comm).

In May 2004 the Chilean forestry company CELCO opened a new cellulose plant in Region XIV in the southern part of the country. Shortly after the opening the swan deaths at the Cruces River wetlands began. During the following 12 months the swan population suffered a dramatic decrease from over 5000 birds to only a few hundreds (Witte, 2009). With the pressure from media and the general public, CELCO was forced to stop its production during a period of time. This case is still well known and a reason for companies to remember that damaging the environment can lead to complications and bad reputation (Romero, 2008 pers.comm).

There are more reasons why Chile wants to continue its effort to improve the environmental state of the country. Romero mentions that there is a wish in Chile to reach a GDP of $20,000 per capita (today the GDP is close to $15,000 per capita). Moreover Chile is aiming to become a member of OECD (Organization for Economic Co-operation and Development). R. Romero points out that one important factor, in order to reach these goals, is a functional system when handling environmental issues. Furthermore, Rodrigo emphasizes that Chile exports a mayor part of its production abroad. This implies that Chile is required to keep a certain standard, also on environmental matters (Romero, 2008 pers.comm)

4 Business opportunities Chile –Sweden

4.1 Chile – Sweden

Although Chile and Sweden are two countries located far away from each other, there are a number of similarities. For example is forestry and mining counted as principal industries in both countries which make the exchange of methods, technologies and know-how beneficial.

Additionally, Sweden is well known among many Chileans. One reason for this is that hundreds of thousands Chileans had to escape their country as a consequence of the military regime with Pinochet in the front. During the years 1973 – 1988 approximately 30,000 – 40,000 refuges came to Sweden. Now when the situation has changed, some of these people have returned. However, there are still approximately 45,000 Chileans living in Sweden (out of these 18,000 are born in Sweden) (The Swedish Embassy, 2007). Consequently, many Chileans have friends and family in Sweden which decreases the distance between the two countries.

4.2 Chile as a trade country

The Chilean market

Chile runs a free market economy where the private business world is the principal player. The public sector is not as dominant but supervises and attempts to prevent market distortions. The official administration is in the process of being modernized to become more efficient. Foreign investors are treated equally to local and corruption is rare. The country has been, and still is, an interesting market for foreign investors. According ECLAC (UN Economic commission for Latin America and the Caribbean) the foreign investments increased with more than 15% during 2006 compared to 2005. Chile is, after Mexico and Brazil, the country in South America which attracts most foreign investors. Figure 3 shows the distribution between the different sectors where the principal investments were made in 2006.

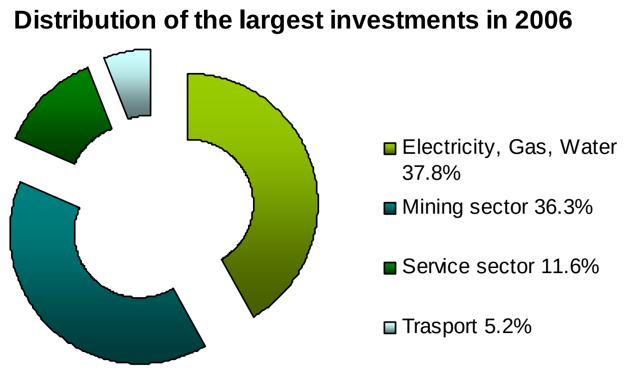


Figure 3. Distribution of the principal investments in Chile between different sectors in 2006
Source: The Swedish Embassy, 2007

Business opportunities

In 2006 approximately 75% of the citizens in Santiago had their wastewater connected to the sewerage system. In order to meet the legal responsibility to treat 100% of the sewage water by 2010, the sewerage network is now being extended and treatment plants are being constructed. In a longer perspective, the demand for fresh water for production industries, mining projects and agriculture is predicted to double within a period of 40 years. Hence this may result in investments opportunities within the water treatment sector. Within the years 2006 to 2016 investments for 649 million USD are being staked into projects for wastewater treatment in Chile (The Swedish Embassy, 2007).

Funding programs

As already mentioned, Chile strives for a free market with little support of tax concessions. However, there are a number of programs with the aim to stimulate the investments within some sectors. This includes the investments from foreign actors. CORFO is the governmental agency which supports Chilean companies to be competitive. They are set to aid the economical development in Chile and focus on innovations, support small and medium sized companies and promote a productive development in the different regions of Chile (CORFO, 2008). Among other programs which are offered by CORFO, there is one which intends to stimulate investments within High-tech projects. Companies which employ new methods to traditional processes can apply for financial support for investment costs which exceed one million USD. The funds can be used for financing feasibility studies, environmental impact assessments, engineering studies, support during start ups and more. For further information about commerce in Chile, Swedish readers are recommended to read the informative guide book “Marknadsguide Chile” from the Swedish Embassy in Santiago.

4.3 The Chilean – Swedish Chamber of Commerce

The chamber was founded in 1990 as a result of the increased commerce exchange between Sweden and Chile. The chamber is an independent, non-profit organization which today aims to promote and develop the commercial relations between the two countries. The chamber is working to further strengthen relations and commercial interchange as well as providing a forum for dialog and distributing information of interest. The chamber has a close collaboration with both the Swedish Embassy in Chile and the Chilean Embassy in Sweden (Camará Suecia, 2008).

4.4 The Chilean-Swedish fund for development

In order to stimulate the cooperation between small and medium sized companies in Chile and Sweden a fund was created by the two countries. Its mission is to promote innovation, knowledge transfer and knowledge exchange. It supports projects that have the aim to increase the competitiveness of the participating companies in their markets. This should be achieved by a common development and application of new technology. The fund was created in 2002 by the Chilean governmental agencies CORFO (National Commission of the Environment) and AGCI (The international cooperation Agency) and the Swedish organization Sida (Swedish International Development Cooperation Agency). Up to 50% of the total project cost can be financed by the fund. The fund monies can be used to finance consultancy, education and technical support (El Fondo Chile Suecia, 2008).

5 Legal provisions applicable to regulation of wastewater management

5.1 CONAMA and SISS

The National Commission of the Environment, CONAMA (La Comisión Nacional del Medio Ambiente), is a state institution which is responsible for setting environmental policies in the country. This includes developing environmental standards, making prevention plans and introducing management tools to enable environmental quality recuperation (Rodriguez, 2008)

To ensure that the set norms are met by industries the Superintendence of Health Services, SISS (La Superintendencia de Servicios Sanitarios) administers a control system where companies within the superintended industries report their effluent values monthly. SISS undertakes site visits and performs tests to validate the reported values. When a company fails to meet the set norms, SISS collaborates with the company to develop an improvement strategy. When the strategy is determined, SISS ensures that it is being followed. SISS imposes economic sanctions on companies which fail to improve in line with the set strategy.

5.2 Description of related laws

According to the SISS annual report 2007, there are three principal sources of contamination of water courses:

(1) Discharge of untreated domestic wastewater.

(2) Contaminants washed off the land surface during rainfall.

(3) Industrial activities which cause contamination.

In Chile, industrial wastewater is referred to as residuos industriales líquidos (“Riles”).

This water commonly has enhanced values of coli form bacteria, suspended solids, fats, oils and shows a high BOD5 value (SISS, 2006).

There are three principal regulations aimed at minimizing the effects of the discharge of industrial wastewater into watercourses. The method used for discharge determines which regulation is applied. The regulations are described below.

5.2.1 Dectreto supremo 90/2000

- Discharge to Marine and Surface Waters

All companies which discharge their wastewater into watercourses must monitor the effluent values in such discharge. If the effluent values in the wastewater reach a certain value, which is based on the emissions of 100 people, the company in question must then take steps to comply with regulation DS 90/2000(Carvallo, 2008).

There are five different charts of maximum outlet values, each of which relates to a different type of recipient water body or watercourse. Table 3 gives the maximum values for some parameters for discharge water to rivers.

Table 3. Maximum values for some parameters for discharging water into rivers. Source: D.S. 90/2000, 2008

Parameter	Max value
pH	6 – 8.5
Temperature	35 º C
Total suspended solids	80mg/l
Oil and grease	20mg/l
Cadmium	0.01mg/l
Phosphorous	10mg/l
BOD_5	35mg O_2/l
Aluminum	5mg/l
Arsenic	0.5mg/l
Cupper (total)	1mg/l
Chrome 6+	0.05mg/l
Iron (dissolved)	5mg/l
Zinc	3mg/l

The regulations allow for companies to exceed the values described in circumstances where the company is discharging water into a larger watercourse. The dilution factor, d, is calculated as followed:

$$d = \frac{\text{Quantity of water in water body}*}{\text{Quantity of effluent water}**}$$

* = The quantity of water in the receiving water body is expressed as water volume per time unit. This is determined by the The General Commission of Water (Dirección General de Aguas).
** = The quantity of effluent is calculated as the total effluent production, calculated on a half-month basis, divided by the number of days that effluent is discharged.

The maximal concentration value for a contaminant is calculated as followed:

$$C_i = T_i \times (1 + d)$$

Where:
C_i = the maximal concentration value for contaminant i.
T_i = the maximal concentration value permitted for contaminant i according to table in regulation D.S. 2000/90.
d = dilution factor.

Regulation 90/2000 prescribes the minimum number of monitoring days for a company as:

(5) 12 per year where maximum discharge is $5,000*10^3$ m^3 /year;

(6) 24 per year where maximum discharge is $5,000 – 20,000 *10^3$ m^3 /year; and

(7) 48 per year where the discharge exceeds $20,000*10^3$ m^3 /year.

The values are reported to SISS on their web based reporting system (SISS, 2008).

5.2.2 Dectreto Supremo 46
- Discharge to Ground Water (Infiltration)

Companies whose wastewater infiltrates the ground water system are required to comply with regulation D.S. 46 if the concentration of contaminants exceeds a certain value.

When the application of D.S. 46 is confirmed, a test to investigate the vulnerability of the aquifer must be performed by the company. There are three different levels of classifications. If the aquifer is classified as low or medium vulnerability, there are two applicable Tables of limits that should be followed (see Table 4 below).

If the vulnerability of the aquifer is classified as high, the quality of the discharged wastewater is required to be of equal or better quality than the aquifer itself. This is something which is hard to achieve and therefore rarely occurs in reality (Carvallo, 2008).

The companies which follow D.S. 46 report their values monthly to SISS through their webpage (SISS, 2008).

Table 4. Maximum values for some parameters for infiltration of water to aquifers of medium and low vulnerability.
Source: D.S. 46, 2008

Parameter	Max value Medium vulnerability.	Max value Low vulnerability
pH	6.0 – 8.5	6.0 – 8.5
Total Nitrogen Kjeldahl	10mg/l	15mg/l
Nickel	0.2mg/l	0.5mg/l
Oil and grease	10mg/l	10mg/l
Cadmium	0.002mg/l	0.002mg/l
Aluminum	5mg/l	20mg/l
Arsenic	0.01mg/l	0.01mg/l
Cupper	1mg/l	3mg/l
Chrome 6+	0.05mg/l	0.2mg/l
Iron	5mg/l	10mg/l
Zinc	3mg/l	20mg/l

Decreto Supremo 609

- *Discharge to the Sewerage system*

Companies that discharge industrial wastewater into the sewerage system, and the wastewater exceeds a given key value on any of a number of parameters, the company in question is required to comply with regulation DS 609.

This regulation came into force in 1989. Its principal purpose is to prevent damage of the sewage grid and treatment plants. Conceivable damages include incrustation, corrosion or the formation of toxic or explosive gases.

Table 5. Maximal values for some parameters for industries which discharge their sewage water into a sewerage system.
Source: D.S. 609,2008

Parameter	Max value
pH	5.5 – 9.0
Temperature	35 º C
Total suspended solids	300mg/l
Phosphor	10-15mg/l
BOD_5	300 mg O2/l
Oil and grease	150mg/l
Cadmium	0.5mg/l
Aluminum	10mg/l
Arsenic	0.5mg/l
Cupper	3mg/l
Chrome 6+	0.5mg/l
Nickel	4mg/l

Each treatment plant is responsible for monitoring the quality of the wastewater it receives. The treatment plant will decide with what frequency monitoring is carried out.

Companies which perform their own treatment before discharging water to the sewage network are responsible for measuring the quality of the discharged water on a monthly basis and providing the results to the receiving wastewater treatment company.

Companies may come to agreements with treatment plants which allow them to exceed the allowable levels of BOD5, phosphor, ammonic nitrogen and total suspended solids in their wastewater. DS 609 provides that the treatment plant and the company in question must sign a contact that specifies which parameters can be exceeded and the financial compensation that the company will pay to the treatment plant.

Although it is the wastewater-producing companies which monitor the effluent, it is the treatment plants which are obliged to provide SISS with the reports from the companies on a half-yearly basis. In this way, SISS indirectly monitors the compliance of wastewater producing companies with regulation D.S. 609. (Carvallo, 2008)

5.3 Legal management

As of December 2007, there where around 3000 companies reporting their emission values to SISS. As illustrated in Figure 4, the most common method of dealing with their wastewater is by discharge into the sewage network. Marine and surface water is the second largest recipient for wastewater. Only a few companies discharge their effluent into groundwater.

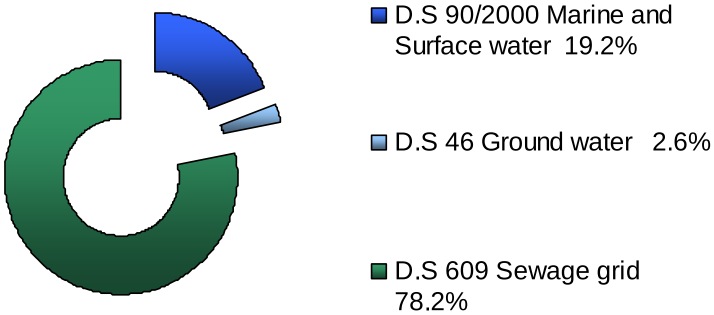


Figure 4. Distribution of recipients for wastewater among the industries which report their effluent values to SISS
Source: SISS, 2007

The companies which discharge sewage water to watercourses and groundwater report directly to SISS through their webpage (SISS, 2007). According to Carvallo, approximately 95% of the registered companies supply their monthly values. Of these, approximately 87% achieve the effluent values applicable to them under the regulations. The non-complying companies are required to formulate a strategy to bring their values into compliance, and if necessary, make the investment necessary to accomplish this (Carvallo, 2008).

Treatment companies are compelled to report the monthly values from the companies they serve to SISS every six months. Therefore companies which use the sewage network as the recipient of their wastewater indirectly report to SISS. Among the companies which discharge to the sewage network, the average percentage of compliance with the regulations reached 61.9% in the year 2007. This was an improvement of almost 5% compared to the previous year (SISS, 2007).

