DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF
NATURAL AND APPLIED SCIENCES

INVESTIGATIONS OF REUSE OPTIONS FOR FERMENTATION INDUSTRY WASTEWATERS

by
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İZMİR

INVESTIGATIONS OF REUSE OPTIONS FOR FERMENTATION INDUSTRY WASTEWATERS

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"INVESTIGATIONS OF REUSE OPTIONS FOR FERMENTATION INDUSTRY WASTEWATERS"** completed by **GONCAGÜL ÖZTÜRK** under supervision of **ASSOC. PROF. DR. NURDAN BÜYÜKKAMACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

The world industrializing with a growing pace has scarcity problems of water at the same time. For this reason, disposal of the wastewaters to rivers, lakes or wetlands is becoming more and more unacceptable, including the uncontrolled use of water supplies. As the result, investigations of the reuse options and the implementation of these options have come into consideration.

This study has been accomplished in accordance with the information gained from the pilot brewery which had been chosen for its appropriateness for the research. Firstly, information about the production steps and the wastewater treatment plant of the brewery has been achieved. Then, the samples that were taken from the influent and the effluent of the treatment plant were analysed to required parameters. According to the results of the analyses, the compatibility of the treated wastewater for industrial use, agricultural irrigation and the groundwater recharge was evaluated. Within the context of this evaluation, recommendations were given for the additional treatment units for the pilot brewery.

Keywords: reuse, industrial wastewater, fermentation, brewery.

FERMANTASYON ENDÜSTRİSİ ATIKSULARININ YENİDEN KULLANIM SEÇENEKLERİNİN ARAŞTIRILMASI

ÖZ

Hızla endüstrileşen dünyamız aynı zamanda hızla su sıkıntıları yaşamaya başlamıştır. Bu sebeple, su kaynaklarının kontrolsüz kullanımı da dahil olmak üzere atıksuların nehirlere, göllere ya da diğer sulak arazilere deşarj edilmesi giderek daha az kabul görmeye başlamıştır. Sonuç olarak da atıksuların yeniden kullanım seçeneklerinin araştırılması ve uygulanması özellikle endüstriyel üretim sahasında büyük önem kazanmıştır.

Bu çalışma, araştırmaya uygunluğu açısından seçilen bir bira üretim tesisinden alınan bilgiler doğrultusunda gerçekleştirilmiştir. Öncelikle tesisin üretim kademeleri ve arıtma tesisi hakkında bilgi temin edilmiştir. Daha sonra, arıtma tesisinin giriş ve çıkış bölümlerinden alınan numuneler gerekli analizlere tabi tutulmuştur. Analiz sonuçlarına göre arıtılmış atıksuyun endüstriyel amaçlı kullanıma uygunluğu, tarımsal sulamada kullanıma uygunluğu ve yeraltına deşarjının uygunluğu değerlendirilmiştir. Bu değerlendirme kapsamında pilot endüstrinin mevcut arıtma tesisi için önerilen ilave arıtma kademeleri hakkında bilgi verilmiştir.

Anahtar Sözcükler: Yeniden kullanım, endüstriyel atıksu, fermantasyon, bira sanayi.

CONTENTS

Page

CHAPTER ONE
INTRODUCTION

1.1 Importance of Water

Water is fundamental to life. It is vital for the human life and natural environment. Clean water is the main building stone of the qualified life. Preserving the quality of fresh water is important for the food production, drinking-water supplies, industrial usage and recreational water usage.

The human body consists of 83% water; muscles about 75% water; bones are about 23% water; and brain is 74% water. Safe water gained from supplies is not only a basic human need, it's crucial to the public health, socio economic life, security, and ecosystems at the same time.

Water is one of nature's most important gifts to mankind. Some general water-use topics are; commercial use, domestic use, public-supply use, irrigation use, industrial use, livestock use, mining use, electricity-production, wastewater treatment. To explain more, the role of water is significant for:

- It is essential for vital organs, tissues of human body.
- It is essential for the body to cool itself.
- It is needed for digesting, absorbing and transporting nutrients.
- It is critical for health because it carries waste products from cells so the waste can be extracted from the body.
- It is also the principal component of many foods like milk, fruits, and vegetables.
- It's a habitat for aquatic life.
- It regulates the earth's temperature.
- It is used for irrigating agricultural area for the plant and crop growth.
- It is utilized for the production of energy, hydroelectric power.
- It is used in the industries as the process water, e.g. fabricating, processing, washing, diluting, etc.

- It is used for cooling purposes, heat transfer, electroplating.
- It is used for scrubbing of gaseous substances
- It is used for the systems of air conditioners
- It is necessary for hygienic needs and general amenity aspects.
- It is used for daily human activities as car washing, ground washing, household works, etc.
- It is used in recreational activities such as swimming, fishing, boating and picnicking.
- It is used for transportation.

1.2 Water Cycle

Water is the only substance found on earth naturally in three forms – solid, liquid and gas. The amount of fresh water on earth is limited. Water covers more than 70% of the earth. More than 96% of this water is salt water and 68% of all fresh water resources are existed in ice forms and glaciers. 30% of the fresh water is reserved as groundwater. Surface resources of fresh water like lakes, rivers constitute 1/150 of the whole world water's 1%. Only 1% of the earth's water is available as a source of drinking. Figure 1.1 shows the movement of water between the earth and the atmosphere.

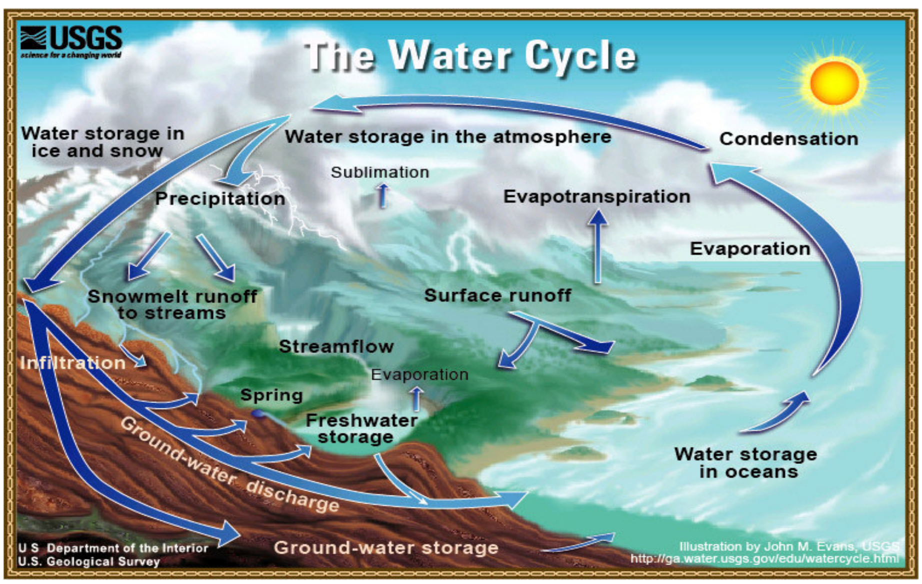

Figure 1.1 Water cycle (U.S. Geological Survey [USGS], 2008a)

The hydrologic cycle (Fig. 1.2) describes the movement and the storage of water between atmosphere and the earth. Water vapor from land surfaces and water circulates through the atmosphere and falls as rain or snow. “Once evaporated, a water molecule spends about 10 days in the air” (USGS, 2008b). When it reaches the earth, water either flows into surface water sources such as streams, oceans and lakes, or penetrates the soil surface. Some water that reaches to the earth surface is hold as soil moisture, which may evaporate directly. Also moisture may move up through the roots of plants and be released by leaves.

Some water percolates downward, accumulating in the so-called zone of saturation to form the groundwater reservoir, the upper surface of which is the water table. Under natural conditions, the water table rises in response to inflowing water and then declines as water drains into natural outlets such as wells and springs (Alpha Omega Marketing, n.d.).

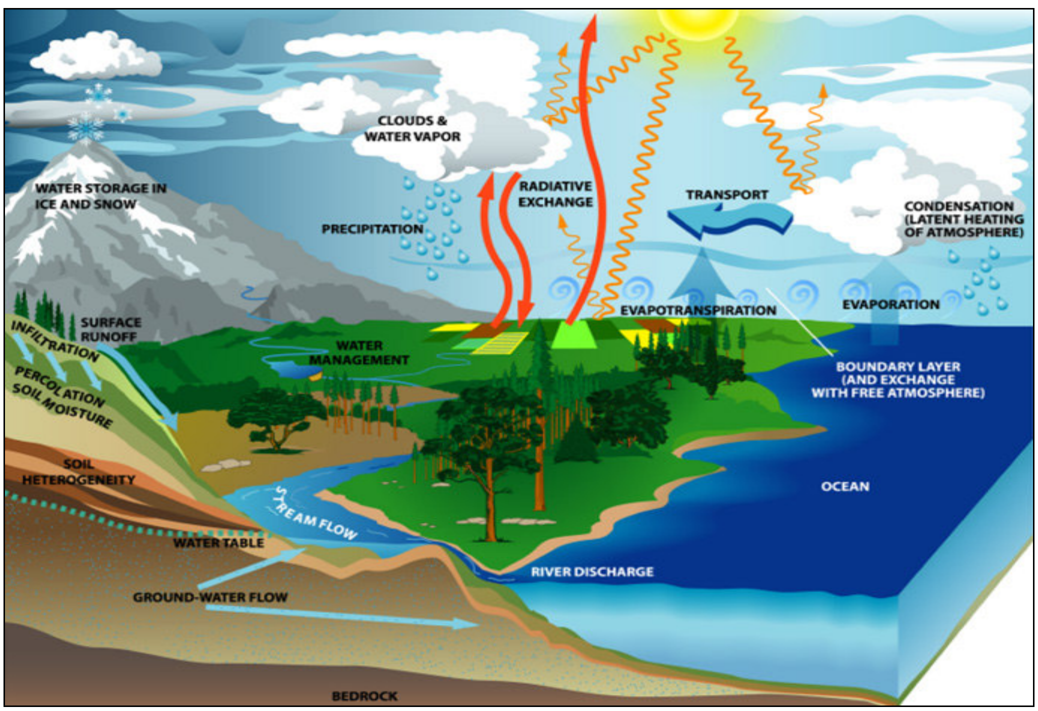

Figure 1.2 Hydrological cycle activities (National Aeronautics and Space Administration [NASA], n.d.)

1.3 Water Demand and Reuse Necessity

In the recent years, comprehensive changes have taken place about the water quality and quantity. The fast-growing states and cities of the world face great challenges about water demands. The need of water is increasing rapidly to meet human and ecological needs because of the growing competition among agricultural, environmental, domestic and industrial uses. Therefore levels of fresh water that the earth included is decreasing with a great rate. As the result of a research accomplished in 2004 about water quantity of water, shows us that we have only 35 million km^3 fresh water (Fig.1.3).

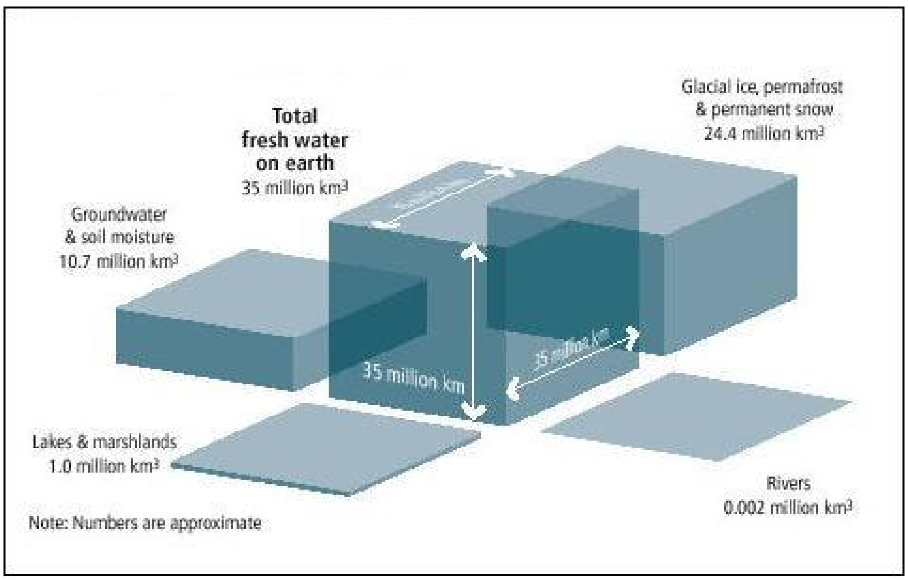

Figure 1.3 World's water supply (Environment Canada, 2004)

In the year of 2006; the total global land precipitation is $110000 km^3/yr$; $70000 km^3/yr$ are evapotranspirated by vegetation, the so-called "green water", to sustain climates, ecosystems and biodiversity, and $40,000 km^3/yr$, the so-called "blue water", is renewable water. Of the renewable water, $30,000 km^3/yr$ flows as uncontrolled streamflows and only $14000 km^3/yr$ constitutes what might be called water resources: a stable source of freshwater supply. Of the total global land precipitation, an average of 40% is used by forests, 36% reaches the ocean, 15% is used by rangelands, 7% is utilized by rain-fed agriculture, 0.9% is used directly by crops in irrigated lands and another 0.9% infiltrates in aquifers and is stored in reservoirs to be withdrawn later on for irrigation, 0.1% is evaporated in reservoirs and lakes, and 0.1% is extracted from rivers, lakes and aquifers for urban uses. Green water is 62.9% and blue water 37.1% of the total global land precipitation (Austria, Hofwegen, 2006, p.32).

The water resources of the world are likely to emerge in the next two 10–15 years if they are not managed correctly and the governments will need to make up to date decisions and arrangements for the alternative actions. As a research result, water withdrawals for domestic, industrial and agricultural uses are shown in Fig. 1.4.

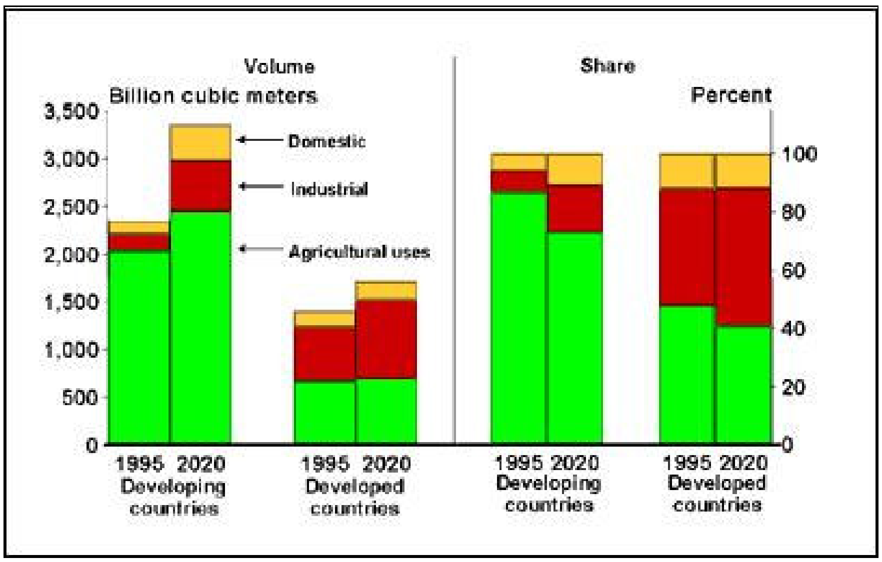

Figure 1.4 Water withdrawals for domestic, industrial and agricultural uses, 1995 and 2020. (International Food Policy Research Institute [IFRI], n.d.)

Global water consumption has increased with a significant rate over the last 50 years. It is assumed that at least 25% of the world's population will be struggling with water shortages by the year 2050. A projection of this rise is shown in Fig.1.5.

The U.S. Environmental Protection Agency defines wastewater reuse as, using wastewater or reclaimed water from one application for another application. The deliberate use of reclaimed water or wastewater must be in compliance with applicable rules for a beneficial purpose (landscape irrigation, agricultural irrigation, aesthetic uses, ground water recharge, industrial uses, and fire protection). A common type of recycled water is water that has been reclaimed from municipal wastewater (Sandy Suburban Improvement District [SSID], n.d.).

The main aims for the reuse of wastewater is managing wastewater, conserving water, and managing water resources. Reclaimed water plays a significant role in water supplies. Finally, implementation of water reuse has proven effective in reducing or avoiding adverse impacts on surface waters associated with surface water discharges. This utilization can reduce the need for water from higher quality water sources which can then be conserved for other purposes, such as municipal drinking water.

