DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

COMPARISION OF UV IRRIDATION AND CHLORINATION IN WASTEWATER

by
Deniz ÜNLÜ

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COMPARISION OF UV IRRIDATION AND CHLORINATION IN WASTEWATER

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by

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We certify that we have read this thesis and **"COMPARISION OF UV DISINFECTION AND CHLORINIZATION IN WASTEWATER TREATMENT"** completed by **Deniz ÜNLÜ** under supervision of **Prof.Dr. Aysen TÜRKMAN** and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

.....

.Prof.Dr. Aysen TÜRKMAN

Supervisor

.....	.....
Prof. Dr. Ayşegül PALA	Assist. Prof. Dr. Vildan GÜNDOĞDU
(Committee Member)	(Committee Member)

Approved by the
Graduate School of Natural and Applied Sciences

Prof.Dr. Cahit HELVACI
Director

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COMPARISON OF UV DISINFECTION AND CHLORINIZATION IN WASTEWATER

ABSTRACT

Disinfection of wastewater which is the last step of treatment is one of the most important step in wastewater treatment. Till recent years, both drinking water treatment and wastewater treatment, chlorination is most the most important disinfection method but it is determined that chlorination causes harmful effects both human and environment health and from this causes increasing of investigations and improving about alternative and environment-friendly disinfection methods. Ultraviolet (UV) disinfection is one of the widespread of these alternative and environment-friendly disinfection methods

With in this thesis, comparison of chlorination with sodium hypochlorite and UV process was investigated with some parameters. Both processes were compared with parameters BOD, COD, pH, AOX. The effluent water from domestic wastewater treatment plant was applied to chlorination and UV process.

When BOD and COD removal rates were investigated, it was seen that the performance of both disinfection systems were almost same. When pH values were investigated it was seen that pH values in chlorination with sodium hypochlorite increased but pH values in UV process did not change significantly. The important difference between two processes could be seen at parameter Adsorbable Organic Halogens (AOX). In chlorination with sodium hypochlorite process AOX values increase too much but in UV process there was no increase in AOX values. As a result of study it can be said that UV disinfection is more environment-friendly process than chlorination with sodium hypochlorite

Keywords: UV**,** chlorinization, adsorbable organic halogens, domestic wastewater.

ATIKSU ARITIMINDA KLORLAMA İLE UV DEZENFEKSİYONUNUN KARŞILAŞTIRILMASI

ÖZ

Atıksu arıtımında en önemli işlemlerden biri en son basamak olan dezenfeksiyon işlemidir. Son yıllara kadar gerek atıksu gerekse içme suyu arıtımında kullanılan en önemli dezenfeksiyon yöntemi olan klorlamanın, gerek insan gerekse çevre sağlığına önemli zararlar verdiğinin belirlenmesi alternatif ve daha çevre dostu dezenfeksiyon yöntemlerinin araştırılmasına ve geliştirilmesine neden olmuştur. Ultraviyole (UV) dezenfeksiyonu bu alternatif ve çevre dostu yöntemlerin en çok kullanılanlarından bir tanesidir.

Bu tez kapsamında evsel atıksu arıtımında sodyum hipoklorit ile klorlama ile ultraviyole prosesinin belli parametreler üzerinden karşılaştırılması incelenmiştir. İki proses KOI, BOI, AOX, pH parametreleri açısından karşılaştırılmıştır. Evsel atıksu arıtma tesisinden alınan çıkış suyu klorlama ve UV prosesinden geçirilmiştir.

KOI ve BOI giderimleri incelendiğinde iki prosesin verimlerinin yakın olduğu görülmüştür. Ph değerleri incelendiğinde sodyum hipoklorit ile klorlama prosesinin pH değerini yükselttiği buna karşın UV prosesinin pH parametresinde fazla değişime neden olmadığı görülmüştür. İki proses arasındaki en önemli farkın Adsorblanabilir Organik Halojenürler (AOX) parametresinde olduğu ortaya çıkmıştır. Sodyum hipoklorit ile klorlama prosesinde AOX değerinin oldukça yüksek olmasına karşın UV prosesinde bu değerin çok düşük olduğu görülmüştür. Çalışma sonucunda UV ile dezenfeksiyon prosesinin sodyum hipoklorit ile dezenfeksiyona göre daha çevre dostu bir işlem olduğu söylenebilmektedir.

Anahtar kelimeler: UV**,** klorlama, adsorblanabilir organik halojenür, evsel atıksu.

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CHAPTER ONE
INTRODUCTION

1.1 Literature Review

Parallel to economical and social developments in humans' life, more water is used by people and for this reason amount of wastewater generated from facilities increases. From this point of view discharge of wastewaters without treatment causes serious pollution problems on water resources. Disinfection is one of the important step in water and wastewater treatment for protecting human health and environment.

1.1.1 What Is Disinfection and Need for Disinfection

Disinfection refers to the partial destruction of disease-causing organisms. The need for water disinfection in the developing world is indisputable. Water-borne diseases cause about five million deaths per year, at least half of children (UNICEF, 1995). All the organisms are not destroyed during the process. Disinfection is used in both wastewater and drinking water treatment. The fact that the entire organisms are not destroyed differentiates disinfection from sterilization, which is the destruction of all organisms.

In the field of wastewater treatment, the impact of untreated domestic wastewater on community reservoirs has raised several health and safety concerns. The organisms of concern in domestic wastewater include enteric bacteria, viruses, and protozoan cysts. Table 1.1 summarizes the most common microorganisms found in domestic wastewater and the types of human diseases associated with them. In response to these concerns, disinfection has become one of the primary mechanisms for the inactivation/destruction of pathogenic organisms. In order for disinfection to be effective wastewater must be adequately treated.

Table 1.1 Infectious Agents Potentially Present In Untreated Domestic Wastewater (EPA, 1999).

Organism	**Disease Caused**
Bacteria	
Escherichia coli	*Gastroenteritis*
Leptospira (spp.)	*Leptospirosis*
Salmonella typhi	*Typhoid fever*
Salmonella (=2100 serotypes)	*Salmonellosis*
Shigella (4 spp.)	*Shigellosis (bacillary dysentery)*
Vibrio cholerae	*Cholera*
Protozoa	
Balantidium coli	*Balantidiasis*
Cryptosporidium parvum	*Cryptosporidiosis*
Entamoeba histolytica	*Amebiasis (amoebic dysentery)*
Giardia lamblia	*Giardiasis*
Helminths	
Ascaris lumbricoides	*Ascariasis*
T. solium	*Taeniasis*
Trichuris trichiura	*Trichuriasis*
Viruses	
Enteroviruses (72 types) e.g.,polio echo and coxsackieviruses	*Gastroenteritis, heart anomalies, Meningitis*
Hepatitis A virus Infectious	*Hepatitis*
Norwalk agent	*Gastroenteritis*
Rotavirus	*Gastroenteritis*

Wastewater treatment plants historically discharge their effluents to natural receiving streams that are often tributaries of larger recreational bodies of water or that are used as water supply sources by downstream communities. City potable water supplies are often extracted from these tributaries or lakes physically and chemically treated and distributed to costumers. The only protection that the recreational users receive is the hope that the wastewater was adequately disinfected prior to discharge. So long as the disinfection guidelines and standards are being met at the sources, public safety and water quality will be protected. The total bacterial

population of human feces has been estimated to reach density of 10^{12}organisms per gram (Berg, 1978).

In Table 1.2 typical compositions of raw wastewater through various levels of treatment are summarized. (EPA, 1999)

Table 1.2 Typical Compositions of Raw Wastewater through Various Treatment Levels

Water Quality	BOD (mg/L)	TSS (mg/L)	Total N (mg/L)	Total Coliforms (#/100 ml)	Fecal Coliforms (# /100 ml)
Raw Wastewater	200	200	35	10^7 -10^8	10^6 -10^7
Primary Effluent	130	100	30	10^7 -10^8	10^6 -10^7
Secondary Effluent	20	20	20	10^5-10^6	10^4-10^5
Filtered Secondary	12	5	18	10^4-10^5	10^3-10^5
Nitrified	7	10	18	10^4-10^5	10^3-10^5
Filtered Nitrified	5	5	18	10^4-10^5	10^3-10^5

The total and fecal coliform (indicator organism) level is a critical design parameter that should be determined on a site specific basis where possible. A suitable disinfection process should be chosen according to this important design parameter.

1.1.2 Disinfection Alternatives

As many as 25 disinfection alternatives could be considered and have been previously identified from the literature without regard for physical or operational constraints (Krause, 1980). The major factors that must be considered when evaluating disinfection alternatives are summarized in Table 1.3. The first four

factors, effectiveness, cost, practically, and pilot study requirements relate to the disinfection process itself. .The fifth factor, potential adverse effects, relates to the effects of the disinfectant on the receiving water and other environmental concerns and considerations (Tonelli, & Ho, 1978). Evaluating and through consideration of all the criteria listed in Table 1.3 relative to the practical, physical and operational constraints of municipal wastewater disinfection reduces the available alternatives to chlorination, hypochlorination, chlorination/ dechlorination with sulfur dioxide, chlorine dioxide, bromine chloride, ozone and ultraviolet light.

Table 1.3 Major Factors in Evaluating Disinfection Alternatives

Effectiveness	• Ability to achieve target levels of selected indicator organisms • Broad spectrum disinfecting ability • Reliability
Cost	• Capital cost • Amortization cost • Operating and maintenance cost • Cost of special wastewater pretreatment
Practically	• Ease transport and storage, or easiness of on-site generation • Ease application and control • Flexibility • Complexity • Ability to predict results • Safety considerations
Pilot Studies Required	• Dose Requirements • Refine design details
Potential Adverse Effects	• Toxicity to aquatic life • Formation and transmission of undesirable bio-accumulating substances • Formation and transmission of toxic, mutagenic or carcinogenic substances

In order to the properly evaluate and select alternative disinfection systems two levels of review are required. In the first level, a number of non-monetary factors are considered. This qualitative assessment is comprised of three primary components, including the previously described technical factors, environmental impacts and safety. In order to assess the disinfection alternatives with respect to their non-monetary factors, a qualitative matrix approach, as shown in Table 1.4 can be used. A relative ranking of the alternatives based on these qualitative assessments can also be made as shown in Table 1.5. The ranking scale is based on a scale of one to five, with one indicating the least impact or best degree of confidence. From these types of analyses, the number of appropriate alternatives can be narrowed, and some alternatives may be completely eliminated.

The remaining acceptable alternatives can then be evaluated in a second more detailed level of review. In this second level of review, a preliminary design can be developed, cost estimates performed, and an economic analysis comparing the alternatives on an equitable basis can then be evaluated. Detailed capital and operation and maintenance costs can be developed for each alternative disinfection systems. Capital costs include structures, process equipment, major auxiliary equipment, special foundation requirements, electrical and instrumentation, site work, miscellaneous process and piping, construction contingencies, engineering, project administration and interest during the estimated period of construction. The operation and maintenance costs are annual costs and include labor, electrical power, chemicals, routine equipment maintenance, and materials and supplies (EPA, 1999).

Table 1.4 Applicability of Alternative Disinfection Techniques (EPA, 1999).

Consideration	**Cl_2**	**Cl_2/deCl_2**	**BrCl**	**ClO_2**	**O_3**	**UV**
Size of plant	All sizes	All sizes	All sizes	Small to medium	Medium to large	Small to medium
Applicable Level of treatment prior to disinfection	All levels	All levels	Secondary	secondary	Secondary	Secondary
Equipment Reliability	Good	Fair to good	?	?	Fair to good	Fair to good
Process Control	Well developed	Fairly well developed	Problematic	No experience	Developing	Developing
Relative Complexity of technology	Simple to moderate	Moderate	Moderate	Moderate	Complex	Simple to moderate
Safety Concerns	Yes	Yes	Yes	Yes	No	No
Transportation on site	Substantial	Substantial	Substantial	Substantial	Moderate	Minimal
Bactericidal	Good	Good	Good	Good	Good	Good
Virucidal	Poor	Poor	Fair to good	Good	Good	Good
Fish Toxicity	Toxic	Non toxic	Slight to moderate	Toxic	None expected	Non-toxic
Hazardous by Products	Yes	Yes	Yes	Yes	None expected	No
Persistent Residual	Long	None	Short	Moderate	None	None
Contact time	Long	Long	Moderate	Moderate to long	Moderate	Short
Contributes Dissolved Oxygen	No	No	No	no	Yes	No
Reacts with Ammonia	Yes	Yes	Yes	No	Yes (high Ph only)	No
Color Removal	Moderate	Moderate	?	Yes	Yes	No
Increased Dissolved Solids	Yes	Yes	Yes	Yes	No	No
Ph Dependent	Yes	Yes	Yes	No	Slight (high ph)	No
O&M sensitive	Minimal	Moderate	Moderate	?	High	Moderate
Corrosive	Yes	Yes	Yes	Yes	Yes	No

Table 1.5 Technical Factors and Feasibility Considerations of Disinfection Alternatives.

Considerations	**Cl_2**	**$Cl/deCl_2$**	**BrCl**	**ClO_2**	**O_3**	**UV**
Flexibility	2	2	2	2	2	2
Reliability	1	2	3	2	3	2
Complexity	2	2	2	3	3	2
Effectiveness	2	2	1	1	1	2
Pilot studies	1	1	4	4	3	3

Rating based on scale of 1 to 5, with 1 indicating best degree of confidence

As a result it can be said that site specific constraints and criteria will set guidelines for selection of appropriate disinfection alternatives. Important considerations include factors such as the size of the plant and effluent discharge quality requirements. The more stringent the effluent requirements, the more feasible alternative disinfectants such as ozone and ultraviolet light become. Capital and operation costs are obviously important factors; however, the costs of any of the disinfection options are a very small part of the total system costs.

In the following section information about different disinfection techniques are given.

1.1.2.1 Chlorination

Chlorine (Cl_2) can be present as a gas or a liquid. Chlorine gas is greenish yellow in color and about 2,48 times as heavy as air. Liquid chlorine is amber colored and about 1,44 times as heavy as water (Metcalf&Eddy, 2003). The properties of chlorine are listed in Table 1.6.