6 Separation technologies

Separation technologies is the gathering name for a number of technology which, in difference from a larger effluent treatment plant, commonly are integrated in the production process to remove specific contaminants. Industrial processes often generate effluent that contains a mixture of substances. In order to reduce the cost of processing this effluent, separation technologies can be integrated in the production line and in this manner remove harmful substances. Separation technologies can with favor be applied to remove substances like heavy metals, anions (metals and non-metals), grease and oil from industrial effluent.

Using separation technologies as part of the production process, for instance as a method of cleaning re-circulating process water, can be more cost-effective than using a larger effluent treatment plant. This approach commonly needs less energy and it allows the recovery and re-use of individual substances (Accepta Water Treatment, 2009). Because of these benefits it is of interest to study to what extent these methods are employed in industries in Chile at present as well as possibilities for further application. In this chapter the basic concepts in relation to common separation technologies are given.

6.1 *Ion exchange technologies*

6.1.1 The principle

The process of ion exchange is regularly achieved by letting fluid pass through a column which is filed with plastic-like orbs with a diameter of a few millimeters. This substance is referred to as the ion exchange mass. As the name indicates, the method entraps ions by replacing them with other ionic compounds which initially are found in the unsaturated ion exchange mass. Thus, undesired positive ions can be exchanged to sodium- or hydrogen ions while negative ions can be replaced with hydroxide- or chloride ions.

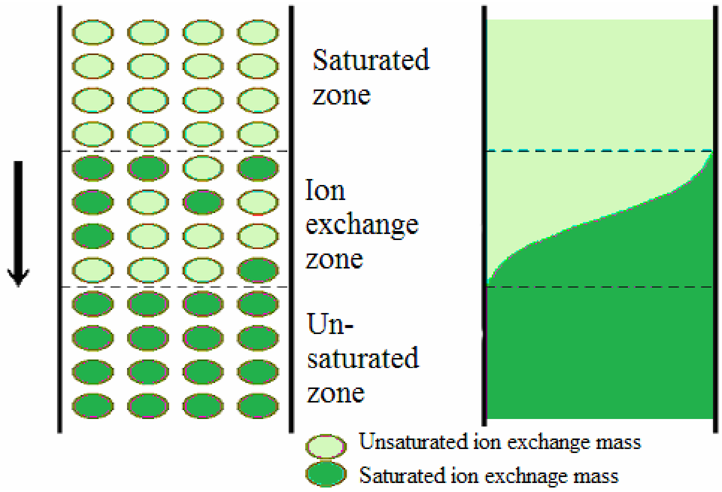


Figure 5. Illustration of the saturation process in the ion exchange mass.

The zone of ion exchange will move through out the column as the upper layers will be saturated. Eventually, no exchangeable ions will be left in the ion exchange mass. In the water treatment process this will result in a breakthrough of undesired ions in the outgoing fluid. The process of saturation is illustrated in Figure 5. When this occurs the mass is required to be refilled with exchangeable ions. This is accomplished by adding a small amount of acid, lye or saline solution, depending on the type of ions desired, to the column. Adding a high amount of the initial ion to the column changes the chemical equilibrium. The caught ions are, as a result of the change in equilibrium, forced out of the column and can be collected. Once again the column will be saturated with exchangeable ions and thus be prepared to use in a treatment process (Persson, 2005).

6.1.2 Types of exchangers and application

Depending on the area of use there are different kinds of ion exchangers. Conventional exchangers can be either weak or strong alkali or acidic weak or strong, depending on if the undesired ions are positive or negative. “Kelat ion exchangers” has a high selectivity towards metals and are therefore generally applied to separate heavy metals from the fluid. Materials inside the column can consist of natural substances like peat for instance, but usually artificial ion exchange masses are employed (Persson, 2005).

6.1.3 Selective ion exchange

Using artificial materials enables a selection of ions which should be separated. This is an advantage since specific, undesired ions can be withdrawn from a fluid in preference to a general “cation or anion exchange mass” which will, to a certain extent, replace all present cat- or anions. As mentioned earlier, more hazardous ions like heavy metals can be separated in preference to more harmless ions like sodium and potassium. One of its cons is the limited capacity – the concentration of undesired ions can not be too high since this will saturate the ions exchange mass too often to make the method functional (Persson, 2005).

6.1.4 Applications

The uses and applications of ion exchange are many and one of the reasons why it is often employed is the relatively low investment and operation costs. Ion exchange is, as an example, employed to reduce the salt content from saline water by changing Na^+ and Cl^- to H^+ and OH^-, which forms water. Additionally, the method is used in galvanization industries where it is applied to clean rinsing water or the reuse of valuable metals from used process fluids. It is favorable to use the principals of ion exchange when the concentration of undesired ions is relatively low. A high concentration of ions will result in a frequent regeneration of the ion exchange mass which makes the method unpractical and expensive. Selective ion exchange methods are successfully applied to detach heavy metals. In practice it is for instance employed to polish treatment after other water treatment technologies, separate metals from drinking water and the treatment of water from mining activities (Mercatus, 2008).

6.2 Evaporation

When applying evaporation the method takes advantage of the difference in boiling temperature between the different compounds in the solution. Since the fluid, which commonly is water based, has a lower boiling temperature than the other compounds it will turn into vapor meanwhile other dissolved and non-dissolved substances stays in the liquid phase. By applying this method, the composite can be separated and an increased concentration of the contaminants can be obtained. One disadvantage when applying this method is the relatively high demand for energy. However, there are a number of different designs in order to adapt the most suitable solution to each case. On way to reduce the operation costs is for instance to use the condensation energy from the vaporized water. More over, the evaporation can be operated at an atmospheric pressure or on different levels of vacuum for energy-saving purposes. Additionally, evaporation is most beneficial to apply to liquids with higher concentrations since this will require a lower consumption of energy (Persson, 2005). Evaporation systems are applied to the purification process of oil and water emulsions as well as creating recyclable processes (Mercatus, 2008).

6.3 Membrane technologies

6.3.1 The principle

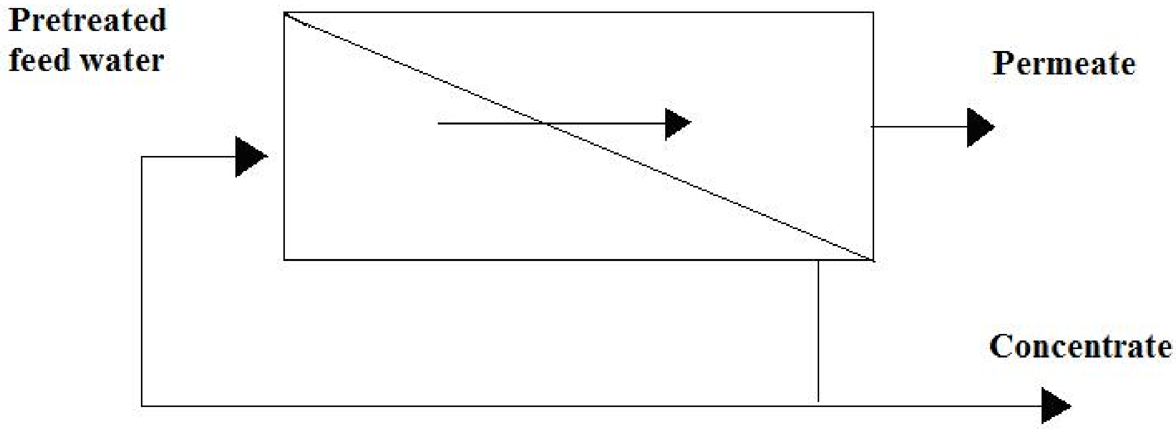


Figure 6. Basic diagram of the Mass transport in a Membrane

Filtration is an operation to remove non dissolved solids from liquids. The size of the pores and the porosity of the filter will decide the limiting size for the particles that can be separated. In a general diagram of a filter the water entering is referred to as the feed water, the filtrated water is named permeate and the contaminants, which is caught and separated by the filter, is the concentrate, see Figure 6 (Hillis, 2002).

The capacity of a filter (i.e. flux) is expressed as the flux of permeate per square meter membrane surface (Q/m^2). Factors which will influence the flux is the size of the pores in the membrane surface, the thickness of the membrane, the difference in pressure over the membrane as well as the temperature and the concentration of particles (Persson, 2005).

For a general filtration process, the pressure over the filter will increase over time as a consequence of the particles clogging the pores in the filter.
All the mentioned pressure driven membrane processes are sensible to clogging which decreases de capacity of the filter. For this reason, when employing these technologies, it is of great importance to adapt a well preformed pre-filtration. How ever, this will not prevent the accumulation of the substances which doesn't bypass the membrane. Consequently, the flux will over time decrease. To prevent the clogging and the decrease in flux, the direction of the feed water is parallel to the membrane surface. This allows the mayor part of particles to follow the feed water out of the process. Permeate can instead be withdrawn from a perpendicular angle, see Figure 7.

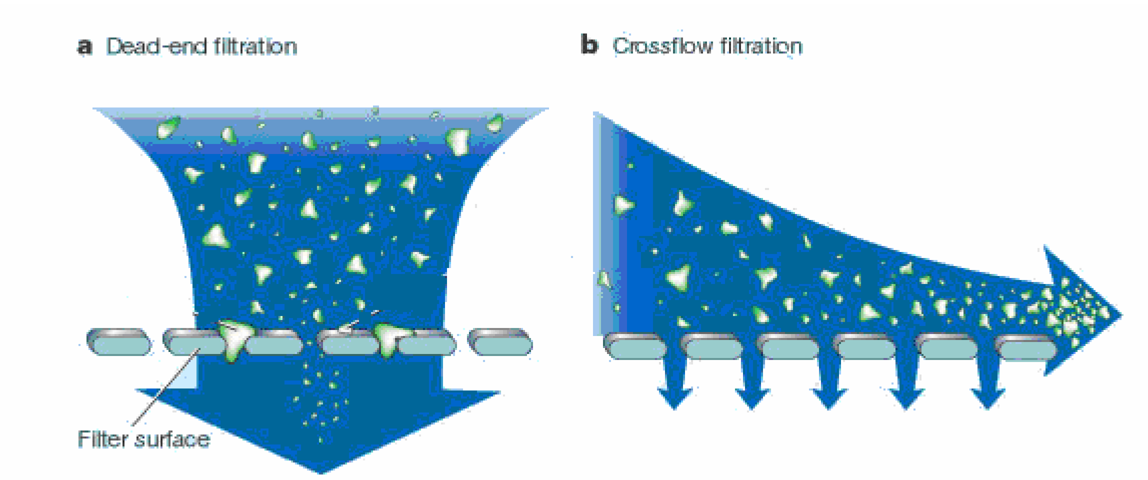


Figure 7. Dead-end verses Cross flow filtration.
Source: Nature, 2009 (with permission)

Nevertheless, the filter will with time have a decrease in flux due to congestion of the membrane surface. To once again obtain the capacity the membrane needs to be washed which most commonly is preformed with acid, alkali or washing chemicals. Even so filters do not last forever. Although it is cleaned frequently, filters need to be altered with time in order to maintain the desired flux. The operation time for membranes varies immensely depending on use and applications (Persson, 2005).

6.3.2 Types of membranes and applications

To adapt filter technologies for suspensions where the solids are of a smaller size, filter technologies like microfiltration, ultra filtration and reverse osmosis can be employed. The decision of which filter technology that should be used is partly depending on the size of the particles that are wished to be separated. The size limits between the different technologies are overlapping.

Table 6. Membrane technologies
Source: Persson, 2005

Membrane process	**Characteristics for separated solids**		**Separation mechanism**
	Diameter (µm)	**Pressure required (MPa)**	
Micro filter, MF	0.2 – 10	0.01 – 0.1	Straining
Ultra filter,UF	0.001 – 0.1	0.2 – 1.5	Straining
Nano filter, NF	0.001 – 0.01	2 – 4	Straining + membrane diffusion
Reverse Osmosis RO	0.0001 – 0.002	2 – 10	membrane diffusion

Micro filter (MF)

Micro filter has the largest pore dimensions of 0.2 – 10µm and for this reason the lowest pressure required for separation. Matters that can be divided are for instance metal hydroxide particles which often occur in effluent from galvanization industries (Persson, 2005).

Ultra filters (UF)

As indicated in Table 8, UF can be used for separation of molecules in the size range of 0.001 – 0.1µm from wastewater. Compared to other methods, UF employs relatively coarse membrane separation at relatively low pressures. For industrial purposes there is a benefit choosing a thin-skinned membrane since this will decrease the friction factors. This in its turn will require a lower pressure to transport the liquid which is a benefit from an energy consumption point of view (Cheremisinoff, 1993).

An ultra filter can be applicable for the purification of water as well as a method for concentrating to enable the recirculation of valuable compounds (Persson, 2005).
Size, shape and molecular weight will determine the separation of molecules. Since the osmotic effect has a smaller impact for UF than for Reversed Osmosis, a lower pressure is usually sufficient to promote permeation (Cheremisinoff, 1993).

UF is used for separations of emulsions, colloids and suspended matters which are difficult to separate gravimetrically. As an example it can successfully be used with the purpose to clean oil emulsions, treatment of water containing pigment from paint and enable a re-use of defatting solvents (Mercatus, 2008).

Nano filters (NF)

Nano filters are applied to separate particles smaller than 10nm. It is for instance used to separate antibiotics and selective demineralization of water or organic solutions (Lundin, 2000).

Reverse osmosis (RO)

When an osmotic membrane is placed between two liquids, where one is for example pure water and the other is a solution with an increased salt quantity, parts of the water from the pure water solution will diffuse through the membrane to the salty solution. The reason for this is the difference in osmotic pressure over the membrane caused by the difference in concentration of salt. An example of a membrane that operates like this is the cell wall in our own body which enables the cell to absorb water without consuming energy. On the contrary, if a hydrostatic pressure, higher than the osmotic pressure, is added to the salt-solution the water from this solution will diffuse through the membrane, leaving the salt as a concentrate. This is the concept of the membrane technology referred to as reverse osmosis.

