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أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

The Impact of Ozonation On Wastewater Treatment And Disinfection

تأثير الاوزون في عملية تطهير وتعقيم المياه العادمة

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THE IMPACT OF OZONATION ON WASTEWATER TREATMENT AND DISINFECTION

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **أحمد حسن محمد أبو ورد** لنيل درجة الماجستير في **كلية *الهندسة* قسم الهندسة المدنية– هندسة مصادر المياه** وموضوعها:

تأثير الأوزون في عملية معالجة وتعقيم المياه العادمة

The Impact Of Ozonation On Wastewater Treatment And Disinfection

وبعد المناقشة التي تمت اليوم الثلاثاء 29 شعبان 1436هـ، الموافق 2015/06/16م الساعة العاشرة والنصف صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/ قسم الهندسة المدنية- هندسة مصادر المياه.**

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

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Abstract

The main goal of the current research is to study the efficiency of ozonation on wastewater treatment and effluent disinfection, investigate the effect of ozonation on the oxidation of organic matter and Fecal coliform and investigate the wastewater quality parameters (COD , FC , NH_3-N,TDS , pH) that can be affected by Ozone .

The samples taken at two stages first stage was 4 liter from Gaza Wastewater Treatment Plant influent, the second stage was 10 liters from the effluent. In each experiment the samples were divided to two parts. First part without disinfection, the second part for disinfection.

Results prove that wastewater treated by ozone leads to reduction of COD parameter ranging from (9%-64%), FC (25% – 83%). However, no major change for NH3-N ,PH and TDS parameters was observed .

The ozonation process added to the samples at different time intervals (30 , 45 , 60, 90 and 120) minutes .

Results show that COD reduction satisfy the Palestinian standard for wastewater reuse .Fecal Coliforms reduction observed satisfy the Palestinian standard for wastewater reuse , NH_3-N reduction observed unsatisfied the Palestinian standard for wastewater reuse .

In conclusion, the ozonation time has clear influence on the reduction of COD,FC and NH_3-N

Dedication:

To my Father and to my Mother, for her kindness

To my Brothers and Sisters

To my Friends, Colleagues

To the Islamic University of Gaza

And to all those who believe in the richness of learning

Ahmed Abu Ward

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Abbreviations

BOD Biochemical Oxygen Demand

CBOD Carbonaceous Biochemical Oxygen Demand

CFU Colony Forming Unit (bacteriology)

COD Chemical Oxygen Demand

CSBE Center for the Study of the Built Environment

DO Dissolved Oxygen

EPA Environment Protection Agency

ESTS Environmentally Sound Technologies

EU European Union

EWASH Emergency Water, Sanitation and Hygiene Group

FC Fecal Coliforms

FOG Fats, Oils and Grease

GWWTP Gaza Wastewater Treatment Plant

LCC Life Cycle Cost

MOH Ministry of Health

MPN Most Probable Number

NBOD Nitrogenous Biochemical Oxygen Demand

RNA Ribonucleic Acid

SS Suspended Solids

TOC Total Organic Carbon

TSS Total Suspended Solid

U.S United State

UNEP United Nations Environmental Program

UNICEF United Nations International Children's Emergency Fund

UV Ultraviolet

WHO World Health Organization

WW Wastewater

WWR Wastewater Reuse

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CHAPTER 1: INTRODUCTION

1.1Background

The reuse of wastewater is one of the main options being considered as a new source of water in regions where water is scarce. However wastewater reuse can also be linked with human health risks – for farmers as well as for crop consumers -as wastewater can contain enteric viruses, pathogenic bacteria and protozoa. Some chemical wastewater components, such as nitrogen, and phosphorus, may have both positive and negative effects on plant growth, crop yields, and the environment. Others, such as suspended solids, high salt levels loads, can be disadvantageous for agricultural soils and irrigation infrastructure. In order to reduce negative impacts, many countries have adopted standards and guidelines, that regulate wastewater reuse in agriculture. (Annika Kramer and Julika Post, 2003)

Treatment and disinfection of wastewater are important to provide water that is both safe and aesthetically appropriate for reuse. Inadequately treated or disinfected wastewater presents a risk of infection to end users from pathogens in the reused wastewater. To date, no incidences of illness linked to wastewater reuse have been reported and so the health risks appear to be low, however, studies on the health impacts of wastewater reuse are limited. The pollutant load of wastewater check is less than that of domestic sewage but the occurrence of fecal indicator bacteria in wastewater (Casanova et al. 2001a; Ottoson and Stenström, 2003a; Friedler, 2004).

Wastewater reuse has become an attractive option for protecting the environment and extending available water resources. In the last few years, there has been a significant diversification of water reuse practices, such as green space and crop irrigation, recreational impoundment, various urban uses including toilet flushing, industrial applications and water supply augmentation through groundwater or reservoir recharge. The safe operation of water reuse systems depends on the reliability of wastewater disinfection, which is the most important treatment process for public health protection. (Lazarova V. et al., 2000)

The health-related microbiological regulations and the more recent impetus of producing virus-free effluents require the development of highly effective advanced disinfection processes. Chlorination is still the most widely used means to inactivate pathogenic microorganisms in water and wastewater, but alternative technologies have to be evaluated because of increasing concern over undesirable byproducts after chlorination and its inefficiency in eliminating some epidemic microorganisms at low chlorine doses. (Levine B. el al.,1997) .

Wastewater treatment technologies must be robust to handle variations in organic and pathogen concentration in wastewater influent, and to consistently produce effluent of an appropriate and safe quality to meet required standards for reuse. Biological processes, which range from state-of-the-art membrane bioreactors to low-tech constructed wetland systems, are considered most appropriate for treatment of wastewater because of their efficient removal of organics (Jefferson et al., 2001; Pidou et al., 2007).

The quality of treated effluent is important because of its impact on reuse applications (Wiel-Shafran et al., 2006) and downstream disinfection. Organics increase disinfectant demand in treated effluent, reducing the efficacy of disinfection (LeChevallier et al., 1981), and provide substrate for pathogen regrowth (Narkis et al., 1995). The removal of suspended solids is also important as particulate matter can shield pathogens from disinfection (Dietrich et al., 2003)

Many researchers initially sought to achieve a measurable level of dissolved ozone residual in treated wastewater, which resulted in high ozone dosages that were not economically feasible. Earlier studies pointed out the need for a thorough investigation of wastewater ozone treatment in order to predict disinfection performance and design the disinfection system for wastewater disinfection.

Ozone is particularly beneficial for the disinfection of potable water because it is effective against both bacteria and viruses and can also remove cysts and eggs (Anderson, 1997; Langlais et al., 1991; Rice and Netzer, 1984); currently, there is considerable interest in its effectiveness against the Cryptosporidium parvum cyst, in particular. In the context of wastewater treatment, the high reactivity of ozone makes it appropriate for achieving certain objectives when applied either alone or in combination with other processes (e.g., filtration). These objectives relate to either the need to achieve higher quality standards prior to final discharge or to meeting standards for effluent recycling. Specifically, the objectives may include color removal, disinfection, the degradation of organic micro pollutants, the conversion of “hard” chemical oxygen demand (COD), and effluent oxygenation.

The heterogeneous nature of municipal wastewaters and the economic limitation of ozone application make it unlikely that organic substrates can be completely degraded (to carbon dioxide and water) by ozone treatment. This has led to concern over the presence of intermediate byproduct compounds that may be of toxicological significance. Many studies have been conducted concerning the reactivity of ozone and its secondary oxidants with a wide range of inorganic and organic substances (Hoigne´, 1998).

Water demand in the Gaza Strip is increasing continuously due to population increase while the water resources are constant or even decreasing due to urban development. The Gaza Strip is classified as a semi-arid region and suffers from water scarcity. The renewable amount of water that replenishes the groundwater system is much less than the demanded amount, and this resulted in deterioration of the groundwater system in both quantitative and qualitative aspects (Jarboo and Al-Najar, 2015). The annual average rainfall varies from (400-200mm) at the north to south respectively. Total abstraction of groundwater in Gaza Governorates exceed 200Mm^3 $year^{-1}$ (PWA, 2014). Around two third of groundwater pumped through more than 10000 wells used for agriculture propose. 110 Mm^3 annual deficit of water balance, due to increasing of the gap between water demand and water supply, as a result of rapid population growth in this small area (PWA, 2014).

Therefore, there is an urgent need to conserve and protect fresh water and to use the water of low quality for irrigation. The use of treated wastewater (reclaimed water) for irrigation could be one of the main options to develop the water resources in the Gaza Strip as it represents an additional renewable and reliable water resource (Al-Najar, 2007).

Using treated effluent for agricultural purposes would reduce the deficit and would reduce the degradation of the groundwater quality compared to its direct disposal to the surface or groundwater bodies. However the use of treated wastewater for irrigation is subject to major concern because of the probable escalating of social and environment problem. In addition, wastewater is a valuable source of plant nutrients and organic matter needed for maintaining fertility and productivity levels of the soil.

On the other hand, wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts. Consequently, mismanagement of wastewater irrigation would create environmental and health problems to the ecosystem and human beings. In the Gaza Strip, it is assumed that there are four Wastewater Treatments Plants: BeitLahia Wastewater Treatment Plant, Gaza Wastewater Treatment Plant, Rafah Wastewater Treatment Plant and Khan Younis Temporary Treatment Plant (KYTTP).

Using treated effluent for agricultural purposes would minimize the deficit and would reduce the degradation of the groundwater quality (Al-Najar, 2011). Contribution in protection the water resources as input to sustainable development plan in the Gaza Stip.

1.2 Problem Definition

Water scarcity is a major constraint for economic and social development in semi-arid areas such as the Palestinian Territories. Such water scarcity will become more critical as domestic and industrial sectors place higher and higher demand on water; Palestine will experience serious water deficit which will be about in year 2020 (Maher Abu-Madi, 2008) .

Water uses in Gaza Strip for domestic purposes varies from 75 l/c/d to 107 l/c/d with an average of 96 l/c/d . The coverage of wastewater network in Gaza Strip,72% for population 1552330 capita the wastewater production 113000 m^3/day . (PWA, 2011)

The severely limited water resources in Palestine forced to search for other water resources, even those with inferior quality; in several locations, wastewater reuse is used by farmers for irrigation of fruit trees and vegetables. Various alternatives including inter basin water transfers and desalination have been recognized for augmenting water availability. However, in most cases, these alternatives are expensive and face daunting logistical and political constraints.