Table 1.6 Properties of Chlorine, Chlorine Dioxide, and Sulfur Oxide (U.S. EPA,1986; White,1999).

Property	Unit	Chlorine (Cl_2)	Chlorine dioxide (ClO_2)	Sulfur dioxide (SO_2)
Molecular weight	Gram	70,91	67,45	64,06
Boiling point (liquid)	^0C	-33,97	11	
Melting point	^0C	-100,98	-59	
Latent heat of vaporization at 0 ^0C	Kj/kg	253,6	27,28	376,0
Liquid density at 15.5^0C	Kg/m^3	1422,4	1640[b]	1396,8
Specific gravity of liquid at 0^0C (water=1)	s.g	1,468		1,486
Vapor density at 0^oC and 1 atm	Kg/m^3	3,213	2,4	2,927
Vapor density compared to dry air at 0^0C and 1 atm	Unitless	2,486	1,856	2,927
Specific volume of vapor at 0^0C and 1 atm	M^3/kg	0,3112	0,417	0,342
Critical temperature	^0C	143,9	153	157,0
Critical pressure	kPa	7811,8		7973,1
Solubility in water at 15.5 ^0C	g/l	7,0	70,0	120

Although the use of chlorine for the disinfection of both potable water supplies and treated wastewater had been of great significance from a public health perspective, serious concerns have been raised for its continued use. Some examples of chlorine contact basins shown in Figure1.1. Chlorine is highly toxic substance that is transported by rail and truck, both of which are prone to accidents. Chlorine is a highly toxic substance that potentially poses health risks to treatment-plant operators and the general public if released by accident. Because chlorine is a highly toxic substance, stringent requirements for containment and neutralization must be implemented as a specified in the uniform fire code (UFC). Chlorine reacts with the organic constituents in wastewater to produce by products, many of which are known to be carcinogenic and/or mutagenic. Residual chlorine in treated wastewater effluent is toxic to aquatic life. Concern exists over the discharge of chloro-organic compounds to the environment whose long-term effects are not known (Metcalf&Eddy, 2003).

After disinfection, chlorine residual can persist in the effluent for many hours. Most states will not allow the use of chlorination alone for pristine receiving waters because of its effect on aquatic species. To minimize the effect, chlorinated

wastewater must often be dechlorinated. Dechlorination is the process of removing the free and combined chlorine residuals to reduce residual toxicity after chlorination and before discharge. Sulfur dioxide, sodium bisulfite, and sodium metabisulfite are the commonly used dechlorinating chemicals. Activated carbon has also been used. The total chlorine residual can usually be reduced to a level that is not toxic to aquatic life. Chlorination/decholorination systems are more complex to operate and maintain than chlorination systems.

Chlorine disinfection is most well-known and used disinfection technology. Advantages and disadvantages of this process are listed in Table 1.7.

Table 1.7 Advantages and Disadvantages of Chlorine Disinfection (Metcalf&Eddy, 2003).

Advantages	**Disadvantages**
Well-established technology	Hazardous chemical that can be a threat to plant workers and the public; thus strict safety measures must be employed
Effective disinfectant	Relatively long contact time required as compared to other disinfectants
Chlorine residual can be monitored and maintained	Combined chlorine is less effective in inactivating some viruses, spores, cysts, at low dosages used for coliform organisms
Combined chlorine residuals can also be provided by adding ammonia	Residual toxicity of treated effluent must be reduced through dechlorination
Germicidal chlorine residual can be maintained in long transmission lines	Formation of trihalomethanes and other DBP_s
Availability of chemical system for auxiliary uses such as odor control, dosing RAS lines, and disinfection plant water systems	Release of volatile organic compounds from chlorine contact basins
Oxidizes sulfides	Oxidizes iron, magnesium, and other inorganic compounds.(consumes disinfectant)
Relatively inexpensive (cost is increasing with implementation of uniform fire code regulations)	Oxidizes a variety of organic compounds (consumes disinfectant)
Available as calcium and sodium hypochlorite considered to be safer than chlorine gas	TDS level of treated effluent is increased
-	Chloride content of the wastewater is increased
-	Acid generation; pH of the wastewater can be reduced if alkalinity is insufficient
-	Increased safety regulations, especially in light of uniform fire code
-	Chemical scrubbing facilities may be required to meet uniform fire code

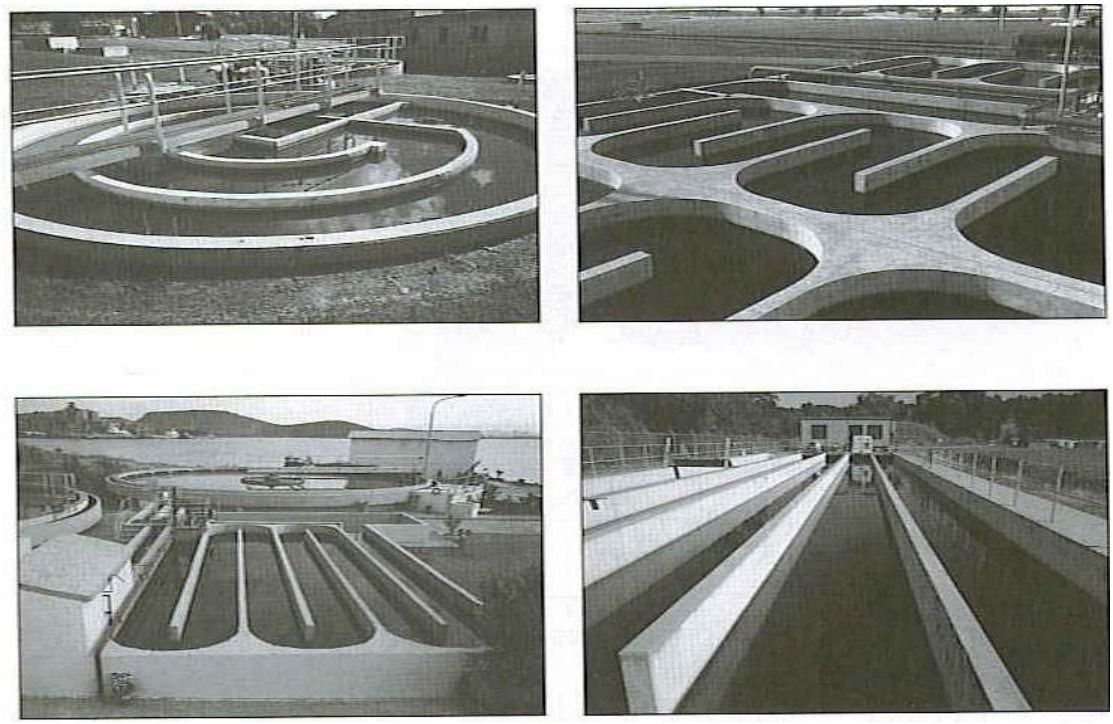

Figure1.1 Some Examples of Chlorine Contact Basins (Metcalf&Eddy. 2003).

Chlorine can be in different forms. Chlorination for disinfection can be done with using chlorine in different forms. Chlorine can be found in forms of sodium hypochlorite, calcium hypochlorite, chlorine dioxide, bromine chloride.

1.1.2.1.1 Sodium Hypochlorite. Many of the safety concerns related to the transport, storage, and the feeding of liquid-gaseous chlorine are eliminated by the use of either sodium or calcium hypochlorite. Sodium hypochlorite (NaOCl) is only available as liquid and usually contains 12,5 to 17 percent available chlorine or manufactured on site. The solution decomposes more readily at high concentrations and is affected by exposure to light and heat. Another disadvantage of sodium hypochlorite is the chemical cost. The purchase price may range from 150 to 200 percent of the cost of liquid chlorine (Metcalf&Eddy, 2003). Sodium hypochlorite reaction is given in equation 2 (Gül, 1998).

$$Cl_2 + 2NaOH \rightarrow NaOCl + NaCl + H_2O$$
$$NaOCl + H_2O \Leftrightarrow HOCl + NaOH. \quad (2)$$

1.1.2.1.2 Calcium Hypochlorite. Calcium hypochlorite ($Ca(OCl)_2$) is available commercially in either dry or a wet form. High-test calcium hypochlorite contains at least 70 percent available chlorine. Because of its oxidizing potential, calcium hypochlorite should be stored in a cool, dry location away from other chemicals in corrosion-resistant containers. Hypochlorite is more expensive than liquid chlorine, loses its available strength on storage, and may be difficult to handle. Because it tends to crystallize, calcium hypochlorite may clog metering pumps, piping, and valves. Calcium hypochlorite is used most commonly at small installations (Metcalf&Eddy, 2003). Usage of calcium hypochlorite is shown in equation 3 (Gül, 1998).

$$Ca(OCl)_2 + 2H_2O \Leftrightarrow 2HOCl + Ca(OH)_2 . \quad (3)$$

Several calcium hypochlorite dosage values for some wastewater treatment types are listed in Table 1.8.

Table 1.8 Calcium Hypochlorite Dosage Values for Some Wastewater Treatment Types $Ca(OCl)_2$ (Şahin, 2003).

Calcium hypochlorite	Septic Tank Effluent	Biologic Treatment Effluent	Sand Filter Effluent
pH 6	35-50	15-30	2-10
pH 7	40-55	20-35	10-20
pH 8	50-65	30-45	20-35

(Contact Time=1 hour, T=20^oC, parameter investigated ideal $Ca(OCl)_2$ dosage (mg/lt).)

1.1.2.1.3 Chlorine dioxide. Chlorine dioxide (ClO_2) is another bactericide, equal or greater than chlorine in disinfecting power. Chlorine dioxide has proved to be an effective virocide, being more effective in achieving inactivation of viruses than chlorine. A possible explanation is that because chlorine dioxide is adsorbed by peptone (a protein), and that viruses have a protein coat, adsorption of ClO_2 on to this coating could cause inactivation of the viruses. In the past ClO_2 did not receive much consideration as a wastewater disinfectant due to its high cost. The environmental impacts associated with the use of chlorine dioxide as a wastewater disinfectant are not well-known. It has been reported that the impacts are less adverse than those associated with chlorination. Chlorine dioxide does not dissociate or react with water

as does chlorine. However, because chlorine dioxide is normally produced from chlorine and sodium chlorite, free chlorine may remain in the resultant than chlorine dioxide solution (depending on the process) and impact the receiving aquatic environment, as do chlorine residuals. A free chlorine dioxide residual will also remain, but it has been found to be less harmful to aquatic life than chlorine (Metcalf&Eddy, 2003). Figure 1.2 shows typical flow diagram for the addition of chlorine dioxide.

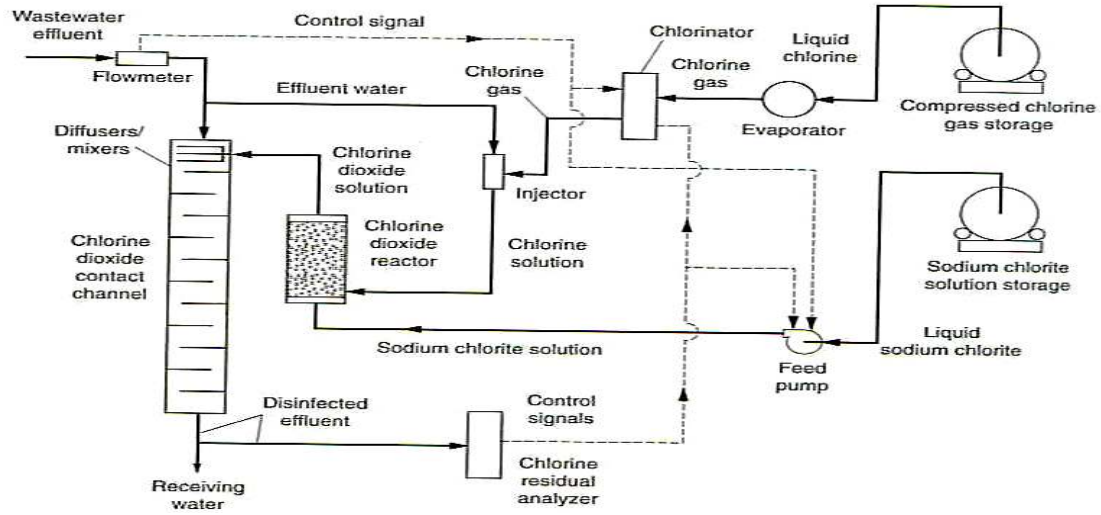

Figure 1.2 Typical flow diagrams for the addition of chlorine dioxide (Metcalf&Eddy, 2003).

1.1.2.1.4 Bromine Chloride. Bromines have been shown to be very effective as a disinfectant with shorter lived residuals compared to chloramines. Because bromamines are more unstable than chloramines, shorter contact times are needed. Environmental impacts associated with bromine chloride disinfection are less adverse than those associated with chlorine. Contrasting results relative to the toxic effects of bromine residuals have been cited in the literature, possibly due to the stability of three bromine residual and their rapid decay to chloride and bromide. Other brominated organic compounds can also be formed during the disinfection process. These compounds may not be produced in appreciable quantities; however, they may be toxic at high enough concentrations and may bioaccumulate.

Bromine chloride is manufactured from bromine and chlorine. It is a hazardous and corrosive chemical and requires special transportation, handling, storage, and use

precautions. Bromine chloride disinfection facilities are very similar to those used for chlorination. It is applied in much same manner as chlorine, using vacuum chlorobrominator to prepare a concentrated solution, which is then mixed with wastewater. Shorter contact times are possible, resulting in a construction cost saving due to a smaller contactor. The use cost is heavily dependent on the cost of the bromine chloride itself. Secondary treated wastewaters require no special pretreatment prior to disinfection; however, bromine chloride use for wastewater disinfection is relatively new and a good data base and track record are presently not available. Bromine chloride disinfection has been proven effective in field-scale applications for wastewater, but problems with the liquid feed equipment have occurred. Brominated organics such as bromoform and mixtures of chlorinated and brominated organics can be expected to be formed.