While Micro- and Ultra filters base their separation process on straining water through the pores of the membrane, a filter using the concept of reverse osmosis is based on the concept of diffusion. The reverse osmoses membrane has a thin microporous surface that rejects impurities, but allows water to pass through. Therefore, in theory, this technology stops all

particles apart from pure water. It is therefore a commonly adapted method to enable the separation of small particles like salts or metal ions with a diameter around 0.001 µm (Mercatus, 2008).
A high concentration of contaminants will cause a high osmotic pressure. Thus, to enable the treatment of this water, a pressure higher than the osmotic pressure needs to be applied. A higher concentration of contaminants has two negative effects; a higher applied pressure will increase the energy consumption and; an increased frequency of cleaning the membrane which shortens its lifetime.Fore these reasons reversed osmoses is favorably applied when the concentration is not exceptionally high (Persson, 2005).

7 Case studies – four industries

7.1 Industry A – Paper Production Industry

7.1.1 Description of the company

This Chilean industry was founded in 1989. The production is focused on three production types for container board. The pulp is produced from OCC (old corrugated container) and the company therefore describes their process as 100% renewable. The company has 160 employees and delivers annually about 100,000 tons of containerboards to the national and international market (employee A1, 2008).

7.1.2 Description of the production process

Pulp production
The pulp production is obtained by recycling old paper and containerboard. In the first step, bales of old paper enter the pulp production where it is broken down and mixed with water to create slurry. Figure 9 gives an illustration of the production line. This first tank has a capacity of 100m^3. In this first step the slurry consist of 3% solids and 97% water. In order to create clean slurry suitable for containerboard, it is carried by pumps through a series of cleaning modules. In the first step of the cleaning process, bigger particles like plastics and nails are separated by the use of a Hydro cyclone, see Figure 8.

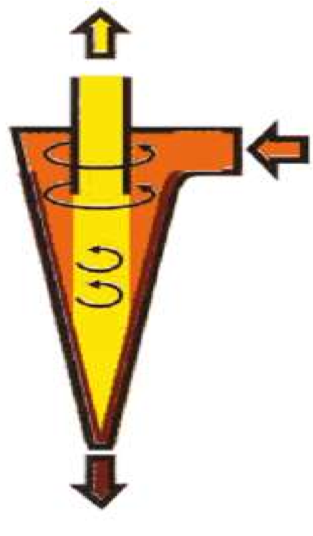


Figure 8. Hydro cyclone. Water enters from the right and the centrifugal force from the rotation motion brings liquid and lighter particles to the surface. Dense objects like nails and stones will by gravity be transported to the bottom.

In the following step finer particles like sand and such are separated from the slurry by using centrifugal forces. The slurry is now clean but contains a high percentage of water. In order to dewater, the slurry is passed through a process which mechanically presses out water. After this step the slurry consists of approximately 80% water. The withdrawn water is sent to the primer step in the water treatment plant. In the final step of the cleaning procedure, the slurry is stored in a 400m^3 storage tank which operates as stock of pulp for the paper production.

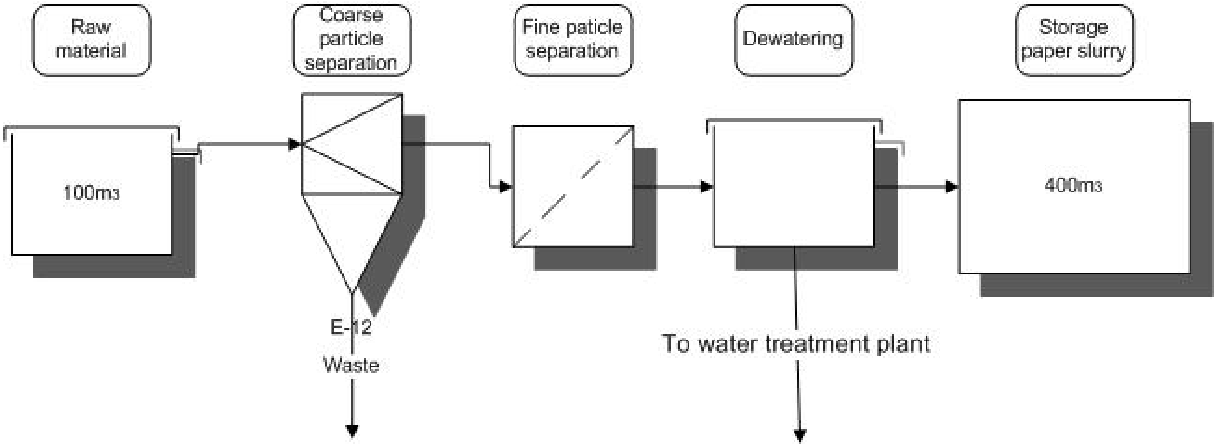


Figure 9. Pulp production.

Paper production
The paper machine has a capacity of 30tons per day. Before paper is produced, the pulp is treated to refine long-fiber fraction in the pulp. Thereafter paper is shaped and water is removed. At this stage the paper web consist of approximately 40% dry material and 60% water. In order to reduce a higher a mount of water, the formed paper web is pressed and dried by pressure, vacuum and steam. After this procedure the web has a 97% of dry material. Excess water is led to the treatment plant. An illustration of the paper production is given in Figure 9.

After being produced, paper is wound into rolls according to the costumers' specification and stored in warehouses ready to be delivered (employee A2, 2008).

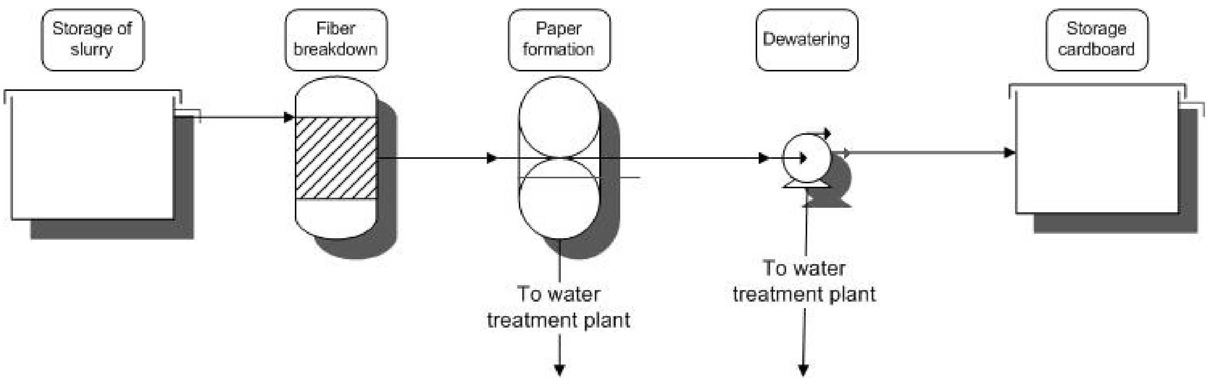


Figure 10. Paper production.

5.1.3 Description of existing water treatment technologies

Water treatment plant
The extracted water from the pulp and paper production has high values of suspended solids and shows a high BOD_5 value. In order to meet the norms for quality of effluent, the industry has a treatment plant consisting of an active sludge process to reduce the BOD_5 and COD values. Thereafter, suspended solids are reduced by using a clarifier. The aim is to reintegrate the effluent into the production cycle. However, today new fresh water is used in the production and the treated effluent is led to a nearby watercourse.

The effluent water from the pulp and paper production enters an aeration tank with the retention time is approximately 2.5 days (tank number one in Figure 11). Here organic material is removed by micro bacterial activity. Dissolved oxygen is necessary to promote the growth of biological flocks that substantially removes organic material. The basin is aerated on the surface by electrical driven propellers which ensure a constant movement of the water to avoid particles from settling. Also, it keeps a sufficient oxygen level for the micro bacterial activity. In the following step water enters a cone-shaped clarification tank (tank number two). By letting a moving bridge strike the open water surface, solids are collected in the center of the tank. Water is removed from the edges and is treated with hypochlorite in a separate chamber (Employee A2, 2008).

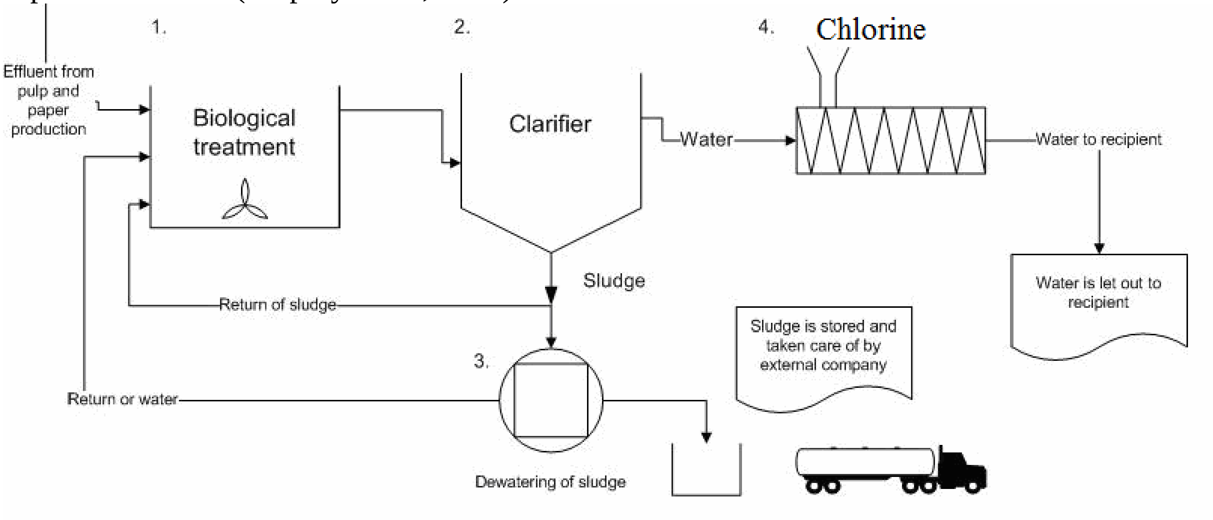


Figure 11. Water treatment plant and the activated sludge process at visited industry.

In order to activate the hypochlorite, the treated water is led through a winding path to extend the retention time to a minimum of 20 minutes (tank number four). Thereafter water is let out to the nearby recipient.

Table 7. Effluent values from visited industry and the maximum values allowed according to regulation D.S. 90/2000
Source: Employee A3, 2009

Parameter	**Effluent values**	**Maximum values allowed**
BOD_5	23mg O_2/l	35mg O_2/l
COD	37mg/l	-
Suspended Solids	20mg/l	80mg/l
Temperature	25ºC	35ºC

As already mentioned, the effluent from the paper production shows a high value of BOD_5 which generates sludge in the water treatment plant. The sludge is mainly extracted from the clarification step. The solids are forced to the center of the cone-shaped clarification tank and from there it is transported by a pumping system to a separate section where water is withdrawn by a mechanical press (step three in Figure 11). Water from this process is lead back to the first step of the treatment plant. Withdrawn sludge is taken care of by an external company which produces soil improvements (compost). The paper mill is charged for this service. A smaller amount of sludge is reused as a bacterial source in the homogenization chamber (Employee A2, 2008).

Problems experienced and requests considering the wastewater technology at the visited company
Today the production of papers requires around 12-15m^3 of water per ton paper. Since the daily production of paper is around 300ton, the existing water consumption reaches around 4500m^3 per day.

The intention is to increase the production. This would lead to a higher demand for water in the future. Today the water is taken from a private well and the company pays for electricity costs and maintenance. However, with regards to a predicted decrease of water abundance and therefore an increase for the cost of fresh water, the company is interested in technologies to reintegrate the effluent to the production cycle (Employee A1, 2008).

7.2 Industry B – Animal oil production

7.2.1 Description of the company

The production is focused on the manufacture of products from animal fat. The industry has been operating during the last 70 years but has recently changed owner and is therefore in the process of upgrading the production chain as well as the water treatment technologies (Contact B1, 2008).

7.2.2 Description of the production process

The raw material consists of fat and rind, mainly from pork, and is bought from local butcheries. In the first step in the production chain, the raw material is boiled to breakdown tissues. Thereafter it is kept in a settling tank. With time the mix will separate into three layers where the top layer with low density has the highest fat-content. The separated parts can then be combined in order to obtain the desired fat-content for the product. In between the batches the settling tanks are cleaned and non useful parts of the batch is flushed out with the effluent (Employee B2, 2008).

7.2.3 Description of existing water treatment technologies

The effluent is discharged into the sewage grid. In order to meet the required limits of grease, suspended solids and BOD_5, the effluent needs to be treated before the discharge (Employee B2, 2008).The effluent that enters the treatment plant has an approximate temperature of 80 degrees Celsius. Thus, in order to decrease the temperature to around 30 degrees Celsius, effluent is kept in a storage tank for a sufficient period of time. From here it is led to a separation tank. Here the pH value is decreased and ferric chloride is added as a coagulant in order to remove suspended materials. Additionally, a polymeric flocculants is added to enhance the flocculation process in which individual particles of a suspension form aggregates. With time, the greasy liquid with suspended solids ideally will divide into three distinct layers; a top layer consisting of mainly grease, middle layer of water and on the bottom, a layer of settled particles. As a result of the decreased pH level and the addition of flocculants, this works to some extent. By using a skimmer, grease is collected from the surface and the settled material is removed from the bottom of the tank. The water from the middle layer is pumped to a set of metal-filters in order to further improve its quality. However, frequently quality of outgoing effluent does not meet the requirements for it to be discharged to the sewage grid. When outgoing effluent appears unclear and greasy, it is therefore simply pumped back to the start of the treatment plant, in order to go through the process until a better result is obtained. Caused by the design of the manufacturing process, the production is made in sequences and the time for producing one batch is estimated to 3.5 hours. Hence, the effluent which enters the treatment plant is not a constant flow, but in intervals of 3-4 hours. The treated effluent is stored in a tank and discharged to the sewage grid two times daily. The total discharge is approximately 25m^3 per day (Employee B2, 2008).