The reuse of treated wastewater, particularly in irrigated agriculture, are the most recommended alternatives for alleviation of the sever water shortage in Palestine(Research and Development, 2007). This is mainly because agriculture dominates the Palestinian water consumption with about 50%, while leaving 50% for domestic and industrial purposes (PWA,2014).

Reuse of treated wastewater in irrigated agriculture would, on one hand, provide additional water supplies and, on the other hand, it would reduce environmental pollution caused by untreated/poorly treated wastewater. The safe operation of water reuse systems depends on the reliability of wastewater disinfection, which is the most important treatment process for public health protection. The health-related microbiological regulations and the more recent impetus of producing virus-free effluents require the development of highly effective advanced disinfection processes.

Chlorination system is installed in most of wastewater treatment plants to disinfect the treated effluent before its disposal to the sea or small scale reuse farms. This system is not anymore functioning and there is much concern given to the undesirable byproduct. This research is the first attempt to study the efficiency of ozonation system on wastewater treatment.

1.3 Objectives

The main goal of the current research is to study the efficiency of ozonation on wastewater treatment and effluent disinfection.

The following objectives are formulated to reach the main goal:

- To investigate the effect of ozonation on the oxidation of organic matter and Fecal coliform.
- To determine the best ozontion time to achieve fecal coliform removal based on the local standards.
- Investigate the wastewater quality parameters that can be affected by Ozone

CHAPTER 2: LETRATUREREVEW

2.1 Introduction

The term "wastewater" properly means any water that is no longer wanted, as no further benefits can be derived out of it. About 99 percent of wastewater is water, and only one percent is solid wastes. An understanding of its potential for reuse to overcome shortage of freshwater existed in Minoan civilization in ancient Greece, where indications for utilization of wastewater for agricultural irrigation date back to 5000 years. Sewage farm practices have been recorded in Germany and United Kingdom since 16th and 18th centuries, respectively.

Irrigation with sewage and other wastewaters has a long history also in China and India. In the more recent history, the introduction of waterborne sewage collection systems during the 19^{th} century, for discharge of wastewater into surface water bodies led to indirect use of sewage and other wastewaters as unintentional potable water supplies. Such unplanned water reuse coupled with inadequate water and wastewater treatment, resulted in catastrophic epidemics of waterborne diseases during 1840s and 50s. However, when the water supply links with these diseases became clear, engineering solutions were implemented that include the development of alternative water sources using reservoirs and aqueduct systems, relocation of water intakes, and water and wastewater treatment systems.

Controlled wastewater irrigation has been practiced in sewage farms many countries in Europe, America and Australia since the turn of the current century. For the last three decades or so, the benefits of promoting wastewater reuse as a means of supplementing water resources and avoidance of environmental degradation have been recognized by national governments.

The value of wastewater is becoming increasingly understood in arid and semi-arid countries and many countries are now looking forward to ways of improving and expanding wastewater reuse practices. Research scientists, aware of both benefits and hazards, are evaluating it as one of the options for future water demands (S. Vigneswaran,2004) .

2.2 Wastewater Treatment

2.2.1 Introduction

Water-related problems are increasingly recognized as one of the most immediate and serious environmental threats to human kind. Water use has more than tripled globally since 1950, and one out of every six persons does not have regular access to safe drinking water. Lack of access to a safe water supply and sanitation affects the health of 1.2 billion people annually (WHO and UNICEF, 2000).

The latest Global Environment Outlook of the United Nations Environmental Program (UNEP) reports that about one third of the world's populations currently live in countries suffering From moderate-to-high water stress, where water consumption is more than 10% of renewable freshwater resources. These problems may be attributed to many factors. Inadequate water management is accelerating the depletion of surface water and groundwater resources. Water quality has been degraded by domestic and industrial pollution sources as well as non-point sources. In some places, water become polluted owing to a lack of sanitation infrastructure and services. Over-pumping of groundwater has also compounded water quality degradation caused by salts, pesticides, naturally occurring arsenic, and other pollutants.

In urban areas, demand for water has been increasing steadily, owing to population growth, industrial development, and expansion of irrigated peri-urban agriculture. Population growth in urban areas is of particular concern for developing countries. Population growth is expected to occur in developing nations, as developed regions are projected to see their population decrease by 6% over the next 50years. The rural population is expected to stabilize at around 3.2 billion, indicating that the growing population will settle in urban areas (WHO and UNICEF, 2000).

Many parts of the world are facing changes in climatic conditions, such as rainfall patterns, flood cycles, and droughts, which affect the water cycle. Faced with these challenges, there is an urgent need to improve the efficiency of water consumption, and to augment the existing sources of water with more sustainable alternatives. Numerous approaches, modern and traditional, exist throughout the world for efficiency improvements and augmentation. Among such approaches, wastewater reuse has become increasingly important in water resource management for both environmental and economic reasons.

Wastewater reuse has primarily a long history of applications, in agriculture, and additional areas of applications, including industrial, household, and urban, are becoming more prevalent. Of them all, wastewater reuse for agriculture still represents the large reuse volume, and this is expected to increase further, particularly in developing countries (UNEP, 2002a).

With such an increase in applications, there is a concurrent recognition that water resource management and proper water cycle maintenance requires up-to-date knowledge about basic practices, benefits and potential risks, capacity building of practitioners and planners, and appropriate policy frameworks to protect human health and the environment. In cities and regions of developed countries, where wastewater collection and treatment have been the common practice, wastewater reuse is practiced with proper attention to sanitation, public health and environmental protection. The situation is different in many developing countries owing to the lack of appropriate capacity and resources to enforce strict wastewater treatment standards for its reuse.

Wastewater reuse for irrigation is quite common in many places; therefore, the poor quality of wastewater may pose substantial health risks for the farmers as well as consumers of those agricultural products. The World Health Organization (WHO) has been working to draw up and update the guidelines for wastewater reuse in agriculture.

2.2.2 Components of Wastewater

Effluent quality is the physical, biological, and chemical characteristics of a liquid flowing from a component or device. The components of wastewater may be divided into four categories:

- biochemical oxygen demand, total suspended solids and fats, oils and grease (BOD_5, TSS, FOG),
- pathogens (fecal coliform, viruses),
- nutrients (nitrogen, phosphorus), and
- Other chemicals.

2.2.3Types of BOD

High-strength wastewater is defined as influent having BOD_5 greater than 300 mg/L; and/or TSS greater than 200 mg/L; and/or fats, oils, and grease greater than 50 mg/L entering a pretreatment component (as defined by NSF Standard 40 testing protocol).

2.2.3.1Biochemical Oxygen Demand

Biochemical Oxygen Demand is the quantity of dissolved oxygen consumed by microorganisms during the microbial and chemical oxidation of the constituents contained in a wastewater sample during an incubation period at a given temperature. The biochemical oxygen demand represents the oxygen utilized during the oxidation of both carbon and nitrogenous compounds.

2.2.3.2Biochemical Oxygen Demand (BOD5)

Biochemical Oxygen Demand – 5-day is the quantity of dissolved oxygen consumed by microorganisms during the breakdown of organic matter in a wastewater sample during a 5-day incubation period and measured in mg/L at 20^oC. It is used as a means to describe the amount of organic matter present in the water.

Biodegradable organic matter is provided in terms of pounds of BOD_5 per person (capita) per day by using the BOD_5 concentration and daily flow. Biochemical oxygen demand is a measure of the oxygen required by bacteria, chemicals, and other organisms to break down organic matter over a five day period. It is an indicator of the overall strength of the wastewater.

2.2.3.3 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is a measure of the amount of organic matter oxidized by a strong chemical oxidant. COD is used to measure organic matter in commercial, industrial, and municipal wastes that contain compounds toxic to biological life where the BOD_5 test would not work. The COD levels in a wastewater sample are almost always greater than BOD_5 levels because more compounds can be chemically oxidized in the COD test than can be biologically oxidized in the BOD test. In most cases, once the COD/BOD_5 relationship is known for a particular facility, the COD concentration of a sample can be used to approximate the BOD_5 concentration. The COD test can generally be done within 2.5 hours, whereas a BOD_5 test takes five days. A COD test is performed when a quick determination of oxygen demand is needed.

2.2.4 Types of microbiological

2.2.4.1 Pathogens

The most critical component, in terms of what must be removed from wastewater, is pathogens. Pathogens are organisms that cause disease; they include viruses, protozoa, parasites, and bacteria. Examples in wastewater include Salmonella, Vibrio cholera, Entamoebahistolytica, and Cryptosporidium although almost all disease organisms could be present in wastewater.

Viruses are organism too small to be seen by light microscopy. They are an obligate parasite dependent on a host cell for its metabolic and reproductive needs. Pathogens may be found in wastewater generated anywhere in the house. Any human contact with water results in the potential to add pathogens to the environment. Because of their role in spreading disease, pathogens in wastewater make wastewater treatment a public health issue.

2.2.4.2 Fecal Coliforms (FC)

Some of the microorganisms found in wastewater can cause disease while others are harmless. It is nearly impossible to identify all the pathogenic organisms in wastewater. Fecal coliform bacteria is an indicator bacteria common to the digestive systems of warm blooded animals that is cultured in standard tests to indicate either contamination from sewage or the level of disinfection generally measured as number of colonies/100 mL or Most Probable Number (MPN). It is the most common test for pathogens because it is a relatively easy and inexpensive test. Fecal coliform defines as the bacteria common to the digestive systems of humans that are cultured in standard tests.

Fecal coliform bacteria are fairly easy to test for, and their presence is an indication that pathogens, which are more difficult to isolate and identify, may also be present. Sometime total coliform bacteria are measured instead of fecal. Total coliform is a broader group of bacteria that constitute most of the intestinal flora of warm blooded animals (including the genera Klebsiella sp., Enterobacter sp., Citrobacter sp., or Escherichia sp.) The removal of these organisms through the soil treatment process is the key design factor for systems, although E-coli are becoming the preferred indicator organism because of their known pathogenic effects.