1.1.2.1.5 Environmental Impacts of Chlorine Disinfection. Chlorination is one of the most commonly used methods for the destruction of pathogenic and other harmful organisms that may endanger human health. Certain organic constituents in wastewater interfere with the chlorination process. Many of these organic compounds may react with the chlorine to form toxic compounds that can have long-term adverse effects on the beneficial uses of the waters to which they are discharged. Representative disinfection by products resulting from the chlorination of wastewater containing organic and selected inorganic constituents are listed in Figure 1.3.

It has been shown that many of the disinfection by products (DBP_s) can cause environmental impacts at very low concentrations. The occurrence of DBPs and compounds raises serious questions about the continued use of free chlorine for wastewater disinfection.

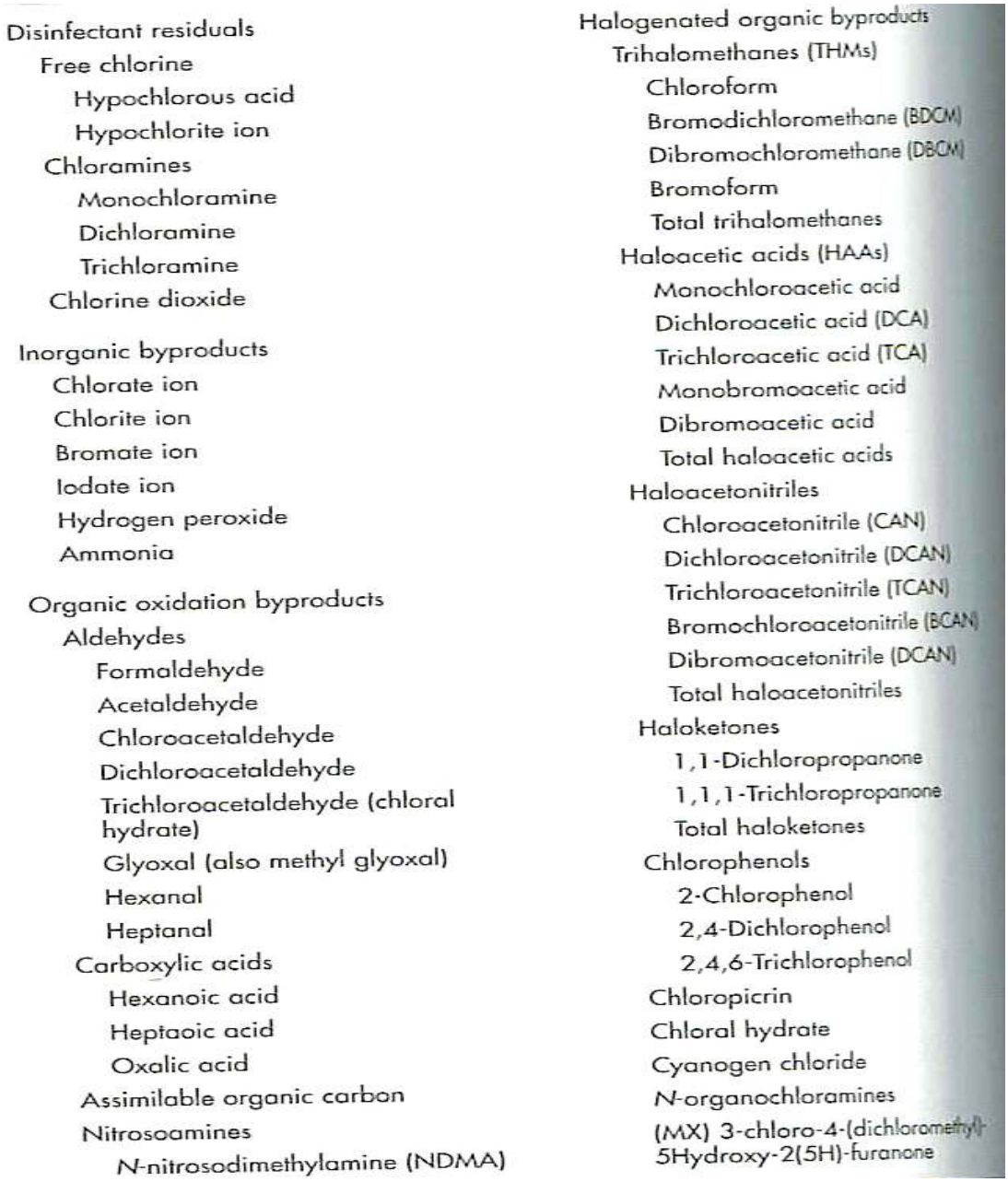

Figure 1.3 Representative Disinfection by Products Resulting from the Chlorination of Wastewater Containing Organic and Selected Inorganic Constituents (US.EPA, 1999).

Another important parameter to explain impacts of chlorine disinfection to the environment is Adsorbable Organic Halogens (AOX). AOX can be defined as adsorbable organically bound halogens. The equivalent amount of chlorine, bromine, and iodine contained in organic compounds, expressed as a chloride when determined according to the European Standard (www.stateoftheart.it, 2002). AOX is an important parameter for the characterization of wastewaters with regard to their

biodegradability. Another definition about AOX is the sum of all halogenoorganic compounds which can be adsorbed by activated carbon. As a large number of these compounds show a significant toxicity on humans and bacteria, sewage water legislation in Germany provides, very strict regulations for the discharge of AOX containing wastewaters. AOX may be removed by reverse osmosis, air stripping or adsorption by activated carbon (Höfl, Sigl, Specht, Wurdack, and Wabner, 1976). The chlorinated compounds have been in the black list since 1976 for their extremely high toxicity and other harmful effects. This parameter; AOX generally investigated for drinking water. All the international drinking water quality standards can be divided into four groups.

- (Micro)biological; bacteria, viruses, cysts etc…
- Toxicological; THM, AOX, pesticides etc…
- Organoleptic (esthetic); odor, taste, color etc…
- Operational; DOC, AOC, pH etc… (Graveland, 1998)

Chlorination process leads to the formation of not only trihalomethanes (THMs) but also numerous other volatile and non volatile organic halogen compounds (Sansebastione et al., 1995). One parameter that represents the whole of these substances is TOX (total organic halogens) or AOX (Jekel and Roberts, 1980).

The dominant chlorination products are chloroform and chlorinated aliphatic acids, especially dichloroacetic acid (DCA) and trichloroacetic acid (TCA). Several studies have shown that the volatile halogenated organics, e.g. THMs, represent only a minor part of the total halo-organics while the larger part exists as non-volatile polar compounds (Peters, et al., 1991).

In Germany, the Drinking Water Regulation gives no limit value for AOX. The critical parameter used is the sum limit value in the Drinking Water Regulation for 5 organic chlorine compounds of 0,01 mg/L (Senate Department of Urban Development, 1992).

AOX analysis has the following applications: (1) Drinking water, (2) Surface water, (3) Ground water, (4) Percolate water, (5) Sludge and sediments, (6) Wastewater, (7) salt water, (8) Pulp and paper products (www.stateoftheart.it, 2002). The AOX content is always low in a clean environment and high concentration indicates chemical pollution.

AOX is mainly generated from industrial activities, such as pulps and mills industry or kraft mill industry. In one of the research in British Colombia, Pulp and Paper Mill Liquid Effluent Control Regulation was introduced on December 13, 1990, in direct response to concerns over dioxins and furans. This paralleled a Federal initiative to regulate the discharge of dioxins and furans to "non-measurable" levels. The B.C. Regulation required all mills to reduce AOX liquid discharges to below 2,5 kg per air-dried tone (ADt) of pulp produced. Subsequent amendments, effective January 17, 1992, required a further reduction of AOX to less than 1,5 kg AOX/ADt by December 31, 1995, with a further requirement for a complete elimination of the AOX produced in the bleaching process by 31 December 2002. The B.C. pulp and paper industry in the intervening years has been able to consistently achieve a zero measurable dioxins/furans discharge record as well as the regulated target of 1,5 kg AOX/ADt by December 1995 or earlier. The average AOX discharge on a province-wide basis declined progressively from around 2,7 kg/ADt in 1991 to around 0,65 kg/ADt in 1996. At the present time, the great majority of mills in B.C. have less than 0,5 kg AOX/ADt in their final effluent. For the majority of mills, the improvements were made through the elimination of elemental chlorine (Cl_2) as a bleaching agent, and the complete substitution with chlorine dioxide (ClO_2) (Royal Road University, 1999).

1.1.2.1.6 Cost Analyses of Chlorination Disinfection. Cost of the chlorination depends on the amount of chlorine that is used and capacity of the treatment plant. Amount of chlorine used depends on contents of the wastewater. For algae removal 3-5 mg/L chlorine is used, for BOD removal amount of used chlorine increases to 10 mg/L. For color removal required chlorine amount changes to origin of color between 1-500 mg/L. Presence of iron in the effluent of treatment plant or wishing

odor removal are other important parameters that influence chlorine consumption. Type of the chlorine used for disinfection is another parameter determines expenses of plant and first investment costs. Transportation of chlorine is difficult and has lots of risks; so to reduce transportation costs and risks chlorine is procured from nearby place. Cost of disinfection process at some plants using chlorine as a disinfectant shown in Table1.9.

As shown in Table 1.10 cost of the chlorine disinfection changes between 400.000 – 10.000.000 $. The total cost of chlorination will be increased by approximately 30 to 50% with the addition of dechlorination.

Table 1.9 Cost of disinfection process at some plants using chlorine as a disinfectant (Darby, 1995).

Flow (m^3/day)		**Chlorine (Cl_2) dosage (mg/L)**	**Estimated capital costs ($)**				**Estimated operating and maintenance costs***
Average dry weather flow	**Peak wet weather flow**		**Chlorination**	**Dechlorination**	**Other**	**Total cost**	
3.750	9.450	5	410.000	290.000	239.000	1.127.000	49.300
37.500	75.700	5	1.804.000	546.000	264.000	3.137.000	158.200
375.000	662.450	5	10.131.000	1.031.000	788.000	14.340.000	660.000
3.750	9.450	10	441.000	370.00	239.000	1.260.000	59.200
37.500	75.700	10	2.051.000	664.000	264.000	3.575.000	226.700
375.000	662.450	10	10.258.000	1.258.000	788.000	14.765.000	721.800
3.750	9.450	20	445.000	374.000	239.000	1.270.000	76.600
37.500	75.700	20	2.113.500	913.500	264.000	3.949.000	379.100
375.000	662.450	20	10.273.000	1.273.000	788.000	14.801.000	1.311.000

*Approx. operating and repairing costs include energy, chemicals used for cleaning, operator and equipment repairs.

1.1.2.2 UV Disinfection

Ray, between X-ray and visible ray, is called ultraviolet ray. Continuous sunlight brings bacteria, viruses activities to an end. Ultraviolet (UV) treatment method has been known as a clean method at wastewater treatment since 1970's. In this method disinfectant has no effects on immunity system such as chlorination. Photons that have UV energy are absorbed by organism's DNA and tie of DNA is damaged. DNA is an organic molecule that has genetic structure of organisms, it matches itself, carries hereditary information of organisms, and transfer it to other generation. Figure 1.4 shows the effect of UV on bacteria that are exposed to UV light.

If the UV dose does not reach the effective lethal dose, the bacterial cells are able to repair the defective DNA by enzymatic processes (photoreactivation). UV water disinfection was first used on a large scale for drinking water in France at the beginning of this century. However, the absence of a residual disinfection effect prevented the employment of that method, because of frequent penetration of environmental pollutants into the unreliable water pipes of the water-distribution system. The characteristics of the UV radiation emitted by the lamps depend on their Hg vapor pressure, on the chemical composition of the quartz tube, on the electrical power input and on working conditions. Low-pressure Hg lamps are < 200 W input, emit almost monochromatic 254 nm radiation and are usually 5-10 times more germicidal than the high and medium-pressure lamps, for the same electrical input. The medium- and high-pressure Hg lamps are very powerful (up to 5,0 kW input) and emit polychromatic radiation. UV irradiation could also be an attractive method for disinfection of effluents (Fluegge, 1981), provided that the sewage treatment processes yield transparent effluents with a high transmittance at 254 m (sand filtration is often required before submitting effluents to disinfection).

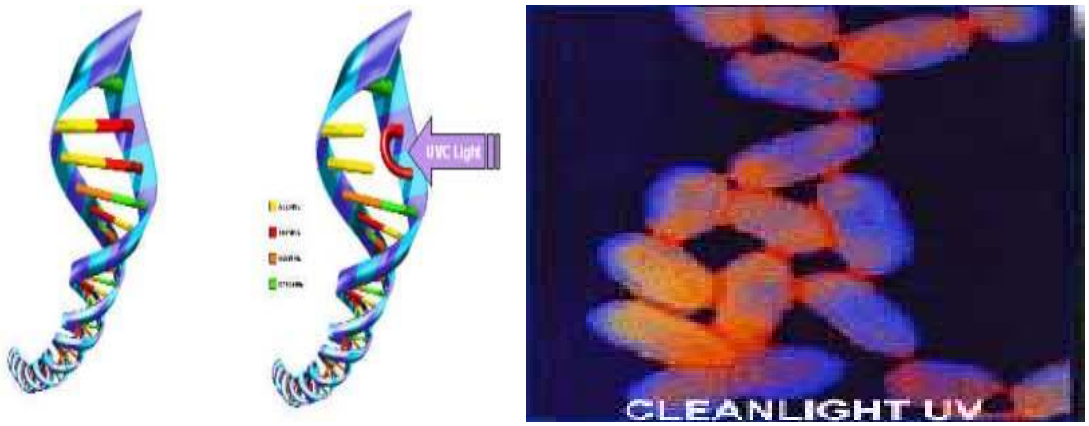

Figure 1.4 Bacteria that are exposed to UV light (http://arbiol.com.tr).

The portion of the electromagnetic spectrum in which UV radiation occurs, is between 100 and 400 nm. The UV radiation range is characterized further according to wavelength as long-wave (UV-A), also known as near-ultraviolet radiation, middle-wave (UV-B), and short-wave (UV-C), also known as far UV. The germicidal portion of the UV radiation band is between 220-320 nm, principally, in

the UV-C range. To produce UV radiation, lamps that contain mercury vapor are charged by striking an electric arc. The energy generated by the excitation of the mercury vapor contained in the lamp results in the emission of UV light. In general, UV disinfection systems fall into three categories based on the internal operating parameters of the UV lamp, (i) low-pressure low-intensity, (ii) low-pressure high-intensity, (iii) medium-pressure high-intensity systems. UV disinfection systems also be classified as open-channel or closed-pipe based on their hydraulic characteristics (Metcalf&Eddy, 2003).