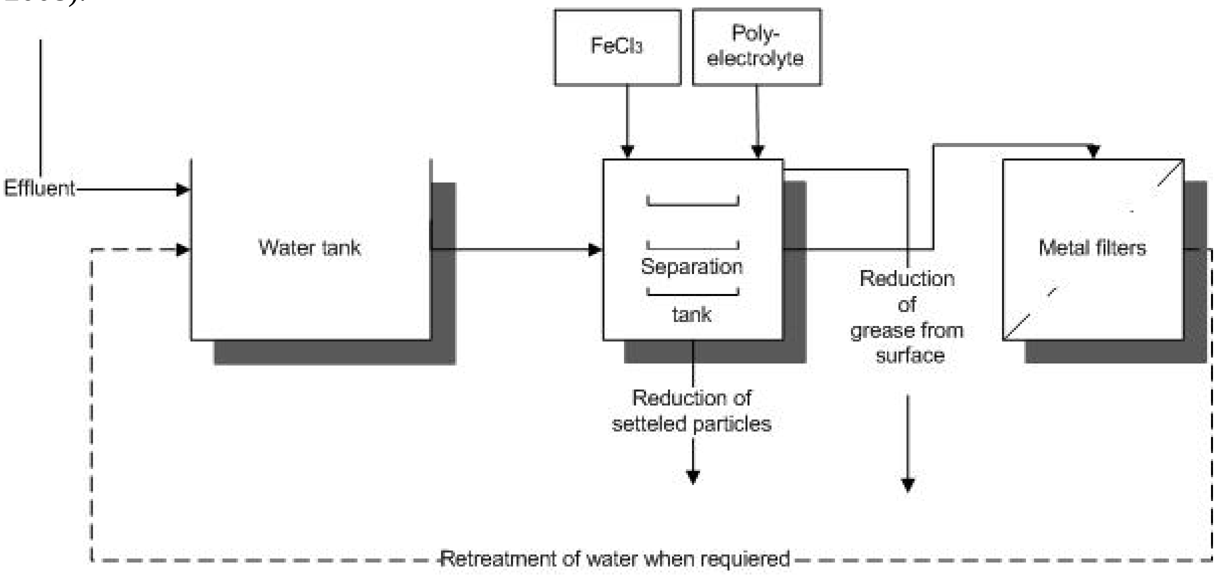


Figure 12. Flow chart of water treatment plant.

Problems experienced and requests considering the wastewater technology at the visited company

As previously mentioned, an up gradation of the processes as well as the existing wastewater treatment technologies is being discussed. According to Rodriguez, problems with enhanced values of grease, suspended solids and proteins are often experienced, see Table 8 . Investigations considering which proportions of flocculent respective coagulant that gives the best results have been carried out to optimize the existing plant. Nevertheless, since values still exceeds the limits, the company is obliged to find other methods. One considered method is DAF (Dissolved Air Solution). In this method, suspended solids are removed by adding small air bubbles which adhere on the molecules which brings them to the surface (ABL Environment, 2009). Additionally other methods like filters and centrifuges have been discussed. It is of interest to find a treatment process which allows the separated grease to be returned to the production since a significant portion of the grease is currently lost in the effluent (Employee B2).

Table 8. Effluent values from visited industry and the required maximum values according to regulation D.S. 609
Source: Contact B1, 2009

Parameter	Effluent values	Values Required
BOD_5	1062mg O_2/l	300mg O_2/l
Oil and Grease	181mg/l	150 mg/l
pH	7.6 – 8.0	5.5 – 9.0
Phosphor	6.6mg/l	15mg/l
Suspended Solids	315mg/l	300mg/l
Temperature	12.2ºC	35 ºC

7.3 Industry C – Production of aluminum cans

7.3.1 Description of the company

The company is on of the world leading producer of consumer packaging and exist in more than 20 countries around the world. They offer a broad range of packaging for different industries, using different materials and technologies. At their industry in Santiago the production is focused on aluminum cans.

7.3.2 Description of the production

Aluminum is cut and shaped to cans. Throughout the process oil is used as a cutting fluid to cool and lubricate the cutting tools. The oil is recycled in the production and will with time contain metals as well as algae and fungus. Consequently, the newly fabricated cans are covered in a film of contaminated oil. For this reason the cans are washed and dried before being printed, packed and stored in order to be delivered to the beverage company (Employee C1,2008).

7.3.3 Description of the treatment plant

The industry has a water treatment plant that was built in 1994. Water from the washing procedure is led to the water treatment plant and approximately 99% of the water entering the treatment plant is from this step. Thus, the water contains oil, Al^{3+}, F^{-}, Cd^{2+}, Ni^{2+}, Pb^{2+}, Zn^{2+} and has a pH-level around 4.5. In order to separate oil and grease, pH is reduced to around 2 by adding H_2SO_4 to the first tank. Oil and grease floats to the surface and can be reduced by blocking the surface part of the trench. In the next step, calcium hydroxide is added to increase the pH level in order to deposit metal ions to metal hydroxide compounds. Additionally, a coagulant is added to aid the deposit of metal hydroxide.

The wastewater is highly contaminated with Fluoride from the use of the detergent Ridoline 120 during the washing process. H_3PO_4 is added in order to reduce the level of Fluoride. Since H_3PO_4 has an acidic effect, more Calcium hydroxide is added to keep the pH on a favorable level, around 8-9.5, for the deposit of hydroxide metal complex. In the following tank a polyelectrolyte is added which facilitates the formation of larger flocks. In the subsequent step, the water enters a flotation tank. Here the wastewater enters from the side of the tank while air and clean water enters through the narrow end at the bottom of the cone-shaped tank. An even pressure is maintained by transporting the water with a constant inflow towards the wider surface of the cone, see Figure 11. Air bubbles will bring flocks to the surface where they are educed by a sludge scrape (Employee C2, 2008).

Figure 13. Sludge scrapes at the surface of the flotation tank.

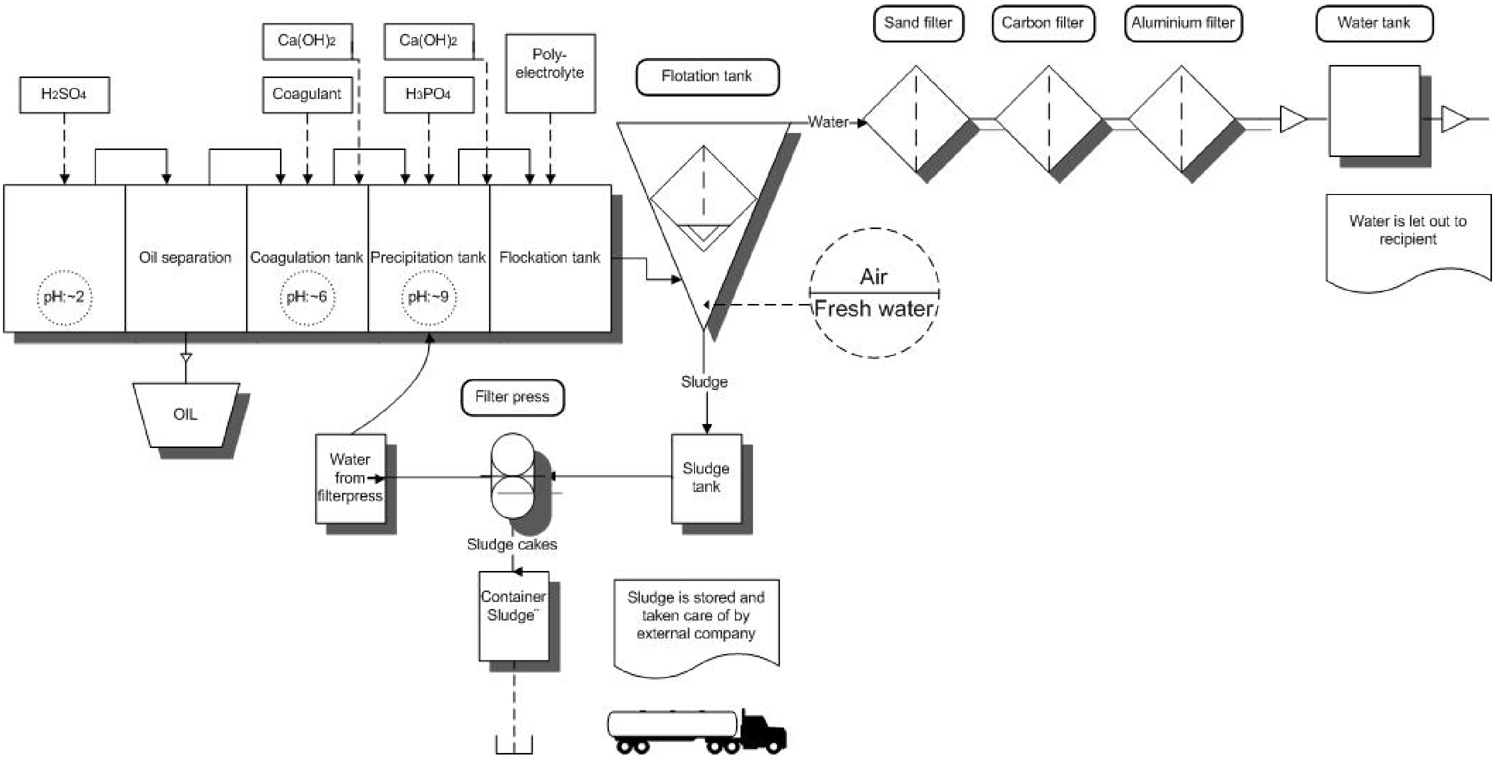


Figure 14. Process scheme of wastewater treatment plant at visited industry

Sludge treatment

The sludge from the flotation tank is thickened by slowly letting the sludge rotate and with time water can be withdrawn from the surface. In the last step for the sludge-treatment, water is reduced by pressing discs of sludge through a filters press, see Figure 12. The end product is sludge with approximately 60-70% water. Since it is contaminated with metals like aluminum, fluorine and chrome it is categorized as hazardous waste and needs to be handled by companies with certain permissions.

Figure 15. Filter press for dewatering of sludge.

Water treatment

From the flotation tank, water continues through a number of filters to further improve its quality. A sand filter captures remaining flocks. The sewage water treatment plant is equipped with three active coal-filters, where one is used at a time to capture organic complexes including remaining oils and grease. In the last step, water is filtrated through two aluminum filters to meet the normative level of Fluoride. Outgoing effluent is measured to approximately four liters per second.

Problems experienced and requests considering the wastewater technology at the visited company

Although taken measures, the industry frequently experience problems with increasing concentration of Fluoride ions in effluent which sometimes exceeds the limits. Moreover, as the sand filter captures contaminants, a pressure is built up in the tank. Consequently, a high pressure gradient throughout the filter tank indicates that the filter needs to be cleaned in order keep its capacity. This is done by a back-flush process of the tank which is carried out approximately every 24 hours. This is a disadvantage since the back flush process of the sand filter has high water consumption. Additionally the sand filter can not be used during the back flush process which means that the effluent needs to be stored during this period of time. Another problem experienced at the industry is the high quantity of sludge that is produced in the treatment plant. After the existing dewatering methods it still contains approximately 60 - 70% water. The sludge is classified as hazardous waste and is taken care of by an external company. There are requests for methods to minimize the sludge produced or a way to dewater the sludge further. The water used in the process is taken from a 100m deep private well. Water is usually not a limiting source but it has occurred that the well almost dried out during extremely dry periods (Employee C1, 2008).

7.4 Industry D – Galvanization industry

7.4.1 Description of the company

The company was founded in 1945 and is in Chile one of the leading companies for the production and surface treatment of screws, screw nuts and other metal objects for construction purposes (Escobar, 2008). The industry has the capacity to reach a monthly production of 1000 tons.

7.4.2 Description of the production process

Pretreatment of material

The raw material for the production is steel which arrives on large rollers, see Figure x. Before screws and objects are shaped, a preparation of screws is required. Different products entail different types of pretreatment; see Figure 14 and 15 for treatment A. and B. However, in order to remove rust and oxidation, all raw materials are treated with sulphuric acid. For the treatment with Calcium the rollers of steel are kept in the tank with a sulphuric acid solution for approximately 30 minutes.

Figure 16. Raw material.

The bath holds a temperature of 60° C. With the purpose to dispose the extra acid, the raw material is first rinsed in a spray rinse and thereafter dipped into a tank of cold water. This step is followed by a bath of calcium and finally a station where the rollers are hanging free in the air to dry. In the alternatively required pretreatment, raw material is kept in the solution of sulphuric acid for approximately ten minutes. Thereafter it is rinsed with the spray technique. In the next step the material is treated with phosphate to get the right surface condition and to some extent give a protection against corrosion. The products are thereafter rinsed and dried (Employee D1, 2008).