2.3 Wastewater Reuse Applications

Wastewater reuse may be applied in agriculture, industry, groundwater recharge, and urban usage, including landscape irrigation and fire protection. Wastewater reuse can be adopted to meet the water demand in different fields and contribute to the conservation of freshwater resources. There is many application for wastewater reuse depends on reuse target and classified as categories. shown Table (2-1)

Table (2-1) applications for wastewater reuse

Category of reuse	Examples of applications
Unrestricted (Urban use)	Landscape irrigation of parks, playgrounds, school yards, golf courses, cemeteries, residential, green belts, snow melting
Restricted (Urban use)	Irrigation of areas withinfrequent and controlled access
Other (Urban use)	Fire protection, disaster preparedness, construction
Food crops(Agricultural)	Irrigation for crops grown for human consumption
Non-food crops and crops consumed after processing (Agricultural)	Irrigation for fodder, fibre, flowers, seed crops, pastures, commercial nurseries, sod farms
Unrestricted (Recreational use)	No limitation on body contact: lakes and ponds used for swimming, snowmaking
Restricted (Recreational use)	Fishing, boating, and other non-contact recreational activities
Environmental enhancement	Artificial wetlands creation, natural wetland enhancement, stream flow
Groundwater recharge	Groundwater replenishment for potable water, salt water intrusion control, subsidence control
Industrial reuse	Cooling system water, process water, boiler feed water, toilets, laundry, construction wash-down water, air conditioning
Residential use	Cleaning, laundry, toilet, air conditioning
Potable reuse	Blending with municipal water supply, pipe to pipe supply

(Asano and Levine, 1998)

2.3.1 Development of Wastewater Reuse

Wastewater reuse has been utilized in rural areas where there are no centralized sewer systems for many decades in Australia and overseas. The systems used were usually simple crude designs used to irrigate the landscape (Jeppesen, 1996). Wastewater reuse systems in urban areas have been used under the regulation of plumbing codes in the United States of America since the 1990’s. This was in response to abating severe future water shortages in areas such as California and Florida (Jeppesen, 1996) and they are similar circumstances under which Australia is now legalizing wastewater reuse in urban areas. Likewise in Japan, but more in response to the increased rates of urbanization and population growth, wastewater reuse systems have been in use for multi-dwelling buildings since 1990’s.

Water reuse strategies in Australia were officially recognized in 1983 when a report into water reuse was initiated by the federal Department of Resources and Energy as part of the Water 2000 project

(GHD, 1983). But it did not consider domestic reuse options seriously and there have been many other Federal Government inquiries since which have recommended conservation and alternative sources of potable water supplies (Emmerson, 1998). However, in 2002 an Australian Senate Inquiry produced the National Water Policy which was focused on wastewater reuse. As a result, in 2003 the Australian Research Council sponsored a review of water reuse in Australia by the Academy of Science and Engineering. In this report wastewater was defined and its reuse options discussed. Concurrently to these reports, some State Governments began to draft or had already introduced legislation to allow limited wastewater reuse systems to be used in sewered urban areas.

State Government policies and guidelines also began to build on earlier experimental wastewater reuse schemes such as the Rouse Hill residential development in Sydney in the late 1990's and the Springfield residential development in Brisbane in early 2001. The promotion of wastewater reuse at policy level and establishment of technical guidelines marks a change in the traditional view of wastewater as being a waste and consequently centrally discharged to it now being recognized as a resource and a source of opportunity. Indeed wastewater is now noted as the only water resource that increases with urban development and planning and design principles are beginning to embrace this as a sustainable resource to reduce the ecological footprint of urban development.

In the United States, the first ozonation plant for the disinfection of municipal effluent was built in 1975. Since then, at least 45 ozone plants have been built. However, in recent years the number of plants has declined because legislation has changed and, in most cases, disinfection is no longer required (Robson and Rice, 1991). There are two operational ozone plants in Canada (Larocque, 1999) and several in Korea. There are approximately 200 ozonation units in Japan treating wastewater effluent and approximately 400 units treating "night soil" wastewater effluent (Matsumoto and Watanabe, 1999). In Europe, there are two major ozone plants in France and 134 plants in Germany treating municipal wastewater effluent and exhaust air.

The use of ozonation for the disinfection of effluents before agricultural use is also increasing in southern Europe (Bo¨hme, 1999; Le Pauloue¨ and Langlais, 1999; Liberti et al., 1999). In the United Kingdom, there is currently one wastewater treatment plant treating its secondary effluent with ozone for color removal (Churchley and Upton, 1997).

2.3.2Wastewater Reuse for Agriculture

Agricultural irrigation is crucial for improving the quality and quantity of production. Worldwide, agriculture is the largest user of water. Agriculture receives 67% of total water with drawl and accounts for 86% of consumption in 2000 (UNESCO, 2000). In Africa and Asia, an estimated 85 to

90% of all the freshwater use is for agriculture. By 2025, agriculture is expected to increase its water requirements by 1.2 times (Shiklomanov, 1999). Large-scale irrigation projects have accelerated the disappearance of water bodies, such as the Aral Sea, the Iraqi Marshlands, and Lake Chad in West Africa. Thus, more efficient use of agricultural water through wastewater reuse is essential for sustainable water management.

The ancient practice of applying wastewater containing human excreta to the land has maintained soil fertility in many countries of Eastern Asia and the Western Pacific for over 4,000 years, and remains the only agricultural use option in areas without sewerage facilities (WHO, 1989). Potential benefits of wastewater reuse for agriculture include the following:

- Conservation and more rational allocation of freshwater resources, particularly in areas under water stress;
- Avoidance of surface water pollution;
- Reduced requirements for artificial fertilizers and associated reduction in industrial discharge and energy expenditure;
- Soil conservation through humus build-up and prevention of land erosion;
- Contribution to better nutrition and food security for many households (WHO, 1989).

Epidemiological studies were performed in a rural area in central Mexico where river water containing partially treated wastewater was used to irrigate vegetables which were eaten by the local population. Risks from bacterial and viral infections associated with the consumption of specific vegetables (cabbages, carrots, green tomatoes, red tomatoes, onions, chilies, lettuce, radishes, cucumbers and coriander) and the total consumption of raw vegetables irrigated with partially treated wastewater (average quality 10 4 fecal coliform bacteria/100 ml) were investigated.

The sample size was sufficient to detect a 15% increase in serological response between exposure categories and a 3% difference in the prevalence of diarrhea between exposure categories among those aged over 5 years. There was no excess infection with diarrhea disease (as measured in a cross-sectional study) among vegetable consumers of all ages related to their total consumption of raw vegetables (that is, the number of raw vegetables eaten each week).

There was also no excess infection with human Norwalk-like virus/ Mexico (Hu/NLV/MX) or enter-oxygenic Escherichia coli (as measured by serological response over one year) associated with their total consumption of raw vegetables. However, consumption of onions, eaten by the majority of the study population, was associated with at least a twofold increase in diarrhea disease (3.5% in adults). Enter-viruses were found on onions at harvest, supporting this epidemiological evidence.

Consumption of green tomatoes was associated with a twofold increase (16%) in serological response to Hu/NLV/MX in schoolchildren. The effects described were observed after controlling for other risk factors.

2.3.3 Public Acceptance

One of the most critical steps in any reuse program is to protect the public health, especially that of workers and consumers. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary.

The fundamental precondition for water reuse is that applications will not cause unacceptable public health risks. Untreated wastewater poses a serious risk of water-borne diseases, such as cholera, typhoid, dysentery, plague and helminthiasis. In the 19^{th} century, large-scale applications of untreated wastewater for agriculture triggered epidemics of such water-borne diseases in Europe.

With medical advancements, and public health links between untreated wastewater and diseases have become better understood, and measures to minimize exposure to such pathogens have been introduced.

Raw (untreated) wastewater, however, continues to be used in some regions for direct crop irrigation, despite the clear health hazards associated with it. Such practice should be discontinued and replaced with irrigation using treated water that meets public health guidelines in order to minimize the exposure of farm workers and consumers.

Some of the key pathogens that are found in raw wastewater are summarized in Table (2- 2). Besides these pathogens, untreated wastewater may contain chemical substances that are harmful to humans and the environment.

Table (2- 2): Example of pathogens associated with municipal wastewater

Waterborne bacteria	Salmonella sp, Vibrio cholerae, Legionellaceae
Protozoa	Giardia lamblia, Cryptosporidium sp
Helminths	Ascaris, Toxocara, Taenia (tapeworm), Ancylostoma (hookworm)
Viruses	Hepatitis A virus, Rotaviruses, Enteroviruses

While wastewater reuse has substantial merits, a trade-off between the benefits and potential health risks of applications should be evaluated carefully. These risks can be minimized by proper treatment, disinfection, and controlled use of reclaimed water. If adequate measures to minimize risk cannot be implemented consistently, wastewater reuse should not be adopted. Proper reuse of wastewater should be encouraged also, because in some places it allows the production of crops that can be exported to other countries that have strict regulations on health risks.

Wastewater reuse has been practiced for various purposes in many areas of the world. In most cases, disinfection is an essential step prior to wastewater reuse in order to minimize environmental and health risks. The purpose of disinfection is to kill or inactivate pathogenic microorganisms, viruses and parasites from treated water. Commonly, disinfection is carried out using strong oxidizers such as chlorine, ozone and bromine, but they do not inactivate helminthes eggs.

The intended application for reused water influences public acceptability. For example, the use of reclaimed water for drinking water or for food preparation receives most opposition, while use for irrigation of recreational parks and golf courses attracts the least public resistance (Asano et al., 2007). Public perception of the relative environmental credentials of disinfection technologies for wastewater reuse may also impact technology selection. For instance, in Germany, chemical disinfection is seen as unfavorable for urban water reuse and so UV disinfection systems are preferred for the disinfection of wastewater (Nolde, 2005).

The main features of the 1989 WHO guidelines for wastewater reuse in agriculture are as follows:

- Wastewater is considered as a resource to be used, but used safely.
- The aim of the guidelines is to protect against excess infection in exposed populations (consumers, farm workers, populations living near irrigated fields).
- Fecal coliforms and intestinal nematode eggs are used as pathogen indicators.
- Measures comprising good reuse management practice are proposed alongside wastewater quality and treatment goals; restrictions on crops to be irrigated with wastewater; selection of irrigation methods providing increased health protection, and observation of good personal hygiene (including the use of protective clothing).
- The feasibility of achieving the guidelines is considered alongside desirable standards of health protection.