Low-pressure low-intensity UV lamps generate essentially monochromatic radiation at a wavelength of 254 nm, which is close to 260 nm. In all cases, mercury-argon lamps are used to generate the UV-C region wavelengths. Approximately 85 to 88 percent of the lamp output is monochromatic at 254 nm, making it an efficient choice for disinfection processes (Metcalf&Eddy, 2003).

Low-pressure high-intensity UV lamps are similar to the low-pressure low-intensity lamps with the exception that a mercury-indium amalgam is used in place of mercury.

Medium-pressure high intensity UV lamps have been developed over the last decade. They operate at temperatures 600 to 800 ^{0}C and pressures of 10^2 to 10^4 mm Hg. Their use is limited primarily to higher wastewater flows, stormwater overflows, or on space limited sites because fewer lamps are required and the footprint of the disinfection system is greatly reduced (Metcalf&Eddy, 2003). Figure 1.4 shows absorption of UV ray by DNA and E.coli.

The UV disinfection of large amounts of water (> 100 m^3/ h) is performed by two methods: (a) a flow-through open channel system in which the water (mainly effluents) to be treated flows gravitationally or (b) a closed-pipe pressured system (mainly drinking water).

When the flow-through channel system is used, the UV modules stainless-steel frames holding the low-pressure UV lamps, are immersed in the water in the channels. The water is flowing parallel to the UV lamps; the recommended distance between the lamps axis is approximately 7 cm; the fluencies of UV radiation should be 30~0 mW.s/cm^2 and the residence time of the water in the channels should be 6-10 s. The size and number of UV modules required in a particular application is determined by the flow rate, the water quality (<2 NTU for effluents) and the disinfection requirements (Achew, Fıscher, Turnheim, Manor 1996). Example of open-channel UV disinfection system is shown in Figures 1.5 and 1.6.

When the second method is used, the pressured water to be disinfected is passed through pipes larger than 100mm in dia., in which are mounted high- or medium-pressure Hg UV lamps, in a single-tube or multi-tube arrangement. Since the linear flow rate of water in these pipes is very high (irradiation time is very short), the use of powerful high-intensity Hg lamps (several kW) is required to ensure at least the minimum UV dose. In both methods the lamp surface is protected against the deposition of organic and/or inorganic materials from the treated water by quartz sleeves. Depending on water quality it is necessary to stop the disinfection operation periodically and to clean the sleeves, in order to re-establish the initial UV emission into the water (Achew, Fıscher, Turnheim, Manor, 1996). In Figure 1.7 typical closed-channel UV system and its typical installations is given.

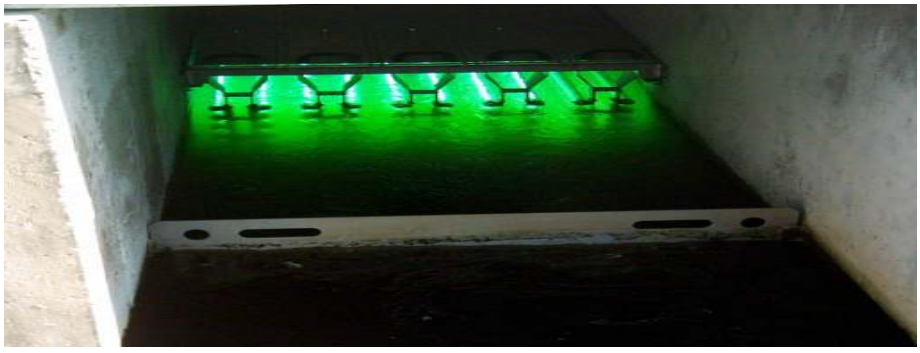

Figure1.5. Open-channel UV Disinfection System in Fethiye Municipal Wastewater Treatment Plant/Turkey.

Figure 1.6 Open-channel UV Disinfection System in Fethiye Municipal Wastewater Treatment Plant/Turkey.

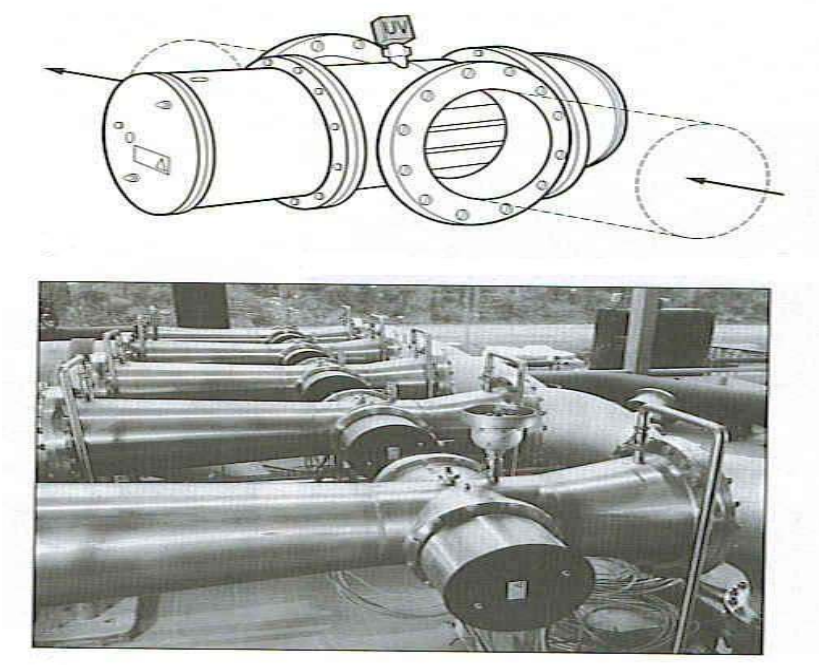

Figure 1.7 Typical Closed-channel UV System and its Typical Installations (Metcalf&Eddy, 2003).

Dissolved contaminants effect UV disinfection either directly via absorbance (increasing absorbance serves to attenuate UV light to a larger degree) or via fouling of UV lamps such that a reduced intensity is applied to the bulk liquid medium. In Table 1.10, impacts of wastewater constituents on the use of UV radiation for wastewater disinfection are given:

Table 1.10 Impacts of wastewater constituents on the use of UV radiation for wastewater disinfection (Metcalf&Eddy, 2003).

Constituents	**Effect**
BOD, COD, TOC etc…	No or minor effect, unless humic materials comprise a large portion of the BOD
Humic materials	Strong adsorbers of UV radiation
Oil and grease	Can accumulate on quartz sleeves of UV lamps, can absorb UV radiation.
TSS	Absorption of UV radiation, can shield embedded bacteria.
Alkalinity	Can impact scaling potential. Also affects solubility of metals that may absorb UV light
Hardness	Calcium, magnesium, and other salts can form mineral deposits on quartz tubes, especially at elevated temperatures.
Ammonia	No or minor effect
Nitrite	No or minor effect
Nitrate	No or minor effect
Iron	Strong adsorber of UV radiation, can precipitate on quartz tubes, can adsorb on suspended solids and shield bacteria by adsorption.
Manganese	Strong adsorber of UV radiation
pH	Can affect solubility of metals and carbonates.
TDS	Can impact scaling potential and the formation of mineral deposits.
Industrial discharges	Depending on the constituents (e.g. dyes) may lead to diurnal and seasonal variations in the transmittance.
Stormwater inflow	Depending on the constituents, may lead to short-term as well as seasonal variations in the transmittance.

On the basis of the evidence to date, it appears that the compounds formed at the UV application for disinfection of wastewater are harmless and chemical substances

are broken down into more innocuous forms. Thus, the disinfection of wastewater with ultraviolet light is considered to have no adverse environmental impacts.

1.1.2.2.1 Cost Analysis of UV Disinfection. Main disadvantage of the UV system is its price. The system has very high first investment costs; but prices and costs are coming down as new and improved technology is brought to the market. Table 1.11 shows Costs of UV systems at different capacities in the Canada.

Table 1.11 Investment Costs of UV Systems at Different Capacities at Municipal Wastewater Disinfection (Robertson, J.L. 1983).

	Q=0-20.000 (m^3/day)	Q=20.000-200.000 (m^3/day)	Q=200.000, and more (m^3/day)
Average first Investment costs ($)	92.000	352.000	3.150.000

A cost researches about UV technologies are done in many countries. In these researches comparison of the disinfection methods are done. Figure 1.8 shows one of this researches result about costs of disinfection technologies.

Disinfection method*				Plant size	
1	2	3	4	$Mm^3 y^{-1}$	MGD
0.36	0.50	0.70	2.4	7.3	5.0
0.33	0.42	0.50	2.1	14.6	10.0
0.30	0.35	0.42	1.6	146.0	100.0

*1, UV light; 2, chlorination; 3, 2 + dechlorination; 4, ozonation.

Figure 1.8 Cost comparisons between disinfection technologies. Costs are US$ per 100 m^3 (Trojan technologies, 1992).

Another research about disinfection alternatives in the US shows that cost of UV system decreases in time. Figure 9 shows cost of some disinfection methods in U.S.

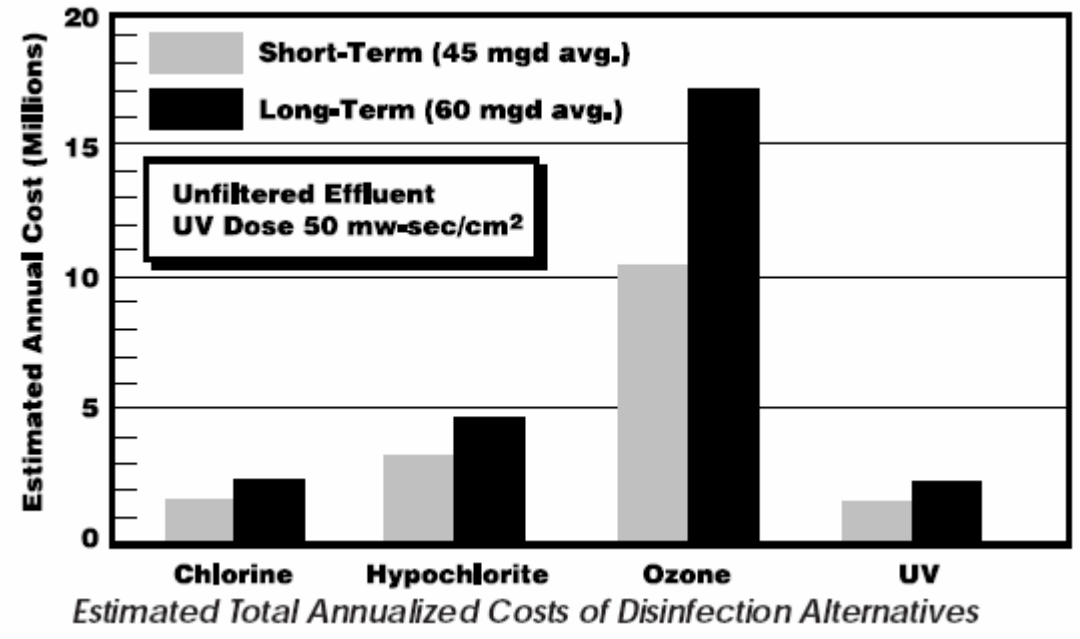

Figure 1.9 Estimated total annualized costs of disinfection alternatives (A.Farrel, J.Burris, 1995).

Advantages and disadvantages of UV disinfection is given in Table 1.12:

Table 1.12 Advantages and disadvantages of UV disinfection (Crites and Tchobanoglous, 1998 and U.S. EPA. 1996).

Advantages	Disadvantages
Effective disinfectant	No immediate measure of whether disinfection was successful
No residual toxicity	No residual effect
More effective than chlorine in inactivating viruses, spores, cysts.	Less effective in inactivating some viruses, spores, cysts at low dosage used for coliform organisms
No formation of DBP_s at dosages used for disinfection	Energy-intensive
Does not increase TDS level of treated effluent	Hydraulic design of UV system is critical
Effective in destruction of resistant organic constituents such as NDMA	Relatively expensive(price is coming down as new and improved technology is brought to the market)
Improved safety compared to the use of chemical disinfectants	Large number of UV lamps required where low-pressure low-intensity system are used
Requires less space than chlorine disinfection	Low-pressure low-intensity lamps require acid washing to remove scale
At higher UV dosages than required for disinfection, UV radiation can be used to reduce the concentration of trace organic constituents of concern	Lack of chemical systems that can be used for auxiliary uses such as odor control, dosing RAS lines, and disinfection of water plant systems.

Ultraviolet disinfection is basically a safe process; the activity is generated on-site; thus there are no transport concerns or from the site, or concerns regarding storage of reactive material. Normal plant safety precautions apply relative to physical layout (railing etc) and to electrical hazards. Power supplies are high voltage, requiring the adherence to normal electrical safety codes. Electrical interlocks should be provided to shut off systems when opened (reactor and panels);

particular attention should be paid to electrical wiring, groundings, and waterproofing. Storage of lamps, quartz sleeves, and ballasts should be in a separate dry area (EPA, 1986).

In this thesis comparison of UV disinfection and chlorination of municipal wastewater treatment plant effluent is studied, in this section various effects of these methods are summarized The characteristic of wastewater and the degree of the treatment significantly affect the effectiveness of the various disinfection technologies, site-specific testing must be conducted to evaluate the effectiveness of alternate disinfection technologies and to establish appropriate dosing ranges. In table 1.13, comparison of chlorination and UV disinfection for some parameters is given.