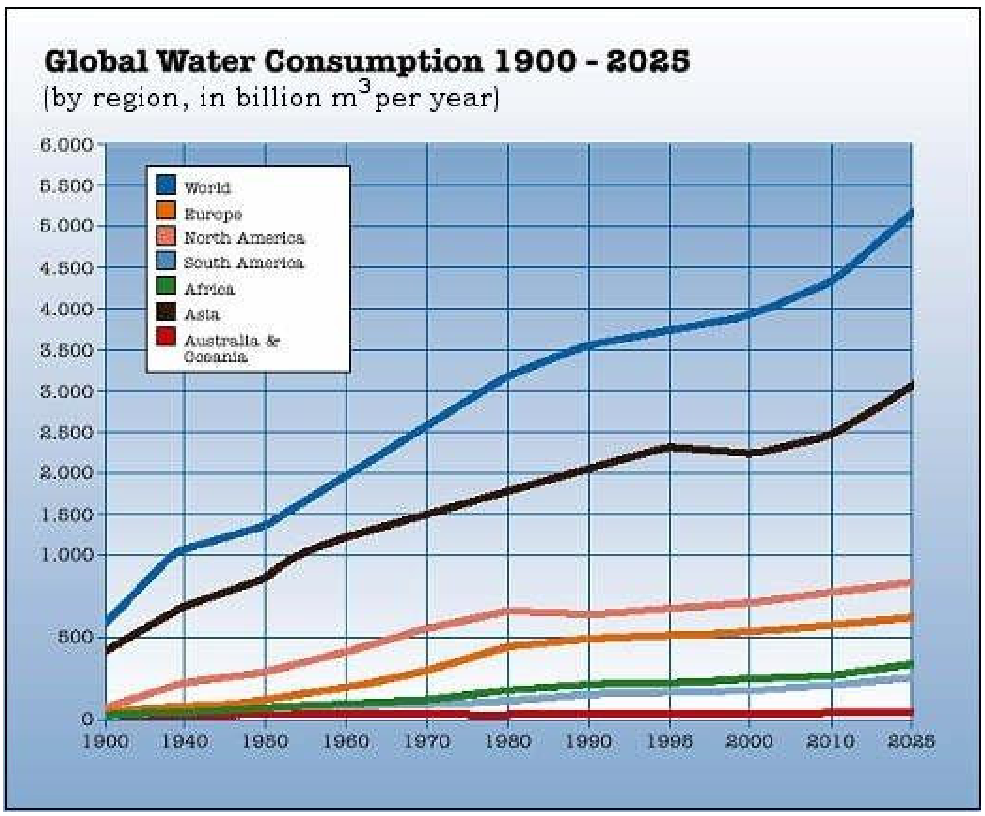

Figure 1.5 Global water consumption (Umweltbundesamt [UBA], n.d.)

1.4 Industrial Uses of Water

Water is more used for agricultural facilities than any other facilities such as industrial or domestic. But as a result of growing population and developing industrial investments, the contamination of the water is caused by industries much more than agricultural processes. This usage has a crucial effect on limited water resources of the earth and this situation can’t be omitted.

The reuse of water which is the most appropriate and fast solution for the decreasing levels, can be a source for electric utility generating stations and other industrial facilities. Some of the reclaimed water use practices for the industries can be listed as:

- Cooling towers
- Boiler-Feeds
- Process water
- Irrigation
- Car washing
- Dust control
- Fire protection systems
- Maintenance

1.4.1 Wastewater Reuse for Cooling

Industrial cooling systems (evaporative cooling) require high volumes of water. Increasing environmental threats to the ecosystem and water sources force the use of treated wastewater as a water supply for cooling systems. Application of this water reuse requires the resolution to some other technical and environmental issues, such as corrosion, microbiological fooling, suspended solids, chemical use for the treatment, technical controls. Treatment processes used for both external and internal treatment of cooling or boiler make-up water are summarized in Table 1.1.

Table 1.1 Processes used in treating water for cooling or boiler makeup (Tchobanoglous, Burton, 2003, p.1418)

	Cooling		
Processes	**Once-through**	**Recirculated**	**Boiler make-up**
Suspended solids and colloids removal:			
Straining	x	x	x
Sedimentation	x	x	x
Coagulation		x	x
Filtration		x	x
Aeration		x	x
Microfiltration		x	x
Dissolved-solids modification softening:			
Cold lime		x	x
Hot lime soda			x
Hot lime zeolite			x
Cation-exchange sodium		x	x
Nanofiltration			x
Alkalinity reduction cation exchange:			
Hydrogen		x	x
Cation-exchange hydrogen and sodium		x	x
Anion exhange			x
Dissolved-solids removal:			
Evaporation			x
Demineralization		x	x
Reverse osmosis / nanofiltration		x	x
Ion exchange		x	x
Dissolved-gases removal:			
Degasification			
Mechanical		x	x
Vacuum	x		x
Heat			x
Internal conditioning:			

Table 1.1 (continued)

Processes	**Cooling** Once-through	**Cooling** Recirculated	**Boiler make-up**
pH adjustment	x	x	x
Hardness sequestering	x	x	x
Hardness precipitation			x
Corrosion inhibition general		x	x
Embrittlement			x
Oxygen reduction			x
Sludge dispersal	x	x	x
Biological control			
Chemicals	x	x	
Ozone		x	
Ultraviolet light		x	

1.4.2 Wastewater Reuse for Boiler-Feed

Whether for generating steam for power generation, heat or some other process, a boiler is a closed vessel in which water or other fluid is heated under pressure. The hot fluid is then circulated out of the boiler for use in various process or heating applications. Industrial boilers have changing requirements for the feed water. The need of the water quality varies up to the pressure. Higher pressure levels require higher quality and different operations. For example low pressure boilers need water softening or de-alkalization and high alkalinity may contribute foaming, resulting in deposits in superheater, reheater, and turbines. The high-pressure boilers require demineralization, control of silica and aluminum, since these may cause of scale build-up in boilers.

1.4.3 Industrial Process Water

The required water quality changes from industry to industry. Such markets as beverages, food, pharmaceutical, textile uses water as raw material. And it has to meet the requirements strictly due to the related process in terms of solids, microbiological presence, salinity, pathogens, turbidity, purity, etc. Thus, in investigating the feasibility of industrial reuse with reclaimed water, the potential users must be contacted to determine specific requirements for process water.

1.5 Agricultural Uses of Water

The most important factor to determine the usability of the reclaimed wastewater for agricultural irrigation is the soil structure and availability. Soil depth, soil texture, soil structure, rooting depth, water holding capacity, slope and infiltration rate, water demand of the plant, internal drainage and chemical characteristics (salinity and sodicity) assigns this irrigability. Below, some of these characteristics are explained briefly:

1.5.1 Factors Effecting the Irrigability

Soil texture refers to the amount of sand, silt, and clay in a soil sample. The distribution of particle sizes specifies the soil type and the soil texture effects the percolation and leaching rates. The assumed pore size for sand is 0.05-2 mm, 0.002-0.05 mm for silt and <0.002 mm for clay. Generally, the soil is a combination of these different sized particles. The particles forms into aggregates in the course of time by the effect of weather, soil mineral composition and the other physical forces applied on the soil. These changes state the structure of soil.

Water holding capacity is the quantity of water held by plants. This water becomes the available water of the plant. High organic matter helps to increase the ability and capacity of the plant to hold more water. Also, roots only grow where there are adequate levels of soil oxygen. Plants with a deeper rooting system reach a larger supply of water and can go longer between irrigations.

Below; the salinity, the sodicity and the root depth are explained.

1.5.1.1 Salinity

Salinization may state a problem for the growth of the crops, the soil quality and the groundwater. Salination means the built up salts in the soil. High levels of soil salts occur when a water table is near the soil surface. High salt levels may decrease crop yields and increase the water requirement of plants. Irrigation may reduce the depth to water table over time in some soils. Irrigation water containing high salt levels may also increase the risk of nonproductiveness and salinization. As salinity increases, crop productivity decreases. Salinity is also related with the percolation rate, leaching ratio and the soil texture.

If the wastewater is going to be used for irrigation it's subjected to required treatment processes but sometimes that's not needed. Instead of treating the wastewater, crops resistant to salinity may be used. As it will be explained in Chapter 1.5.4, leaching and drainage are two necessary water management practices to avoid salinization of soils. Commonly, salinity of the water is formed as four groups (C_1-C_4):

C1 class water has low-salinity content

C2 class water has mid-salinity content and plants with moderate tolerance to salinity can be grown.

C3 class water has high-salinity content and plants with good salt tolerance can be grown.

C4 class water has very high-salinity content and it's not suitable for irrigation. If in need, very salt-tolerant plants can be used.

1.5.1.2 Sodicity

Sodicity refers to the amount of sodium present in irrigation water and generally occurs in arid and semi-arid areas. Sodicity may be caused by water tables near the surface or by the changes in weather. Salinity may also be caused by the over-irrigation. In sodic soils, sodium represents more than about 10% of all the cations.

Increased sodium levels may cause yield reduction and the increase of the sodium levels doesn't occur suddenly and it's not formed in a short time period. So, it's important to make periodic measurements for the qualified water and soil management. Sodicity of the water is classified in a scale from S_1 to S_4:

S_1 class water has low sodium content and is suitable nearly for all types of crops.

S_2 class water has medium sodium content. Permeability of the soil is the determinative factor for the required processes.

S_3 class water has high sodium content and may need extra water to overcome the accumulation problems.

S_4 class water has very high sodium content and it is not preferred for agricultural irrigation. However, if the salinity of the water is in lower degrees; it may form a healing effect for the use of the S4 class water.

1.5.1.3 Root Depth

Soil depth shows how thick the soil cover is and depends on the potential rooting depth of plants and any restrictions included by the soil that may prevent rooting depth. Effective root depth is the depth to the impermeable layer or to the water table.

The effective root depth is used in determinations as the soil depth when the irrigation is projected. However, occasionally the water table or the impermeable layer may be near to the soil surface. In this situation, the effective soil depth is considered in determinations of the irrigation water as the depth of the soil.

Commonly the crops that grow up in deep layers of soil, receive the water needed from the upper side of the root part. Thus, it's enough to irrigate the effective root depth instead of irrigating the entire root. This is also the feasible and the source protective way for the water use. Table 1.2 shows the effective rooting depth for selected crops.

Table 1.2 The effective root depth of some selected crops in the maturation period (Aydın, n.d.)

Plant	Effective Root Depth (cm)	Plant	Effective Root Depth (cm)
Safflower	90	Flax	90
Sunflower	90	Cabbage	45
Vineyard	120	Lettuce	45
Pea	90	Fruit trees	120
Pepper	60	Corn	90
Meadow	90	Banan	60
Strawberry	60	Cotton	90
Tomato	90	Potato	60
Artichoke	90	Aubergine	60
Bean	60	Onion	45
Carrot	60	Sorghum	90
Cucumber	60	Soybean	90
Cereals	90	Sugar beet	90
Spinach	60	Citrus fruits	120
Pumpkin	60	Tobacco	90
Watermelon	90	Peanut	60
Melon	90	Clover	90

1.5.2 Irrigation Water Quality

According to the soil constitution the most suitable irrigation is determined. Several different factors work together in irrigation management including the; rooting depth, evapotranspiration (ET), leaching, the soil's water holding capacity and the plant's ability to extract water from the soil.

The following parameters and categories are used commonly by the researchers to determine the effect of irrigation on crop production and soil quality: Salt content, Sodium amount and the ratio of this amount to the calcium and magnesium ions, pH, alcalinity, content of boron, chloride, nitrite, nitrate, heavy metals and microbiological formations.

Irrigation water quality guidelines and regulations have been discussed in Chapter 3. The guidelines are depending on the local climate, soil conditions, health aspects and other factors. In addition, farm practices, such as the type of crop to be grown, irrigation method and soil type helps us to determine the suitability of irrigation water.

1.5.3 Calculation of The Required Water For Irrigation

Most of the water content of the plants is lost by evapotranspiration. Evapotranspiration rate changes according to various affects, generally to the climatic factors. The water requirements of different crops have been listed in Table 1.3. The water requirement of crops is equal to the evapotranspiration requierement; ET_c. The common equation used to determine the ET_c is given below.

$$ET_c = K_c * ET_0$$

In this equation;

ET_c : crop evapotranspiration [mm d^{-1}]
K_c : crop coefficient [dimensionless]
ET_o : reference crop evapotranspiration [mm d^{-1}]

Before the equation above The FAO-56 Penman-Monteith equation estimates the reference crop evapotranspiration, ET_0 as follows:

$$ET_0 = \frac{0.408(R-G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

In this equation;

ET_o : reference evapotranspiration [mm day^{-1}]
R_n : net radiation at the crop surface [MJ m^{-2} day^{-1}]
G : soil heat flux density [MJ m^{-2} day^{-1}]
T : air temperature at 2 m height [°C]
u_2 : wind speed at 2 m height [m s^{-1}]
e_s : saturation vapour pressure [kPa]

e_a : actual vapour pressure [kPa]

e_s - e_a : saturation vapour pressure deficit [kPa]

Δ : slope vapour pressure curve [kPa °C^{-1}]

γ : psychrometric constant [kPa °C^{-1}]

Table 1.3 Water requirements, sensitivity to water supply and water utilization efficiency of some selected crops (Pescod, 1992)

Crop	**Water requirements (mm/growing period)**	**Sensitivity to water supply (ky)**	**Water utilization efficiency for harvested yield, Ey, kg/m^3 (% moisture)**
Alfalfa	800-1600	low to medium-high (0.7-1.1)	1.5-2.0 hay (10-15%)
Banana	1200-2200	high (1.2-1.35)	plant crop: 2.5-4 ratoon : 3.5-6 fruit (70%)
Bean	300-500	medium-high (1.15)	lush: 1.5-2.0 (80-90%) dry : 0.3-0.6 (10%)
Cabbage	380-500	medium-low (0.95)	12-20 head (90-95%)
Citrus	900-1200	low to medium-high (0.8-1.1)	2-5 fruit (85%, lime: 70%)
Cotton	700-1300	medium-low (0.85)	0.4-0.6 seed cotton (10%)
Groundnut	500-700	low (0.7)	0.6-0.8 unshelled dry nut (15%)
Maize	500-800	high (1.25)	0.8-1.6 grain (10-13%)
Potato	500-700	medium-high (1.1)	4-7 fresh tuber (70-75%)
Rice	350-700	high	0.7-1.1 paddy (15-20%)
Safflower	600-1200	low (0.8)	0.2-0.5 seed (8-10%)
Sorghum	450-650	medium-low (0.9)	0.6-1.0 grain (12-15%)
Wheat	450-650	medium high (spring: 1.15; winter: 1.0)	0.8-1.0 grain (12-15%)

The crop coefficients (K_c) and the maximum height that these crops may reach are listed in Table 1.4. This table is used with the FAO-56 Penman-Monteith equation.

Table 1.4 Single (time-averaged) crop coefficients, K_c (international) and mean maximum plant heights for non stressed, well-managed crops in sub-humid climates ($RH_{min} \approx 45\%$, $u_2 \approx$ 2 m/s) (Allen, Pereira, Raes & Smith, 1998)

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	**Maximum Crop Height (h) (m)**
Small Vegetables	**0.7**	**1.05**	**0.95**	
Broccoli		1.05	0.95	0.3
Brussel Sprouts		1.05	0.95	0.4
Cabbage		1.05	0.95	0.4
Carrots		1.05	0.95	0.3
Cauliflower		1.05	0.95	0.4
Celery		1.05	1.00	0.6
Garlic		1.00	0.70	0.3
Lettuce		1.00	0.95	0.3
Green Onion		1.00	1.00	0.3
Spinach		1.00	0.95	0.3
Vegetables - Solanum Family	**0.6**	**1.15**	**0.80**	
Egg Plant		1.05	0.90	0.8
Sweet Peppers (bell)		1.05	0.90	0.7
Tomato		1.15	0.70-0.90	0.6
Vegetables - Cucumber Family	**0.5**	**1.00**	**0.80**	
Cucumber- Fresh Market	0.6	1.00	0.75	0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Sweet Melons		1.05	0.75	0.4
Watermelon	0.4	1.00	0.75	0.4
Roots and Tubers	**0.5**	**1.10**	**0.95**	
Potato		1.15	0.75	0.6
Sweet Potato		1.15	0.65	0.4
Turnip (and Rutabaga)		1.10	0.95	0.6
Sugar Beet	0.35	1.20	0.70	0.5
Legumes	**0.4**	**1.15**	**0.55**	
Beans, green	0.5	1.05	0.90	0.4
Beans, dry and Pulses	0.4	1.15	0.35	0.4
Peas (fresh)	0.5	1.15	1.10	0.5
Soybeans		1.15	0.50	0.5-1.0
Perennial Vegetables	**0.5**	**1.00**	**0.80**	
Mint	0.60	1.15	1.10	0.6-0.8
Strawberries	0.40	0.85	0.75	0.2
Fibre Crops	**0.35**			
Cotton		1.15-1.20	0.70-0.50	1.2-1.5
Flax		1.10	0.25	1.2
Sisal		0.4-0.7	0.4-0.7	1.5

Table 1.4 (continued)

Crop	**$K_{c\ ini}$**	**$K_{c\ mid}$**	**$K_{c\ end}$**	**Maximum Crop Height (h) (m)**
Oil Crops	**0.35**	**1.15**	**0.35**	
Safflower		1.0-1.15	0.25	0.8
Sesame		1.10	0.25	1.0
Sunflower		1.0-1.15	0.35	2.0
Cereals	**0.3**	**1.15**	**0.4**	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4	1
Maize, Field (grain)*(field corn)*		1.20	0.60-0.35	2
Sorghum (grain)		1.0-1.10	0.55	1-2
Rice	1.05	1.20	0.90-0.60	1
Sugar Cane	**0.40**	**1.25**	**0.75**	**3**
Tropical Fruits and Trees				
Banana (1st year)	0.50	1.10	1.00	3
Cacao	1.00	1.05	1.05	3
Coffee (with weeds)	1.05	1.10	1.10	2-3
Date Palms	0.90	0.95	0.95	8
Palm Trees	0.95	1.00	1.00	8
Pineapple (with grass cover)	0.50	0.50	0.50	0.6-1.2
Grapes and Berries				
Berries (bushes)	0.30	1.05	0.50	1.5
Grapes (wine)	0.30	0.70	0.45	1.5-2
Hops	0.3	1.05	0.85	5
Fruit Trees				
Almonds, no ground cover	0.40	0.90	0.65	5
Apples, Cherries, Pears	0.45	0.95	0.70	4
Apricots, Peaches, Stone Fruit	0.80	1.15	0.85	3
Avocado, no ground cover	0.60	0.85	0.75	3
Kiwi	0.40	1.05	1.05	3
Olives	0.65	0.70	0.70	3-5
Pistachios, no ground cover	0.40	1.10	0.45	3-5
Walnut Orchard	0.50	1.10	0.6518	4-5
Wetlands - temperate climate				
Cattails, Bulrushes, killing frost	0.30	1.20	0.30	2
Cattails, Bulrushes, no frost	0.60	1.20	0.60	2
Short Veg., no frost	1.05	1.10	1.10	0.3
Reed Swamp, standing water	1.00	1.20	1.00	1-3
Reed Swamp, moist soil	0.90	1.20	0.70	1-3

1.5.4 Technical Aspects For a Controlled Irrigation

1.5.4.1 Drainage

Drainage is defined as the removal of excess surface or sub-surface water from the soil. However; after irrigation, rise of the groundwater transports the salts to the soil surface. And this causes salt accumulation on the soil surface because of the continued evaporation. In such cases, the rise of water table and the secondary salinization can be controlled by means of appropriate drainage.