Table (2-3) WHO guidelines for using treated wastewater in agriculture

Category	Reuse conditions	Exposed Group	Fecal coliforms (geometric mean no. per 100 ml)c	Wastewater treatment expected To achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks d	Workers, consumers, public	≤ 1000	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	Retention in stabilization ponds for 8–10 days or equivalent helminthes and fecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Pretreatment as required by irrigation technology but not less than primary sedimentation

a US-EPA/USAID Guidelines for agricultural reuse of wastewater

(adapted from suggested guidelines for water reuse (US-EPA/USAID, 1992)

Table (2-4) guidelines are based on water reclamation and reuse practices in the U.S., and theyare especially directed at states that have not developed their own regulations or guidelines.

Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring
Agricultural Reuse – Non Food Crops Pasture for milking animals; fodder, fiber and seed crops	Secondary [1] · Disinfection	pH = 6-9 ≤ 30 mg/l BOD ≤ 30 mg/l SS ≤ 200 FC/100 ml [2] 1 mg/l Cl2 residual (min.)	·pH - weekly · BOD - weekly · SS - daily · Coliform - daily · Cl_2 residual -continuous

SS= suspended solids; FC= fecal coliforms

Footnotes:

[1]Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and many stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and SS do not exceed 30 mg/l .

[2]The number of fecal coliform organisms should not exceed 800/100 ml in any sample. Some stabilization pond systems may be able to meet this coliform limit without disinfection.

[Source: EPA, Process Design Manual: Guidelines for Water Reuse, Cincinnati, Ohio, 1992: Report No. EPA-625/R-92-004] 1

Table (2-5) Recommended Guidelines by the Palestinian Standards Institute for Treated Wastewater Characteristics according to different applications

Quality Parameter (mg/l except otherwise indicated	fodder Irrigation		Gardens, Playgrounds, Recreational	Industrial Crops	Landscapes	Trees	
	Dry	Wet				Citrus	Olive
BOD_5	60	45	40	60	60	45	45
COD	200	150	150	200	200	150	150
pH	6 - 9	6 - 9	6 - 9	6 - 9	6 - 9	6 - 9	6 - 9
FC (CFU/100 ml)	1000	1000	200	1000	1000	1000	1000

2.4 Wastewater Treatment Methods

In order to reuse wastewater, it is necessary to treat raw wastewater to meet specific needs and public safety. Some basic information on wastewater treatment technologies is given and the terminology explained. Wastewater treatment processes can be categorized into the following three:

1- Physical process: include processes where no gross chemical or biological changes are carried out and strictly physical phenomena are used to improve or treat the wastewater. Examples would be coarse screening to remove larger entrained objects and sedimentation (or clarification). In the process of sedimentation, physical phenomena relating to the settling of solids by gravity are allowed to operate. Usually this consists of simply holding a wastewater for a short period of time in a tank under quiescent conditions, allowing the heavier solids to settle, and removing the "clarified" effluent. Sedimentation for solids separation is a very common process operation and is routinely employed at the beginning and end of wastewater treatment operations. While sedimentation is one of the most common physical treatment processes that is used to achieve treatment, another physical treatment process consists of aeration - that is, physically adding air, usually to provide oxygen to the wastewater. Still other physical phenomena used in treatment consist of filtration. Here wastewater is passed through a filter medium to separate solids. An example would be the use of sand filters to further remove entrained solids from a treated wastewater. Certain phenomena will occur during the sedimentation process and can be advantageously used to further improve water quality. Permitting greases or oils, for example, to float to the surface and skimming or physically removing them from the wastewaters is often carried out as part of the overall treatment process.In certain industrial wastewater treatment processes strong or undesirable wastes are sometimes produced over short periods of time. Since such "slugs" or periodic inputs of such wastes would damage a biological treatment process, these wastes are sometimes held, mixed with other wastewaters, and gradually released, thus eliminating "shocks" to the treatment plant. This is call equalization. Another type of "equalization" can be used to even out wide variations in flow rates. For example, the wet well of a pump station can receive widely varying amounts of wastewater and, in turn, pump the wastes onward at more uniform rates.

2- Chemical process: commonly used in many industrial wastewater treatment operations is neutralization. Neutralization consists of the addition of acid or base to adjust pH levels back to neutrality. Since lime is a base it is sometimes used in the neutralization of acid wastes. Coagulation consists of the addition of a chemical that, through a chemical reaction, forms an insoluble end product that serves to remove substances from the wastewater. Polyvalent metals are commonly used as coagulating chemicals in wastewater treatment and typical coagulants would include lime (that can also be used in neutralization), certain iron containing compounds (such as ferric chloride or ferric sulfate) and alum (aluminum sulfate). Certain processes may actually be physical and chemical in nature. The use of activated carbon to "adsorb" or remove organics, for example, involves both chemical and physical processes. Processes such as ion exchange, which involves exchanging certain ions for others, are not used to any great extent in wastewater treatment.

3- Biological process: Use microorganisms, mostly bacteria, in the biochemical decomposition of wastewaters to stable end products. More microorganisms, or sludges, are formed and a portion of the waste is converted to carbon dioxide, water and other end products. Generally, biological treatment methods can be divided into aerobic and anaerobic methods, based on availability of dissolved oxygen. The purpose of wastewater treatment is generally to remove from the wastewater enough solids to permit the remainder to be discharged to a receiving water without interfering with its best or proper use. The solids which are removed are primarily organic but may also include inorganic solids. Treatment must also be provided for the solids and liquids which are removed as sludge. Finally, treatment to control odors, to retard biological activity, or destroy pathogenic organisms may also be needed. While the devices used in wastewater treatment are numerous and will probably combine physical, chemical and biological methods, they may all be generally grouped under six methods.

Degrees of treatment are sometimes indicated by use of the terms primary, secondary and tertiary treatment. Tertiary treatment, properly, would be any treatment added onto or following secondary treatment.

2.5Treatment by Disinfection

Disinfection can be achieved in a number of ways, but generally should only be done where biological treatment is carried out first. One of the most common methods of disinfection is to add chlorine, often (in the case of onsite systems) through the use of chlorine tablets. Ultraviolet (UV) disinfection may also be considered, but its effectiveness is highly dependent on the water quality and the transmission of light through the water, and is adversely affected by particulates and colloidal particles, biological treatment and filtration is often a prerequisite to UV disinfection. Ozonation is another means of disinfection that can be considered, involving the onsite generation of ozone gas, and diffusion of that gas into the liquid. Unless there is risk of human contact with the wastewater there is no particular need to disinfect the wastewater before use. Pathogens present in the wastewater are typically removed through a relatively short distance of unsaturated soil. Disinfection is very important in life because they are cleansing of all diseases are likely to occur, Table (2-6) included a list of some organism and disease caused that could be avoided by using the Disinfection .

Organism		Disease caused
Bacteria	Escherichia coli (enterotoxigenic)	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
	Entamoebahistolytica	Amebiasis (amoebic dysentery)
	Giardia lamblia	Giardiasis
Heminths	Ascarislumbricoides	Ascariasis
	T. Solium	Taeniasis
	Trichuristrichura	Trichuriasis
Viruses	Enteroviruses (72 types)	Gastroenteritis , heart anomalies , meningitis
	Hepatitis A virus	Infectious hepatitis
	Norwalk agent	Gastroenteritis
	Rotavirus	Gastroenteritis

The Environment Protection Agency (EPA,1986) defines 4 pathways by which transmission of these can occur:

- direct ingestion of untreated water
- direct ingestion of treated drinking water
- ingestion of aquatic food species infected with pathogens absorbed from contaminated waters
- Invasion resulting from skin contact with contaminated water.

These micro-organisms have various methods of protection that must be over-come in order to achieve disinfection. The most common means for this are by the use of:

- Chemical agents (e.g. Cl , O_3, H_2O_2, etc..)
- Physical agents (e.g. heat and light)
- Mechanical means (e.g. screens, filters, etc..)

Table (2-7) Description for the Micro-organismin the wastewater

Micro-organism	Description
bacteria	ca. 0.2 - 10 µm in length
	unicellular , lacking a distinct nuclear membrane , but with an unique cell wall (complex polymers of polysaccharides & amino acids)
	coliform bacteria are commonly used as indicators of fecal contamination & presence of pathogenic species
parasites	protozoa ca. 2- > 50 µm
	Unicellular with endoplasm & protective layer of ectoplasm
	helminths (worms)
viruses	ca. 0.01 - 0.3 µmin cross-section
	Nucleic acid core surrounded by an outer coat of protein

2.5.1 Disinfection via Chlorination

Chlorine kills micro-organisms by destroying cellular material. This chemical can be applied to wastewater as a gas, a liquid or in a solid form similar to swimming pool disinfection chemicals. However, any free (uncombined) chlorine remaining in the water, even at low concentrations, is highly toxic to beneficial aquatic life. Therefore, removal of even trace amounts of free chlorine by de-chlorination is often needed to protect fish and aquatic life. Due to emergency response and potential safety concerns, chlorine gas is used less frequently now than in the past

This is a method of treatment which has been employed for many purposes in all stages in wastewater treatment, and even prior to preliminary treatment. It involves the application of chlorine to the wastewater for the following purposes :

-Disinfection or destruction of pathogenic organisms.
- Prevention of wastewater decomposition : (a) odor control, and (b) protection of plant structures.
- Aid in plant operation : (a) sedimentation, (b) trickling filters, (c) activated sludge bulking.
- Reduction or delay of biochemical oxygen demand (BOD).

While chlorination has been commonly used over the years, especially for disinfection, other methods to achieve disinfection as well as to achieve similar treatment ends are also used. Among the most common is the use of ozone. In view of the toxicity of chlorine and chlorinated compounds for fish as well as other living forms, ozonation may be more commonly used in the future. This process will be more fully discussed in the section on disinfection. (EPA,2004)

2.5.2 Disinfection via ozone

In municipal wastewater treatment, ozone has been used primarily for effluent disinfection. Generally, the need for effluent disinfection has arisen through the enactment of legislation that has defined specific microbiological standards for effluent discharge quality. These standards not only vary with the specific country or region of application, but they also depend on whether the effluent is to be discharged to a sensitive water body or used for agricultural or reuse purposes.