Table 1.13 Comparisons of Chlorination and UV Disinfection for Some Parameters

Parameter	**Chlorination**	**UV disinfection**
Performance (reliability)	Very good	Good
Effectiveness	Average	Good
Flexibility to the variety	Good	Average
Application easiness	Average	Average
Cost of energy	Low	High
Maintenance requirement	High	High
Effluent quality	Average	Very good

Chlorination is the most well known and applied disinfection technologies at water and wastewater all around the world; but it is the fact that this method has many harmful effects to the environment and human life. There are many organic materials that depend on wastewater characteristic in wastewater and these organic substances become cancerogen and toxic materials with chlorine disinfection. These toxic materials have unexpected effects on environment at place where treated wastewater discharged. Chlorine that is used in disinfection tries deactivating all microorganisms and living organisms in wastewater but extra chlorine is used because of not to be known absolute chlorine powerty. Therefore residual chlorine

disinfects at discharging media. In addition to this chlorine oxidizes organic materials in wastewater because of its high oxidizing capacity. Chloroamin and chloroform are oxidizing products and have cancerogen effects on human life and living organisms. If chlorinated wastewater is reused such as irrigation, cancer risks rises. It is known that if chlorinated products that formed after chlorination are mixed with drinking water treated water causes different types of cancer like belly, intense, urethra cancer.

Dechlorination is another point that creates questions. Although it is good for removing chlorinated materials, another chemical is used for this process. After all this reasons chlorination becomes a suspicious method for disinfection.

With the improving technologies new and environment friendly disinfection methods are being developed. UV disinfection is a new disinfection technology and is used since 30 years for water and wastewater disinfection. This method has high efficiency and has no residual materials and toxicity after disinfection. This process is known environment-friendly disinfection method. Using different wavelengths for different microorganism is one of the attractive parts of this process. It's costs are most disputatious subject but especially in recent years many researches results shows that there is significant improvement about decreasing UV process costs. Many researchers clarify that this environment-friendly disinfection method becomes cost-friendly also. Because of this point and rising of cancer illness all around the world, increases UV disinfection- environment-friendly disinfection method-attraction and usage.

1.1.2.3. Ozone Disinfection

Ozone is unstable gas that is produced when oxygen molecules are dissociated into atomic oxygen and subsequently collide with another oxygen molecule to produce ozone (Klein M.J, 1975) Ozone is an extremely reactive oxidant and a very effective bactericide and virucide.

Unlike some of the other chemical disinfecting agents, ozone can exert beneficial impacts on the environment. Since ozone decomposes rapidly to oxygen after application, the dissolved oxygen levels in the treated effluent can be elevated significantly, often to saturation levels. In most, if not all cases, the needed for effluent reaeration to meet required dissolved oxygen water quality standards can be eliminated. Ozone residuals can be acutely toxic to aquatic life; however, since ozone dissipates rapidly, residuals are normally not found in the effluent by the time it reaches receiving water. Ozonation has been shown in some instances to produce toxic mutagenic and/or carcinogenic compounds, but little is presently known about these organic byproducts (Stover, E.L., 1993).

Gaseous ozone is explosive at ozone concentration of 240 g/m^3 (20 percent wt in air) (Manley, T.C. and S.J. Niegowski., 1967). The transfer of ozone in to the wastewater is the first step in meeting the disinfection objective, since ozone must be transferred and residual oxidants produced before effective disinfection will occur (Farooq, S, 1976). Once transferred, the residual oxidants, such as ozone hydroxide, or peroxide, must come into contact with the organisms in order for the disinfection action to proceed. Therefore, similar requirements and kinetic relationships used for chlorine disinfectants can also be used for ozone disinfection.

Contact time has been the subject of much controversy for ozone disinfection. Studies have shown that effective disinfection can occur at contact times as short as one minute (Stover, E.L, 1980) but most existing ozone disinfection systems have contact times that are 10 to 15 minutes. Effective ozone disinfection is due to the combined results of high transfer efficiency good mixing, adequate contact time, and minimal short-circuiting in the contactor. These factors are all interrelated, thus isolating contact time as a particular variable during kinetic analyses has not been practical. As a result, kinetic relationships in terms of transferred ozone are residual concentrations have been utilized (EPA, 1986).

Additional work has shown that it was possible to empirically relate effluent fecal coliform concentration to the production of contactor of gas concentration and liquid contact time (Venosa A.D, 1984)

The ozone disinfection process consists of a liquid and a gas flow. The feed-gas is typically air or high purity oxygen. A small amount (from 1 percent wt in air to 4 percent wt in oxygen) of the feed-gas is converted to ozone with in the ozone generator. The ozone containing feed-gas is directed to a contact basin where it combines with the wastewater. Typically, a high percentage of the ozone, but only a small percentage of the total feed-gas flow, is transferred to the liquid in the contact basin. The disinfection action proceeds in the contact basin. The gas and liquid flows separate after the contact basin. The off- gas is treated to remove the un-reacted ozone and is reused, recycled, or discharged to the atmosphere. The disinfected wastewater is discharged to the receiving water. Any residual ozone in the wastewater is reacted or is reverted bav to oxygen (EPA, 1986).

Ozone disinfection processes are typically distinguished by the type of feed-gas used. The most common types are air-feed and oxygen-feed. Oxygen recycle systems have been used on some occasions. Oxygen –fed systems are typically used in conjunction with an oxygen activated sludge treatment system, where the unused oxygen from the ozone disinfection system is used in the biological treatment process (EPA, 1986).

The ozone disinfection contacting units are similar for all feed-gas systems. In the contact basin some disinfection action occurs through direct contact of the microorganism with the ozone in the gaseous phase; however “effective” disinfection appears to exist only when residual oxidants or ozone residual is present (Stover, E.L, 1976). In order to obtain residual oxidants or residual ozone, a sufficient amount of ozone must be transferred to the wastewater

As a result ozone is an effective disinfectant. In addition to this ozone is a toxic gas and like chlorine can cause severe illness and death if inhaled in sufficient

quantity. However, ozone systems have safety advantages not available with the chlorine disinfection process. Ozone is generated on-site, thus eliminating transportation hazards. Also, the generation system can be shut down if an ozone leak develops. Another safety advantage is the physical characteristic of ozone that allows it to be detected (smelled) at concentrations much lower than harmful levels.

CHAPTER TWO
MATERIALS AND METHODS

2.1. Sampling

The experimental study has been done with samples taken from municipal wastewater at FETHIYE. Activated sludge process is applied at Fethiye Municipal treatment plant. The process depends on oxidation ditch. There is carbon and nutrients removal such as nitrogen and phosphorus. At the last step of treatment plant UV disinfection takes place as a disinfection process. The samples were taken from effluent of treatment plant before and after disinfection.

BOD, COD, AOX and pH measurements were applied to all samples. There were three group of sample. First group was influent of chlorination and influent of UV disinfection. These both influent samples were taken from influent of UV disinfection plant. Second groups of samples were taken before UV disinfection unit and chlorinated in order to determine the differences between wastewater qualities that occur after chlorination of UV. The third groups of samples were effluent of UV disinfection plant. These groups of samples were taken from effluent of UV disinfection plant.

2.2 Wastewater Composition

A natural wastewater was used throughout the experiments. The composition of raw wastewater is given in table 2.1. Wastewater treatment plant depends on biological treatment. There was nutrient removal at treatment plant. UV disinfection was used as a disinfection process at last step of treatment plant. Treated wastewater was discharged to the river nearby the treatment plant. Receiving media discharge criteria was applied for treatment plant.

Table 2.1. Raw Wastewater Composition from Fethiye Municipal Wastewater Treatment Plant

	PARAMETER			
DATE	**COD (mg/L)**	**BOD(mg/L)**	**AOX**	**PH**
30.07.2004	32	15	1128	7,45
06.08.2004	23	18	1050	7,25
13.08.2004	38	19	874	7,33
20.08.2004	48	25	674	7,40
27.08.2004	64	30	960	7,28
03.09.2004	40	22	826	7,42
04.09.2004	64	32	852	7,30
10.09.2004	50	28	886	7,10
11.09.2004	45	20	1144	7,20
17.09.2004	48	20	622	7,12
18.09.2004	40	19	872	7,10
24.09.2004	28	21	220	7,05
25.09.2004	32	18	590	6,97
01.10.2004	23	18	432	7,16
02.10.2004	20	14	594	7,08
08.10.2004	22	14	620	7,25
09.10.2004	38	20	636	7,05
15.10.2004	32	21	726	6,83
16.10.2004	16	12	500	6,90
22.10.2004	23	18	1012	7,01
23.10.2004	20	14	1046	7,08
29.10.2004	23	18	898	7,22
30.10.2004	20	14	1004	7,15

2.3. Experimental Set-up

2.3.1. Chlorination Experiment

The chlorination experiments were applied by using 100 liter tank. The tank was made up of stainless steel with dimensions of 4 meter height, 5 meter length and 5 meter width. At the beginning of each series of experiments, 100 liter composite sample is taken from influent of UV disinfection plant. This sample was put in a 100 liter tank and continuous stirring was applied to the tank. Liquid sodium hypochlorite (NaOCl) was used for chlorine disinfection. Liquid sodium Hypochlorite contains % 15 available chlorine. Chlorine was stored in a cool, dark room. Dosing pumps was used for dosing liquid chlorine to the tank. Chlorine dosage was chosen 10 mg/ L according to the EPA standards. (EPA 1986) (White, 1999) 30 minutes was chosen for contact time.

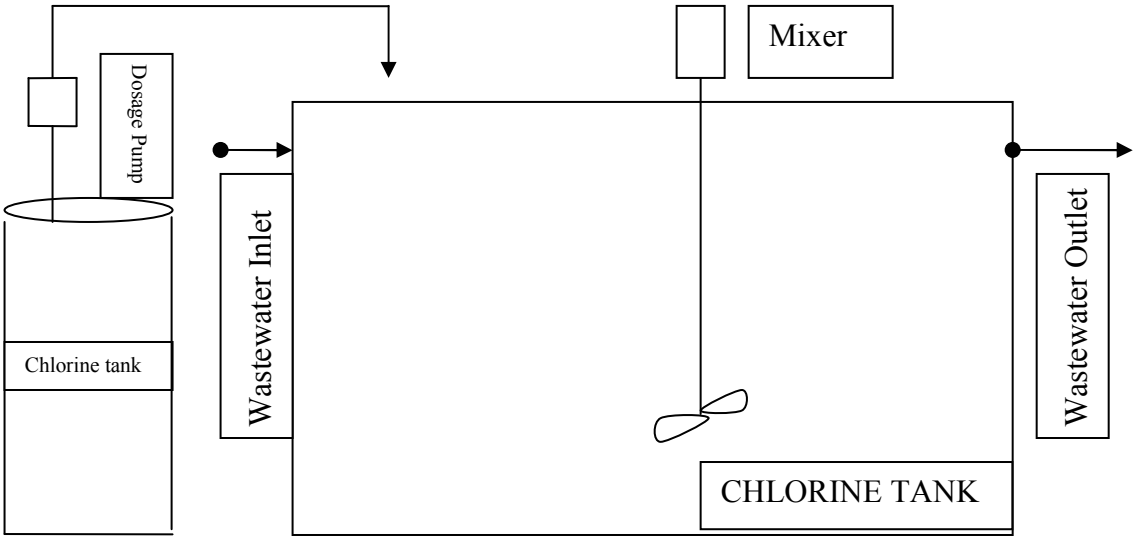

Figure 2.1 Schematic diagram of chlorination system used in laboratory studies.

2.3.2. UV Experiments

These groups of composite samples were taken continuously from the effluent and influent of UV disinfection plant. All samples were analyzed in wastewater treatment plant laboratory.

2.4. Analytical Methods

2.4.1. Sampling

Weekly samples were taken for three months. Samples from influent of UV disinfection plant were taken to the chlorination tank and continuous stirring has been applied for chlorination experiments. At the same time automatic dosing pump was started and after 30 minutes pump was stooped. And then samples of chlorination were taken. At the same time samples from UV disinfection plant effluent was also taken. COD, BOD, AOX, and pH parameters were monitored during this study for each groups of sample.

2.4.2. BOD Analysis

To determine BOD in laboratory studies Azide-winkler method is used. 300-mL glass stopper BOD bottle was filled with sample water. 2mL of manganese sulfate was added immediately to the collection bottle by inserting the calibrated pipette just below the surface of the liquid. The pipette was squeezed slowly so no bubbles were introduced via the pipette. 2 ml of alkali-iodide-azide reagent was added in the same manner. The bottle was stopped with care to be sure no air was introduced. The sample was mixed by inverting several times. Air bubbles were checked; the sample was discarded and was started over if any were seen. If oxygen was present, a brownish-orange cloud of precipitate or floc appeared. When this floc settled to the bottom, the sample was mixed by turning it upside down several times and was let it settle again.

2 ml of concentrated sulfuric acid was added via a pipette held just above the surface of the sample; and then carefully stopper and invert several times to dissolve the floc. At this point, the sample was "fixed" and could be stored for up to 8 hours if kept in a cool, dark place. As an added precaution, distilled water was squirted along the stopper, and the bottle was capped with aluminum foil and a rubber band during the storage period.

In a glass flask, 200 ml of the sample was titrated with sodium thiosulfate to a pale straw color. Titration was done slowly by dropping titrant solution from a calibrated pipette into the flask and was stirred or swirled the sample water. 2 mL of starch solution was added so that a blue color forms. It was kept on slowly titrating until the sample turned clear. As this experiment reached the endpoint, it took only one drop of the titrant to eliminate the blue color. The concentration of dissolved oxygen in the sample was equivalent to the number of milliliters of titrant used. Each milliliter of sodium thiosulfate added in steps 6 and 8 equals 1 mg/L dissolved oxygen.

2.4.3 COD Analyses

The COD measurements were carried out according to Standard Methods, titrimetric method 522 C. The solutions used in experiments are as follow as:

- Standard potassium dichromate digestion solution, 0.0167 M: 4.913 g $K_2Cr_2O_7$, primary standard grade, previously dried at 103 ^{0}C for 2 h, 167 ml conc. H_2SO_4, and 33.3 g were added to about 500 ml distilled water. Waited to dissolve and cooled to room temperature, and diluted to 1000 ml
- Sulfuric acid reagent: Ag_2SO_4 reagent in powdered form was added to conc. H_2SO_4 at a rate of 5.5 g Ag_2SO_4 /kg H_2SO_4. It was waited to dissolve for 1 to 2 days.
- Ferroin indicator solution: This indicator was bought in commercial form.
- Standard ferrous ammonium sulfate titrant (FAS), approximately 0.10 M: 39.2 g $Fe(NH_4)_2(SO_4)_26H_2O$ was dissolved in distilled water and 20 ml conc. H_2SO_4 was added. Before diluting to 1000 ml the solution was cooled.