1.5.4.2 Leaching

In the root zone of the plant, salt accumulation is the main problem, commonly. This accumulation can be prevented by the leaching technique. As a result of evapotranspiration, the salt content of the plant may increase with an unexpected rate. In this instance, extra irrigation water is needed to subject the salts to remove. This irrigation water goes through the root zone and actualizes the leaching. So this process may be summarized as removing the salt content by dissolving it away from the plant or soil. For the salination control the leaching fraction (LF) ratio, below is used.

$$LF = \frac{DepthOfWaterLeachedBelowTheRootZone}{DepthOfWaterAppliedAtTheSurface}$$

The necessity of the leaching demand may be estimated by using LF. However, it's important to estimate the required water volume, also. This is formulated as the leaching requirement (LR). The leaching requirement can be estimated from the crop tolerance salinity, as defined by the electrical conductivity (ECe), and the salinity of the irrigation water, as defined by the electrical conductivity of the applied irrigation water (ECw). LR can be estimated by using the following equation:

$$LR = \frac{EC_W}{5(EC_e) - EC_W}$$

In Figure 1.6 the relationship between the electrical conductivity of the irrigation water and the crop tolerance salinity is shown. The EC_w and the EC_e values are in dS/m.

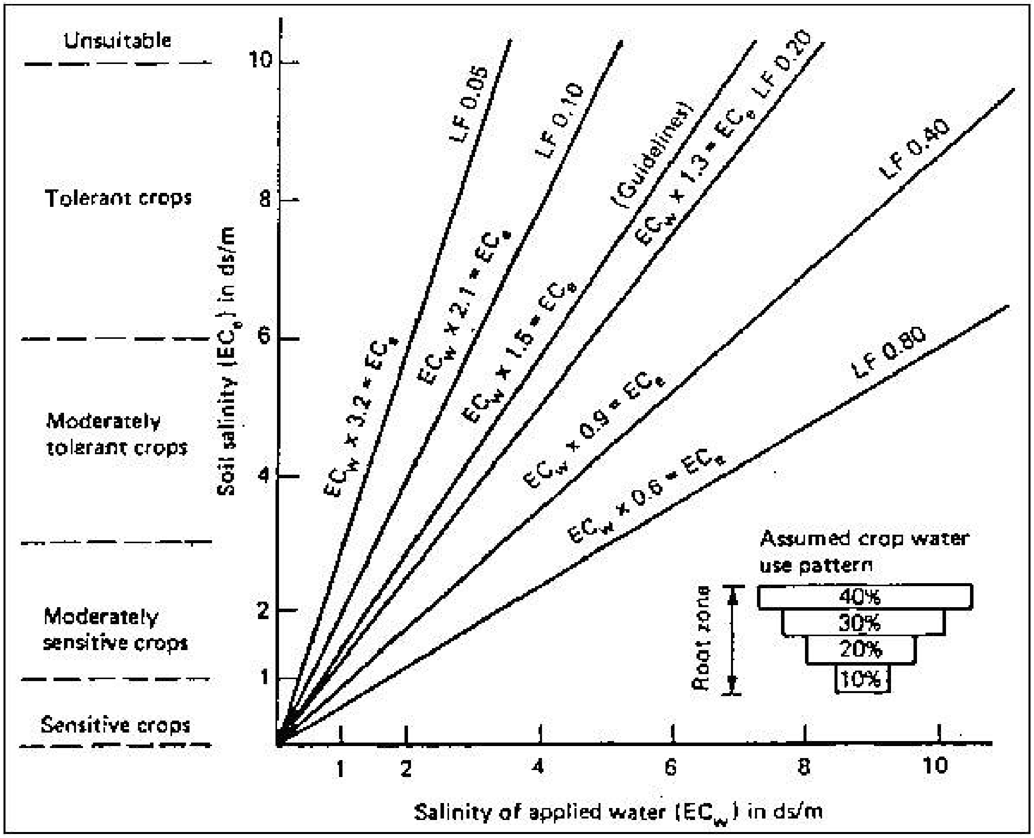

Figure 1.6 Relationship between applied water salinity and soil water salinity at different leaching fractions (Pescod, 1992).

1.6 Basis For Cost Estimates

The cost evaluation of wastewater reclamation and reuse includes capital costs, annual operation costs, distribution system costs, life cycle costs and maintenance costs. As Fatta & Kythreotou (2005, p.3) describe**,** “Total reclamation system life cycle cost is estimated by combining amortized capital cost with annual operation and maintenance costs and converting to €/m^3 (by dividing the estimated life cycle cost, €/yr, by the reclamation facility capacity, m^3/yr)”. Commonly; for cost evaluation, the life cycle is assumed as a 20-year period.

1.7 Aim & Scope of the Thesis

In the literature, while there are countless studies about the reuse options for domestic wastewaters, the studies are fewer for industrial wastewaters. This thesis is prepared to stage a directory source for the fermentation industry that has an important ratio in Turkey's industrial distribution. The scope of this thesis is to consider the reuse options for the reclaimed wastewater of a fermentation industry. Thus, the investigations have been done for the brewing industry that has been selected as the pilot plant for the thesis as a guide for fermentation industry. In this manner, the aim is:

- To compare the results of the analyses made for a brewery's wastewater with the standards specified by the related regulations,

- To determine the efficiency of reclaimed brewery wastewater on the usage for industrial purposes, agricultural irrigation and groundwater recharge.

- To recommend required additional treatment units and the appropriate flowcharts for commonly accepted reuse options.

CHAPTER TWO
FERMENTATION INDUSTRY

2.1 Industrial Fermentation

Fermentation can be explained as a process of energy production in a cell in a situation that no oxygen presents (anaerobic environment). Generally fermentation is a type of anaerobic respiration. Also it can be defined as respiration in an anaerobic environment (e.g. mammalian muscle) with no external electron acceptor.

Sugars are the main substrate of fermentation. Hydrogen, lactic acid, butyric acid, acetone and alcohol are the certain fermentation products. Yeast performs fermentation in the production of alcohol content (ethanol) in beers, wines and any other alcoholic drinks.

“The use of fermentation is an important process in the industry. Though fermentation can have stricter definitions, when speaking of it in industrial fermentation, it more loosely refers to the breakdown of organic substances into simpler substances” (Wikimedia Foundation Inc [WFI], n.d.).

2.2 Beer

Beer can be described as “a low alcohol content beverage produced by fermenting sugars extracted from various types of cereals. Different beer types exist that vary in the use of raw material, and the strength, taste profile, and packing of the final product.” (International Finance Corporation [IFC], 2007, p.13). Generally, each brewery has its own container mix and specific product.

In Turkey, beer consumption is 11.5L per capita for the year 2008. There are seven main beer manufacturers in the private sector (Turkish State Planning Organisation, 2007). Total production values for the last three years (Table 2.1) and the production data for the first eight months of 2008 (Table 2.2) are listed below.

Table 2.1 Manufactured beer data for 2005, 2006 & 2007 (Economic Research Forum [ERF], 2008)

Year	**2005**	**2006**	**2007**
Total (L)	937,218,400	894,229,800	920,470,800

Table 2.2 Manufactured beer index for 2008 (ERF,2008)

Month	**January**	**February**	**March**	**April**
Index (L)	67,540,720	75,154,860	89,679,810	86,227,090
Month	**May**	**June**	**July**	**August**
Index (L)	95,353,720	108,155,800	117,811,900	103,392,600

Production methods differ by brewery, as well as according to beer types, equipment, and parameters specified by the national legislation. Most beer is produced from malted barley.

There are four main ingredients in a beer:

- Water
- Malt
- Hop
- Yeast

2.2.1 Water

The final-ready beer consists of approximately 80-95% water. Pure water is an essential ingredient in good beer and brewers pay scrupulous attention to the source and purification of their brewing water. The water used in brewing is purified to standards which are very strict.

The concentration of the mineral ions in the brew water influences the brewing. The ion-related hardness of the water measured in carbonates and bicarbonates increases the water's pH value or hydrogen-ion concentration. The value is important for many of the brewing sub processes which will run more smoothly in a slightly acidic environment with a low degree of. In many beer-producing areas, the water used for brewing has to be decalcified beforehand or adjusted during the brewing process (The Carlsberg Group, n.d.).

2.2.2 Malt

Barley is the raw material used to make brewers' malt.

In malting processes, barley is soaked, germinated, and then dried and/or kilned/roasted to arrest further growth. During the period of controlled growth in the malting plant, specific barley enzymes are released to break down the membranes of the starch cells that make up most of the kernel. But these are internal changes only; apart from a slight change in color, the external characteristics remain essentially unchanged. When the malt leaves a malting plant, it still looks like barley. In the brewery, the malt is screened. This process not only prevents the extraction of undesirable materials from the husks but also allows them to act as a filter bed for separation of the liquid extract formed during mashing (Tourism Victoria, n.d.).

2.2.3 Hop

The favorite aroma for brewers is to add the flower of the hop (Fig.2.1) vine to the beer. When a drink with alcohol is kept in a oak cask, the wood may give a natural aroma to the liquid. But most modern beers are too light in flavor to cope with this process. The hops add alpha and beta acids that provide bitterness and aroma to the final product. Hops are chosen for their content in these products as required by the beer being produced. They are also added at different stages in the process depending on whether they are being used to provide bitterness or aroma (Green, 2001).

Figure 2.1 Hops (Smith, 2008)

2.2.4 Yeast

Yeast is a tiny one-celled organism that multiplies by oxidation. Yeast readily adapts to a life without oxygen by using the available sugar from which it produces alcohol and CO_2. Temperature is the main factor that effects the growth of yeasts. Two varieties of yeast are used for beer brewing:

2.2.4.1 Top-Fermenting Yeast :

Top fermenting yeast sets in action a short (4-6days) and relatively warm fermentation (15-20^{o}C). The cells appear in chains and flow to the top during the fermentation process. Green (2001) says that "These are yeasts that form foam on the top of the beer during fermentation. This foam is skimmed at a certain stage in the fermentation and used to start the next beer fermenting."

2.2.4.2 Bottom-Fermenting Yeast :

Bottom-fermenting yeast functions at colder temperatures (6-9^{o}C), and the process lasts approximately 8 days. The yeast cells appear individually has a relatively small surface settle at the bottom during the process.

As Green (2001) explained, “The temperature … must be controlled to prevent undesirable products being produced that can affect the final flavor. The sugar content of the liquid is monitored throughout the fermentation and the process is stopped when the desired alcohol strength is reached.”

2.3 The Production of Beer

There are 5 main steps for the production of beer. These are:

i. Malting
ii. Brewing
  a. Mashing
  b. Lautering
  c. Boiling and Hopping
  d. Hop Separation and Cooling
iii. Fermentation
iv. Filtration
v. Bottling and Packaging

This production flow is shown below in Figure 2.2

2.3.1 Malting

Malting is the first step of the production. Barley the raw-material is the most important ingredient used in the production of beer. First the barley is weighed and then quality controls are done before being transported to large silos.

Barley is first shifted and screened to remove dust and broken kernels. The barley is now soaked with water, in periods, for approximately one day, in a process called stepping which water enters the grain via the embryo ensures and the barley will encourage to germinate.

The grains are then transferred to malting beds where germination is allowed to proceed over a period of 5-7 days. The speed of germination is controlled by temperature and aeration of the malt bed. During germination, the cell walls are broken down by the enzymes present inside the kernel in order to liberate the starch molecules. These enzymes are crucial to the brewing process and must be preserved. The barley is now called green malt.

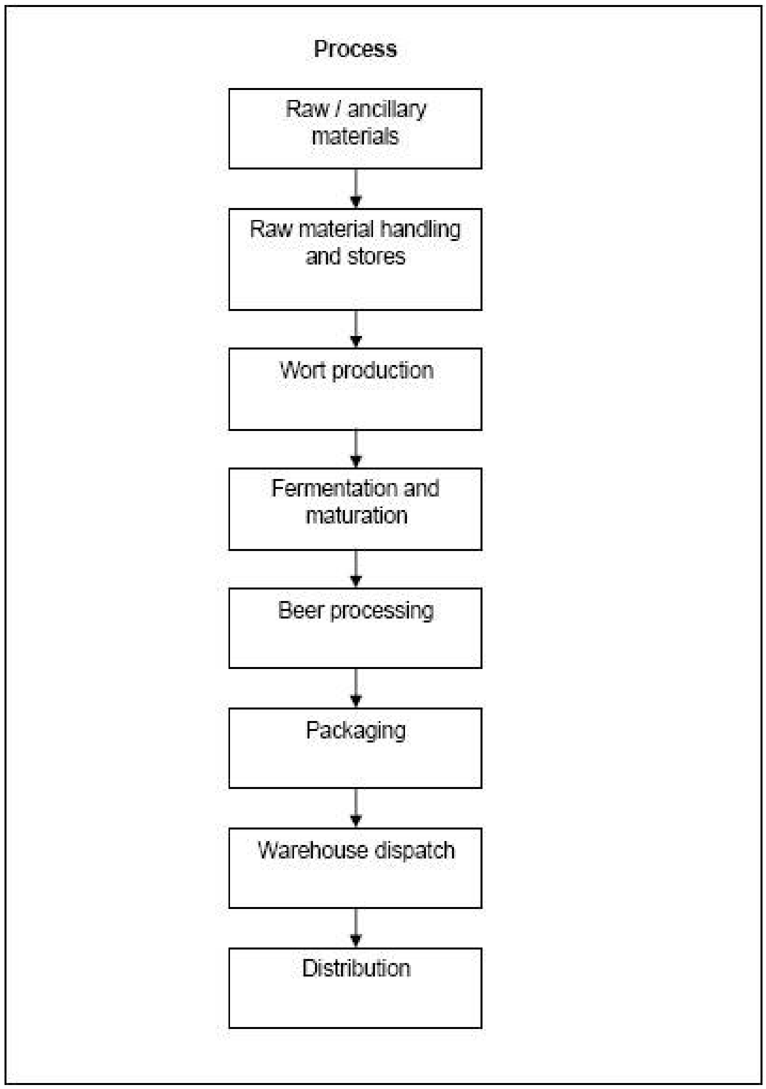

Figure 2.2 Supply chain process for beer production (IFC, 2007, p.17)

After the germination period, the green malt is dried with hot air to prevent further growth. This process is called kilning, for approximately one day (24h.). Then the malt is separated from its rootless and is subjected to cooling operation and stored in malt silos. The finished malt assumes the aroma and color which will assess the characterization (The Carlsberg Group, n.d.).

2.3.2 Brewing

2.3.2.1 Mashing

After malting, in the brew house the barley-malt is milled and mixed with water to form the so-called mash and to produce a fine mixture of flour and husks known as grist. The mash is gradually heated to 76°C in the mash coppers and this process is called as infusion or decoction. The enzymes in the malt break down the starch to release soluble sugars – glucose and maltose. Approximately 70% of the content of the barley is starch.

2.3.2.2 Lautering

The mashing process takes about 3 hours, after which the mash passes through a filter, the so-called mash-filter or lautertun, and the clarified wort (now the mash is called as wort, not beer yet) is transferred to wort coppers to be boiled with hopes for approximately one hour. The spent grains which are the separated material from the mash-filter are used as cattle fodder (The Carlsberg Group, n.d.).

2.3.2.3 Boiling and Hopping

The brew kettle which the wort is boiled in under carefully-controlled conditions is made of shiny copper or stainless steel. It is fitted with coils or a jacketed bottom for steam heating. This boiling process serves to concentrate the wort to a desired specific gravity, to sterilize it and to obtain the desired extract from the hops. The hop resins contribute flavor, and characteristics to the brew. When the hops give flavore to the brew, they are removed. When in need, highly-fermentable syrup may be added to the kettle. Undesirable protein substances that come from the mash mixer are coagulated and forced to leaving the wort clear (The Carlsberg Group, n.d.).

2.3.2.4 Hop Separation and Cooling

After the beer has taken on the flavor of the hops, the wort then proceeds to the "hot wort tank"(Brewers Association of Canada, n.d.). It is then cooled, usually in a simple apparatus called "plate cooler". As the wort and a coolant flow past each other on opposite sides of stainless steel plates, the temperature of the wort decreases to about 10 to 15.5 °C in a few seconds.

2.3.3 Fermenting

The chilled wort is then moved to the fermenting vessels and yeast is added. A living single-cell fungi organism, the yeast feeds off the sugars and other nutrients extracted from the malt, producing carbon dioxide, aroma and alcohol. The fermentation lasts from 8 to 12 days. During the process, the tank is kept at a temperature of 14°C. During the last couple of days of this phase, the beer temperature is regulated to 8°C, and the yeast falls to the bottom and is removed.

When most of the sugars have been used up, the yeast becomes inactive and the fermentation is complete.

After fermentation, though before filtering and bottling, the beer matures in the tank, at approximately -2°C, to develop its desired taste, aroma and shelf-life.

Fermentation tanks are generally vertical and made of stainless steel. Caps are covered on the top of the tanks to keep the beer at the desired temperature. As a technical detail, the largest of the tanks can hold more than 5300 hectoliters of beer, corresponding to some 1.5 million bottles (The Carlsberg Group, n.d.).