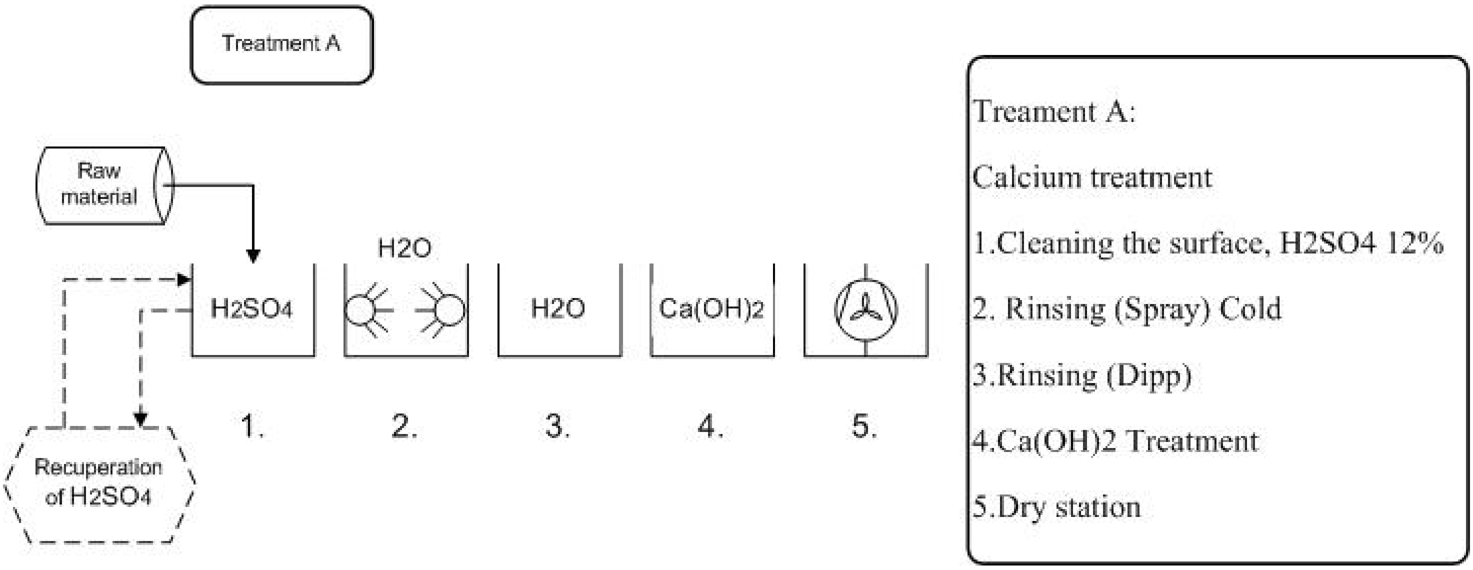


Figure 15. Pretreatment A. of raw material

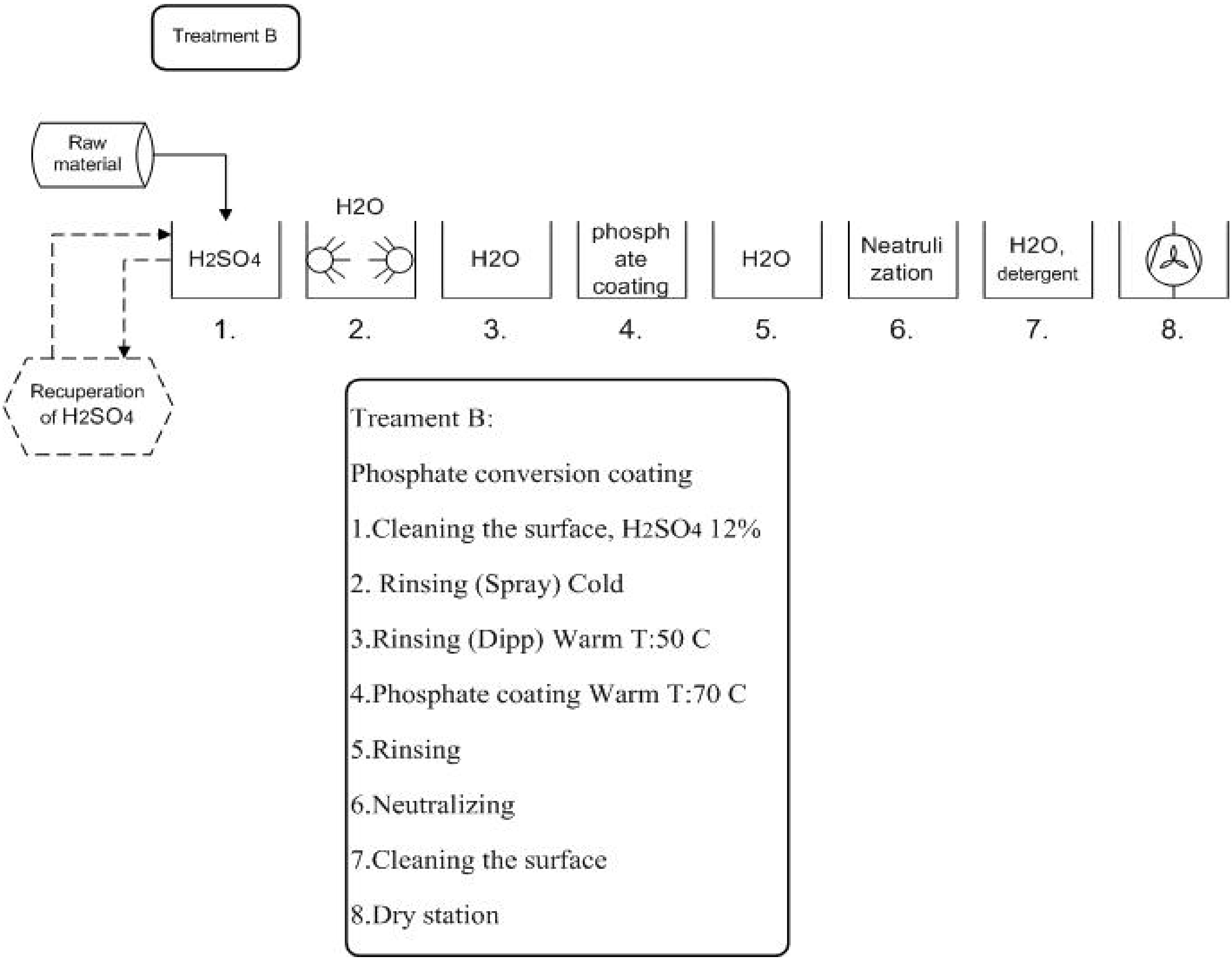
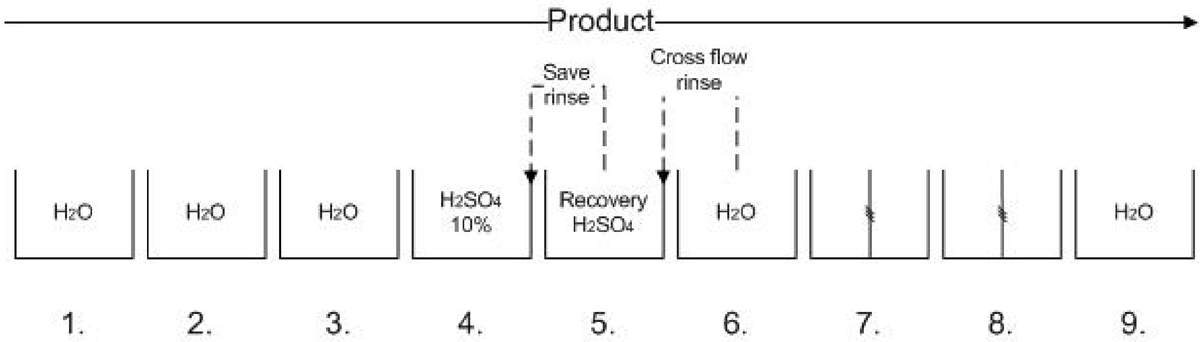


Figure 16. Pretreatment B. of raw material

Production
When the steel is dry it is unrolled to be cut and shaped to various products such as nails, screws and similar. In these processes, oil emulsions are commonly used as cutting fluids for the machineries. Hence, the newly fabricated objects are oily and therefore needs to be washed before further handling. Small items like screws and such are cleaned in a circular conduit. Here the products are sprayed with an alkali solution with a pH-level of 12 – 13 for approximately two minutes. Thereafter the conduit dries the products by working as a centrifuge. Bigger items which do not fit into the conduit are defatted in a thermo process. Here the products are washed with an alkali solution and thereafter kept in 500º C to dry (Employee D2, 2008).

Galvanic surface treatment of products
To give the products the required surface layer, including an improved protection against oxidation and ware, the products are being treated in the process described in Figure 16 and 17. In the first part of the treatment products are kept in a tank with a solution containing sulphuric acid. Thereafter the surface is being encrusted with zinc and a last polish of chrome (Employee D2, 2008).



Treament:

1.Rinsing (Dipp)

2.Rinsing (Dipp)

3.Rinsing (Dipp) Warm

4.H_2SO_4 10%

5.Recovery of H_2SO_4 10%

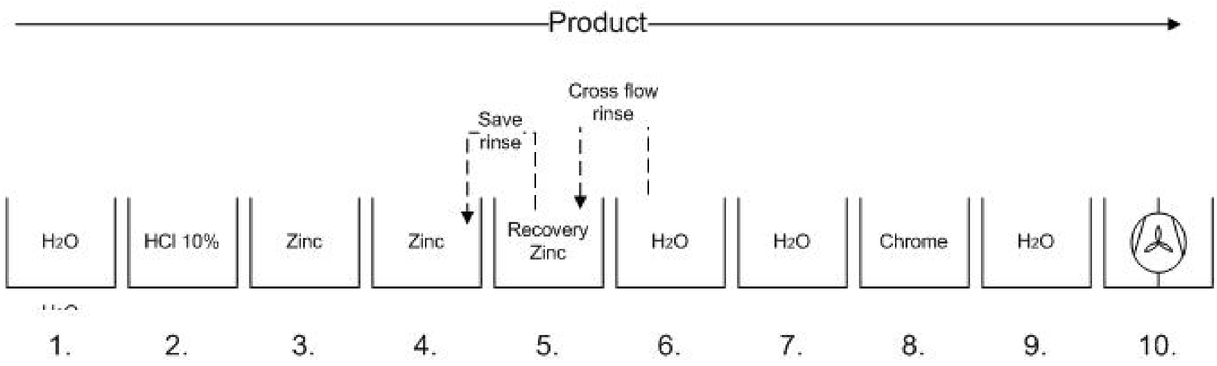
6.Cross flow rinsing system

7.Electrolytic defattening

8.Electrolytic defattening

9. Rinsing (Dipp)

Figure 17. Galvanic surface treatment of products, Process A



Treament:

1.Rinsing (Dipp)

2.Surface activation, HCl 10%

3.Galvanization, Zinc

4.Galvanization, Zinc

5.Recovery of Zinc

6.Cross flow rinsing system

7.Rinsing (Dipp)

8.Surface treatment, Chrome

9. Rinsing (Dipp)

10. Dry station

Figure 18. Galvanic surface treatment of products, Process B

7.4.3 Description of existing water treatment technologies

Effluent from the industry is led to the sewage network and from there to an external treatment plant. The industry itself does not comprise a treatment plant. However, a number of measures have been taken to obtain a more efficient production and minimize the use of water and chemical solvents.

Recuperation of Sulphuric acid
In the pretreatment the sulphuric acid is recycled. When the concentration of iron in the solvent exceeds 12% it is led to an external building where it is being recuperated. This is done by crystallize iron to $FeSO_4 * 7H_2O$ by cooling the solvent. The crystals are separated by sedimentation and centrifugation and can be used in agricultural. The remaining sulphuric acid solvent can be reused in the pretreatment (Employee D2, 2008).

Rinse technologies
In the pretreatment, raw material is being rinsed by spraying the rollers with fresh water before sinking them into the rinsing tank. Hence, less solvent from the sulphuric acid tank will contaminate the rinsing tank which enlarges its lifetime. In the surface treatment of produced objects they use a cross flow rinsing technique. This technique implies that fresh water is added to the last tank and flows towards the process tank. The products are treated in the opposite direction. This allows the final rinse water to be reused as initial rinse when it becomes contaminated (Grunden, Westerlund, 1993). Figure 18 illustrates the principals of this technique. However, in the illustration three tanks are connected for the cross flow rinsing whereas only two tanks are working are connected at the visited industry. By applying this method water can be saved and discharges are reduced (Klingspor, 1997). A cross flow rinsing system should always be employed when it is technically possible (Grunden, Westerlund, 1993).

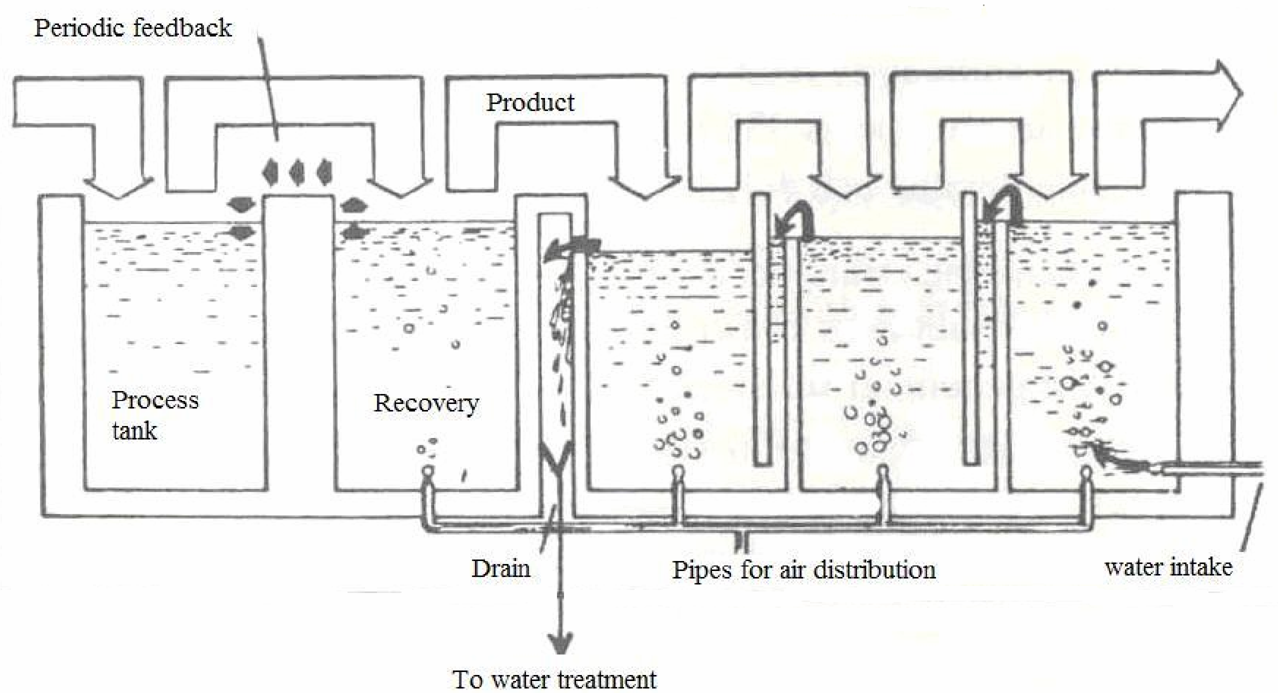


Figure 19. A combined save- and cross flow rinsing system including three cross flow tanks. Source: Klingspor, 1997.

In addition to the cross flow rinsing technique the industry are employing a save rinsing method by using a recovery tank as a direct step after the process tank. The recovery tank will contain a high level of sulphuric acid which allows it to be added to the process tank when a refill is required. This saves solvent as well as minimizing the discharge (Klingspor, 1997).

Evaporation of hazardous solvents
The effluent from the industry contains metals like zinc and chrome as well as oily, acidic and alkali solvents. Thus, in order to meet the applied norm for effluent sent to the sewage grid the hazardous solutions are collected and stored in a tank outside the factory. To reduce the quantity heat is added which allows water to vaporize. When a solid liquid is obtained it is stored in barrels and are taken care of by an external company specialized in hazardous waste.

Settling chamber
Water led to the sewage grid passes a chamber where the velocity is low. This allows suspended solids to sink to the bottom of the chamber and not disturb the external pipes and treatment plants.

Problems experienced and requests
Today there are according to Employee D2 no acute problems considering the treatment process. However, the strategy for meeting the norm is simply to separate hazardous solvents from the effluent. Thus all hazardous components like oil, metals and solvents are mixed into one solvent. This is according to the Swedish Environmental Protection Agency (EPA) not recommended since this will complicate the treatment and hinder recycling strategies (Klingspor, 1997).