Within countries of the European Union (EU), current legislation concerning effluent discharge to receiving waters involves the EU bathing waters directive (CEC, 1976), which sets microbiological and physicochemical standards for inland and coastal waters designated as bathing areas . Although ozone is approved for short-term field trials only in the United Kingdom, in other countries ozone has been applied to wastewater effluents primarily for disinfection. Ozonation has also been used for COD “polishing” (i.e., lowering of residual concentrations) and enrichment of effluent with oxygen .

Ozone has been found to be very effective at inactivating a wide range of microorganisms. The mechanism of bacterial inactivation by ozone is thought to occur by general inactivation of the whole cell. Thus, ozone causes damage to the cell membrane, to the nucleic acids, and to certain enzymes. Ozone is particularly effective against viruses, where its use can achieve the highest standards (Tyrrell et al., 1995).

The mechanism of viral inactivation involves coagulation of the protein and oxidation of the nucleobases forming the nucleic acid. Protozoan cysts, specifically Giardia and Cryptosporidium, and bacterial spores are more resistant to ozone than bacteria and viruses, although moderate degrees of inactivation have been demonstrated under realistic ozonation conditions (Owens et al., 2000).

It has been reported that microorganism reactivation after ozonation is unlikely to occur (CES, 1988; U.S. EPA, 1986). Lazarova et al. 1998, did not observe any measurable re-growth of Escherichia coli , Because of its high oxidation potential, ozone reacts with a wide range of organic and inorganic compounds in water. Chemical oxidation by ozone occurs via two distinct reaction mechanisms, namely a molecular ozone reaction pathway and a hydroxyl radical (OH•) reaction mechanism. The molecular reaction mechanism is more selective than the radical reaction pathway, but the latter mechanism results in much greater reaction rates. The predominant mechanism or relative contribution of each mechanism, in an ozonation process depends on various water quality parameters such as pH, alkalinity, and organic content because these determine the presence and influence of species that act as radical initiators, promoters, and scavengers.

Many previous ozonation studies established that ozone attacks aromatic and unsaturated compounds, thereby affecting the chemical composition and the overall quality of the water (Hoigne´, 1998). Following the ozonation of four municipal secondary effluents, Gardiner and Montgomery (1968) observed a reduction in COD, an initial increase followed by a decrease in 5-day biochemical oxygen demand (BOD_5), and a reduction of TOC and of suspended solids concentration. Ozone also removed 50 to 90% of anionic and non anionic detergents. Four different types of pesticides and five types of phenols spiked into the wastewater effluent samples were also substantially removed after ozonation.

In a pilot-plant study using ozone for the disinfection of secondary municipal effluent, (Nebel et al. ,1973) observed the removal of turbidity and color after ozonation, and a 30% average reduction of COD. The TOC remained primarily unaffected whereas the BOD_5 decreased, although there were cases where increases in BOD_5 were observed. The work of Legube et al. (1987) indicated a 25 and 50% reduction of COD and BOD_5, respectively. Langlais et al. (1992) also found a complete or partial elimination of aromatic compounds, a reduction of unsaturated fatty acids, and a 50% reduction of anionic detergents. In the same study, the concentration of combined amino acids and polysaccharides decreased after ozonation. Sasai et al. (1997) reported a 12% reduction of TOC and a 33% reduction of COD after ozonation of a secondary effluent. Paraskeva et al. (1997, 1998) observed a 30% reduction in COD, a decrease in BOD in the range of 10 to 60%, a reduction in color between 25 and 55%, and a 254-nm reduction in UV absorbance between 15 and 40%, whereas parameters such as TOC and pH remained unaffected.

Chemical oxidation has the potential to remove from wastewater organic materials that are resistant to other treatment methods, whether those methods are biological or the longer trains of processes known as tertiary or advanced treatment (Evans 1975). The most popular chemical oxidants used for water and wastewater treatment are: chlorine, hydrogen peroxide, potassium permanganate, and ozone. Among them, ozone (O_3), a gas, is clean and is safe, and has the highest chemical reactivity (Rice and Browning, 1981).

Ozone is the most efficient chemical oxidant used in water and wastewater treatment. Because of the strong oxidizing proprieties of ozone, its applications in aqueous solutions include removal of iron, manganese and other inorganic, color, taste, odor-causing components, algae, organics, suspended solids, micro flocculation of dissolved organics, as well as pretreatment before biological processes, bacterial disinfection, and viral inactivation. Due to these remarkable proprieties, ozone has become an important agent for treatment of water and wastewaters resulting from various activities, including aquaculture (Rice, 1986).

When considering use of ozonation as part of a water or wastewater treatment scheme, the optimal use of ozone is determined by the rates of reaction of the impurities to be oxidized. Oxidation rates of refractory materials will be reaction rate controlled, while oxidation rates of readily oxidized materials will be controlled by the rate of mass transfer of ozone into solution (Rice and Browning, 1981). Ozone, a colorless gas at room temperature, is an allotropic form of oxygen, with a molecular formula O_3 and molecular weight of 48.00 grams per mole. It can be generated from air or pure oxygen by different methods, which is the most widely-used procedure (Masschelein, 1994). The process involves the passage of air (or oxygen) between electrodes across which an alternating high-voltage potential is maintained, producing a uniform blue-violet glow discharge throughout the gas, ionizing some of the molecular oxygen (Diaper, 1975).

Ozone is formed by recombination of ionized oxygen atoms and ionized molecular oxygen. In this process, only 4 – 12% of the energy supplied is used for the formation of ozone and the rest is transformed to heat (Ozone k et al., 1994). Ozone is an unstable gas under conditions normal to water and wastewater treatment, and hence, it cannot be manufactured, stored, or transported, and must be generated at its point of use (Rice, 1997). Ozone is thought to have a mechanism of oxidation described by the reaction: $O_3 \rightarrow O_2 + O$. where nascent oxygen produces a high-energy oxidation via a free radical reaction (Raiton, 1972).

The polarized ozone can react with the substances by physical interaction. It can chemically oxidize reactive molecules. Organic chemists have long made use of the ability of ozone to cleave carbon-carbon bonds in synthetic and structure determination procedures (Rice and Browning, 1981). This reaction may induce increased solubility of the materials, biodegradability, and so on; oxidation is usually fast, and the oxidation by-products are not evidently toxic for the environment.

As one of the most reactive gases known, ozone is recognized as the most powerful oxidizing agent available for the treatment of water and wastewater (Martin and Elmghari-Tabib, 1982; Rice, 1997). When molecular ozone dissolves into water, the molecule can remain as O_3 or can decompose by various mechanisms, ultimately producing the hydroxyl free radical (HO°), and a stronger oxidizing agent than molecular ozone. Therefore, the chemical effects of ozone in water are a result of its direct reaction with dissolved compounds, its decomposition in reactive free radicals, or the subsequent reaction of these free radicals with solutes (Rice, 1997).

The mechanisms of disinfection using ozone include:

- Direct oxidation/destruction of the cell wall with leakage of cellular constituents outside of the cell.
- Reactions with radical by-products of ozone decomposition.
- Damage to the constituents of the nucleic acids (purines and pyrimidines).
- Breakage of carbon-nitrogen bonds leading to depolymerization.

Ozone is tri-atomic oxygen (O_3) and is typically produced by introducing oxygen gas with an electric discharge, splitting oxygen molecules into atoms, which then combine with the remaining oxygen molecules to form ozone. Ozone is highly reactive and its use in water leads to the production of hydroxyl radical ($OH\cdot$) species, which is powerful, non-specific oxidants (Haag and Yao, 1992). Ozone will react with bacterial cell components, including DNA (Ishizaki et al., 1987), to cause inactivation and has been shown to cause inactivation of viruses by breaking the protein capsid and disrupting adsorption to host cells (Kim et al., 1980). The high oxidative power of ozone means that, as well as providing disinfection, it can also significantly improve the overall quality of wastewater by oxidizing organics and reducing turbidity, odor, and color (Paraskeva et al., 1998; Pokhrel and Viraraghavan, 2004).

Disinfection with ozone is impacted by the presence of organic and particulate material in water. Organics in water can encourage the decomposition of ozone by promoting chain reaction of decomposition (Staehelln and Hoigne, 1985; Pi et al., 2005), reducing the available ozone and free OH· radicals available for disinfection.

Studies have shown reduced ozone inactivation rates of bacteria in the presence of organic material and attributed this to the increased ozone demand created by the organics (Restrain et al., 1995; Hunt and Marinas, 1999). The ability of ozone to inactivate particle-associated microorganisms is limited by ozone demand which must first be met before ozone diffusion into particles will occur (Dietrich et al., 2007). An important concern with ozone disinfection is the potential for bacterial re-growth following disinfection. Ozone decays with time (Paraskeva et al., 1998) and upon reaction with impurities in the wastewater, leaving no residual disinfectant. In addition, ozone can increase the bioavailability of organic matter in wastewater as a result of the oxidization of previously non-biodegradable compounds (Xu, et al., 2002) and can also increase the microbial available phosphorous, increasing the re-growth potential of heterotrophic microbes (Lehtola et al., 2001) .s

Biological treatments are inexpensive and reliable methods for eliminating pollutants from wastewater, but there are substances with which they are unable to deal. On the other hand, advanced oxidation processes utility for toxic compound elimination, but total mineralization through these methods is very expensive. Consequently, a combination of both kinds of processes provides a cheaper option for total organics degradation from a wastewater (Marco et al., 1997). The idea of using combined chemical/biological processes for the treatment of wastewaters became popular around the mid-1980s, when found a viable treatment option (Gottschalk et al., 2000; Gunukula and Tittlebaum, 2001). Water and wastewater ozonation mostly is performed in directly gassed systems, where ozone-containing gas is produced by an electrical discharge ozone generator and introduced into the reactor by a gas diffuser (Gottschalk et al., 2000).