2.3.4 Filtration

The beer is stored cold for one to three weeks and then filtered to prepare it for bottling. After the maturing stage, the beer is piped to the filter-room, where it first passes through beer centrifuges, which separate some of the cloudiness and yeast. The beer is then subjected to a very thorough filtration, making it clear and ready for bottling.

2.3.5 Bottling & Packaging

Bottling takes place in large halls. After sorting, the empty bottles pass through a bottle washer where they receive a thorough cleaning, then finally rinsed in hot and cold water.

After rinsing, the bottles pass inspection machines to be checked for potential defects and then continue, via a conveyor belt, to the filter, where they're filled with beer. To prevent foaming, filling takes place under counter-pressure. The bottles then pass through the crown cork machine which seals them. Beers are pasteurized in order to preserve the character of the product until it's consumed.

Now the bottles are ready to be labeled and get a final check before they are ready for automatic packaging. Finally, the packages are conveyed to the palleting station and to the warehouses and distribution centers before reaching the consumer (The Carlsberg Group, n.d.).

2.4 Environmental Issues for Brewing Industries

As mentioned by IFC (2007, p.2), in a brewery the following environmental issues occur:

- Energy consumption
- Water consumption
- Solid waste and by-products

- Effluent wastewater
- Emissions to air

2.4.1. Water Consumption

Brewing water requires high amounts of qualified water. In breweries, water standards established by the regulations are much stricter than other industries. Breweries use water as raw material. Beer is composed mostly of water (90%) and an efficient brewery uses between 4-6 liters (L) of water to produce 1 L of beer. Water consumption for individual process stages, as reported for the German brewing industry, is shown in Table 2.3.

Table 2.3 Water consumption reported for the German brewing industry (The World Bank Group [WBG], 1998, p.272)

Process Step	Water consumption*
Gyle (unfermented wort) to whirpool	2.0 (1.8-2.2)
Wort cooling	0.0 (0.0-2.4)
Fermentation cellar and yeast treatment	0.6 (0.5-0.8)
Filter and pressure tank room	0.3 (0.1-0.5)
Storage cellar	0.5 (0.3-0.6)
Bottling (70% of beer produced)	1.1 (0.9-2.1)
Barel filling (30% of beer produced)	0.1 (0.1-0.2)
Wastewater from cleaning vehicles, sanitary use, etc.	1.5 (1.0-3.0)
Steam boiler	0.2 (0.1-0.3)
Air compressor	0.3 (0.1-0.5)
Total	**6.6 (4.9-12.6)**

* m^3/m^3 of sold beer; numbers in parentheses are ranges

The total beer production values for Turkey has been listed in Table 2.1. So, for the year 2007 (920,470,800 L beer) the water consumption of Turkey for beer production can be calculated as 4,602,354,000 L (~0.0046 km^3) on average.

Some general recommendations to reduce water consumption in breweries include:

- Reclaiming water from cooling and rinsing processes.
- Limiting water used in wort cooling
- Avoiding the overloading of the tanks, basins or boxes.

- Replacing older bottle washers with new energy efficient bottle washers
- Applying regular maintenance and control programs for technical instruments, such as regular monitoring, replacing the old valves or nozzles with the newer, enviro-friend ones.
- Optimizing cleaning-in-place (CIP) plants
- Implementing closed-loop systems for the cooling and recirculating of pasteurization process water if it's feasible.

2.4.2. Effluent Water Quality

Breweries generates of 3-10 L of effluent per production of 1 L beer. Effluents of brewing industries contain high organic content, suspended solids varies between 10–60 milligrams per liter (mg/L), biochemical oxygen demand (BOD) of up to 1500 mg/L, chemical oxygen demand (COD) in the range 1,000–4,000 mg/L, and nitrogen in the range 30–100 mg/L. Phosphorus can also be present at concentrations of the order of 10–30 mg/L.

> Effluents from individual process steps are variable. For example, bottle washing produces a large volume of effluent that contains only a minor part of the total organics discharged from the brewery. Effluents from fermentation and filtering are high in organics and BOD but low in volume, accounting for about 3% of total wastewater volume but 97% of BOD. Effluent pH averages about 7 for the combined effluent. Effluent temperatures average about 30°C (WBG, 1998, p.272).

Brewery processes generates liquid waste such as the weak wort and residual beer, which the brewery should reuse rather than allowing it to enter the effluent stream. The main sources of residual beer include process tanks, kieselguhr filter, pipes, beer rejected in the packaging area, returned beer, and exploding bottles in the packaging

The following protective and preventive practices used to reduce the organic load of brewery effluent: Weak wort can be collected, reducing the residual beer can be provided with implementation of good housekeeping, keeping bottle washer clean can be implemented, and overfilling of fermentation boxes can be prevented. Collection and reuse of rinsing water from the last cleaning in the first cleaning-in-place (CIP) cycle is also a good practice.

Primary treatment is an obligatory for the brewing industry and also the secondary and anaerobic treatment is advised for the solution to high organic content rich wastewater.

CHAPTER THREE
REGULATIONS FOR WASTEWATER REUSE

3.1 Guidelines and Regulations for Wastewater Reuse

Industrial wastewater reuse is a proven and required technology that has been used for many years in the world. It is a renewable supply of water that will prevent water resources of shrinking, help living things to survive and keep water tables from dropping. To get these vital advantages, governments or legal authorities form and publish guidelines or regulations.

In this context, guidelines belong to EPA, World Health Organization (WHO) and Turkey for the reuse of wastewater is mentioned to compare with the results of the analyses that have been practiced for this study.

3.1.1 United States Environmental Protection Agency (EPA) Guidelines

The 2004 Guidelines for Water Reuse examines opportunities for substituting reclaimed water for potable water supplies where potable water quality is not required. It presents and summarizes recommended water reuse guidelines, along with supporting information, as guidance for the benefit of the water and wastewater utilities and regulatory agencies, particularly in the U.S.(EPA, 2004, p.iii).

EPA regulations and guidelines may be classified as the following reuse categories:

- Unrestricted urban reuse (parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments).
- Restricted urban reuse (golf courses, cemeteries, and highway medians).
- Agricultural reuse on food (for direct human consumption).

- Agricultural reuse on non-food crops.
- Unrestricted recreational reuse (no limitations for water usage).
- Restricted recreational reuse (no body contact).
- Environmental reuse.
- Industrial reuse (cooling/boiler-feed/process water and general washdown).
- Groundwater recharge.
- Indirect potable reuse.

The guidelines address all important aspects of water reuse and include recommended treatment processes, reclaimed water quality limits, monitoring frequencies, setback distances, and other controls for various water reuse applications. The guidelines address water reclamation and reuse for nonpotable applications as well as indirect potable reuse by groundwater recharge and augmentation of surface water sources of supply. The treatment processes and generalized reclaimed water quality limits recommended in the guidelines for various reclaimed water applications are given in Table 3.4.

Both reclaimed water quality limits and wastewater treatment unit processes are recommended for these reasons:

i) Water quality criteria involving surrogate parameters alone do not adequately characterize reclaimed water quality;

ii) A combination of treatment and quality requirements known to produce reclaimed water of acceptable quality obviate the need to monitor the finished water for certain constituents;

iii) Expensive, time-consuming, and in some cases, questionable monitoring for pathogenic microorganisms is eliminated without compromising health protection;

iv) Treatment reliability is enhanced.

In the U.S., total and faecal coliforms are the most commonly used indicator organisms in reclaimed water. The total coliform analysis includes organisms of both faecal and non faecal origin, while the faecal coliform analysis is specific for coliform organisms of faecal origin. Therefore, faecal coliforms are better indicators of faecal contamination than total coliforms, and the authors of the guidelines, upon the recommendation of noted microbiologists, chose the use faecal coliform as the indicator organism. The guidelines state that either the membrane filter technique or the multiple-tube fermentation technique may be used to quantify the coliform levels in the reclaimed water (Asano, 1998, p.680).

Quality requirements for boiler-feed make-up water are dependent on the pressure at which boilers are operated, as shown in Table 3.1. Generally, the higher the pressure, the higher quality of water required.

Table 3.1 Recommended industrial boiler-feed water quality criteria (EPA, 1992, p.76)

Parameter	**Low Pressure (<150 psig)**	**Intermediate Pressure (150-700 psig)**	**High Pressure (>700 psig)**
Silica, mg/L	30	10	0.7
Aluminum, mg/L	5	0.1	0.01
Iron, mg/L	1	0.3	0.05
Magnesium, mg/L	0.3	0.1	0.01
Calcium, mg/L	--	0.4	0.01
Magnezyum, mg/L	--	0.25	0.01
Ammonia, mg/L	0.1	0.1	0.1
Bicarbonate, mg/L	170	120	48
Sulfate, mg/L	--	--	--
Chloride, mg/L	--	--	--
Dissolved solids, mg/L	700	500	200
Copper, mg/L	0.5	0.05	0.05
Zinc, mg/L	--	0.01	0.01
Alkalinity, mg/L	350	100	40
pH	7-10	8.2-10	8.2-9
Suspended solids, mg/L	10	5	0.5
COD, mg/L	5	5	1

The most frequent water quality problems in cooling water systems are corrosion, biological growth, and scaling. These problems arise from contaminants in potable water as well as in reclaimed water, but the concentrations of some contaminants in reclaimed water may be higher than in potable water (EPA, 2004, p.15). Table 3.2 provides recommended specifications and treatment plant effluent values for cooling water.

Table 3.2 Cooling water recommended specifications (EPA, 1992, p.74)

Parameters	**Recommended Limit Value**
Cl^{-1}, mg/L	500
Total Dissolved Solids, mg/L	500
pH	6.9-9.0
COD, mg/L	75
Total Suspended Solids, mg/L	100
BOD, mg/L	25
NH_4^{+}-N, mg/L	1.0
PO_4^{-3}, mg/L	4
SiO_2, mg/L	50
Al^{+3}, mg/L	0.1
Iron, mg/L	0.5
Mn^{+2}, mg/L	0.5
Ca^{+2}, mg/L	50
Mg^{+2}, mg/L	0.5
SO_4^{-2}, mg/L	200

The suitability of reclaimed water for use in industrial processes depends on the particular use. For example, the electronics industry requires water of almost distilled quality for washing circuit boards and other electronic components (EPA, 1992, p.75). In investigating the feasibility of industrial reuse with reclaimed water, the potential users must be contacted to determine specific requirements for process water. Industrial water reuse quality concerns and potential treatment processes are given in Table 3.3.

Table 3.3 Summary of water quality issues of importance for industrial water reuse (EPA, 1992, p.77)

Parameter	**Potential Problem**	**Advanced Treatment Process**
Residual organics	Bacterial growth, slime/scale formation, foaming in boilers	Nitrification, carbon adsorption, ion exchange
Ammonia	Interferes with formation of free chlorine residual, causes stress corrosion in copper-based alloys, stimulates microbial growth	Nitrification, ion exchange, air stripping
Phosphorus	Scale formation, stimulates microbial growth	Chemical precipitation, ion exchange, biological phosphorus removal
Suspended Solids	Deposition, “seed” for microbial growth	Filtration
Calcium, magnesium, iron, and silica	Scale formation	Chemical softening, precipitation, ion exchange

Table 3.4 Suggested guidelines for reuse of wastewater (EPA, 2004, p.167-170)

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Urban Reuse All types of landscape irrigation (e.g., golf courses, parks, cemeteries) also vehicle washing, toilet flushing, use in fire protection system and commercial air conditioners, and other uses with similar Access or exposure to the water.	• Secondary[4] • Filtration[5] • Disinfection[6]	• pH = 6-9 • ≤ 10 mg/L BOD[7] • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] •1 mg/L Cl_2 residua (min.)[11]	• pH – weekly • BOD – weekly • Turbidity – continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve ≤ 14 fecal coli/100 mL, may be appropriate at controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens. • Reclaimed water should be clear and odorless. • Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • Chlorine residual of 0.5 mg/L or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Restricted Access Area Irrigation					
Sod farms, silviculture sites, and other areas where public Access is prohibited, restricted, or infrequent.	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • 1 mg/L Cl_2 residual (min) [11]	• pH – weekly • BOD – weekly • SS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• If spray irrigation, TSS less than 30 mg/L may be necessary to avoid clogging of sprinkler heads.
Agricultural Reuse – Food Crops Not Commercially Processed[15]					
Surface or spray irrigation of any food crop, including crops eaten raw.	• Secondary[4] • Filtration[5] • Disinfection[6]	• pH = 6-9 • ≤ 10 mg/L BOD[7] • ≤ 2 NTU[8] • No detectable fecal coli/100 Ml[9,10] •1 mg/L Cl_2 residual (min.) [11]	• pH – weekly • BOD – weekly • Turbidity – continuous • Coliform - daily • Cl_2 residual - continuous	• 50 ft (15 m) to potable water supply wells	• Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens[12]. • Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • High nutrient levels may adversely affect some crops during certain growth stages. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Agricultural Reuse – Food Crops Commercially Processed[15] Surface Irrigation of Orchards Vineyards					
	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • 1 mg/L Cl_2 residual (min)[11]	• pH – weekly • BOD – weekly • TSS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• If spray irrigation, TSS less than 30 mg/L may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • Provide treatment reliability.
Agricultural Reuse – Non Food Crops					
Pasture for milking animals; fodder, fiber, and seed crops	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14] • 1 mg/L Cl_2 residual (min)[11]	• pH – weekly • BOD – weekly •TSS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to potable water supply wells • 100 ft (30 m) to areas accessible to the public (if spray irrigation)	• If spray irrigation, TSS less than 30 mg/L may be necessary to avoid clogging of sprinkler heads. • High nutrient levels may adversely affect some crops during certain growth stages. • Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 mL, should be provided if this waiting period is not adhered to. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Recreational Impoundments					
Incidental contact (e.g., fishing and boating) and full body contact with reclaimed water allowed.	• Secondary[4] • Filtration[5] • Disinfection[6]	• pH = 6-9 • ≤ 10 mg/L BOD[7] • ≤ 2 NTU[8] • No detectable fecal coli/100 Ml[9,10] • ≥ 1 mg/L Cl_2 residual (min)[11]	• pH – weekly • BOD – weekly • Turbidity – continuous • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Reclaimed water should be non-irritating to skin and eyes. • Reclaimed water should be clear, odorless. • Nutrient removal may be necessary to avoid algae growth in impoundments. • Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. • The reclaimed water should not contain measurable levels of pathogens[12]. • A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. • Fish caught in impoundments can be consumed.
Landscape Impoundments					
Aesthetic impoundments where public contact with reclaimed water is not allowed.	• Secondary[4] • Disinfection[6]	• ≤ 30 mg/L BOD[7] • ≤ 30 mg/L TSS • ≤ 200 fecal coli/100 Ml[9,13,14] • ≥ 1 mg/L Cl_2 [11]	• pH – weekly • TSS – daily • Coliform - daily • Cl_2 residual - continuous	• 500 ft (150 m) to potable water supply wells (minimum) if bottom not sealed	• Nutrient removal processes may be necessary to avoid algae growth in impoundments. • Dechlorination may be necessary to protect aquatic species of flora and fauna. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Construction Uses Soil compaction, dust control, washing aggregate, making concrete.	• Secondary[4] • Disinfection[6]	• ≤ 30 mg/L BOD[7] • ≤ 30 mg/L TSS • ≤ 200 fecal coli/100 Ml[9,13,14] •1 mg/L Cl_2 residual (min)[11]	• BOD – weekly • TSS – daily • Coliform - daily • Cl_2 residual – continuous		• Worker contact with reclaimed water should be minimized. • A higher level of disinfection, e.g., to achieve ≤ 14 fecal coli/100 mL, should be provided where frequent worker contact with reclaimed water is likely. • Provide treatment reliability.
Industrial Reuse Once – through cooling	• Secondary[4] • Disinfection[6]	• pH = 6-9 • ≤30 mg/L BOD[7] • ≤ 30 mg/L TSS • ≤ 200 fecal coli/100 Ml[9,13,14] •1 mg/L Cl_2 residual (min)[11]	• pH – weekly • BOD – weekly • TSS – daily • Coliform - daily • Cl_2 residual – continuous	• 300 ft (90 m) to areas accessible to the public.	• Windblown spray should not reach areas accessible to users or the public.
Recirculating cooling towers	• Secondary[4] • Disinfection[6] (chemical coagulation and filtration[5] may be needed)	• Variable, depends on recirculation ratio. • pH = 6-9 • ≤30 mg/L BOD[7] • ≤ 30 mg/L TSS • ≤ 200 fecal coli/100 Ml[9,13,14]	• pH – weekly • BOD – weekly • TSS – daily • Coliform - daily • Cl_2 residual - continuous	• 300 ft (90 m) to areas accessible to the public. May be reduced if high level of disinfection is provided.	• Windblown spray should not reach areas accessible to users or the public. • Additional treatment by user is usually provided to prevent scaling, corrosion, biological growths, fouling and foaming. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Other industrial uses	Depends on site specific uses				
Environmental Reuse Wetlands, marshes, wildlife habitat, stream augmentation	• Variable • Secondary[4] and disinfection[6] (min.)	Variable, but not to exceed : • ≤ 30 mg/L BOD[7] • ≤ 30 mg/L SS • ≤ 200 fecal coli/100 mL[9,13,14]	• BOD – weekly • TSS – daily • Coliform - daily • Cl_2 residual – continuous		• Dechlorination may be necessary to protect aquatic species of flora and fauna. • Possible effects on groundwater should be evaluated. • Receiving water quality requirements may necessitate additional treatment. • The temperature of the reclaimed water should not adversely affect ecosystem. • Provide treatment reliability.
Groundwater Recharge By spreading or injection into aquifers not used for public supply	• Site-specific and use dependent • Primary (min) for spreading • Secondary[4] (min.) for injection	• Site-specific and use dependent	• Depends on treatment and use	• Site-specific	• Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers. • For spreading projects, secondary treatment may be needed to prevent clogging. • For injection projects, filtration and disinfection may be needed to prevent clogging. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Indirect Potable Reuse					
Groundwater recharge by spreading into potable aquifers.	• Site-specific • Secondary[4] • Disinfection[6] (min.) • May also need filtration[5] and/or advanced wastewater treatment[16]	• Site-specific • Meet drinking water standards after percolation through vadose zone.	Includes, but not limited to, the following: • pH – daily • Coliform - daily • Cl_2 residual – continuous • Drinking water standards – quarterly • Other[p] – depends on constituent • BOD weekly • Turbidity-continuous	• 500 ft (150 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The depth to groundwater (i.e., thickness of the vadose zone) should be at least 6 feet (2 m) at the maximum groundwater mounding point. • The reclaimed water should be retained underground for at least 1 year prior to withdrawal. • Recommended treatment is site-specific and depends on factors such as type of soil percolation rate, thickness of vadose zone native groundwater quality, and dilution. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • The reclaimed water should not contain measurable levels of pathogens after percolation through the vadose zone[12]. • Provide treatment reliability.