The molarity of FAS solution was adjusted according to the volume of FAS used for blank titration:

$$M = \frac{\text{Volume of 0.0167 M } K_2Cr_2O_7 \text{ solution titrated, ml}}{\text{Volume of FAS used in titration, ml}} * 0.10$$

In COD measurements 10 ml cells were used. The volumes of the sample and the reagents added were: 2.5 ml sample, 1.5 ml standard potassium dichromate digestion solution and 3.5 ml sulfuric acid reagent. Before addition of the sample and the reagents, cells are washed with 20% H_2SO_4 to prevent contamination. The cells were placed in to the heater, which was preheated to 148 ^{0}C, and heated for 2 hours. The cells were waited to cool to room temperature, 1-2 drops of ferroin indicator was added and titrated with FAS solution. After ferroin addition the color turned off from yellow to green. With the addition of FAS the color changes from green to blue and the end point was a sharp color change from blue to reddish brown. The COD was calculated from the equation given below:

$$\text{COD as mgO}_2\text{/L} = \frac{(A-B) * M * 8000}{\text{ml sample}}$$

Where:

A: ml FAS used for blank

B: ml FAS used for sample,and

M: Molarity of FAS (Greenberg et al., 1992)

The materials used in this experiments were :

- Heater (Velp EC08)
- 10 ml cells.

2.4.4 pH Analyses

pH values were measubed by using WTW series 720 pH meter. Calibration of pH meter was carried out with standard solutions.

2.4.5. AOX Analyses

For AOX analyses samples were taken and then ph of the samples wereadjusted to pH=2 with sulfuric acid. AOX values were measured by using WTW series 720 AOX meter.

CHAPTER THREE
RESULTS AND DISCUSSIONS

The study contains chlorination and UV disinfection experiments. In the both chlorination and UV disinfection experiment, the effect of both processes on AOX, BOD, COD, pH parameters were examined. After two disinfection processes is applied on wastewater, comparison of two process efficiency on AOX, COD, BOD and pH parameters were investigated.

3.1 Chlorination Experiments

100 liter tank and natural wastewater was used for chlorination experiments. Samples were taken twice for a week. Samples were taken from effluent of domestic wastewater treatment plant and liquid sodium hypochlorite was put in to the tank by the dosage pump 10 mg/l was chosen as a chlorine dosage. 30 minutes was chosen as a contact time. Continuous stirring was taken place during chlorine dosage. After 30 minutes samples were taken out of tank

3.1.1 Effect of Chlorination on Parameter COD

Chlorination takes place at last step of domestic wastewater treatment. First aim of chlorination, providing the disinfection of treated wastewater. There was reduction on COD concentrations at chlorination process. Figure3.1. shows the effect of chlorination on COD removal. Average COD concentration at influent of chlorination was 34,30 mg/L .Average COD concentration in effluent of chlorination was 19,39 mg/L. Average COD removal was % 43.46. Maximum COD removal rate was obtained at 11.09.2004. Removal efficiency was %71. Minimum removal efficiency was obtained at 22.10.2004 and 01.10.2004. Removal efficiency was %21.74.

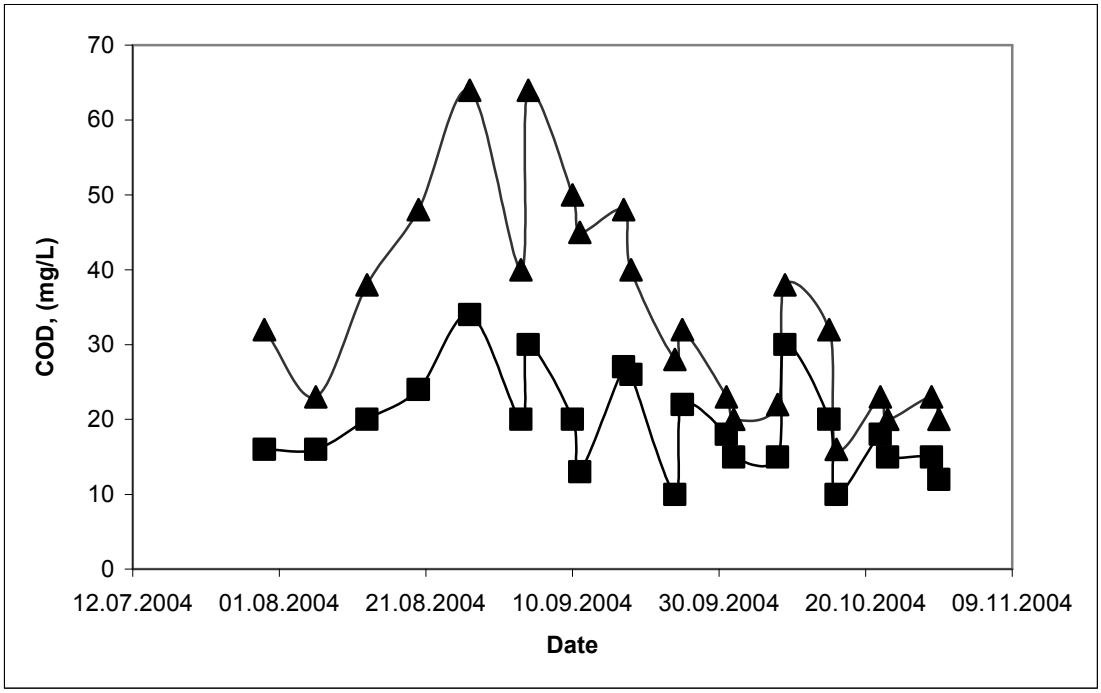

Figure 3.1 Variation of influent of UV disinfection plant and effluent of chlorination with time and different COD concentrations (—▲— influent of UV disinfection plant, —■— effluent of chlorination plant).

3.1.2 Effect of Chlorination on Parameter BOD

There was reduction on BOD concentrations at chlorination process also. Figure3.2. shows the effect of chlorination on BOD removal. Average BOD concentration at influent of chlorination was 19,56 mg/L .Average BOD concentration in effluent of chlorination was 6,30 mg/L. Average BOD removal was % 67,79. Maximum BOD removal efficiency was obtained at 30.10.2004. Removal efficiency was %85,71. Minimum removal efficiency was obtained at 24.09.2004. Removal efficiency was %51,38. Chlorination was more effective in BOD removal than COD removal.

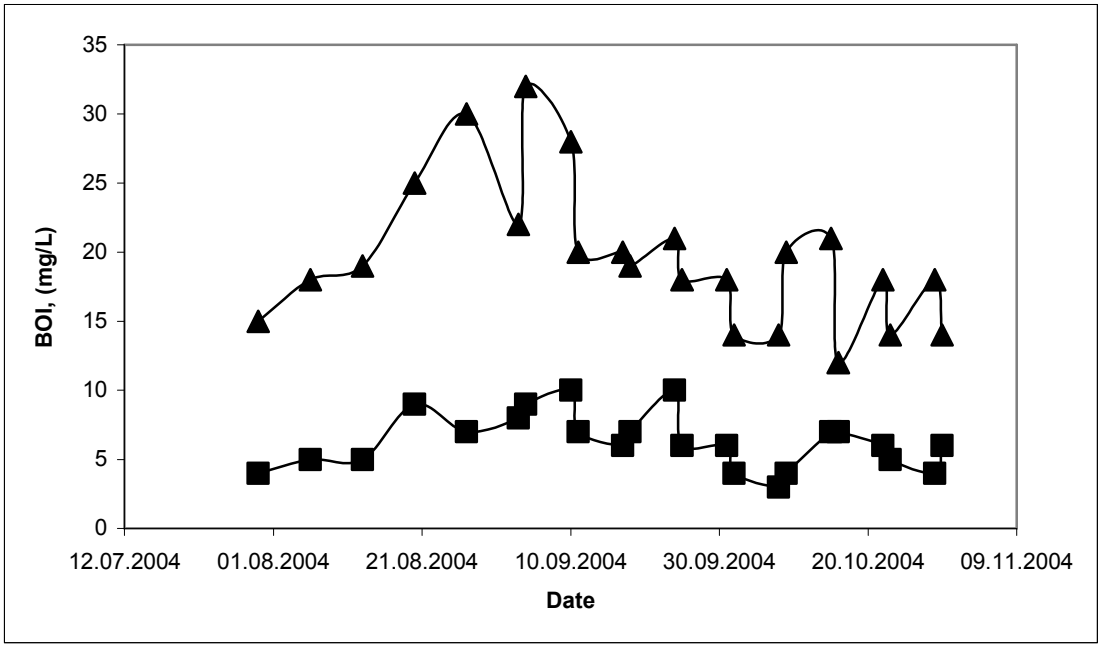

Figure 3.2 Variation of influent of UV disinfection plant and effluent of chlorination with time and different BOD concentrations (—▲— influent of UV disinfection plant, —■— effluent of chlorination plant).

3.1.3 Effect of Chlorination on Parameter AOX

AOX is the most important parameter to the environment. This parameter is important factor about choosing environment friendly disinfection method. There was no reduction on AOX concentrations at chlorination process. There was also increase at AOX concentrations in chlorination process. Figure3.3. shows the effect of chlorination on AOX removal. Average AOX concentration at influent of chlorination was 789,20 mg/L .Average AOX concentration in effluent of chlorination was 3029,91 mg/L. There was no reduction at AOX concentrations. Chlorination increased AOX concentrations in wastewater .Average AOX increase was % 320 . Maximum AOX increase was obtained at 08.10.2004. Increase efficiency was %950. Minimum increase was obtained at 30.10.2004 and 22.10.2004. Increase efficiency was %51. Chlorination process increased AOX concentrations in huge amounts.

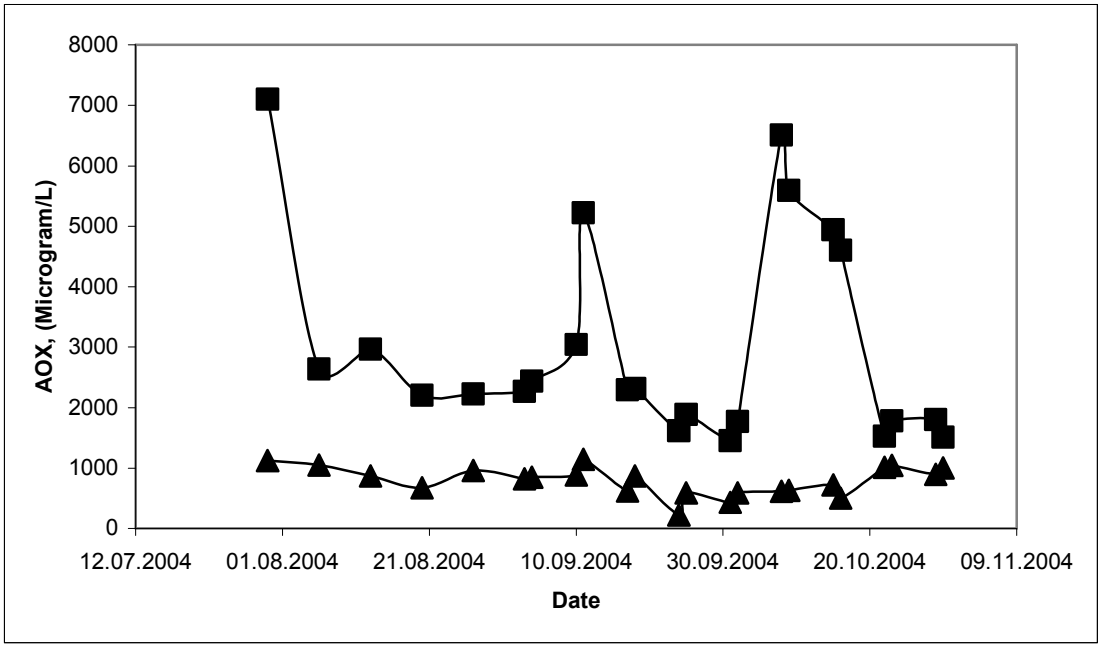

Figure 3.3 Variation of influent of UV disinfection plant and effluent of chlorination with time and different AOX concentrations (—▲— influent of UV disinfection plant, —■— effluent of chlorination plant).

3.1.3 Effect of Chlorination on Parameter pH

Effect of chlorination process on parameter ph was investigated also. Figure3.4. shows the effect of chlorination on pH. Average pH value at influent of chlorination was 7,18. Average pH value in effluent of chlorination was 8, 17. Chlorination caused a little increase at pH value. Average increase was % 114. The most identified increase was detected at date 30.07.2004. The increase was %118. The minimum identified increase at pH value was detected at date 03.09.2004. The increase was %108.