More and more countries are taking measures to reuse wastewater. This has been prompted by the ever decreasing availability of good quality raw water and the increasing cost of producing potable water. Disinfection is a major treatment step in the direct reuse of reclaimed wastewater to ensure environmental and public health protection. Disinfection is the destruction, inactivation or removal of those micro-organisms likely to cause subsequent infection of people. Wastewater disinfection refers to the use of a process designed specifically to reduce the numbers of viable, infectious microbial organisms in an effluent (Wright, 1997). Because of its high oxidation potential and specific lethality, ozone is the most effective disinfectant (killing bacteria, inactivating viruses and protozoa).In addition to disinfection, wastewater treatment must address other factors such as lowering the COD (Chemical Oxygen Demand), and to a lesser extent sometimes the BOD (Biological Oxygen Demand), as well as making improvements in color and odor. With ozone, oxidation of organic matter and precipitation of metals further improve the water quality and allow its reuse.

Ozone has been proved to be one of the most effective disinfectants and is widely used to inactivate pathogens in drinking water, especially in Europe (United States Environmental Protection Agency 1999). Design engineers in the US began to evaluate ozone for wastewater disinfection in the early 1970s. However, because of operational and maintenance problems that appeared in the first generation of facilities, it has been considered to be a less attractive alternative to chlorine than UV disinfection. Ozone is the second most powerful sterility in the world and its function is to destroy bacteria, viruses and odors. An ozone supply of 10 g/h/m^3 water with an exposure time of 1 h is sufficient to kill all pathogens.

Ozone can generate hydroxyl radicals via side reactions with compounds used extensively for drinking water disinfection. Combining ozone with biological filtration may create the optimal method for removing the trace compounds with the reduced presence of byproducts and lower toxicity. Ozone bio filtration is a process that is employed in pretreatment of surface water for drinking water treatment. So, it is both familiar and reasonably well understood. (Ozone for Treatment of Water for Reuse Spartan Environmental Technologies, Air and Water Treatment) waste disinfection by ozone was investigated at pilot scale on different wastewater effluents. Design parameters of ozonation were proposed for two types of regulations, and for effluents of different qualities. In all cases, viruses were totally inactivated; consequently, viruses do not constitute a limiting factor in wastewater disinfection by ozone.

The standard drinking water model failed to match the experimental data obtained on real wastewater effluents. A modified approach was successfully developed, based on the simultaneous consumption of ozone by the microorganisms and the organic matrix. Wastewater reuse has become an attractive option for protecting the environment and extending available water resources. In the last few years, there has been a significant diversification of water reuse practices, such as green space and crop irrigation, recreational impoundment, various urban uses including toilet flushing, industrial applications and water supply augmentation through groundwater or reservoir recharge. Chlorination is still the most widely used means to inactivate pathogenic microorganisms in water and wastewater, but alternative technologies have to be evaluated because of increasing concern over undesirable byproducts after chlorination and its inefficiency in eliminating some epidemic microorganisms at low chlorine doses (Xu P, et.al. 2001).

Treatment is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective. Ozone is a very strong oxidant. Oxidation, the major mechanism by which wastewater pollutants are controlled, occurs through a variety of biological, chemical, and physical-chemical processes.

Several researchers have conducted studies on the treatment of mature landfill leachate using ozone. Tizaoui et al. (2007) obtained 27% removal for COD after 60 min ozonation of raw leachate. In the same tendency, Hagman et al. (2008) obtained 22% COD reduction. Rivas et al. (2003) obtained a 30% depletion of COD. Accordingly, the efficiency of ozone technique for solely removing organics and ammonia from leachate is relatively weak; the technique is more efficient for colour removal, which may be attributed to the strength of organic components in leachate, improving the removal efficiency in lower initial COD concentration . Thus, many researchers have employed several advanced oxidation agents and techniques to improve the efficiency of ozone for leachate treatment, such as hydrogen peroxide (H_2O_2) and UV (Wu et al., 2004; Tizaoui et al., 2007).

Hamidi Abdul Aziz et al., 2014 obtained removal efficiencies varied between 4% and 27.2 % for COD, Fenton reagent was used to improve oxidation efficiency during ozonation of the stabilized leachate. The removal efficiencies ranged from 10% to 79.3% for COD, 19% to 99% for color, and 0 to 41% for ammonia. In the $O_3/H_2O_2/ Fe_2+$ system, Fenton ions reacted with H_2O_2 to form hydroxyl radicals (•OH) ; •OH has the potential to destroy and degrade organic pollutants (Hermosilla et al., 2009).

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^{-} + OH^{\cdot}$$

The reaction of ozone with H_2O_2 also generates •OH radicals. H_2O_2 is dissolved in water and dissociates into the hydro peroxide ion (HO_2^-), which rapidly reacts with ozone to initiate a radical chain mechanism that generates hydroxyl radicals (Staehelin and Hoigne 1982; Glaze et al., 1987), as demonstrated in Equations :

$H_2O_2+2O_3^{2}\rightarrow OH+3O_2$

$HO^{2-}+O_3\rightarrow HO_2+O_3$

Several works have been conducted on leachate treatment using ozone-based advanced oxidation processes (AOPs). (Tizaoui et al, 2007) used H_2O_2 to improve ozone efficiency in landfill leachate treatments for COD (from 27% to 50%) and color (from 87% to 94%) . (Wu, et al., 2004)performed O_3/UV to enhance the Biodegradability of and color elimination in leachate. (Cortez et al, 2011) improved COD removal from 46% to72% using O_3/OH and H_2O_2 after Fenton as pre-treatment process.

In comparing the optimal conditions for the ozone/Fenton process (90 min in one treatment stage with 78% COD removal) with those of Fenton oxidation followed by ozonation, the results showed that around 50% of the reaction time was reduced, and removal efficiency increased from 58% and 95% to 78% and 98.5% for COD and colour, respectively. (Goi et al. 2009) obtained a 77% COD removal efficiency at 240 min of ozonation after Fenton oxidation. Persulfate reagent was used to improve oxidation efficiency during ozonation of the stabilized leachate . The removal efficiencies were varied between 29 and 75.8% for COD, 63 and 96 for color and between 29 and 81% for ammonia, respectively at different operational conditions.

Hamidi Abdul Aziz et al, 2015 shows the removal of COD and NH_3-N for leachate wastewater by ozone /Fenton increase with the contact time and ozone dose as shown in Table (2-8)

Table (2-8): Ozone dosage, time and its response values for COD and NH_3 removal efficiency for experimental conditions (ozone/fenton). Source: Hamidi Abdul Aziz et al, 2015

ozone dose (mg/l)	pH	Fe (mole/l)	H_2O_2 (mole/l)	pH	time (min)	COD removal %	NH_3-N removal %
30	3	0.005	0.005	3	10	17	2
80	7	0.005	0.05	7	90	39.5	11
55	5	0.0275	0.0275	5	50	72.4	11.3
80	3	0.05	0.005	3	90	69.5	23
80	7	0.005	0.05	7	10	10	1
55	5	0.0275	0.0275	5	50	72.8	10.6
30	7	0.005	0.005	7	90	37	9
30	5	0.0275	0.0275	5	50	79	26
80	3	0.05	0.05	3	90	55	14
30	7	0.005	0.005	7	10	10.2	1

But for ozone alone the removal observe less than removal ozone /Fenton as shown in Table (2-9).

Table (2-9): response values for different experimental conditions (ozone oxidation) Hamidi Abdul Aziz et al, 2015

ozone dose (mg/l)	COD concentration (mg/l)	time (min)	COD removal %	NH_3-N removal %
80	250	60	27.2	8.5
55	1125	35	18.8	1.1
30	250	10	16	0
55	2000	35	21	0
80	2000	10	10	0
55	250	35	24	6.5
55	1125	35	17.5	1.2
80	2000	60	15	0
55	1125	35	18	1.1
55	1125	35	18.5	1.2

It is concluded from the previous studies the effect of ozone process increase with many factors like (contact time, ozone dose, oxidization admixture, surface area of ozone bubble, component sample like: organic matter concentration, FC , ammonia)

2.5.3 Impact of ozone

Chemical Agents:

Not only does ozone have a higher electrochemical oxidation potential than other oxidants but also a superior dose-effect curve with respect to disinfection. This means that to achieve the same disinfection effect in wastewater as other oxidants, ozone is used in smaller amounts with shorter contact times.

Table (2-10)A comparison by Hoff 1986, illustrates the greater effectiveness of ozone as compared to other wastewater treatment disinfectants.

Micro-organisms	Ozone pH : 6 to 7	Chlorine pH : 6 to 7	Chloramines pH : 8 to 9	Chlorine dioxide pH : 6 to 7
E. coli	0.02	0.034-0.05	95-180	0.4-0.75
Poliovirus 1	0.1 -0.2	1.1-2.5	770-3740	0.2-6.7
Rotavirus	0.006-0.06	0.01-0.05	3806-6480	0.2-2.1
Giardia lamblia cysts	0.5-0.6	47->150	-	-
Giardia muris cysts	1.8-2.0	30-630	-	7.2-18.5

Being the tri-atomic form of oxygen, ozone oxidizes the substances in wastewater with nothing other than oxygen atoms. Ozone is a powerful oxidant that destroys micro-organisms through an irreversible physicochemical action. Ozone does not have to penetrate the body of the micro-organism to inactivate it. On the contrary, the action of ozone is instantaneous and irreversible, first on the micro-organisms protective wall and then on the semi-permeable membrane (Finch, 1999).

Such action modifies the chemical structure of the micro-organism through a coagulation effect that causes a hindrance on any exchange of product with the outside. As a result, the microorganisms "suffocate" to death or inactivation. The protective wall and the semi-permeable membrane are composed of molecules that are very rich in electron sites. This favors a very selective, and therefore efficient, action of ozone. These physic -chemical reactions present extremely rapid kinetics .

Oxidation of inorganics

Thiocyanate is oxidized to cyanide, Rapid oxidation of free cyanide ions and many stable metal cyanide complexes to less toxic cyanate ions ammonia and nitrites, Sewage treatment Ammonia is not readily oxidized. Nitrite ions are oxidized rapidly, Sulphide ions are oxidized to sulphite and finally sulphatescations of Mn (II), Fe (II), Hg (I), As, Al, Pb, Ni, Cr, Cu, Co, Ba, Zn & Cd Paint & varnish industry, photo-processing, etc. Oxidized to less soluble, higher oxidation states for removal by filtration or settling.