Types of Reuse	Treatment	Reclaimed Water Quality[2]	Reclaimed Water Monitoring	Setback Distances[3]	Comments
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	• Secondary[4] • Filtration[5] • Disinfection[6] • Advanced wastewater treatment[16]	Includes, but not limited to the following: • pH = 6.5 - 8.5 • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] •1 mg/L Cl_2 residual (min)[11] •<3mg/L TOC •≤0.2mh/L TOX • Meet drinking water standards	Includes, but not limited to the following: • pH – daily • Turbidity – continuous • Coliform - daily • Cl_2 residual – continuous • Drinking water standards – quarter • Other[17] – depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The reclaimed water should be retained underground for at least 9 months prior to withdrawal. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • Recommended quality limits should be met at the point of injection. • The reclaimed water should not contain measurable levels of pathogens at the point of injection[12]. • Higher chlorine residual and/or a longer contact time may be necessary to assure virus inactivation.
Augmentation of surface supplies	• Secondary[4] • Filtration[5] • Disinfection[6] • Advanced wastewater treatment[16]	Includes, but not limited to the following: • pH = 6.5 - 8.5 • ≤ 2 NTU[8] • No detectable fecal coli/100 mL[9,10] • 1 mg/L Cl_2 residual (min)[11] •≤3mg/L TOC • Meet drinking water standards	Includes, but not limited to the following: • pH – daily • Turbidity – cont. • Coliform - daily • Cl_2 residual – continuous • Drinking water standards – quarterly • Other[17] – depends on constituent	• Site-specific	• Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. • The reclaimed water should not contain measurable levels of pathogens[12]. • Higher chlorine residual and/or a longer contact time may be necessary to assure virus inactivation. • Provide treatment reliability.

Footnotes

1. These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in may areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries (see Chapter 8). It is explicitly stated that the direct application of these suggested guidelines will not be used by USAID as strict criteria for funding.
2. Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.
3. Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.
4. Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and may include stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30 mg/L.
5. Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite, filter cloth, or the passing of wastewater through microfilters or other membrane processes.
6. Disinfection means the destruction, inactivation, or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, UV radiation, ozonation, other chemical disinfectants, membrane processes, or other processes. The use of chlorine as defining the level of disinfection does not preclude the use of other disinfection processes as an acceptable means of providing disinfection for reclaimed water.
7. As determined from the 5-day BOD test.
8. The recommended turbidity limit should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If TSS is used in lieu of turbidity, the TSS should not exceed 5 mg/L.
9. Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation-tube technique may be used.
10. The number of fecal coliform organisms should not exceed 14/100 ml in any sample.
11. Total chlorine residual should be met after a minimum contact time of 30 minutes.
12. It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementation of a reuse program.
13. The number of fecal coliform organisms should not exceed 800/100 ml in any sample.
14. Some stabilization pond systems may be able to meet this coliform limit without disinfection.
15. Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.
16. Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange.
17. Monitoring should include inorganic and organic compounds, or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

3.1.2 World Health Organization (WHO) Guidelines

The WHO Guidelines are an integrated prescriptive and preventive management framework for increasing the public health benefits of wastewater reuse. The guidelines are built around the health part and the implementation part of the life cycle. Thus, the protection of health is dependent on both elements.

> WHO water-related guidelines are based on scientific consensus and best available evidence and are developed through broad participation. The guidelines for the safe use of wastewater, excreta and grey water are designed to protect the health of farmers (and their families), local communities and product consumers. They are meant to be adapted to take into consideration national, socio-cultural, economic and environmental factors. Where the guidelines relate to technical issues - for example, wastewater treatment – technologies that are readily available and achievable (from both technical and economic standpoints) are explicitly noted, but others are not excluded. Overly strict standards may not be sustainable and, paradoxically, may lead to reduced health protection, because they may be viewed as unachievable under local circumstances and, thus, ignored. The guidelines therefore strive to maximize overall public health benefits and the beneficial use of scarce resources (WHO, 2006, p.vii).

Recommended microbiological guidelines published by WHO for wastewater use in agricultural activities is categorized into classes like A, B and C. These classes differ between each other about reuse conditions and exposed groups. The relationship between the treatment technologies, the health aspects is explained below in Table 3.5.

As an explanation, Asano (1998, p.695) mentions that “The WHO guidelines are significantly less restrictive than regulations or guidelines of many industrialized countries”.

Table 3.5 World health recommended microbiological guidelines for wastewater use in agriculture [a] (WHO, 1989)

Category	Reuse Conditions	Exposed Group	Intestinal nematodes[b] (arithmetic mean no. of eggs per liter) [c]	Fecal Coliforms (geometric mean no. per 100mL)	Wastewater Treatment Expected To Achieve the Required Microbiological Quality
A	Irrigation or crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	_<1	1.000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment.
B	Irrigation of cereal crops, industrial crops, fodder crops pasture and trees[e]	Workers	_<1	No standards recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	No standards recommended	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

a In specific cases, local epidemiological, socio-cultural, and environmental factors should be taken into account, and the guidelines modified accordingly
b Ascaris and Trichuris species and hookworms.
c During the irrigation period.
d A more stringent guideline (200fecal coliforms per 100 mL) is appropriate for public lawns, with which the public may come into direct contact.
e In the case of fruit trees, irrigation should cease 2 weeks before fruit should be picked off the ground. Sprinkler irrigation should not be used.

3.1.3 Wastewater Reuse Standards of Turkey

The Water Pollution Control Regulations (WPCR) was designed firstly in September 4, 1988 to overcome the diverse effects of water pollution in a multipurpose form, classifying quality both on the basis of municipal/industrial discharge standards and on the basis of the receiving media and this regulation had been published by Directorate General of Legislation and Publication of the Prime Ministry via the Official Gazette (No: 19919). This regulation was revised and re-published by the authorities via the Official Gazette (December 31, 2004; No: 25687).

It's an obligatory for industries to treat their effluent up to the standards specified for the category where they belong to the environmental legislation and as described in the water pollution control regulations, at least.

The main objective is to supply a clean receiving environment both for inland waters and surrounding seas. The anticipated result is a better and more efficient use of fresh and marine resources for consumption, boating, fishing and other recreational facilities. It is a representative for being the main tool for management with respect to its enforcement on a national scale. In this context, the Environment Act was promulgated in 1983 and this development was amended in Official Gazette, no.18132.

The Water Pollution Control Regulation is based on polluter pays principle. The fundamental economic instrument that takes place in wastewater management is water charges that are paid by consumers (domestic, public, commercial and industrial). Within this principle every kind of industry has its own effluent limits ant the charges are calculated on the basis of each industry's pollution coefficient. Industries are categorized according to their production types within the meaning of the WPCR and 16 sectors types are formed. The effluent standards specified for breweries are shown in Table 3.6.

Table 3.6 Effluent standards for alcoholic beverages (Malting, brewing, etc.) (WPCR, 2004, p.26)

Parameter	**Unit**	**Composit (2 h)**	**Composit (24 h)**
Chemical Oxygen Demand (COD)	(mg/L)	120	100
pH	-	6-9	6-9

As is the case in other commonly used or known regulations, Turkish WPCR also has much more limitations or standards for the wastewater reuse for agriculture than the other uses of reclaimed water. Kamizoulis, Bahri, Brissaud, & Angelakis (2003, p.11) explain this situation as "The increasing need for irrigation system encourage the specialists to focus on the topic… . Agricultural wastewater reuse is an element of water resources development and management that provides innovative and alternative options for agriculture.".

This regulation consists of a number of guidelines to describe the principles in the implementation of methods. Technical Aspects Bulletin is one of these guidelines, related with the reuse of treated wastewater in irrigation and recommends the applicable irrigation methods and faecal coliform limits (Table 3.7).

Table 3.7 Basic requirements and technical limits for the control of agricultural reuse of wastewaters in Turkey (WPCR Technical Aspects Bulletin, 1991, p.17)

Crops	**Technical limits**
Orchards and vineyards	• No sprinkler irrigation • Fruits dropped on the ground shouldn't be eaten • Faecal coliform no < 1000/100 mL
Leafy and seed crops	• Surface or sprinkler irrigation • Biological treatment and chlorination in sprinkler irrigation. • Fecal coliform < 1000/100 mL
Forage, industrial, nonraw eaten crops and ornamentals	• Surface irrigation (Mechanical treatment)

Reclaimed water is classified up to its characterization and one of the identifier of this classification is sodium absorption rate (SAR). SAR is the absorption of sodium content of reclaimed water used for irrigation by irrigated grounds. This index quantifies the proportion of sodium (Na^+) to calcium (Ca^{++}) and magnesium (Mg^{++}) ions in a sample and evaluated as:

$$SAR = \frac{Na^+(meq/L)}{\sqrt{\dfrac{Ca^{++}(meq/L) + Mg^{++}(meq/L)}{2}}}$$

Classification of irrigation water can be determined via taking into consideration the ratio between electrical conductivity and SAR as shown in Figure 3.1.

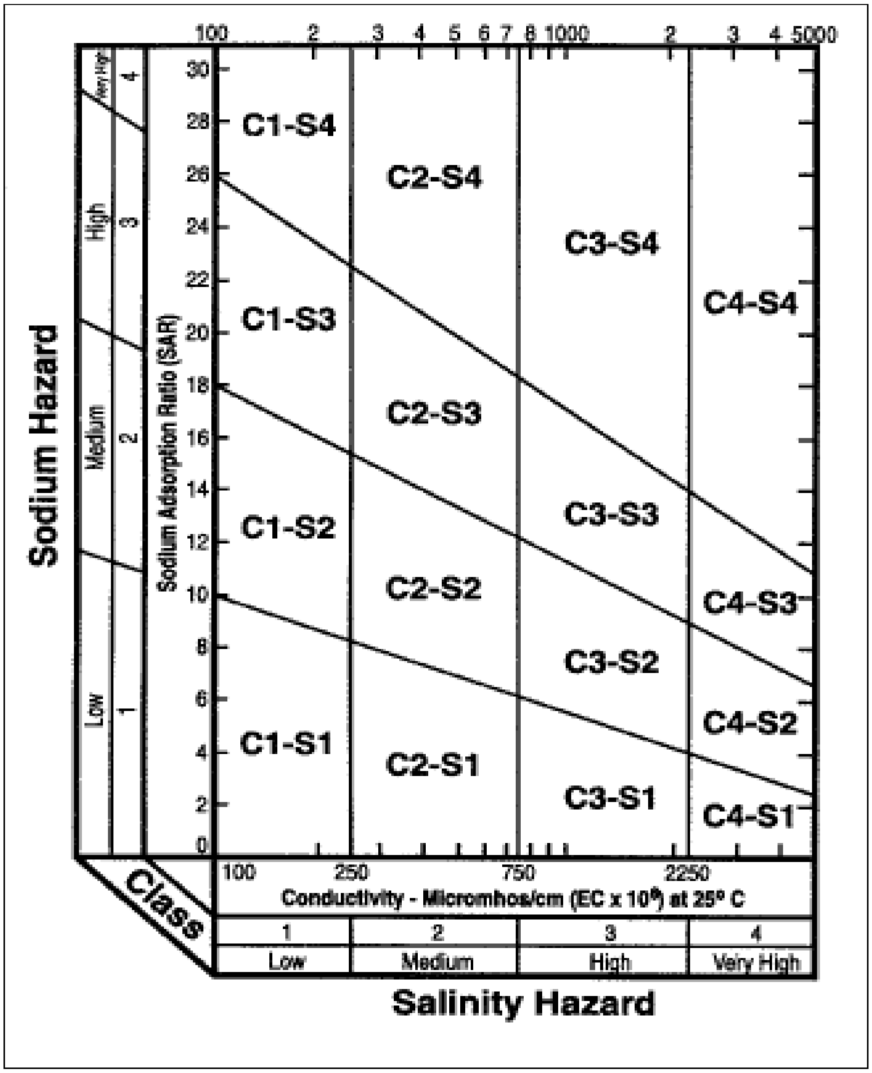

Figure 3.1 Classification of irrigation water (WPCR Technical Aspects Bulletin, 1991, p.15)

The values shown in Table 3.8 are compared with the chosen range by using Figure 3.1 to be in accordance with the regulation and to determine whether any other unit/equipment should be installed or not.

Table 3.8 Turkish water quality criteria for irrigation, according to classes (WPCR Technical Aspects Bulletin, 1991, p.16)

Quality Criteria	**Class I (Perfect)**	**Class II (Satisfactory)**	**Class III (Usable)**	**Class IV (Usable with care)**	**Class V (Improper harmful)**
EC_{25} (microhos at 25 °C) $\times 10^6$	0-250	250-750	750-2,000	2,000-3,000	>3,000
Sodium (Na, %)	<20	20-40	40-60	60-80	>80
SAR	<10	10-18	18-26	>26	
Residual Sodium Carbonate (RSC) in meq/l or mg/L	>1.25 <66	1.25-2.5 66-133	>2.5 >133		
Chloride (Cl^-) in meq/l or mg/L	0-4 0-142	4-7 142-249	7-12 249-426	12-20 426-710	>20 >710
Sulphate ($SO_4^=$) in meq/l or mg/L	0-4 0-192	4-7 192-336	7-12 336-575	12-20 575-960	>20 >960
Total Salt Concentration (mg/L)	0-175	175-525	525-1,400	1,400-2,100	>2,000
Boron Concentration (mg/L)	0-0.5	0.5-1.12	1.12-2.0	>2.0	-
Class of Irrigation Water*	C_1S_1	C_1S_2, C_2S_2, C_2S_1	C_1S_3, C_2S_3, C_3S_3, C_3S_2 C_3S_1	C_1S_4, C_2S_4, C_3S_4, C_4S_4, C_4S_3, C_4S_2 C_4S_1	-
NO_3^--N or NH_4^+-N (mg/L)	0-5	5-10	10-30	30-50	>50
Faecal Coliform**1/100 ml (CFU in 100 ml)	0-2	2-20	20-100	100-1,000	>1,000

Table 3.8 (continued)

Quality Criteria	**Class I (Perfect)**	**Class II (Satisfactory)**	**Class III (Usable)**	**Class IV (Usable with care)**	**Class V (Improper harmful)**
BOD_5 (mg/L)	0-25	25-50	50-100	100-200	>200
TSS (mg/L)	20	30	45	60	>100
pH	6.5-8-5	6.5-8.5	6.5-8.5	6.5-9	<6 or >9
Temperature (^{o}C)	30	30	35	40	>40

* determined using Figure 3.1, ** varies according to type of plantation

Concentrations of heavy metals are also an identifier for the agricultural irrigation. Limit values specified by Turkish WPCR for heavy metals and trace elements are given in Table 3.9.

Table 3.9 Acceptable maximum heavy metals and toxic elements concentration for irrigation water (WPCR Technical Aspects Bulletin, 1991, p.17).

Elements	**Maximum total amount to unit area kg/ha**	**Acceptable maximum concentrations (mg/L)**	
		Continuous irr. for each ground, mg/1	**Applied < 20 years to clay ground with pH value 6,0-8,5, mg/1**
Aluminium (Al)	4600	5.0	20.0
Arsenic (As)	90	0.1	2.0
Beryllium (Be)	90	0.1	0.5
Boron (B)	680	-[3]	2.0
Cadmium (Cd)	9	0.01	0.05
Chrome (Cr)	90	0.1	1.0
Cobalt (Co)	45	0.05	5.0
Copper (Cu)	190	0.2	5.0
Fluoride (F)	920	1.0	15.0
Iron (Fe)	4600	5.0	20.0
Lead (Pb)	4600	5.0	10.0
Lithium (Li)[1]	-	2.5	2.5
Manganese (Mn)	920	0.2	10.0
Molybdenum (Mo)	9	0.01	0.05[2]

Table 3.9 (continued)

Elements	Maximum total amount to unit area kg/ha	Acceptable maximum concentrations (mg/L)	
Nickel (Ni)	920	0.2	2.0
Selenium (Se)	16	0.02	0.02
Vanadium (V)	-	0.1	1.0
Zinc (Zn)	1840	2.0	10.0

[1]0.075 mg/1for irrigated citrus
[2] allowed conc. only for acidic clay groundswith high conc. of iron
[3]given in Table 3.10

Because Turkey is the richest country of the world with its boron reserves, an additional irrigation classification is needed for the resistance of the plants to the existence of boron. Actually all of the plants need some limited amount of boron for their growth. The classification shown in Table 3.10 should be taken into consideration while using reclaimed water for irrigation.