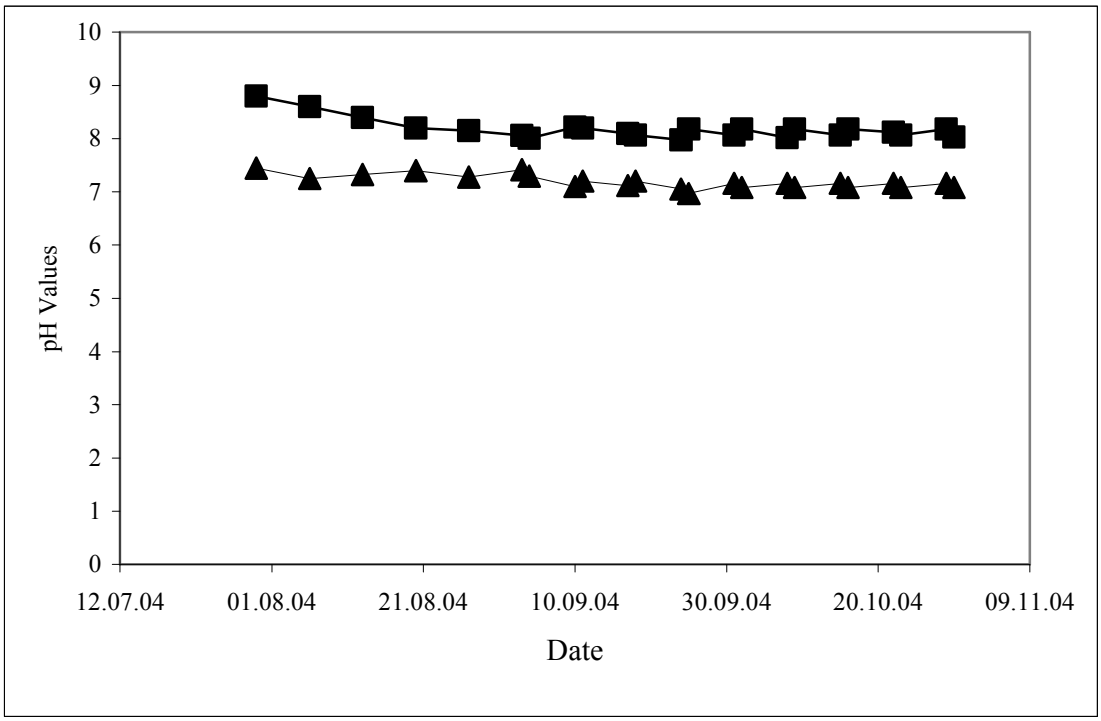

Figure 3.4 Variation of influent of UV disinfection plant and effluent of chlorination with time and different pH values (—▲— influent of UV disinfection plant, —■— effluent of chlorination plant).

3.2 UV disinfection Experiments

In the second part of study, UV disinfection process performance on parameters COD, AOX, BOD and pH was investigated. The samples were taken at the same time with chlorination experiments samples. Samples were taken from effluent of a UV plant that exists in the treatment plant.

3.2.1. Effect of UV Disinfection Process on Parameter COD

The effect of UV disinfection on COD was investigated. There was reduction on COD concentrations at UV disinfection process. Figure3.5. shows the effect of chlorination on COD removal. Average COD concentration at influent of UV plant was 34,30 mg/L .Average COD concentration in effluent of UV plant was 21,73 mg/L. Average COD removal was % 36,64. Maximum COD removal rate is obtained at 11.09.2004. Removal efficiency was %65. Minimum removal efficiency obtained at 09.10.2004. Removal efficiency was %16.

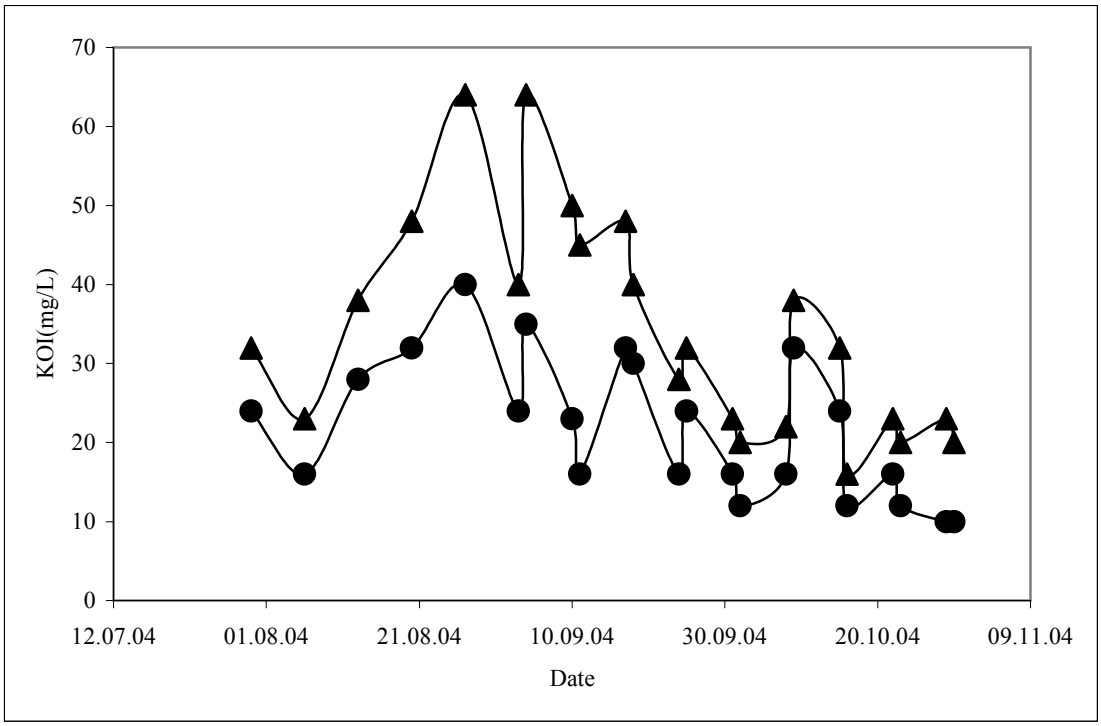

Figure 3.5 Variation of influent of UV disinfection plant and effluent of UV disinfection plant with time and different COD values (—▲— influent of UV disinfection plant, —●— effluent of UV disinfection plant).

3.2.2. Effect of UV Disinfection Process on Parameter BOD

Effect of UV disinfection on BOD parameter was investigated. There was reduction on BOD concentrations at UV disinfection process. Figure3.6. shows the effect of UV disinfection process on BOD removal. Average BOD concentration at influent of UV plant was 19,56 mg/L .Average BOD concentration in effluent of UV plant was 5,52 mg/L. Average BOD removal was % 72. Maximum BOD removal efficiency was obtained at 02.10.2004 and 08.10.2004. Removal efficiency was %85,71. Minimum removal efficiency was obtained at 24.09.2004. Removal efficiency was %38.

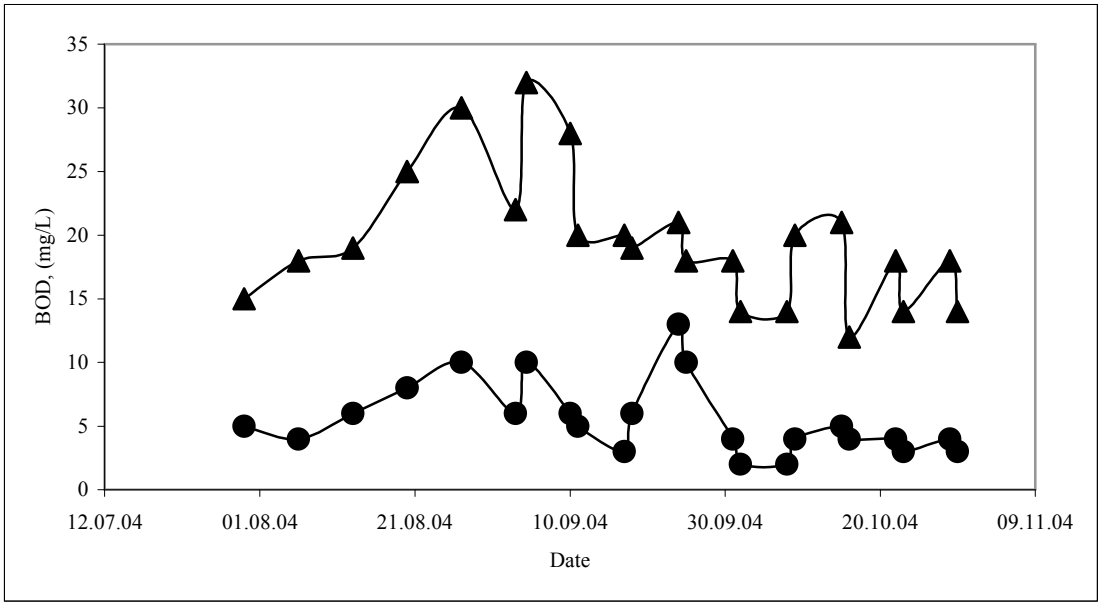

Figure 3.6 Variation of influent of UV disinfection plant and effluent of UV disinfection plant with time and different BOD values (—▲— influent of UV disinfection plant, —●— effluent of UV disinfection plant).

3.2.3. Effect of UV Disinfection Process on Parameter AOX

AOX is the most important parameter to the environment. This parameter is important factor about choosing environment friendly disinfection method. There was reduction on AOX concentrations at UV disinfection process. Figure3.7. shows the effect of UV disinfection process on AOX removal. Average AOX concentration at influent of UV plant was 789,20 mg/L .Average AOX concentration in effluent of UV plant was 660,69 mg/L. Average reduction was obtained at AOX in UV disinfection process was %14,75. Maximum AOX removal rate was obtained at 15.10.2004. Removal efficiency was %48. Minimum removal efficiency was obtained at 23.09.2004. Removal efficiency was %1.21

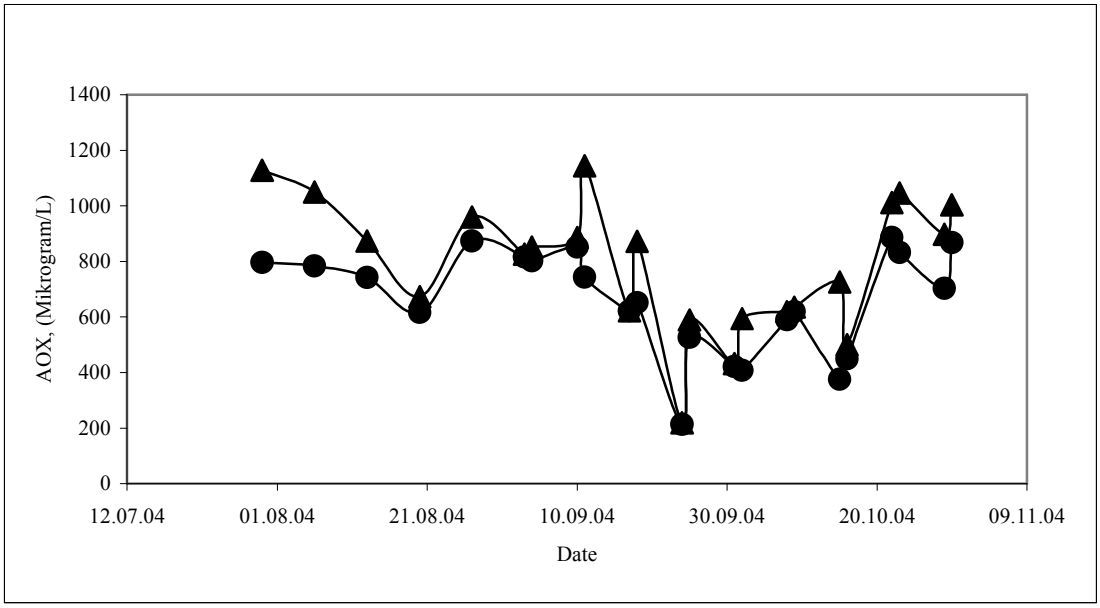

Figure 3.7 Variation of influent of UV disinfection plant and effluent of UV disinfection plant with time and different AOX values (—▲— influent of UV disinfection plant, —●— effluent of UV disinfection plant).

3.2.4. Effect of UV Disinfection Process on Parameter pH

Effect of UV disinfection process on parameter ph was investigated also. Figure3.8. shows the effect of chlorination on pH. Average pH values at influent of UV plant was 7,18. Average pH value in effluent of UV plant was 8, 17. Generally UV disinfection process had no effects on pH parameter. At six samples effluent ph values were less than influent pH values. At other samples there was a small pH increase at pH. When there was an increase most identified increase was detected at date 15.10.2004. The increase was %104. The minimum identified increase at pH value was detected at date 18.09.2004. The increase was %100,27. When there was a decrease most identified decrease was detected at date 30.07.2004. The decrease rate was %5. The minimum identified decrease was detected at date 04.09.2004. The decrease rate was %2.09.

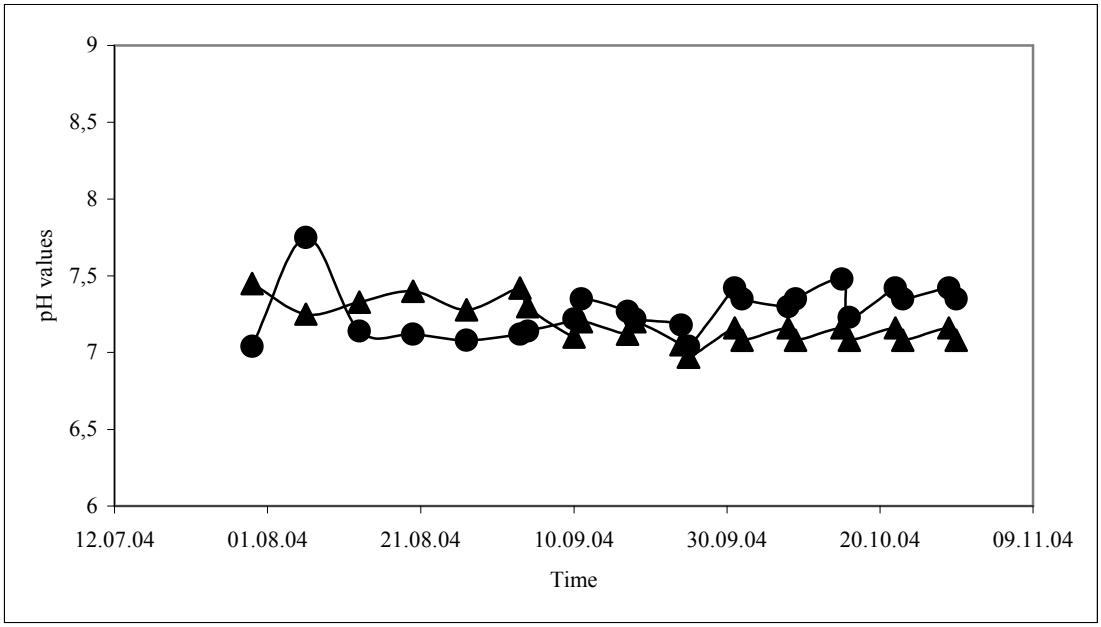

Figure 3.8 Variation of influent of UV disinfection plant and effluent of UV disinfection plant with time and different pH values (—▲— influent of UV disinfection plant, —●— effluent of UV disinfection plant).