Oxidation of organics

Ozone oxide Phenols, Chemicals, plastics & synthetics, petroleum refineries, iron & steel (coke) plants, soaps & detergents, pulp & paper, textiles. Complete oxidation to carbon dioxide and water may not occur. Pesticides Agriculture, Some are oxidized completely, others are hardly affected. Used in combination with hydrogen peroxide hydroxyl radicals are produced that result in the effective destruction of compounds that resist ozone alone.

Generally organic macro molecules with conjugated carbon-carbon double bonds cause color. Ozone cleaves these double bonds removing > 90% color. Unpleasant odors can be removed by partial oxidation yielding smaller molecules. Hydrogen sulphide, phenols and trichlorphenols are also easily destroyed. Other oxidants, e.g. chlorine, may transform some substances with weak odor characteristics to substances with strong odor: phenols to chlorophenols precursors of TriHaloMethanes (THM).

Reduction of COD and BOD

During ozonation of secondary effluent the ozone carrier gas is introduced into the liquid by diffusion. This may result in a flotation process. If in the contacting sample of wastewater is provided the foam containing suspended solids (SS) and the destabilized colloidal matter can be removed. Sewage ozonised in such a manner shows a considerable reduction in COD, SS, TDS and turbidity. Ozone partially oxidizes organic materials: large molecules and refractory materials are broken down into smaller biologically degradable molecules that can be removed by filtration over sand or activated carbon (which may in turn develop a biological activity) and filtration with any other biological system (which is particularly efficient with a fixed bed bio-filter).shown table(2-11) and table (2-12)

Table (2-11) summary of COD reduction by ozone treatment of secondary effluents :-

ozone dose(mg/L)	Initial COD (mg/L)	Reduction (%)
5-41	26-56	50
12-16	20-40	23
6-9	20-35	25-14
6-12	33-75	25
14	40-170	5
20	120-200	30-50
15	20	35
2.5-5	22-49	3-50

Table (2-12) summary of BOD reduction by ozone treatment of secondary effluents :-

ozone dose (mg/L)	Initial BOD_5 (mg/L)	Reduction (%)
80	12	58
12-16	10-25	15
6-12	5-23	50
18	26-48	-4
5-10	5-30	16-67

(Panagiot Prskeva , Nigel J. D Grahm , 2002)

Other Beneficial Impacts Of Ozone

Many properties of ozone, other than disinfection, are important for wastewater treatment and their dual application can improve the economics of a particular scheme. For example, using ozone for color removal will give the additional benefits of disinfection and increased 7 dissolved oxygen content in the effluent. Oxidation wastewater contains a significant amount of oxidisable contaminants, giving ozone a number of applications. Generally, if an organic is resistant to oxidation by ozone it will be resistant to oxidation by other oxidants (Rice & Browning, 1980).

Advantages and disadvantages

Advantages

- Ozone is more effective than chlorine in destroying viruses and bacteria.
- The ozonation process utilizes a short contact time (approximately 10 to 30 minutes). There are no harmful residuals that need to be removed after ozonation because ozone decomposes rapidly.
- After ozonation, there is no re-growth of microorganisms, except for those protected by the particulates in the wastewater stream.
- Ozone is generated onsite, and thus, there are fewer safety problems associated with shipping and handling.
- Ozonation elevates the dissolved oxygen (DO) concentration of the effluent. The increase in DO can eliminate the need for re-aeration and also raise the level of DO in the receiving stream.
- The technology may diminish the volume of wastewater discharged, resulting in a beneficial impact on the aquatic environment.
- Operation and maintenance are relatively simple except in direct reuse systems, where more extensive technology and quality control are required.
- Provision of nutrient-rich wastewaters can increase agricultural production in water-poor areas.
- Pollution of seawater, rivers, and groundwater may be reduced.
- Lawn maintenance and golf course irrigation is facilitated in resort areas.

Disadvantages

- Low dosage may not effectively inactivate some viruses, spores, and cysts.
- Ozonation is a more complex technology than is chlorine or UV disinfection, requiring complicated equipment and efficient contacting systems.
- Ozone is very reactive and corrosive, thus requiring corrosion-resistant material such as stainless steel.
- Ozonation is not economical for wastewater with high levels of suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand, or total organic carbon.
- Ozone is extremely irritating and possibly toxic, so off-gases from the contactor must be destroyed to prevent worker exposure.
- The cost of treatment can be relatively high in capital and in power intensiveness

- Reuse of wastewater may be seasonal in nature, resulting in the overloading of treatment and disposal facilities during the rainy season; if the wet season is of long duration and/or high intensity, the seasonal discharge of raw wastewaters may occur. Health problems, such as water-borne diseases and skin irritations, may occur in people coming into direct contact with reused wastewater.
- Gases, such as sulfuric acid, produced during the treatment process can result in chronic health problems.
- In some cases, reuse of wastewater is not economically feasible because of the requirement for an additional distribution system.
- Application of untreated wastewater as irrigation water or as injected recharge water may result in groundwater contamination.

CHAPTER 3: METHODOLOGY

3.1 Introduction

To achieve objective of the research, parameters of influent and effluent of GWWTP studied to measure the effectiveness of the ozone disinfection. The methodology steps are as shown in Figure (3-1).

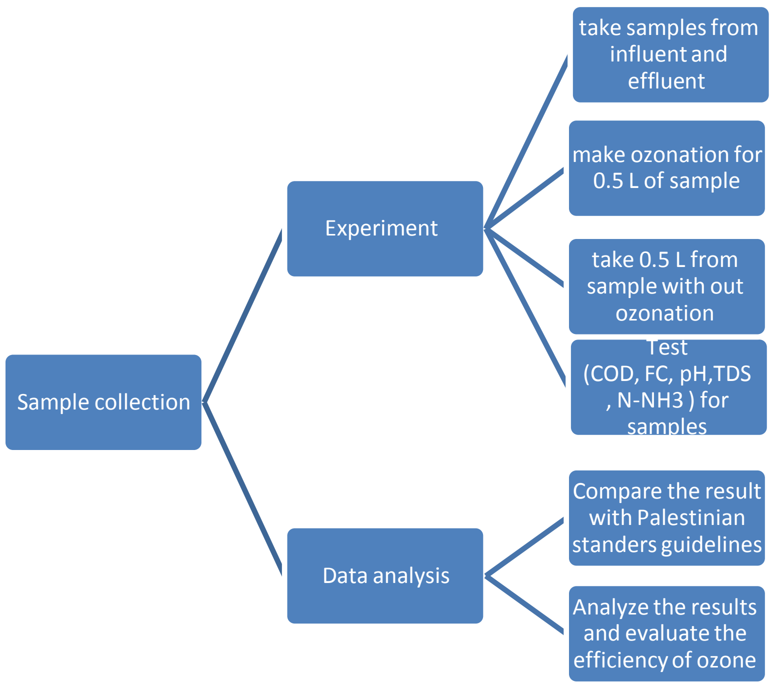

Figure (3-1) : The methodology steps

EWASH, 2009 reported that GWWTP discharge about 50MLD of partially treated Wastewater directly into the sea. About 10 MLD of untreated Wastewater has currently discharged directly into the sea of Gaza City. Wastewater in Gaza Strip contains significant numbers of pathogenic, which ultimately reach the sea.

The population of Gaza Strip continues to grow rapidly, thus increasing the amounts of poorly treated or untreated sewage being discharged into the coastal water. With a Palestinian population growth rate of around 4.8 percent per annum, which would result in a doubling of the population in 15 years, effective management and sustainable development of Gaza resources will be a huge challenge for the Palestinian Authority (UNEP, 2003).

In the Gaza Strip, wastewater treatment has been neglected to a certain extent; where most of the attention has been focused on measures to solve water quantity and supply problems. The lack of operational and efficient wastewater treatment plants makes wastewater the main source of pollution of the coastal zone of Gaza Strip. Most of the wastewater is discharged untreated or partially treated along the shoreline resulting in pollution of most of the shoreline.

In Gaza City, there is only one insufficient and inefficient wastewater treatment plant (GWWTP) which is considered as the largest in the Gaza Strip. Insufficient means that the quantity of the wastewater discharged from the city and arrived to the plant exceeds its capacity, while, inefficient means that the plant suffers from a lot of lack of maintenance and operational problems.

According to the previous reports of Ministry of health (MOH,2014), many of the diseases among the Gaza, particularly in summer, are attributed to the pollution due to the discharged untreated or even partially treated wastewater to the sea water and near the recreational areas.

The lack of proper wastewater treatment facilities leads to the discharge of untreated or partially treated sewage directly to the seashore and indirectly through Wadi Gaza from the middle camps (Nuseirat, Bureij, Maghazi) and finally reaches the sea. This results in the poisoning of water and soil and consequent major health risks for swimmers and marine life. (EQA and UNEP, 2005).

Coastal waters are facing a variety of pressure affecting both the ecosystem and human health through wastewater discharge and disposal practices that may lead to introduction of high nutrient loads, hazardous chemicals and pathogens causing diseases. The adverse public health, environmental, socio-economic, food quality and security, and aesthetic impacts from sewage contamination in coastal areas are well documented (Luger and Brown, 1999; Tyrrel, 1999).

To solve most of these problems we use ozone to disinfect the WW and reduce the amount of pollutants Prepare small device to disinfect the WW effluent and compare it with Palestinian standard. Therefore first experiment step is take samples from GWWTP influent to disinfect it by ozone to study the change in main parameter of wastewater (COD, FC, pH, TDS) , and test parameters for Wastewater and after ozone disinfection, to study ozone efficiency and the other objective is compare the parameters of WW with WHO guideline for discharge WW to the sea to prevent grow pollution .

The second experiment step is take a sample from GWWTP secondary treatment effluent to disinfect it by ozone to study the concentration of chemical parameters in wastewater (COD, FC, PH,TDS , N-NH3) at different time intervals. After show all the result of experiment we compare it with the parameter of Palestinian Standards for irrigation and charge it to the sea.

3.2 Sample collection and size

The samples taken at two stages first stage was 4 liter from GWWTP influent, the second stage was 10 liters from GWWTP second treatment effluent. In each experiment split the samples to two parts first part without disinfection and the second part for disinfection.