8 Discussion and analysis

8.1 Situation

Environment
Risberg (2006) describes the water quality in the rivers in the Santiago region as “bad” or “very bad”. Accroding to information from CONAMA, the water in the rivers in Santiago RM still is of bad quality. However, Dr. M. Rocco, a researcher within the field of Environmental Chemistry at the University of Santiago, points out that the water quality in the rivers in Chile has improved during the last year. According to him, the improvement of water quality is more noticeable in other regions. For instance the river Loa in northern Chile and Bio-Bio in the southern part of the country are showing better values today than a few years ago. Nevertheless, he adds that Río Mapocho also has shown signs of improvement. For example the odor from the water has been reduced significantly during the last few years. However, Río Mapocho is still contaminated, mainly due to untreated domestic water. The reason for the improvement is not unambiguous, but it is likely that it is a consequence of the amendments for norm D.S. 90/2000 (Rocco, 2008 pers. comm.).

The amount of hazardous waste which is taken care of by the company Hidronor is constantly rising as an effect of stricter laws for industrial waste disposal in the country (Romero, 2008). The correct handling of hazardous waste prevents serious damage of the environment. However, by studying reports from SISS it is clear that larger companies follow the norms to a greater extent that smaller (SISS, 2008). Thus, the smaller industries still compose a negative effect on water quality in recipients.

The increasing control of effluent and handling of hazardous waste indicates that Chile’s environmental work is in progress. However, today the focus is on the avoidance of contaminating the nature. The outcome could improve further by adapting a more sustainable approach to the environmental policies. For example, many industries mix a variety of hazardous waste before sending it to an external company for required handling. According to the Swedish Environmental Protection Agency (EPA), mixing different compounds complicates the treatment and minimizes possibilities for recycling (Klingspor, 1997). By applying strategies which enables a reuse of solvents to a greater extent, the volume of hazardous waste could decrease. Also, the avoidance of mixing solvents with different characteristics if not necessary would facilitate the handling and the recycling of products.

Water resources
As shown in Chapter 2.2, the abundance of water varies immensely between the different regions in Chile with a wet climate in the southern parts and extremely dry conditions in the northern parts of the country. Moreover, the mining activity in the north has a high water demand and the majority of the population is concentration in the central regions. Consequently, there is a high demand for water far away from the south where it is well abundant. Not counting the public water demand, water is a requirement for important economic sectors like agriculture and mining (Neary, Garcia-Chevesich, 2008). Furthermore, water is an extremely important factor for the production of energy since 50% of the energy production in Chile is delivered from hydroelectrical power plants (The Swedish Embassy, 2007).

Parts of Chile have during the last La Niña event in 2007-2008 experienced less precipitation than usual during these circumstances. Chile's Public Works Ministry Undersecretary J.E. Saldivia described the deficit of precipitation during 2007 as the worst in 100 years. He alleged that it would threaten the water supply for over 200,000 people (Vargas et al, 2008).

In the market guide to Chile by the Swedish embassy it is mentioned that the demand for fresh water from production industries, mining projects and agriculture is predicted to double in a time period of 40 years (The Swedish Embassy, 2008). Together with the suspected trend of reduction in precipitation, the increasingly limited surface and ground waters have to be reallocated amongst competing economic sectors, including human water supply demands (Neary, Garcia-Chevesich, 2008). It seams reasonable that this situation would increase the price for fresh water.
Three of the visited industries were interested in strategies which enabled them to reduce the consumption of water. Separation technologies, like those that are being described in chapter 6, can be important tools to accomplish a decrease in water use.

8.2 Business opportunities Chile-Sweden

Sweden helped many Chilean citizens during the 1970s and 1980s and as a result Sweden has a good reputation among many Chileans. The increase in commercial exchange between the two countries in the 1990s could be a consequence of the gained relation. The fact that Sweden is well recognized and that a number of Chilean citizens have a connection to Sweden is a benefit for Swedish companies with commercial projects in Chile.

Chilean industries with the desire to upgrade existing technology in the production and treatment plant can ask for financial support. The endowments that are described in chapter 3.1 are examples of funds from which Chilean industries could profit when investing in water treatment technology.

8.3 Legal provisions

8.3.1 Effects from the closing date for D.S. 90/2000

The third of September 2006 was an important milestone in the decontamination process of watercourses in Chile. From this day, all existing industries which discharge their sewage water to watercourses had to have had their processes regulated in order to meet the standards in norm DS90/2000. Additionally all new established industries are committed to follow the norms. Moreover, from this date industries that are obligated to follow the norm DS 90/2000 are required to sample their sewage water and send it to a hired laboratory on a monthly basis.

The laboratory will then send a certificate with the results back to the industry and they are reported on the web based report system which is coordinated by SISS. The laboratory must be accepted by SISS in order to determine the veracity of the reported results. Moreover, the companies should save the certificates to enable SISS to compare them with the reported results. SISS visits approximately half of the industries during one year. The visits are made randomly. Visits are also made to companies whose reported values are suspiciously low. The number of industries which are obligated to report their values to SISS has increased substantially during the last five years. In year 2003 SISS received values from approximately 150 companies which today have increased to 754, see Figure 20 (Carvallo, 2008 pers. comm).

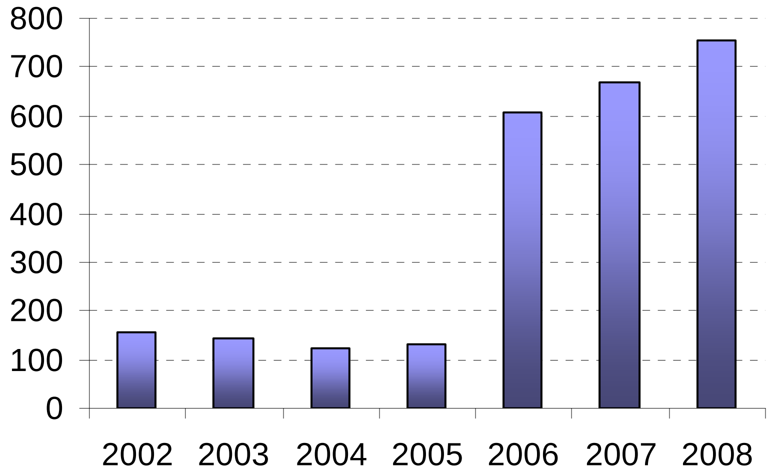


Figure 20.
The number of reporting industries has increase from 155 in 2002 to 754 in December 2008 (SISS, 2007, 2008)

In order to reach the objectives of the norm DS 90/2000 companies have had to employ different strategies to achieve a cleaner production. Industries have had to invest in the construction and operation of sewage treatment plants in order to meet the normative emission values (SISS, 2006).

8.3.2 Development of legal provision applicable to regulation of wastewater treatment

Producción Limpia

A new policy has been set up to promote and support the development of cleaner production including efficiency of water and energy use. Methods and strategies for a cleaner production have been established by The Council of Clean Production, CPL (Consejo de producción Limpia). CPL is defined as the forum for a dialog and action taking between the public sector, companies and employees. It has the mission to spread knowledge about strategies to obtain a cleaner production including efficiency of water and energy (Producción Limpia, 2009).

Directemar

Until recently SISS has been the controlling body for industries which discharge their effluent into the ocean. However, a special division for this category of industries is now in process. This is according to Carvallo (2008) a result from the increasing number of industries that are reporting their effluent values to SISS . Therefore, the Maritime authority has taken over the legal responsibility for industries which affect the ocean. This enables SISS to have sufficient capacity to control and follow up the remaining cases. Industries which are affecting the ocean are controlled by The General Direction for Marine Territory and the Marine Merchant, DIRECTEMAR (Dirección General de Territorio Marítimo y de Marina Mercante). During the year 2007 SISS and DIRECTEMAR together created criteria how the supervision of the industries which have their outlets in the sea should be supervised in order to avoid duplicity. Since this is still in the changing process, the concerned industries still report there emission values to SISS' webpage, but it is DIRECTEMAR who is responsible for the control and follow-up of their emission values (SISS, 2008).

8.4 Evaluation of the existing treatment technology and suggestions for improvements at the visited industries

8.4.1 Industry A – Paper production

Evaluation of existing water treatment technology
The existing treatment is a classic end of pipe solution including an active sludge process. According to Employee A1 (2008) there are no major problems experienced with the plant. The water in the outlet fulfills the quality according to Norm D.S. 90/2000. However, further development can be made in order to achieve the ambition to return the effluent to the production.

Suggestions for improvement
In order to find which solution that could be successfully applied, the industry has been compared with McKinley Paper Company's mill in New Mexico, USA. This paper mill is known for being the best "Zero effluent" paper mills in the world (Hillis, 2000). Furthermore, it holds a number of similarities with the Chilean paper mill. See Table 9.

Table 9: Comparison between the "Zero effluent mill" in New Mexico with the visited paper mill.
Source: Hillis, 2000. : Employee **A1, 2008**

	Paper mill, Chile	**Paper mill, New Mexico, U.S.A.**
Production	Test liners	Test liners
Raw material	OCC	OCC
Annual production	100 000 ton (with intentions to increase the production)	165 000 ton
Estimated raw water consumption	12-15 m3/ton product	1.5 m3/ton product

The effluent from board production and OCC handling at McKinley is treated biologically in an SBR (Sequenced batch reactor type of activated sludge treatment plant). On the contrary from the active sludge treatment used at the industry in Chile, this kind of reactor allows the biologically treated effluent to be aerated and clarified in the same basin. This is achieved by simply turning off the aeration during clarification and the sludge is settled to the bottom of the basin. Excess sludge from this process is then removed from the bottom for dewatering and the clear effluent is removed from the surface of the basin. The water flow to the biological treatment at McKinely is approximately 1500m^3/d.

Table 10: Comparison between the effluent values from the “Zero effluent mill” (after the biological step) in New Mexico with the values from the visited paper mill.
Source: Hillis, 2000. : Employee A1, 2008

Typical values of the influent into the treatment plant.	**Paper mill, Chile**	**Paper mil, New Mexico, U.S.A.**
COD	1500mg/l	3000-5500mg/l
TSS	100mg/l	250mg/l
Typical values of the effluent out of the treatment plant.	**Paper mill, Chile**	**Paper mil, New Mexico, U.S.A.**
COD	32mg/l	450-500 mg/l
TSS	20mg/l	40-50 mg/l

In order to achieve a “Zero effluent plant” McKinley has adapted Membrane technologies after the biological treatment. The biologically treated effluent contains approximately 40-50 mg/l suspended solids. This is removed by the application of a mico filtration system. After this treatment the TSS has decreased to TSS< 1 mg/l. In order to remove remaining salts Reverse Osmosis membrane is employed. In order to achieve a “zero effluent industry” the concentration from the Reversed Osmosis plant is crystallized and in this way turning the remaining liquid into solid waste (Hillis, 2000).

There have not been many examples of this kind of construction built over the years. The reason for this is probably the fact that most paper mills are located to areas where the cost of using fresh water to the production is lower than the cost for a complete recirculation of the effluent. This does not imply that water can not be used to a higher degree than what is done today in the Chilean paper mill. On the contrary, it is according to J. Kastensson a common approach, in Sweden and other countries, that water is reused from the effluent to the paper production (Kastensson, 2009).

A functional solution, in order to decrease the use of fresh water, could be achieved by employing an Ultra filter in the production line for the effluent from stage three in the paper production. However, if there is an aversion to interact the effluent treatment and the paper production an Ultra filter or Micro filter can be applied after the biological treatment.
A membrane module of the type “Hollow fiber” offers a high degree of membrane surface on a small surface which is an advantage in this case. The values shown in Table 10 indicate that the effluent from the treatment plant meets the required quality in order to not clog the fine fibers in the hollow fiber module (Kastensson, 2009).

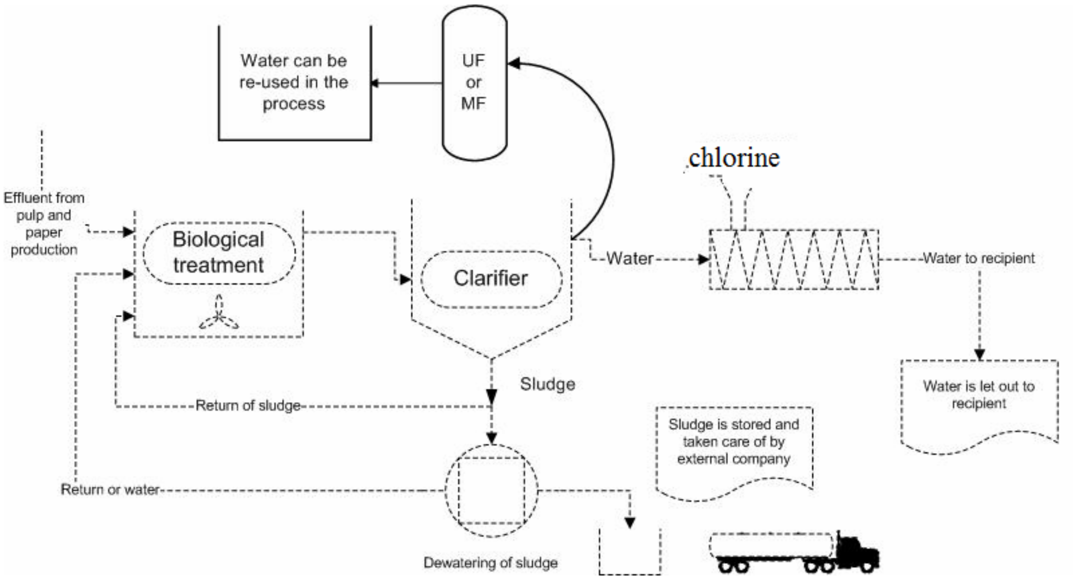


Figure 21. Flow chart of the existing treatment plant including the possibility to employ Ultra filter or Micro filter. This would allow a recycling of to the production process.

This approach is an alternative if the fresh water from the well is the limiting source for an increased production or if there is a concern that the well might periodically dry out. Consequently, by applying Ultra filtration or Micro filter to all or parts of the effluent, water can be re-used which decreases the amount of fresh water required for an increased of production.

8.4.2 Industry B – Oil production from animal products

Evaluation of existing water treatment technology
The existing treatment is not sufficient in order to meet the current norms considering the values of fat and grease, BOD_5 and suspended solids. The separation does work to some extent, but in order to improve the quality, further developments need to be employed.

Suggestions for improvement
Since the water is contaminated with animal products such as animal grease, proteins and suspended solids, the present grease is most likely not dissolved in the solution. In order to remove particles and enable a reuse of separated material in the production process, an ultra filter (UF) could be employed in the entrance of the treatment procedure. At this primer stage, the water still has a favorable temperature of 80 degrees C from the production. This will facilitate the function and the capacity of the UF process. A pretreatment consisting of filter with holes in the size range of 2mm is required for a functional process. Since the contamination is limited to animal products, the treated water obtained from UF treatment is believed to meet the existing norms. Additionally, a concentrate of animal products will be obtained which can be returned to the production to avoid loss of raw material in the effluent. Thus, this method is believed to be a good solution from an environmental and technical aspect (Kastensson, 2009).