Table 3.10 Classification of irrigation water with respect to resistance of plants to boron mineral (WPCR Technical Aspects Bulletin, 1991, p.18)

Classification of irrigation water	Boron concentration in irrigation water (mg/L)		
	Boron concentration sensitive plants*	Boron concentration semi-sensitive plants**	Boron concentration tolerable plants***
I	< 0.33	< 0.67	< 1.0
II	0.33-0.67	0.67-1.33	1.00-2.00
III	0.67-1.00	1.33-2.00	2.00-3.00
IV	1.00-1.25	2.00-2.50	3.00-3.75
V	> 1.25	> 2.50	> 3.75

* e.g. walnut, lemon, fig, apple, grape and bean.
** e.g. barley, wheat, maize, oats, olive and cotton.
*** e.g. sugar beet, clover, horse bean, onion, lettuce and carrot.

To have a general consideration about irrigation techniques upon the industry type, Table 3.11 is listed below.

Table 3.11 Suitability of industrial wastewaters used in irrigation (WPCR Technical Aspects Bulletin, 1991, p.17)

I	II	III
It can be used for irrigation water if a suitable field is near the plant	It is suitable if specific conditions are provided *	It is not suitable for irrigation
Beer, malt, wine, yeast, potatoes, vegetables, canned food, marmalade, fruit, milk, potatoes, starch	Sugar, rice and grain starch, leather glue bone glue plants, slaughterhouse, meat facilities, tannery, margarine plants, paper plants, cardboard plants, textile industry, wool washing, fish flour, canned-fish, mining	Polish and paint plants, soap plants, inorganic heavy chemical industry, medicine plants, metal plants, sulfide cellulose plant, viscose artificial silk plant, Pyrolise institution, coal, gas institution, generator gas turbine, metallic oil industry, coal washing, dynamite industry, Wood pyrolise institute

* In the case of treated industrial wastewater at the concentration level given in Table 3.7 and 4.9

CHAPTER FOUR
MATERIALS AND METHODS

4.1 Introduction of The Pilot Plant

In this study, a brewery which is located in Izmir, Turkey has been selected as the pilot plant. Throughout the explanation of the study name of this plant will not be expressed.

4.1.1 Process Description

Generally, steps in the brewing process are similar for most of the breweries. The process flow chart for the chosen brewery is given below in Figure 4.1. For this brewery the beer production mainly includes the following steps:

- Malt Production
- Milling of the malt
- Mashing
- Filtration
- Boiling with hop
- Wort cooling
- Fermentation
- Maturing
- Filtration
- Pasteurization and bottling

The barley is subjected to the processes below after the arrival to production plant:
Primary cleaning;

- Sieving for the pre-cleaning
- Debearder
- Rootlet sweeping
- Weighing in the primary cleaning weigher
- Storing in the silos

Afterwards, the following equipments are used;

- Stone separator
- Cracked separator
- Classification machine

Barley collected in the silos is dispatched to wetting tanks. There are three tanks for wetting in the related factory plant. The barley is soaked with water and this process is called as stepping. Afterwards, the barley starts to germinate. The temperature of the germinated barley bulks is kept as 18°C via aeration. The waiting span of the bulks is five days. The CO_2 gas is absorbed from beneath the bulks via air canals. Then the barley is called as green malt.

The green malt goes through a kiln for the kilning process. Then it's called as malt. The kilning process concludes when the heat approximately comes up to 65 – 80°C. There are two kilns and one of them is installed over the other one. So, the humidity rate of the upper-kiln, can be saved in the required and desired limits via the hot air rising from the lower-kiln. After kilning, the finished malt is gained and the malt is milled to allow grains to absorb the water. Milled malt and the water are mixed for the mashing process.

The boiling process is actualized in 90 °C. The liquid filtering from this tank (wort) is mixed with water and by the way, the outlet temperature is kept as 12 °C. The separated spent grain is sold out as cattle fodder. The compressed hop that is kept in the temperature of 5 °C is added into the tank during the boiling. After the cooling process, fermentation process begins. Of the total withdrawn water for the pilot brewery operations, 85% is used for beer manufacturing and malting, 5% is used for cooling purposes.

The duration of fermentation is approximately, twenty days. The carbon dioxide gas is released when the wort and the yeast are inosculated and the fermentation process ends when this gas production stops. The carbon dioxide gas is collected and reclaimed for the usage in the bottling process.

The beer coming out of fermentation is filtered and stocked in 2 °C. Then the bottling process takes place. Beer is filled into sterilized and cleaned glass, plastic or aluminum-made bottles. During filling into the bottles, carbon dioxide gas is given also. In this pilot plant, 80000 bottles are filled per hour and the beer production capacity is announced as 300,000,000 L per year. Pasteurization process is done by heating. A cold-hot shock is applied to the bottles. Finally, the packaging, storing and dispatching of the products begins.

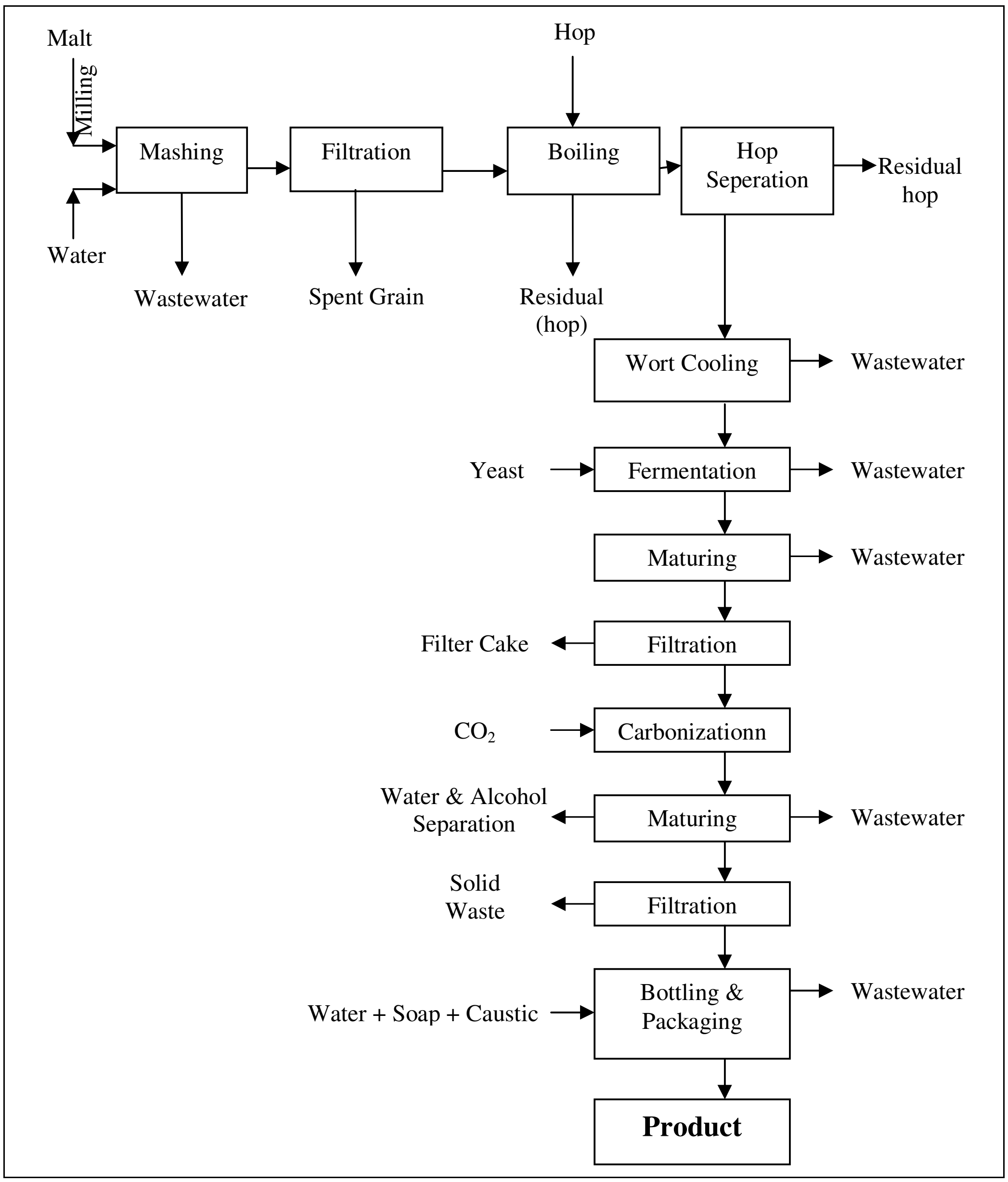

Figure 4.1 Process flow chart for the pilot plant

4.1.2 Wastewater Treatment Plant

The wastewater treatment plant of the brewery is located within in the factory plant. The flow scheme of the treatment plant is given in Fig. 4.2.

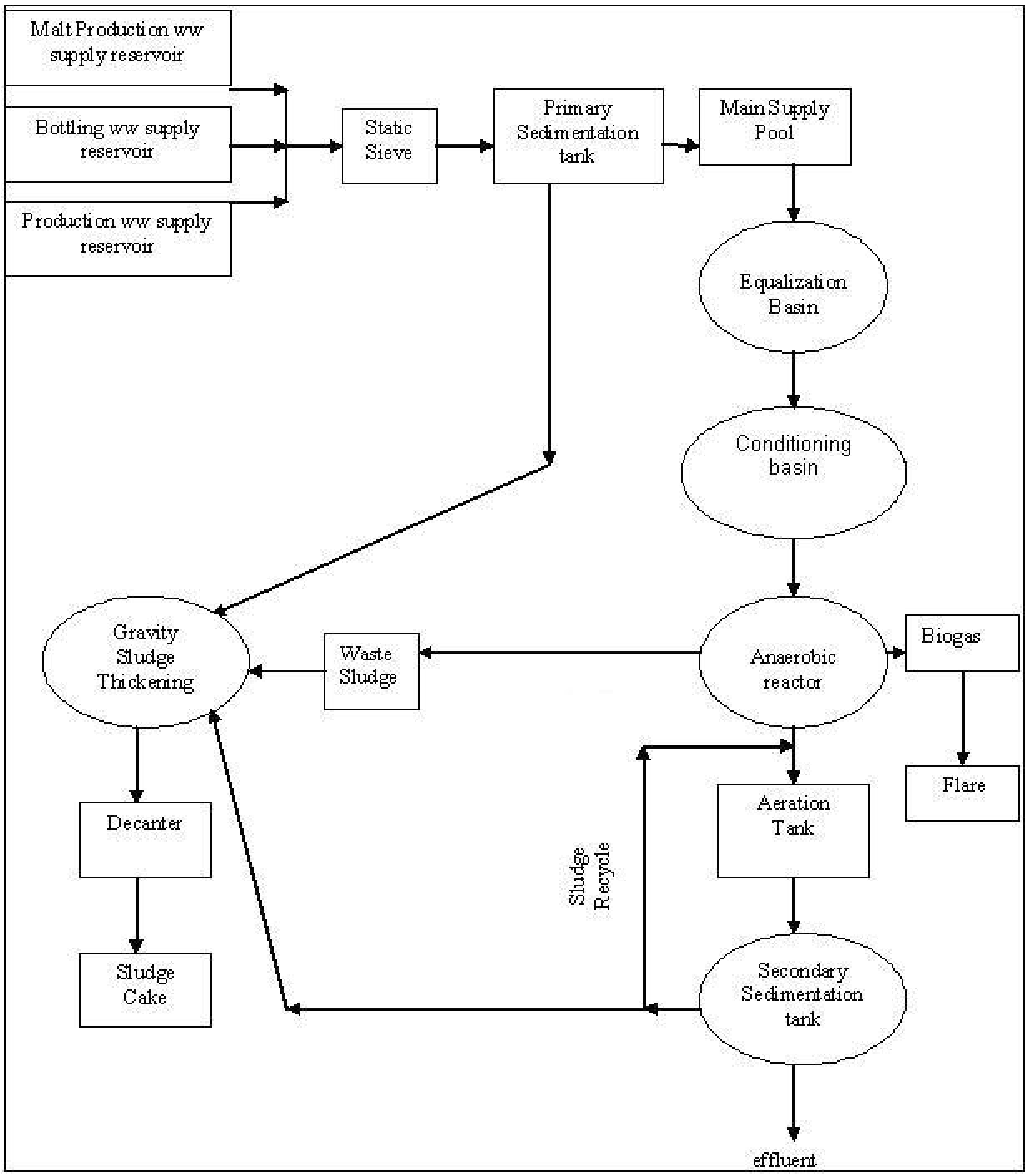

Figure 4.2 The Flow scheme of the pilot brewery's wastewater treatment plant

The aim of the pilot brewery's treatment plant is to obtain the compatibility between the effluent water quality and the regulations specified by the authority.

Treatment plant is 4-stage designed to elicit these regulatory values. These stages are:

- Primary treatment
- Anaerobic treatment
- Aerobic treatment
- Sludge handling and disposal

Wastewater sourced from production is collected in three separate reservoirs. These are; malting reservoir, bottling reservoir, and manufacturing reservoir. Water used in the production plant is brought from three separate deep wells to the softening unit by level controlled pumps to gain it as reusable within the plant structure.

Within the structure of the softening unit, wastewater is firstly subjected to filtration. The odour is separated via activated carbon including silica gel. Then water is canalized through the reverse osmosis tanks. There are two separate reverse osmosis tanks with a capacity of 65 ton/h in the pilot plant.

The resultant wastewater generated during this softening process, is used for car washing, field irrigation. The water quantity used for washing and social activities composes 10% of the total water consumption in this brewery. As information, if the wastewater directly goes to the treatment plant this action costs 50 cents more per tonnes. Additionally, a clor-dioxide system is existed within the plant. Two kinds of chemicals are used to remove the pathogens. One of them is Divosan CD7.5, another is Divosan H9.

4.1.2.1 Primary Treatment

Water from the reservoirs are assembled, sieved and transferred to the primary sedimentation tank. Suspended solids value is eliminated in this tank by a majority. The outgoing water is pumped to main supply pool and to the equalization basin in order. In the equalization basin, flow rate is stabilized. By this means, overloading of the treatment plant is prevented. The homogenization is gained by using submersible pumps. Sludge sourced from the primary sedimentation is pumped to sludge dewatering units without chemical dosing and the surface water is pumped to main supply pool.

4.1.2.2 Anaerobic Treatment

Wastewater is transferred by pumps to the conditioning basin from equalization basin with a flowrate control mechanism. In this basin, the supplemental of macro and micro nutrients and the controls for the pH is done. Then water is directed to the steel-made expanded granular sludge bed (EGSB) anaerobic reactor. The biogas occurred after anaerobic decomposition is sent to the flare and moved away via burning. This biogas can be used in electric generation if desired. There has been an anaerobic sludge tank in the treatment plant, as an explanation for the loss of biomass.

Sludge production, energy demand and the nutrient demand of the anaerobic treatment system is 1/10-20 less than the aerobic systems'. Also the produced biogas is a vital source of energy.

4.1.2.3 Aerobic Treatment

The outgoing water of the anaerobic reactor is transferred to column over the special-designed conditioning basin and then to the aeration tank. The treatment plant includes two aeration tanks and these tanks have three blowers. The blowers step in and pump air, according to the value displayed by the oxygen meter or the demand determined previously. When the blower is shut down, the pressure increases, the blower period decreases and by this means energy saving is gained.

Bacteria in the wastewater are eliminated, when the required stagnant hydraulic conditions are obtained after giving activated sludge in the aeration tank to the sedimentation tank. The settled sludge is drawn and transferred to the sludge tank.

Some of the sludge is recycled to the aeration tank. The residual sludge is transferred to the sludge thickening tank via special sludge pumps.

4.1.2.4 Sludge Thickening

Most of the occurring sludge is sourced by primary sedimentation tank. Waste sludge coming from the aerobic system is sent to the sludge thickening tank and mixed with the sludge of primary sedimentation tank. This mixture is subjected to gravity concentration operation. The sludge drawn from the bottom part of sludge thickening tank is pumped to the decanter. For more effective dewatering, polymer is added to the sludge line. The anaerobic waste sludge comes to this unit, also.

4.1.3 Sources & Characteristics of Wastewater

Characteristic and the quantity of the wastewater of a brewery, varies for the process that generates wastewater. Characteristics for brewing wastewater are described below.

4.1.3.1 Malting Process Wastewater

Most of the malting wastewater is sourced of germination and wetting. The BOD concentration is about 800-1000 mg/L and the quantity is about 5.5 kg water per 1 kg barley.

4.1.3.2 Wort Production Wastewater

Wastewater occurred during the wort production composes the 25% of the total. Composition of nutrition solution for the wort production is shown in Table 4.1.

4.1.3.3 Fermentation Wastewater

Fermentation waste and BOD in order, consists of 3% and 60 % of total waste produced after boiling, fermentation and bottling processes. Typical composition for the fermentation wastewater is shown below (Table 4.2).

Table 4.1 Composition of nutrition solution for the wort production (Şengül, 1991, p.139)

Parameter	**Concentration/Value**
Total Solids, ppm	10-20000
Suspended Solids, ppm	50-200
Volatile Solids, ppm	7000-15000
Total Nitrogen, ppm	800-900
Total Organic Nitrogen, ppm	500-700
Total Carbon, ppm	3800-5500
Organic Carbon, ppm	3700-5500
BOD, ppm	2000-15000
Sulphate, ppm (SO_4^{-2})	2000-2500
Phosphate, ppm (P_2O_5)	20-140
pH	4.5-6.5

Table 4.2 Typical composition for the fermentation wastewater (Şengül, 1991, p.139)

Parameter	**Concentration/Value**
BOD, ppm	4500
pH	6-7
Total Solids, ppm	10000
Settleable Suspended Solids, ml/L	25

4.1.3.4 Bottling Wastewater

BOD parameter of the bottling wastewater is lower then the other processes but the waste quantity is higher. Bottling wastewater amount and BOD value composes of 72% and 12% of the total wastewater produced during all processes, in order.

4.2 Analytical Methods

During the study, approved analytical methods have been used to analyze the water samples. The main aim was to meet the legal monitoring requirements and to match with the procedures specified by regulations.