CHAPTER FOUR
CONCLUSIONS AND DISCUSSIONS

The comparison of UV irridation and chlorination was investigated. The natural domestic wastewater was used in experiments. The chlorination experiments were done in a special reactor with 100 liter volume, 30 minutes contact time and 15 mg/L NaOCl concentration. For the UV experiment UV plant in Fethiye domestic wastewater treatment was used. The UV dose was 254 nm. The effects of two disinfection process on parameters COD, BOD, AOX and pH were investigated.

The chlorination process is effective at disinfection. Many years people use this process. The chlorination decreased COD in wastewater. NaOCL reacted with organics in wastewater so reduction at COD parameter was seen. The experimental studies indicated that average COD concentration at influent of chlorination was 34,30 mg/L .Average COD concentration in effluent of chlorination was 19,39 mg/L. Average COD removal was % 43.46.Maximum removal efficiency was %71. Minimum removal efficiency was %21.74. Chlorination was effective on COD removal and for domestic wastewater treatment plant provides lower COD concentrations at effluents.

The effects of chlorination on BOD were same as effect on COD parameter. There was reduction on BOD concentrations at chlorination process. Average BOD concentration at influent of chlorination was 19,56 mg/L .Average BOD concentration in effluent of chlorination was 6,30 mg/L. Average BOD removal rate was % 67,79. Maximum BOD removal efficiency was %85,71. Minimum removal efficiency was %51,38. Chlorination was more effective in BOD removal than in COD removal.

AOX is the most important parameter to the environment. This parameter is important factor about choosing environment friendly disinfection method. There was no reduction on AOX concentrations at chlorination process. There was also increase at AOX concentrations in chlorination process. Average AOX concentration at influent of chlorination was 789,20 mg/L .Average AOX concentration in effluent

of chlorination was 3029,91 mg/L. There was no reduction at AOX concentrations. Chlorination increased AOX concentrations in wastewater .Average AOX increase was % 320 . Maximum AOX increase efficiency was %950. Minimum increase was %51. Chlorination process increased AOX concentrations in huge amounts. This caused many problems at discharge areas. Recent years carcinogenic effects of chlorine are argued so much. Parameter AOX shows carcinogenic effects of wastewater. The experimental studies show that chlorination was not the environment-friendly disinfection method at domestic wastewater disinfection.

Effect of chlorination process on parameter ph was investigated also. Average pH values at influent of chlorination was 7,18. Average pH value in effluent of chlorination was 8, 17. Chlorination caused a little increase at ph value. Average increase was % 113. The most identified increase was %118. The minimum identified increase at pH value was %108. The chlorination did not cause ph problems.

In summary for chlorination experiments, chlorination was effective on the COD and BOD removal; but chlorination increased AOX values in treated wastewater. This increase may cause a problem on discharge areas. In chlorination AOX values in effluent of process were almost four times bigger than values in effluent. Chlorination had no important effect on parameter ph; but if pH of raw wastewater was high this little increase may cause a problem about providing discharge criteria.

In the second part of study, UV disinfection process performance on parameters COD, AOX, BOD and pH was investigated. The samples were taken at the same time with chlorination experiments samples. Samples were taken from effluent of a UV plant that exists in the treatment plant. The effect of UV disinfection on COD was investigated. There was reduction on COD concentrations at UV disinfection process. Average COD concentration at influent of UV plant was 34,30 mg/L .Average COD concentration in effluent of UV plant was 21,73 mg/L. Average COD removal was % 36,64. Maximum COD removal rate was %65. Minimum removal efficiency Removal efficiency was %16. UV disinfection process showed lower performance than chlorination at COD removal.

Effect of UV disinfection on BOD parameter was investigated. There was reduction on BOD concentrations at UV disinfection process. Average BOD concentration at influent of UV plant was 19,56 mg/L .Average BOD concentration in effluent of UV plant was 5,52 mg/L. Average BOD removal was % 72. Maximum BOD removal efficiency was %85,71. Minimum removal efficiency was %38. UV disinfection shows almost same performance with chlorination on BOD removal.

The most important difference between chlorination and UV disinfection was seen on parameter AOX. There was reduction on AOX concentrations at UV disinfection process. Average AOX concentration at influent of UV plant was 789,20 mg/L .Average AOX concentration in effluent of UV plant was 660,69 mg/L. Average reduction obtained at AOX in UV disinfection process was %14,75. Maximum AOX removal rate was %48. Minimum removal efficiency was %1.21

Effect of UV disinfection process on parameter ph was investigated also. Average pH values at influent of UV plant was 7,18. Average pH value in effluent of UV plant was 8, 17. Generally UV disinfection process had no effects on pH parameter. At six samples effluent ph values were less than influent pH values. At other samples there was a small pH increase at pH. When there was an increase most identified increase was %4. The minimum identified increase at pH value was %0,27. When there were a decrease maximum identified decrease rate was %5. The minimum identified decrease rate was %2.09.

Finally, the experimental results indicated that the there were no difference between chlorination and UV disinfection process on removal of COD,BOD and pH at domestic wastewater. The significant difference was detected on removal of parameter AOX which is too important about carcinogenic effects on discharge areas. This difference between UV disinfection process and chlorination makes UV disinfection process more environment-friendly disinfection process. UV disinfection process could be used at big domestic wastewater treatment plants.

CHAPTER FIVE
RECOMMENDATIONS

Chlorination is well-known disinfection process that is used for many years in both wastewater and drinking water treatment. Especially in recent years because of chlorine bad effects on human beings and aquatic life, many studies about developing environment-friendly disinfection methods have been done. UV disinfection process is one of these environment-friendly disinfection methods. UV gives satisfying results about disinfection. However UV systems need further studies understand the possible effects on carcinogenic substances in waster and wastewater. These carcinogenic substances are determined as AOX. AOX contains large group of chemicals. Therefore the following studies are recommended as further studies;

1. The effect of UV dose about removal of AOX shown in wastewater and drinking water can be investigated,
2. The comparison of UV disinfection and chlorination about removal of AOX in industrial wastewaters can be investigate,
3. Differences about applying UV technology to the wastewater and effects of this different applying methods on AOX can be investigated,
4. The different chlorine compounds can be applied to the wastewater as a disinfectant. The effects of this different chlorine compounds on parameter AOX can be searched,
5. Studies about extending UV lamps life and effects in discharge line can be investigated.

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APPENDICES

RAW DATA OF EXPERIMENTAL STUDIES

TableA.1 Raw data of Influent and effluent of chlorınızatıon for COD analyse

Date	Influent COD(mg/L)	Effluent COD(mg/L)	Removal Rate (%)
30.07.2004	32	16	50
06.08.2004	23	16	30
13.08.2004	38	20	47
20.08.2004	48	24	50
27.08.2004	64	34	47
03.09.2004	40	20	50
04.09.2004	64	30	53
10.09.2004	50	20	60
11.09.2004	45	13	71
17.09.2004	48	27	44
18.09.2004	40	26	35
24.09.2004	28	10	64
25.09.2004	32	22	31
01.10.2004	23	18	22
02.10.2004	20	15	25
08.10.2004	22	15	32
09.10.2004	38	30	21
15.10.2004	32	20	38
16.10.2004	16	10	38
22.10.2004	23	18	22
23.10.2004	20	15	25
29.10.2004	23	15	35
30.10.2004	20	12	40

Table A.2 Raw data of influent and effluent of chlorinization for BOD analyses

Date	Influent BOD(mg/L)	Effluent BOD(mg/L)	Removal Rate (%)
30.07.2004	15	4	73
06.08.2004	18	5	72
13.08.2004	19	5	74
20.08.2004	25	9	64
27.08.2004	30	7	77
03.09.2004	22	8	64
04.09.2004	32	9	72
10.09.2004	28	10	64
11.09.2004	20	7	65
17.09.2004	20	6	70
18.09.2004	19	7	63
24.09.2004	21	10	52
25.09.2004	18	6	67
01.10.2004	18	6	67
02.10.2004	14	4	71
08.10.2004	14	3	79
09.10.2004	20	4	80
15.10.2004	21	7	67
16.10.2004	12	7	42
22.10.2004	18	6	67
23.10.2004	14	5	64
29.10.2004	18	4	78
30.10.2004	14	6	57

TableA.3 Raw data of influent and effluent of chlorinization for AOX analyses

Date	Influent AOX (mg/L)	Effluent AOX (mg/L)	Increase Rate (%)
30.07.2004	1128	7104	530
06.08.2004	1050	2638	151
13.08.2004	874	2964	239
20.08.2004	674	2202	227
27.08.2004	960	2224	132
03.09.2004	826	2266	174
04.09.2004	852	2434	186
10.09.2004	886	3046	244
11.09.2004	1144	5218	356
17.09.2004	622	2294	269
18.09.2004	872	2312	165
24.09.2004	220	1616	635
25.09.2004	590	1886	220
01.10.2004	432	1454	237
02.10.2004	594	1768	198
08.10.2004	620	6510	950
09.10.2004	636	5592	779
15.10.2004	726	4938	580
16.10.2004	500	4600	820
22.10.2004	1012	1528	51
23.10.2004	1046	1780	70
29.10.2004	898	1802	101
30.10.2004	1004	1512	51

Table A.4 Raw data of influent and effluent of chlorinization for pH analyses

Date	Influent pH	Effluent pH	Increase Rate (%)
30.07.2004	7,45	8,8	18
06.08.2004	7,25	8,6	19
13.08.2004	7,33	8,4	15
20.08.2004	7,4	8,2	11
27.08.2004	7,28	8,15	12
03.09.2004	7,42	8,06	9
04.09.2004	7,3	8,01	10
10.09.2004	7,1	8,22	16
11.09.2004	7,2	8,2	14
17.09.2004	7,12	8,1	14
18.09.2004	7,2	8,07	12
24.09.2004	7,05	7,98	13
25.09.2004	6,97	8,18	17
01.10.2004	7,16	8,07	13
02.10.2004	7,08	8,18	16
08.10.2004	7,16	8,02	12
09.10.2004	7,08	8,18	16
15.10.2004	7,16	8,07	13
16.10.2004	7,08	8,18	16
22.10.2004	7,16	8,12	13
23.10.2004	7,08	8,07	14
29.10.2004	7,16	8,18	14
30.10.2004	7,08	8,03	13

TableA.5 Raw data of influent and effluent of UV for COD analyses

Date	Influent COD(mg/L)	Effluent COD(mg/L)	Removal Rate (%)
30.07.2004	32	24	25
06.08.2004	23	16	30
13.08.2004	38	28	26
20.08.2004	48	32	33
27.08.2004	64	40	38
03.09.2004	40	24	40
04.09.2004	64	35	45
10.09.2004	50	23	54
11.09.2004	45	16	64
17.09.2004	48	32	33
18.09.2004	40	30	25
24.09.2004	28	16	43
25.09.2004	32	24	25
01.10.2004	23	16	30
02.10.2004	20	12	40
08.10.2004	22	16	27
09.10.2004	38	32	16
15.10.2004	32	24	25
16.10.2004	16	12	25
22.10.2004	23	16	30
23.10.2004	20	12	40
29.10.2004	23	10	57
30.10.2004	20	10	50

Table A.6 Raw data of influent and effluent of UV for BOD analyses

Date	Influent BOD (mg/L)	Effluent BOD (mg/L)	Removal Rate (%)
30.07.2004	15	5	67
06.08.2004	18	4	78
13.08.2004	19	6	68
20.08.2004	25	8	68
27.08.2004	30	10	67
03.09.2004	22	6	73
04.09.2004	32	10	69
10.09.2004	28	6	79
11.09.2004	20	5	75
17.09.2004	20	3	85
18.09.2004	19	6	68
24.09.2004	21	13	38
25.09.2004	18	10	44
01.10.2004	18	4	78
02.10.2004	14	2	86
08.10.2004	14	2	86
09.10.2004	20	4	80
15.10.2004	21	5	76
16.10.2004	12	4	67
22.10.2004	18	4	78
23.10.2004	14	3	79
29.10.2004	18	4	78
30.10.2004	14	3	79

TableA.7 Raw data of influent and effluent of UV for AOX analyses

Date	Influent AOX (mg/L)	Effluent AOx (mg/L)	Removal Rate (%)
30.07.2004	1128	796	29
06.08.2004	1050	784	25
13.08.2004	874	742	15
20.08.2004	674	616	9
27.08.2004	960	874	9
03.09.2004	826	816	1
04.09.2004	852	802	6
10.09.2004	886	852	4
11.09.2004	1144	744	35
17.09.2004	622	622	0
18.09.2004	872	652	25
24.09.2004	220	214	3
25.09.2004	590	526	11
01.10.2004	432	422	2
02.10.2004	594	408	31
08.10.2004	620	590	5
09.10.2004	636	620	3
15.10.2004	726	376	48
16.10.2004	500	450	10
22.10.2004	1012	886	12
23.10.2004	1046	832	20
29.10.2004	898	704	22
30.10.2004	1004	868	14

Table A.8 Raw data of influent and effluent of UV for pH analyses

Date	Influent pH	Effluent pH	Removal&Increase Rate (%)
30.07.2004	7,45	7,04	6
06.08.2004	7,25	7,75	-7
13.08.2004	7,33	7,14	3
20.08.2004	7,4	7,12	4
27.08.2004	7,28	7,08	3
03.09.2004	7,42	7,12	4
04.09.2004	7,3	7,14	2
10.09.2004	7,1	7,22	-2
11.09.2004	7,2	7,35	-2
17.09.2004	7,12	7,27	-2
18.09.2004	7,2	7,22	0
24.09.2004	7,05	7,18	-2
25.09.2004	6,97	7,04	-1
01.10.2004	7,16	7,42	-4
02.10.2004	7,08	7,35	-4
08.10.2004	7,16	7,3	-2
09.10.2004	7,08	7,35	-4
15.10.2004	7,16	7,48	-4
16.10.2004	7,08	7,23	-2
22.10.2004	7,16	7,42	-4
23.10.2004	7,08	7,35	-4
29.10.2004	7,16	7,42	-4
30.10.2004	7,08	7,35	-4