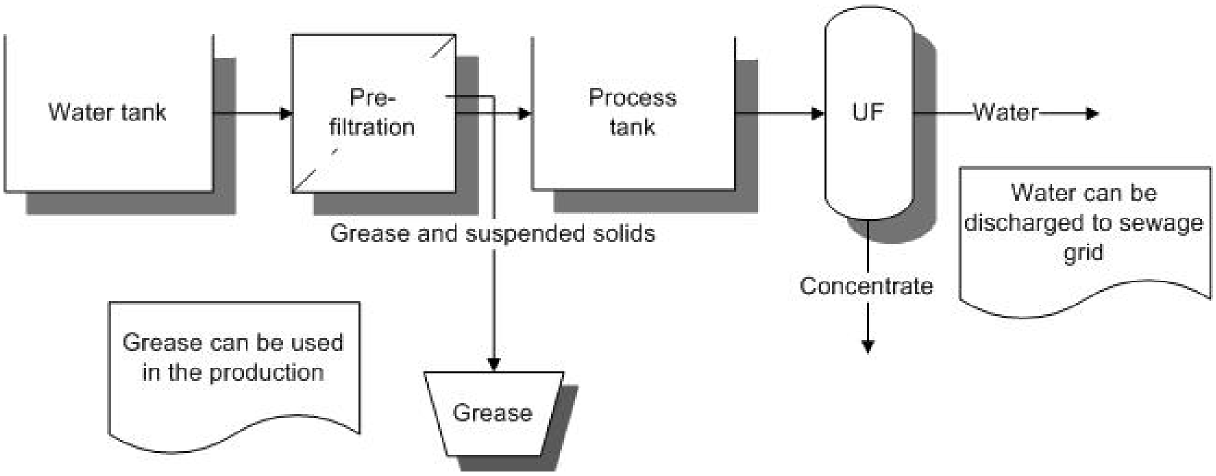


Figure 22. Flow chart of a possible treatment process including Ultra filter technology.

The required membrane system for treating the effluent of 25liters per day has an investment cost of approximately 55 000 – 120 000 USD (February, 2009). Consequently, this solution is a good option in order to decrease the enhanced values of grease, protein and suspended solids in the effluent but has a relatively high investment cost. However, the investment would allow a regeneration of the concentrate, which would decrease the loss of raw material which is one of the stated benefits that are being considered when investigating treatment solutions.

Moreover, an alternative to the application of an Ultra filter treatment is to further develop the existing flotation method to make it more efficient. A technology like using air bubbles to enhance the separation has already been considered at the industry. However, an option to blowing bubbles into the tank is using a pressure gradient. In this method clean water is saturated with oxygen under a high pressure in a separate tank. Secondly this water is led to the separation tank and enters through a number of small holes distributed on the bottom of the tank. When entering the flotation tank the pressure drops. With a decreased pressure, water will be saturated when containing a lower level of oxygen. Thus, the water entering the flotation tank will release some of the oxygen. The micro bubbles that are produced then rise to the surface and, while doing this, grease and suspended solids in the effluent will attach to the bubbles and be brought to the surface. In order to not increase the water use at the industry, part of the treated water can be saturated with oxygen under an increased pressure and entered into the flotation tank as an oxygen source. By using a skimmer, grease and fat can be taken off the surface (Kastensson, 2009).

8.4.3 Industry C – Aluminum cans production

Evaluation of existing water treatment technology
According to the Swedish Environmental Protection Agency, EPA, it is important that oil is separated before the deposit of metal hydroxides which is done at the Chilean industry (Klingspor, 1997). However, the oil is today removed by decreasing the pH and then mechanically separating it from the effluent. Before the visit an accident in the oil separation had occurred and oil was therefore found in the tank where metal hydroxide flocks are formed which will, according to Klingspor (1997), have a negative effect on the formation of flocks of metal hydroxide.

Metal deposition
Separation of metals in sewage water is commonly done by adjusting the pH-value to enable metal ions to form metal hydroxide complexes. Nevertheless, since the water usually contains various metal ions this is not an easy procedure. The solubility of metal ions varies and consequently the optimum pH-value for deposit is not equal for the ions present in the water. To optimize the formation of hydroxide compounds the deposit can be made in sequences with a variation of pH-levels. However, for economical reasons the most common solution is to perform tests in order to find a pH-value where most metal ions deposit to an expecTable degree (Persson, 2005).

The Swedish EPA mentions that an optimal pH level for a successful deposit is usually 8.5 – 10. These recommendations agree with the practice at Chilean industry, where the favorable pH level for deposition is belied to be between 8 and 9.5. Sulfuric acid is used in the visited industry to change the pH-value. The Swedish EPA mentions sodium hydroxide and sulfuric acid as the most common chemicals to adjust the pH-level (Klingspor, 1997).

Calcium hydroxide is used in the visited industry for the deposition of metal ions. There is a possibility to use calcium hydroxide and sodium hydroxide for this purpose. The advantage of calcium hydroxide is a better sedimentation and dewatering possibilities of the metal hydroxide deposit. The disadvantage of using calcium hydroxide is the increased sludge production including the formation of gypsum when sulfate ions are present. Moreover deposition with calcium hydroxide can cause an increased content of suspended solids in effluent water (Klingspor, 1997). There is an interest at the visited industry to decrease the volume of produced sludge. Therefore it would be interesting to investigate further the water quality and sludge production if sodium hydroxide is being used instead of calcium hydroxide for the deposition of metal ions.

Flotation tank
In order to separate deposit metal hydroxide, water is passed through a flotation tank. Small air bubbles are blown into the bottom of the tank bringing the particle to the surface. Using a flotation tank instead of a settling tank is favorable when oil is present in the effluent and flocks of metal hydroxide therefore have absorbed oil particles (Klingspor, 1997).
Flotation is an energy-consuming separation method but it is a compact technique and is therefore useful when space is limited (Persson, 2005).

Sand filter
At the visited industry a sand filter is used to capture flocks which were not separated in the flotation tank. The Swedish EPA points out the benefit of employing a pressure driven sand filter compared to a non-pressure driven filter. One benefit is a higher amount of water per time unit that can pass through the filter i.e. a higher capacity of the filter is obtained. Nevertheless, the intermittent operation time and the high quantity of water which is required for the cleaning procedure are mentioned as disadvantages for this technique. According to the Swedish EPA the back flush for the cleaning procedure generally uses around 10% of the filtered water which is required to be returned to the treatment process (Klingspor, 1997).

Dewatering of sludge
The Swedish EPA mentions the importance of water reduction in sludge for economical and environmental purposes. There are a number of methods to dewater industrial sludge including centrifugation, various press filters and vacuum filters. The filter press employed in

the Chilean industry is one of the most commonly methods to dewater metal hydroxide sludge.

To further reduce the water content in the sludge it can be dried. A simple, but space demanding solution is to leave the sludge from the filter press to dry in open containers for a period of time. The water content is commonly around 70% after the filter press and by letting the sludge dry for six months the water content can be down to 50%. Other methods are drying the sludge by adding heat or by store it in a closed location where the humidity is kept low. These are both energy demanding methods but an applicable when low water content is of great importance. (Klingspor, 1997)

Suggestions for improvements

End of pipe treatment

In order to investigate which methods that could improve the treatment plant at the Chilean industry their production and wastewater treatment methods has been compared with the Swedish industry Rexam Sweden which has a similar production process. Their treatment plant consists of the following six steps:

1. Neutralization tank.
2. Floccation tank with a stirring device.
3. Lamella separator with sludge pockets and clean water slot.
4. Chemical addition device.
5. Sludge treatment equipment.
6. Measurement and control device.

In the neutralization tank lime is added as premixed slurry. Hereby aluminum is partly deposited as well as calcium and fluoride. Additionally oil is adsorbed to the flocks and is in this way reduced. The deposition takes place when pH is approximately 9-10 and the dosage of lime is done in relation to pH value of incoming water. In the next step water enters a floccation tank where polyelectrolyte is added to further facilitate the formation of flocks. From this tank, water is led to a lamella settling tank which, as a result of the lamellas, has a sedimentation surface which reaches $60m^2$. Here flocks are captured and reduced at the bottom of the tank whereas the clear water can be collected at the surface. The clear water is led to the sewage grid (Persson, 2009).

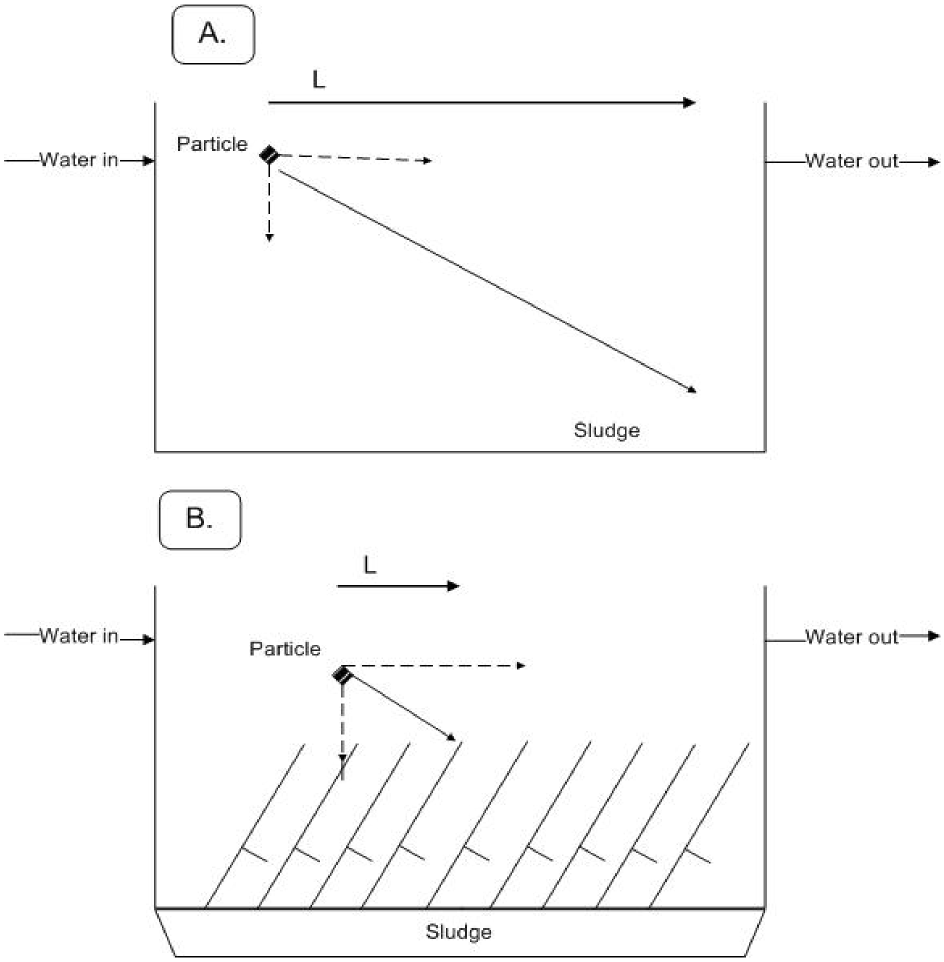


Figure 23. Principles of a traditional settling tank (A.) and Lamella settling tank (B.). As illustrated, the distance for a particle to settle (L) decreases in method (B.) hence making the settling process more efficient (Kastensson, 2009).

Sludge is dewatered by a decantation process where the clear face can be reduced from the surface and returned to the water treatment plant. To reduce the water content further, sludge is pressed in filter presses (Persson, 2009).

An interesting observation is that no further filtration is required after the separation tank in the Swedish industry. This is interesting because one of the mentioned problems at the Chilean industry is the water and time consuming maintenance of the sand filter.

Consequently, the Swedish industry is still obtaining good results even though no further treatment is used after the lamella separator. Thus, it is likely that using lamella separator with sludge pockets including a controlled addition of solvents is sufficient for a treatment at the Chilean industry. This would make the filters that today are employed after the flotation tank unnecessary. This is an advantage since the cleaning of the sand filter is a time and water demanding process.

Ion exchange technology

Moreover, the Swedish industry for aluminum cans has applied ion exchange technology to the production. After the cans are being washed in the production process, they pass various rinsing steps. In the second last rinsing step water is treated with ion exchange technology. This enables rinsing water to be reused and in this manner reduce the amount of water which requires treatment in the treatment plant. Thus, the Chilean industry could reduce its water consumption by applying ion change technology to the rinsing step in the production.

Ultra filter
Furthermore, there is a possibility to use Ultra filter technology to remove oil in the first step of the water treatment plant (Kastensson, 2009). This would reduce the amount of acid which is currently added to the wastewater in the Chilean industry in order to separate the oil from the water. Also, an Ultra filter would almost certainly allow the oil to be reused as cutting fluid in the production process.