In order to determine the wastewater characteristics of brewing industry, wastewater samples were taken both from the inlet and the outlet of the treatment plant. All of the analyses were put into practice for the influent and the effluent wastewater. The measurements were done three times for verification.

Analytic methods have been performed for the parameters like; pH, temperature, salinity, conductivity, biological oxygen demand (BOD_5), chemical oxygen demand (COD), total organic carbon (TOC), suspended solid (SS), dissolved solids (DS), alkalinity, hardness, residue chlorine, oil-grease, total nitrogen (TN), ammonium nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), boron (B), sulphate (SO_4^{-2}), chlorine (Cl^-), iron (Fe^{2+}), manganese (Mn^{2+}), total phosphorus (TP), heavy metals, fecal coliforms, total coliforms, silica.

All analyses were done according to Standard Methods that published by American Public Health Association, American Water Works Association, & Water Environment Federation (APHA, AWWA, WEF, 2005). Na^+, Mg^{2+}, Ca^{2+}, and K^+ concentrations were analyzed using an ICP-QMS (Perkin Elmer-Optima 2100DV). Total nitrogen, nitrate nitrogen and ammonium nitrogen were analyzed by using spectroquant cell test of Merck. TOC analyses were done using a DOHRMANN DC-190 high temperature analyzer. pH, salinity, and conductivity were measured by WTW model 340i multi analyzer.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Characteristics of Influent and Effluent Wastewater

Wastewater samples taken from the pilot brewery's treatment plant were analysed as explained in Chapter 4.2. Eventually, obtained concentrations and values of the measured parameters are shown in Table 5.1.

Table 5.1 Influent and effluent water specifications of the pilot brewery's wastewater treatment plant

Parameter	Influent	Effluent
pH	6.1	6.96 ± 0.5
Salinity	‰0.2	‰1.2
Conductivity	1.78 dS/m	3.4 ± 0.1 dS/m
Na^{+}	632.20 mg/L	412.39 ± 20 mg/L
Mg^{++}	17.32 mg/L	3.48 ± 2 mg/L
Ca^{++}	48.7 mg/L	90.82 ± 10 mg/L
K^{+}	87.6 mg/L	42.6 ± 10 mg/L
Suspended solid	672 mg/L	76 ± 5 mg/L
Dissolved solid	77592 mg/L	2140 ± 30 mg/L
Boron	0.48 mg/L	0.124 ± 0.1 mg/L
Sulphate, SO_4^{3-}	263 mg/L	82 ± 5 mg/L
TOC	269.1 mg/L	66.27 mg/L
Iron, Fe^{++}	0.908 mg/L	0.824± 0.4 mg/L
Manganese, Mn^{++}	0.187 mg/L	0.06 ± 0.05 mg/L
Total nitrogen	92 mg/L	<5 mg/L
NH_3-N	22.75 mg/L	43.82 ± 0.5 mg/L
NO_3-N	42.95 mg/L	6.9 ± 0.5 mg/L
Total phosphorus	3.07 mg/L	6.87 ± 0.5 mg/L
COD	4960 mg/L	200 ± 10 mg/L
BOD_5	3000 mg/L	700 ± 20 mg/L

Table 5.1 (continued)

Parameter		Influent	Effluent
Fecal coliform		Too many to count	800 ± 10 unit/100ml
Total coliform		Too many to count	950 ± 10 unit/100ml
Residue Chlorine		177.25 mg/L	-
Silica		20.85 mg/L	38.5 ± 10 mg/L
Temperature		22°C	10 ± 1 °C
Heavy Metals (mg/L)	**Zn**	0.465 mg/L	0.074 ± 0.01 mg/L
	Cr	<0.01 mg/L	<0.01 mg/L
	Cu	0.02 mg/L	<0.01 mg/L
	Al	0.197 mg/L	0.126 ± 0.01 mg/L
	Ni	0.043 mg/L	<0.01 mg/L
	Mo	<0.01 mg/L	<0.01 mg/L
	As	0.057 mg/L	0.078 ± 0.01 mg/L
	Co	<0.01 mg/L	<0.01 mg/L
	Pb	0.024 mg/L	<0.01 mg/L
	V	0.137 mg/L	<0.01 mg/L
	Cd	<0.01 mg/L	< 0.01 mg/L
	Nb	0.232	<0.01
SAR		19.8	11.5 ± 0.1

(µS/cm /1000 = dS/m; dS/m * 640 =ppm=mg/L)

5.2 The Evaluation of Industrial Reuse

Reclaimed water quality for industrial uses needs to be protective. So, water quality specifications are highly variable according to the type of industrial use. Industrial utilization of reclaimed water within enclosed systems will minimize the risk to workers and allow the use of a lower class of reclaimed water. For the open systems in industrial reuse, Class A reclaimed water is generally needed to protect worker and public health.

Microbiological quality concern for industrial reuse states the potential of risk to health of workers and the public. Chemical quality is the main determinative factor for the corrosion of pipes and machinery, scale formation, foaming etc. and physical quality of reclaimed water specifies the threat for solids deposition, fouling, blockages. Suspended solids content of the reclaimed water forms the physical quality. Also, nutrients such as phosphorus and nitrogen may cause slime formation and microbial growth. In this sense, projection of the required treatment steps must be aware of these potential problems. Generally, industrial reuse of the reclaimed water is classified into three categories as cooling water, boiler-feed water, and process water and as other uses. The compatibility of reuse options is discussed in the following topics, below.

5.2.1 Compatibility as Cooling Water

Cooling water recommended specifications and treatment plant effluent values specified by EPA were given in Table 3.2 and Table 3.4. Also effluent values of the pilot brewery's treatment plant were given in Table 5.1. So, a comparison is done below for these results (Table 5.2). It's seen that the values of TDS, COD, BOD, NH_4^+- N, PO_4^{-3}, Fe^{++}, Ca^{+2}, and Mg^{+2} parameters are exceeding the limits.

According to the EPA limits, the number of fecal coliform organisms should not exceed 800/100 ml in any sample. Hence, disinfection is needed to regard this limit. Disinfection may be accomplished by chlorination, UV radiation, ozonation, other chemical disinfectants, membrane processes, or other processes. Some stabilization pond systems may be able to meet this coliform limit without disinfection. Especially for the recirculating cooling towers, chemical coagulation, and filtration (e.g. membrane processes) may be needed as treatment processes.

Table 5.2 Comparison of the recommended cooling water values and the brewery effluent values

Parameters	Recommended Limit Value	Effluent
Cl^{-1}, mg/L	500	-
Total Dissolved Solids, mg/L	500	**2140 ± 30**
pH	6.9-9.0	6.96 ± 0.5
COD, mg/L	75	200 ± 10
Total Suspended Solids, mg/L	100	76 ± 5
BOD, mg/L	25	**700 ± 20**
NH_4^+-N, mg/L	1.0	**43.82 ± 0.5**
PO_4^{-3}, mg/L	4	**6.87 ± 0.5**
SiO_2, mg/L	50	38.5 ± 10
Al^{+3}, mg/L	0.1	**0.126 ± 0.01**
Fe^{++}, mg/L	0.5	**0.824 ± 0.4**
Mn^{+2}, mg/L	0.5	0.06 ± 0.05
Ca^{+2}, mg/L	50	**90.82 ± 10**
Mg^{+2}, mg/L	0.5	**3.48 ± 2**
SO_4^{-2}, mg/L	200	82 ± 5

Setback distances which are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water; are provided as suitable to the standards for the location of pilot brewery.

Generally, for the removal of suspended solids and colloids sedimentation is recommended. For the removal of dissolved solids, reverse osmosis or nanofiltration may be implemented. Also, activated sludge, carbon adsorption and reverse osmosis steps may be applied.

Copper and nickel values are in ranges, so that there’s no threat for galvanic corrosion. But salinity may cause corrosion.

To sum up, the EGSB type reactor may be changed with a UASB type reactor. Also carbon adsorption and reverse osmosis may be used for the pilot treatment plant. Carbon adsorption has high removal rates for BOD, TSS, total coliform, phosphorus, TOC and iron. Reverse osmosis system has high removal rates for BOD, COD, TDS, TSS, phosphorus and TOC. The recommended treatment plant is given in Figure 5.1. The addition of the recommended units is applied to the effluent of secondary sedimentation tank, which was shown in Figure 4.2.

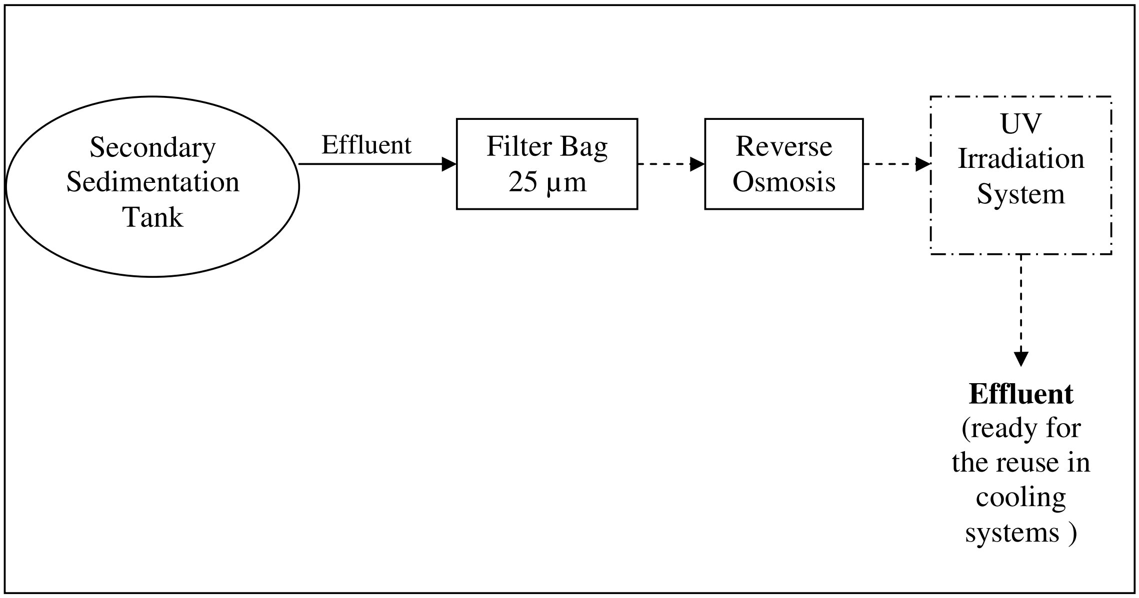

Figure 5.1 Recommended treatment processes for the reuse as cooling water

5.2.2 Compatibility as Boiler-Feed Water

Boiler-Feed water recommended specifications and treatment plant effluent values specified by EPA were given in Table 3.1. Also effluent values of the pilot brewery's treatment plant were given in Table 5.1. So, a comparison is done below for these results (Table 5.3).

Table 5.3 Comparison of the recommended boiler-feed water values and the brewery effluent values

Parameters	**Low Pressure (<150 psig)**	**Medium Pressure (150-700 psig)**	**High Pressure (>700 psig)**	**Effluent**
Silica, mg/L	30	10	0.7	**38.5 ± 10**
Aluminum, mg/L	5	0.1	0.01	**0.126 ± 0.01**
Iron, mg/L	1	0.3	0.05	**0.824 ± 0.4**
Manganese, mg/L	0.3	0.1	0.01	**0.06 ± 0.05**
Calcium, mg/L	--	0.4	0.01	**90.82 ± 10**
Magnesium, mg/L	--	0.25	0.01	**3.48 ± 2**
Ammonia, mg/L	0.1	0.1	0.1	**43.82 ± 0.5**
Dissolved Solids, mg/L	700	500	200	**2140 ± 30**
Copper, mg/L	0.5	0.05	0.05	<0.01
Zinc, mg/L	--	0.01	0.01	**0.074 ± 0.01**
pH	7-10	8.2-10	8.2-9	6.96 ± 0.5
Suspended Solid, mg/L	10	5	0.5	**76 ± 5**
COD, mg/L	5	5	1	**200 ± 10**

The higher pressure of the boilers needs higher quality of feeding water, according to the Table 5.3. Thus, pilot brewery's effluent is not sufficient in almost all values and the plant needs more additional units to reach the standard values.

For the highest quality of water; hardness, insoluble salts of calcium and magnesium, silica and aluminum values must be controlled and kept in required ranges since these are the principal causes of scale build-up in boilers.

Nitrification and denitrification processes can be used for the removal of NH_3-N and NO_3-N. However, reverse osmosis system can be preferred because of the removal ability of NH_3-N, NO_3-N, BOD, TOC, TSS, phosphorus, metals, and TOC, as a membrane process. Also lime addition is needed for the pH adjustment. However, high alkalinity may contribute foaming, resulting in deposits in superheater, reheater, and turbines.

Coagulation, flocculation and sedimentation processes can be applied for the removal of heavy metals and softening of water as a chemical treatment. On the other hand, UV disinfection is a very expensive disinfection method and chlorine may cause some residual problems. Therefore, ozone may be preferred for disinfection.

Depending on the characteristics of the reclaimed water, flocculation, sedimentation, recarbonation, carbon adsorption, reverse osmosis and disinfection processes are recommended as shown in Figure 5.2.

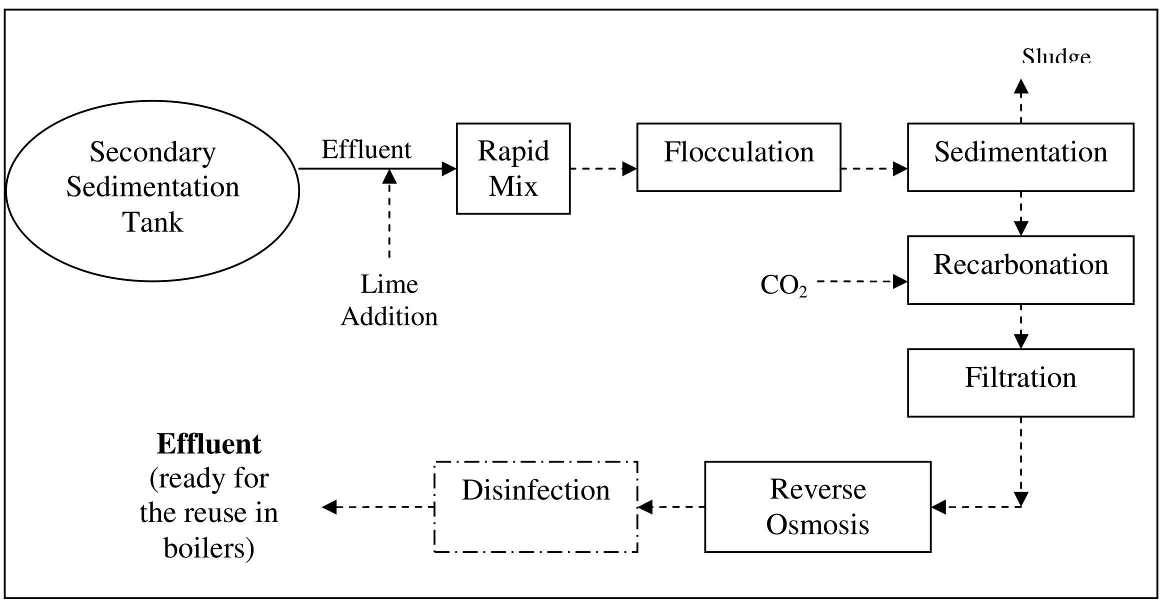

Figure 5.2 Recommended treatment processes for the reuse as high pressure boiler-feed water

5.2.3 Compatibility as Process Water

The appropriateness of reclaimed water for industrial processes changes up to the usage. Quality and quantity of process water effluent entering the treatment plant can vary significantly, depending upon the different processes that are taking place within the brewery. Generally, the organic loading of breweries is higher than any other industries and most of the organic content is derived from the wort extraction process. In table 3.3, the potential problems that may occur during the operations and the required treatment processes were given.

In case of using the treated wastewater as process water, treatment should be done until very clean and fresh water quality is gained. If there's no guidance for the treatment steps, the steps taken for boiler water can be taken for process water as well. Because, boiler water standards are strict enough to eliminate any extreme value.

For breweries, installing recirculating systems on cooling water circuits, using high pressure, low volume hoses for equipment cleaning and re-using the rinsing water supplies; can be the methods for decreasing water consumption and re-using as process water.

5.3 The Evaluation of Groundwater Recharge

Reclaimed water can potentially be used to feed groundwater supplies. By this means, water is stocked as in natural reservoirs and then it can be extracted from these systems and reused. Reclaimed water quality used for groundwater recharge would need to meet drinking water standards.

The pilot brewery which was chosen for this study is located in an industrial area. In this area every industry has its own treatment plant. The effluents coming from these plants are being given to the sewage system after getting the required values specified by the regulations. In this area no groundwater recharge is observed, but the groundwater aquifers are used to gain process water. As specified by Turkish regulations, in all of the seaside regions, safe drawing fixations must be done to avoid saltwater intrusions to protect the quality of the groundwater. Groundwater classification of is done as 3 groups according to the WPCR:

- Class I : High quality groundwater

- Class II : Mid-quality groundwater
- Class III: Low quality groundwater

Class I groundwater supplies can be used as drinking water and food industry water supplies. Only disinfection may be needed to use safely. Class II supplies may need a primary treatment and disinfection. Class III groundwater needs to be treated according to its contamination content and the usage type.

The comparison of drinking water standards with the brewery effluent values are shown in Table 5.4. In this table standards specified by EPA, WHO and Turkish Standards Institute (TSE) are used as reference. Table 3.4 is also another detailed guide for the ranges and the determination of the required treatment processes.

According to the table 5.4, total coliform, arsenic, antimony, iron, manganese, TDS and sodium values are higher than the standards.

Recommended treatment processes depend on the type of the soil, the slope, thickness of the vadose zone and percolation rate. Also, setback distances which were listed in Table 3.4 must be provided. For groundwater recharge, advanced wastewater treatment is needed generally. Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange. Reverse osmosis and nanofiltration are the most common membrane technologies used for production of drinking water.