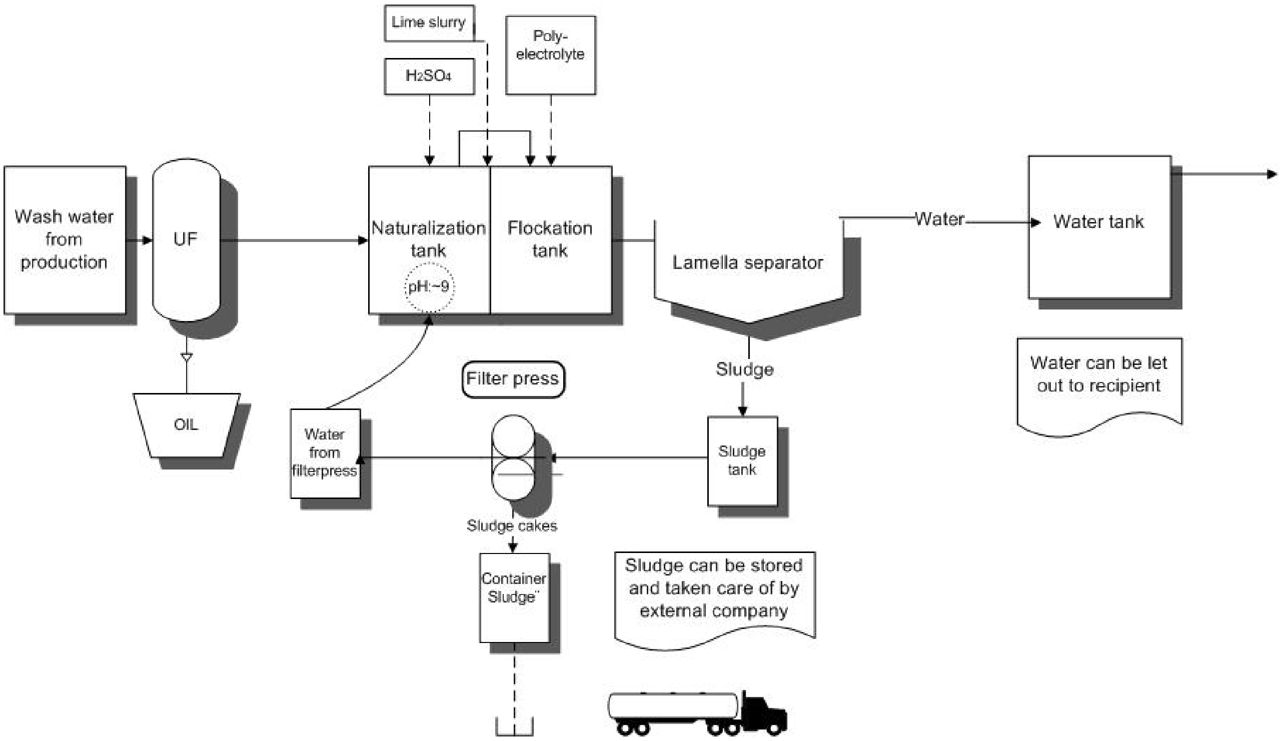


Figure 24. Alternative wastewater treatment plant including Ultra filter and lamella settling tank.

The treatment plant illustrated in Figure 24 is a first reflection of how separation technologies could improve the efficiency at the industry. Deeper analyzes of the processes and the wastewater characteristics are essential to distinguish the optimal solution

8.4.4 Industry D – Galvanization industry

Evaluation of existing water treatment technology
As mentioned in chapter 5.4, a number of measures have been taken in order to minimize the amount of water required for production. The installation of cross flow rinsing system combined with the recovery of sulphuric acid is a well known method recommended for decreasing the water use (Persson, 2005). The method used for the recuperation of sulphur acid is the most commonly used for this purpose (Klingsporr, 1997). However, the visited industry can go further in order to become even more efficient and decrease the discharge of hazardous waste.

Suggestions for improvement

Recuperation of hydrochloric acid

It is possible to recuperate the hydrochloric acid by preheating the solvent and thereafter roast it in an oven. The acid and water will in this process vaporize while FeC_{12} is converted into Fe_2O_3 and can be separated as powder. The Hydrochloric acid can be absorbed into water and an acid with the concentration 18 – 20% is obtained. The loss of hydrochloric acid for each time of recuperation is around 1 – 2% (Klingspor, 1997).

Treatment of oily water with Ultra filter

The wash water contains oil as well as alkali detergents. The Swedish industry Bulten in Hallstahammar produces fasteners to the car industry in Europe. They treat the contaminated wash water in an integrated process where both Ultra filter and Ion Exchange is applied. The treated water is led to the local sewage grid (Tammaru, 2009).

Selective Ion Exchange for Chrome and Zinc in rinse water from the surface treatment

Employing the technology of selective Ion exchange to the recirculation process of rinsing water brings many economical and environmental advantages. The consummation of fresh water can be reduced to up to 95% in comparison with not employing any recycling techniques. This also decreases the effluent which requires treatment.

When applying the ion exchange technology, the contaminants are concentrated in the ion exchange mass which can be regenerated when it is saturated (See chapter 6.1). The concentration takes up less than one percentage of the purified water volume. By connecting the rinse water after the zinc and chrome process tanks to selective ion exchangers the amount of rinsing water can be reused.

Selective Ion Exchange is applied at the Swedish industry Bulten in Hallstahammar. To protect the produced fasteners from corrosion, they use a galvanization treatment similar to the one at the Chilean industry. The water from the surface treatment contains metals like ions like Cr^{6+}, Cr^{3+}, Zn^{2+} and Ni^{2+}. The used rinsing water after the Chrome treatment contains both Cr^{3+} and Cr^{6+} these are both reduced by Selective Ion Exchange. Other rinsing water is treated by neutralization to deposit the majority of metal ions as hydroxide complexes. Thereafter it is polished in an Ion Exchanger to allow the water to be recycled in the production process (Tammaru, 2009).

Today the industry combines all hazardous solvents and sends it to en external company. The different solvents could instead be treated separately in order to minimize the volume of hazardous waste and enable water to be recycled to a larger extent than today. Figure 27, 28 and 29 illustrate possible designs for treatment procedures for the Chilean industry. However, this is only a first reflection of how separation technologies could improve the efficiency at the industry. Deeper analyzes of the processes and the wastewater characteristics are essential to distinguish the optimal solution.

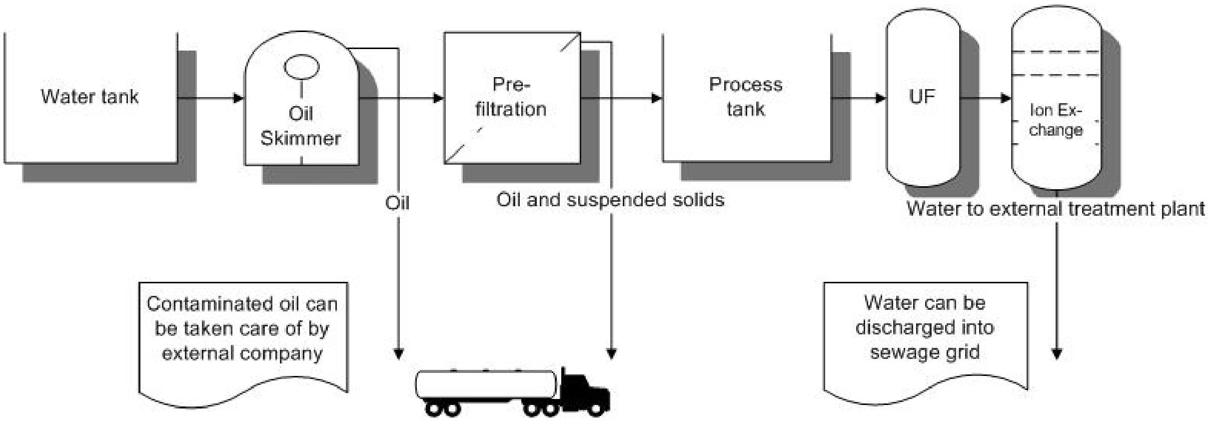


Figure 25. An illustration of a possible treatment of the oil emulsion including alkali wash water.

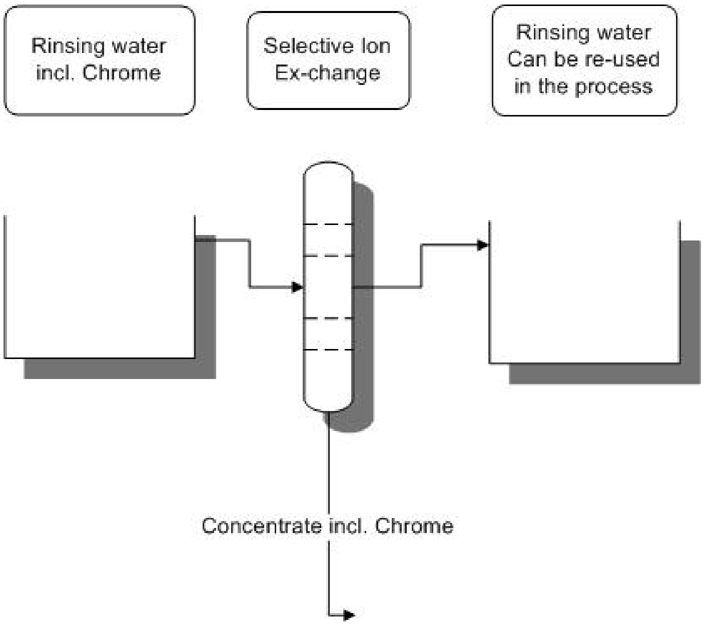


Figure 26. An illustration of a possible treatment process of rinsing water including Chrome.

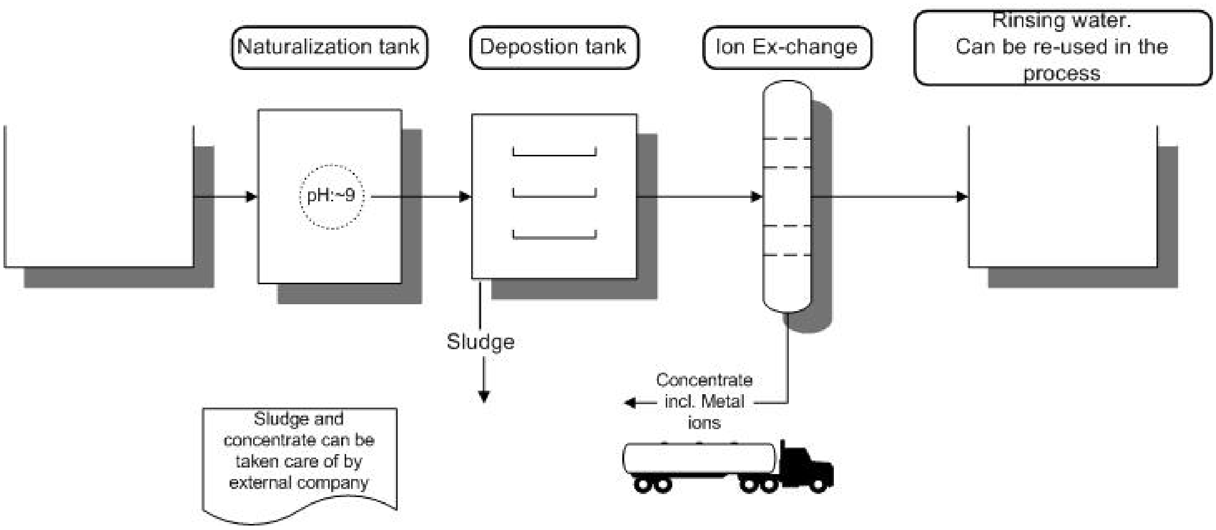


Figure 27. An illustration of a possible treatment process of other rinsing water from the galvanization process.

8.5 Additional opportunities for the application of separation technologies in Chile

The principal industrial activities in Chile are mining industry, fishing, pulp and paper production and agriculture. They all play an important role for export as well as for the domestic market. In several of these industries there are potentials for the application of separation technologies like those described in chapter 6.

The technology for ion exchange is already in practice in Puerto Montt in South Chile. Here it is employed to allow a re-use of water in the cleaning procedure of the nets used for fishing. The nets are painted to prevent the accumulation of algae. The paint contains cupper which partly comes off when the nets are being washed. The effluent from this process is led to a treatment plant where it is neutralized for the deposition of metals. This is followed by a cationic ion exchange process which polishes the water from cupper ions. The water is then reused in the cleaning process (Escobar, 2008).

Large quantities of water are required for the ore processing and therefore mining is sometimes limited by a scarce water supply. Additionally, smelting is a big consumer of electrical energy. There is, to some extent, possibilities to use ion exchange technology in order to purify leached water (Mercatus, 2008). If the employment makes it possible to purify sufficient amount of water this could be reused in the ore process.

The Pulp and paper industry can employ both Ultra filters and Reverse Osmosis in order to reuse water and in this way cut the water. See case study 5.1 for more details.

9 Conclusion

Chile still faces environmental challenges. The river systems in the Santiago region have poor water quality. Nevertheless, the implementation of governmental policies is forcing industries to take responsible for their waste products and effluent. During the last seven years the number of industries which monthly report their effluent values to the government has increased by approximately 80%.

Today the majority of industries which meet the norms are achieving this by collecting hazardous solvents in tanks. The tanks are sent to external companies for restricted handling. Currently, few companies have employed separation technologies to enable a reuse of water and a minimization of hazardous waste products.

The water abundance in Chile varies immensely between the different regions. Industries which require water for their production are obliged to share the water supply with mining activities, agriculture, energy production and domestic use. The industrial development in Chile, and in particular in the Santiago region, is expected to increase. Additionally, there is a predicted decrease in the water supply in the country, especially during La Niña conditions. Therefore, strategies and technologies that allow a decrease in water demand for industrial production will be of great importance.

Sweden is well recognized among Chilean citizens. This is favorable for Swedish companies which are looking for commercial opportunities in Chile. A variety of funds are available to Chilean companies that are looking to invest in enhanced technology.

The methods and technologies used to deal with industrial effluent vary between the visited industries. At three of the industries an effluent plant is employed to ensure acceptable quality of the effluent. At one of the industries methods such as save- and cross-flow rinsing systems are employed in the production process to decrease the water consumption. None of the visited industries are currently using separation technologies such as those that are described in chapter 6. Separation technologies which enable efficiency in terms of water use at each industry include:

Industry A – Paper production:

- Ultra filter or Micro filter
- Reverse Osmosis

Industry B – Oil production

- Ultra filter

Industry C – Aluminum cans production

- Ion exchange
- Ultra filter

Industry D – Galvanization industry

- Ion exchange
- Ultra filter

The separation technologies suggested in this project are a first reflection on how such processes may improve the efficiency at the studied industries. Deeper analyzes of the processes and the wastewater characteristics are essential for selecting the optimal solution at each industry.

At the visited industries there was a general positive altitude towards enhanced technologies to make their wastewater treatment more efficient. However, a large amount of hazardous waste is taken care of by external companies in the Santiago region. This makes it reasonable to think that the cost for this service is not exceptionally high. There are not stringent standards applied to the separation of waste that is delivered, allowing different compounds such as oil, acids and heavy metals to be mixed before delivered. For these reasons it might still be unbeneficial from an economical perspective to invest in improved technologies such as separation technologies. To determine the economical result, a cost benefit analyses can be carried out at each industry.

At three of the visited industries they were interested in methods to decrease the water consumption in the production. Employing the suggested separation technologies would enable a reuse of water and therefore a reduction of water needed for the production processes.

Separation technologies can also successfully be applied to save water in the mining industry and the pulp and paper production, two of the principal industrial sectors in Chile. Today there are examples where the technology for ion exchange is applied in the fishing industry. This enables recycling of water in the washing procedure of the fishing nets.

If water in the future will be regarded as a limited source, industries will have to adapt a more efficient approach to their water consumption. When doing so, there is a better chance that the remaining supply will be sufficient to meet the demands from agricultural activities and domestic use.

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