Due to the direct injection method has the strictest ranges; the recommended flowchart is arranged assuming this method as the chosen. By this means, the recommended treatment flow is shown below in Figure 5.3.

Table 5.4 Comparison of drinking water standards with the pilot brewery's effluent (Pollet Water Group [PWG], n.d.)

Parameter	TSE 266	WHO	EPA	Effluent
Total Coliform (unit/100ml)	<1	0	<1	**300**
Aluminum,Al	0,2	0,2	1	0.126
Arsenic, As	0,05	0,05	0,05	**0.078**
Barium, Ba	0,3		1	**
Cadmium, Cd	0,01	0,01	0,01	< 0.01
Chrome, Cr	0,05	0,05	0,05	< 0.01
Fluoride, F	1,5	1,5	0,7-2,4	**
Lead, Pb	0,05	0,05	0,05	< 0.01
Mercury, Hg	0	0	0	**
Nitrate, NO_3	50	50	45	6.9
Selenium, Se	0,01		0,01	**
Argent, Ag	0,01		0,05	**
Antimony, Sb	0,01		0,01	**0.121**
Colour (platinum cobalt)	20	15	15	**
Copper, Cu	3		1	< 0.01
Iron, Fe^{2+}	0,2		0,3	**0.824**
Manganese, Mn^{2+}	0,05	0,5	0,05	**0.06**
pH	6,5-9,2	6,5-8,8	6,5-8,5	6.96
Sulphate, SO_4^{-2}	250	250	250	82
TDS	1500	1000	500	**2140**
Zinc, Zn	5		5	0.074
Calcium, Ca^{2+}	200			90.82
Magnesium, Mg^{2+}	50			3.48
Potassium, K^+	12			1.09
Sodium, Na^+	175	200		**412.39**

* All values are in mg/L except turbidity, total coliform, colour and pH

** This value's not measured

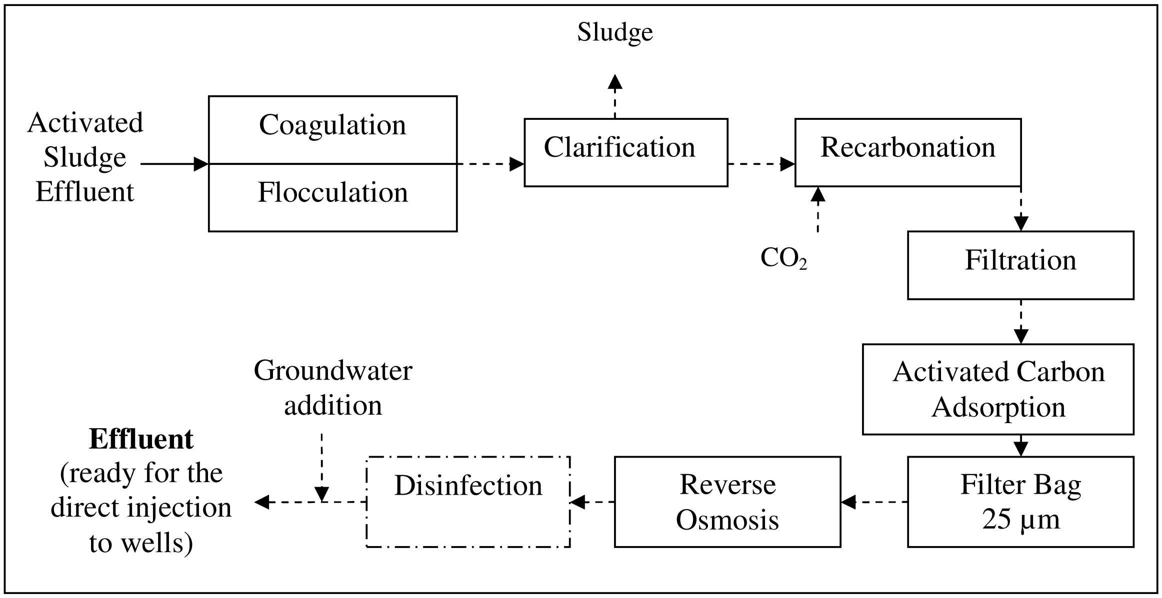

Figure 5.3 Recommended treatment processes for groundwater recharge

5.4 *The Evaluation of Agricultural Reuse*

Irrigation water recommended characteristics and limit values specified by EPA, WHO and the Turkish authorities have been given in Chapter 3. The EPA and the WHO guidelines have more common definitions; however, the Turkish standards are more detailed. In this wise the effluent characteristics of the pilot brewery will be compared with the regulations.

As an initial overview, the brewery wastewaters are classified within the first group in Table 3.11 and so, the wastewater is categorized as it can be used for irrigation water if a suitable field is near the plant.

Then the SAR and the electrical conductivity values are used to determine the irrigation water class of the reclaimed water using Figure 3.1. The effluent SAR ratio of the pilot plant was 11.5 and electrical conductivity was 3.4 dS/m. So the class of the water can be determined as C_3S_3. Comparison of the Table 5.1 and the Table 3.9 is below (Table 5.5) to determine if there's a problem about the heavy metal concentrations.

Table 5.5 Comparison of the effluent values and the heavy metal concentration limits

Elements	Effluent	Acceptable maximum concentrations (mg/L)	
		Continuous irr. for each ground, mg/L	Applied < 20 years to clay ground with pH value 6,0-8,5, mg/L
Aluminium (Al)	0.126	5.0	20.0
Arsenic (As)	0.075	0.1	2.0
Beryllium (Be)	-	0.1	0.5
Boron (B)	0.124	-[3]	2.0
Cadmium (Cd)	<0.01	0.01	0.05
Chrome (Cr)	<0.01	0.1	1.0
Cobalt (Co)	<0.01	0.05	5.0
Copper (Cu)	<0.01	0.2	5.0
Fluoride (F)	-	1.0	15.0
Iron (Fe)	0.824	5.0	20.0
Lead (Pb)	<0.01	5.0	10.0
Lithium (Li)[1]	-	2.5	2.5
Manganese (Mn)	0.06	0.2	10.0
Molybdenum (Mo)	<0.01	0.01	0.05[2]
Nickel (Ni)	<0.01	0.2	2.0
Selenium(Se)	-	0.02	0.02
Vanadium (V)	<0.01	0.1	1.0
Zinc (Zn)	0.074	2.0	10.0

As seen above, all the parameters are in required ranges, including Boron that is also listed in Table 3.10. So, the irrigation water is classified as the Class-I category according to the boron concentration value.

The class of the irrigation water has been determined as C_3S_3 for its salinity and sodicity values. As per Table 3.8, the SAR, salinity, fecal coliform, BOD and the TSS values are out of ranges. The other parameters ensure the Class III properties.

For the treatment systems secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30 mg/L. In this case, there should be some changes in the secondary treatment processes of the advanced treatment processes should be implemented to gain the required values. The recommended flow chart is shown in Figure 5.4.

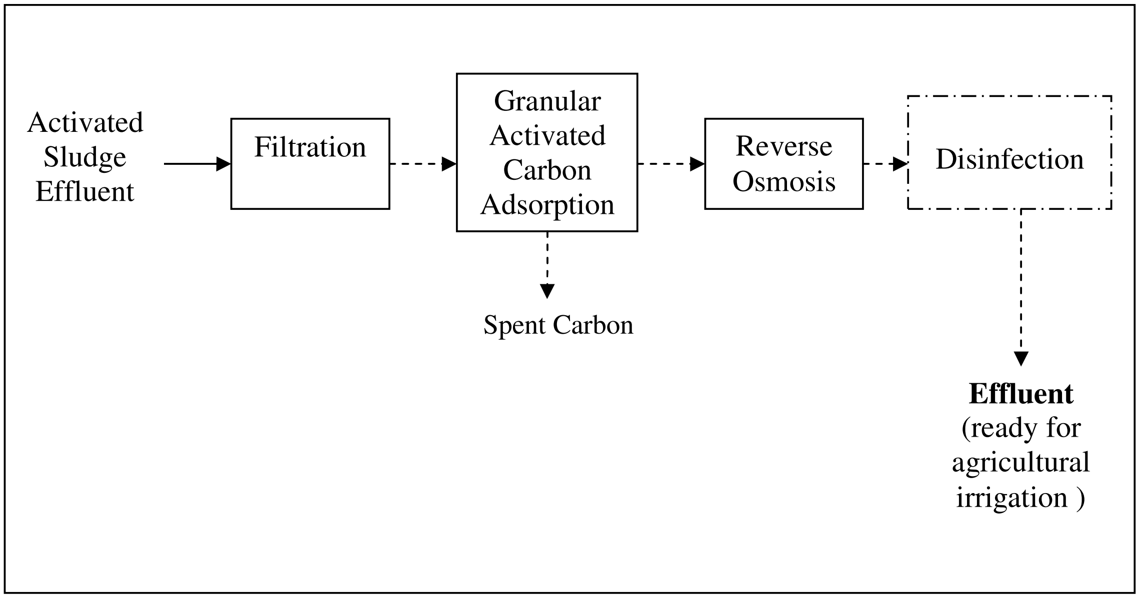

Figure 5.4 Recommended treatment processes for agricultural irrigation

5.4.1 Examples for The Calculation of Required Water

Calculation method for the required irrigation water has been explained in Chapter 1.5.3. So, the calculations are predicated on the equation, $ET_c = K_c * ET_0$.

According to Chapter 1.5.3 and using the flowrate data (5500 m^3/day) sourced by the treatment plant of the pilot brewery, the water demands of some selected crops such as cotton, grape and maize, are calculated as in the following. The growth periods of these crops are divided into four stages and these stages are:

- I. Period: Sowing, germination and early vegetative period.
- II. Period: Quick vegetative development.
- III. Period: Flowering and generative period.

- IV. Period: Ripening and harvest.

The data that belongs to İzmir city which is located in Turkey are used for the determinations. Crop coefficient (K_c) values are for İzmir city and listed in Table 5.6.

Table 5.6 Crop coefficient (K_c) values for cotton, maize and grape (Jochum, 2006, p.15).

CROPS	**Sowing Date**	**Harvest Date**	**Growth Periods and Crop Coefficients**								
			I		II		III		IV		Total
			Days	K_c	Days	K_c	Days	K_c	Days	K_c	Days
Cotton	May.01	Oct. 31	20	0.4	35	0.7	70	1.1	58	0.65	183
Maize	Apr. 04	Oct. 04	30	0.3	39	0.7	32	1.1	71	0.8	172
Grape	Mar.06	Oct. 15	15	0.4	56	0.75	61	0.95	91	0.7	223

Also the reference crop evapotranspration rates (ET_0) belong to Kemalpaşa, which is located within the borders of İzmir, are listed in Table 5.7.

Table 5.7 Reference crop evapotranspration (ET_0) values for Kemalpaşa (Atpulat, 2004, p.41).

Month	**January**	**February**	**March**	**April**	**May**	**June**
ET_0 (mm/month)	55.10	66.37	108.35	147.21	197.25	237.93
Month	**July**	**August**	**September**	**October**	**November**	**December**
ET_0 (mm/month)	251.92	232.65	174.00	116.06	66.68	49.35

According to the values listed above, the calculated results are shown in Table 5.8.

Table 5.8 Evapotranspiration values for some crops.

Cotton	**Growth Periods**	**I**	**II**	**III**	**IV**
	ET_C (m/period)	$50.90*10^{-3}$	$183.34*10^{-3}$	$595.79*10^{-3}$	$177.23*10^{-3}$
Maize	**Growth Periods**	**I**	**II**	**III**	**IV**
	ET_C (m/period)	$50.72*10^{-3}$	$198.95*10^{-3}$	$284.548*10^{-3}$	$376.31*10^{-3}$
Grape	**Growth Periods**	**I**	**II**	**III**	**IV**
	ET_C (m/period)	$20.97*10^{-3}$	$212.90*10^{-3}$	$440.22*10^{-3}$	409.30

The flowrate of the pilot wastewater treatment plant's effluent is 5500 m^3/day. So, the volume of water is calculated by using the numbers of days listed in Table 5.6 which have been certained specifically for each period. In Table 5.9 it's shown that how much area can be irrigated by using the effluent water of the pilot brewery; for the crops cotton, maize and grape.

Table 5.9 Potential of irrigation of the pilot brewery treated wastewater.

Cotton	**Growth Periods**	**I**	**II**	**III**	**IV**
	Field (ha)	216	105	65	180
Maize	**Growth Periods**	**I**	**II**	**III**	**IV**
	Field (ha)	325	108	62	104
Grape	**Growth Periods**	**I**	**II**	**III**	**IV**
	Field (ha)	393	145	76	122

5.5 The Wastewater Reclamation Cost

For the calculation of total reclamation system life cycle cost, time value of the money should be regarded. Thus Asano (1998, p.83) mentions that "Interest rate factors have been developed to allow us to calculate the value of a monetary transaction made at one time to the value at another time. The interest rate is the measure of the time value of money". In Table 5.10 life cycle costs estimated for several reuse alternatives are given.

Table 5.10 Summary of estimated water reclamation treatment process life cycle costs (Fatta, & Kythreotou, 2005)

Reuse alternative	**Recommended treatment process**	**Annual costs (€/m³)[a, b]**
Agricultural irrigation	Activated sludge	0.16-0.44
Livestock and wildlife watering	Trickling filter	0.17-0.46
Power plant and industrial cooling	Rotating biological contactors	0.25-0.47
Urban irrigation – landscape	Activated sludge, filtration of secondary effluent	0.19-0.59

Table 5.10 (continued)

Reuse alternative	Recommended treatment process	Annual costs (€/m³)[a, b]
Groundwater recharge – spreading basins	Infiltration – percolation	0.07-0.17
Groundwater recharge – injection wells	Activated sludge, filtration of secondary effluent, carbon adsorption, reverse osmosis of advanced wastewater treatment effluent	0.76-2.12

(a): Costs are estimated for facility capacities ranging from 4,000 to 40,000 m^3/d. Lower cost figure within each treatment process category represents cost for a 40,000 m^3/d reclamation plant while the upper cost limit is presented for a 4,000 m^3/d facility, (b): Annual costs include amortized capital costs based on a facility life of 20 years and a return rate of 7 %.

Occasionally the present treatment capacities of industries may not be sufficient for the required reuse standards that regulations specify when in the aim of reuse. In these situations, the construction or installation of advanced treatment units may be needed. Generally recommended additional tertiary treatment technologies in the figures of Chapter 5 are; membrane technologies (MF/UF/NF/RO), coagulation-flocculation units, UV/ozonation disinfection, activated carbon adsorption and bag filter. In table 5.11 average unit costs for some of these processes per m^3 wastewater in Turkish market are given as to form a basis. These values have been evaluated for the flowrate of 5500 m^3/d and the effluent characteristics expressed in Table 5.1 that the pilot brewery has.

Table 5.11 Average unit costs for several treatment processes (N. Merdan, personal communication, September 13, 2008)

Treatment process*	Cost (€/m³)
Reverse Osmosis (RO)	2775
Filtration	794
Activated Carbon Adsorption	794
UV disinfection	500

* Each process has a cost of 350 € for daily service, in average.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Wastewater reclamation and reuse reap lasting benefits for the conservation of water supplies, and recycling of nutrients. Reclamation and reuse avoids the contamination and consuming of water supplies. Reuse of effluent from wastewater treatment plants is possible in a wide range of categories, from agricultural to industrial purpose. In accordance with this study, the decided conclusions and recommendations are given below.

6.1 Conclusions

- According to the wastewater treatment plant's effluent flowrate data and the production capacity of the pilot brewery; the annual water used in the brewery can be estimated as 1,500,000,000L (1,500,000 m^3) on average.
- In a year; 1,275,000,000 L (85% of the total) water is used in beer production and malting processes; 75,000,000 L (5% of the total) is used for cooling purposes and 150,000,000 L (10% of the total) is used for social activities and washing in the pilot brewery.
- The main problem determined of the pilot brewery's wastewater is high values of COD, BOD, TSS, salinity and fecal coliform.
- Effluent of the studied brewery wastewater treatment plant, can not be used for any reuse option directly; such as, industrial purposes (cooling water and boiler-feed water), agricultural irrigation and groundwater recharge. Additional treatment processes need to be constructed/installed.
- Additional treatment processes means additional costs at the same time. But it's inevitable because of the waterlessness problem that the world faces with.
- Salinity may cause corrosion problems if the aim is to use the reclaimed water within the industry.
- Concentrations of heavy metals don't state any problem, in general. Exceeding heavy metals can be removed by simple process additions that

have been recommended. To the boron concentration, plants of walnuts, lemons, figs, apples, grapes and beans may be appropriate to be irrigated.

- According to the calculations it's possible to irrigate 65ha of cotton, 62ha of maize and 76ha of grape. Grape can be chosen as the most appropriate crop to be irrigated with the brewery's treated wastewater.
- Ultraviolet (UV) disinfection may be used for the removal of fecal coliforms. But, the recommended reverse osmosis systems have the ability to remove high rates of coliforms. So it would be more feasible to use any disinfection method that is simpler and feasible in cost. On the other hand over chlorination has adverse affects on living things such as animals, plants. So, the newest and healthier ozonation method may be useful.

6.2 Recommendations

The development and implementation of advanced treatment technologies for recycling industrial wastewater brings out extra costs at the same time. Unfortunately, wastewater reuse cost is not well-documented. For a good water management the economic considerations of reuse investments should be regarded. Studies for cost-benefit analyses must be carried out.

This study has been accomplished for a chosen pilot brewery throughout fermentation industry. Alternatives of reuse options for other industries should be ascertained.

According to this study's sight, the agricultural irrigation with the reclaimed brewery wastewater can be endeavored on much more than the other reuse options.

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