3.3 Disinfection by ozone

The experiment is disinfection for Wastewater by ozone, the source of ozone is fresh air come to an ozone device then pumped to the sample.Experiments were performed in a continuous-flow of ozone with different time to evaluate ozone disinfection performance on different parameters, The temperature is the room temperature (23 - 25) ^{o} C.

Ozone have many uses one of them is to use ozone to disinfect the wastewater and change the properties of wastewater to reach the suitable guide line to take chance for using the treated wastewater in many objectives like irrigation , agriculture and recharge groundwater and pump treated wastewater to the sea .

3.3.1 Ozone Generator Theory

The fresh air contain 21% oxygen when the oxygen meet height voltage break the bond O_2 to make two ionic O-O charge O_2 with O^-, The free O^- search to bond with any atom to reach the stability ,O^- face molecular O_2 in the fresh air inside the device to compound O_3. ozone device prepared by Mohammed Mattar . shown figure (3-2) .

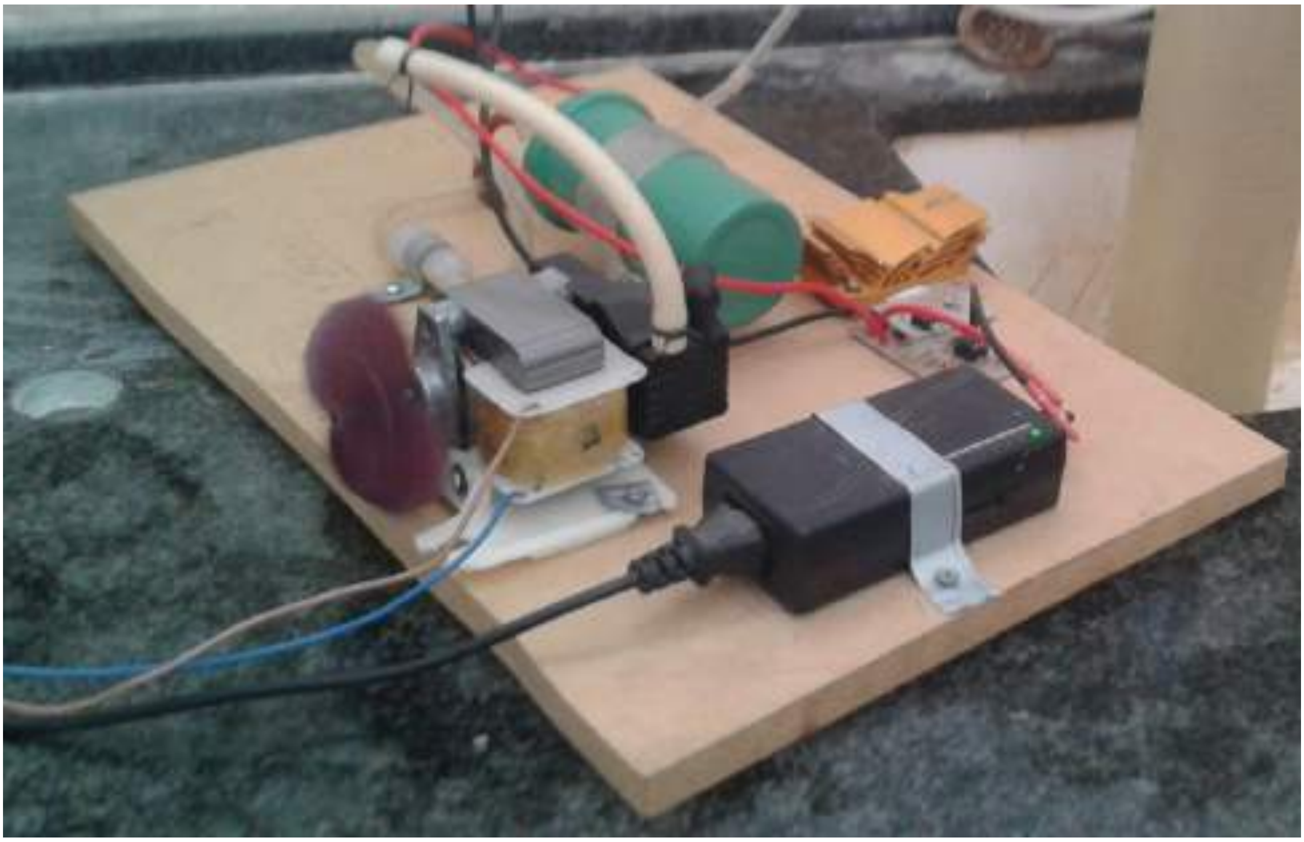

Figure (3-2) : ozone generator device with all component

3.3.2 Operation Mechanism

1- Operate HVG outlet voltage reach the electrode which in the glass tube.
2- Air pump transfers the air in the tube from inlet to outlet.
3- The electrode ionic the fresh air, charge O_2 with O- to form O_3 .
4- The air pass throw filter to absorb wetness to avoid form other component like NO_2, NO_3 and NH_4 .
5- Control device used to control the voltage between (10 – 17) KV depend on the experiment case .

3.3.3 Calculate the concentration of solute ozone

Pass the ozone (O_3)for thirty min. through a certain concentration of KI solution , then calibrate the solution by $S_2O_3^{--}$, put starch for color indicator . as shown Figure (3-3)

1- prepare certain concentration KI solution

$$K + 2I = KI_2$$

2- Pump ozone in the solution for 30min.
3- put starch in the solution

4- during pump ozone the solution color change from white to red according to oxide KI and breakdown I , Figure (3-3)

Starch + I = violet color

5- stop pump ozone , add S_2O_3 until the solution back to the white color .

The amount of S_2O_3 is the amount of ozone demand.

I2 + S2O3 with starch = blue color

The amount of solute ozone is 48 mg O3/ hr .

Figure (3-3) : pump ozone in the sample to calculate ozone concentration

3.4 Sampling and analysis

The samples were taken from GWWTP and transfer it to IUG laboratory at the same day to save them in a bottle with low temperature less than 4 C to keep them with the same parameters without any change or internal operation to day of experiment, next day bring 4 liters for the test, these samples were taken from GWWTP influent. take one liter sample and make good mix (20 time) up-down to make homogeneous sample after that the sample was divided to two parts each part 0.5 liter, as shown Figure (3-4).The first part without disinfection and put it in a cylinder, mean while, the second part put it in a cylinder but with disinfection, the two partsfaced the same condition (temperature, container volume, surface area) but the different is the ozone disinfection. make another good mix for first part after 30 minutes under ozone disinfection and good mix for the other sample and send two parts to the laboratory to measure (PH , COD , TDS , FC) .then we repeat same steps for interval time (45 ,60 , 90 and 120) min. the same procedure was done to the samples collected from GWWTP second treatment effluent , and measure the parameters (PH , COD , TDS , FC, $N\text{-}NH_3$)

Figure (3-4) disinfection by ozone for the first sample 0.5 liter

3.4.1Chemical Oxygen Demand (COD) : " Close Reflux Method "

Chemical oxygen demand (COD) test has used as a measure of oxygen requirement of a sample that is susceptible to oxidation by strong chemical oxidant. COD reduce the time period to oxidize the organic material, where it takes only hours or few minutes.

Procedures:

1- Prepared standard KHP solution (working solution) 1000mg O_2/L from Stock solution.
2- Prepared standard solutions (0, 50, 100, 200 , 300 , 500 ,750 ,1000 mg O2/L).
3- filled the COD screw cap tube [16*100mm] with (2.5mL of sample or standard solution+1.5mL of Digestion solution+3.5mL of sulfuric acid reagent, total =7.5mL).
4- After shaking the sample we put this tubes in heating block(COD reactor) at 150 ^{o}C for two hours .
5- Turned on the Spectrophotometer (λ= 600 nm)..
6- Zeroing the Spectrophotometer using distilled water.

7- Put the standard solutions in the Spectrophotometer.
8- Took the Spectrophotometer measurements for absorbance of the standard solutions.
9- plot absorbance vs concentration .
10- Calculate COD for the sample .

3.4.2Total Dissolved Solids (TDS)

Solids refer to matter suspended or dissolved in water or wastewater. Solids may affect water or effluent quality adversely in a number of ways.

Procedures:

1- Calibrate the EC meter by standard solutions of electrical conductivity.
2- Immerse the electrodes into the sample of water (whose conductivity is to be determined) and wait up to one minute for steady reading.
3- The reading is observed after the indicated value becomes constant.
4- Calculate TDS (mg/L) = 0.64 * EC (µS/cm).

Hint:

- Estimate total dissolved solids (mg/L) in a sample by multiplying conductivity (in micromhos per centimeter) by an empirical factor.
- This factor may vary from 0.55 to 0.9, depending on the soluble components of the water and on the temperature of measurement.
- Relatively high factors may be required for saline or boiler waters, whereas lower factors may apply where considerable hydroxide or free acid is present

3.4.3pH test:

The pH of a solution is a measure of hydrogen (H^+) ion concentration, which is, in turn, a measure of acidity. The intensity of Acidic and basic character of a solution is indicated by ph or hydrogen ion, at a given temperature.

The measurement of pH is now almost universally done using electronic pH meters.

Procedures:

1- Calibrate the electrodes with two standard buffer solutions of pH.
2- Immerse the electrodes into the sample of water (whose pH is to be determined) and wait up to one minute for steady reading.
3- The reading has observed after the indicated value becomes constant.

3.4.4Ammonia Determination (By Using Nesslerization Method

The principle of this experiment is: the existence of NH_4+-in water can be reflected by adsorption of the light by sample contained Nessler Reagent which produces graduated yellow to brown color.

The ammonium have a maximum absorbance at λ=425nm.

Procedures:

1- We prepared working solution of 100ppm from Standard NH3-N solution (Stock solution of 1000ppm) as in the previous experiment.
2- After that we prepared standard solutions (2,5,7,10 ppm) by dilution process as shown in the comments.
3- We turned on the Spectrophotometer and wait about 20min for using it.
4- We add the blank(Ammonia free water) for zeroing the spectrophotometer
5- We put 50ml of each standard solutions in the quartz cell of the Spectrophotometer we add 1mL of K-Na Tartarate plus 1mL of Nessler reagent for each standard solutions
6- Using the Spectrophotometer we read the absorbance of the standard solutions at λ =425nm & tabulate it.
7- We read the absorbance of the unknown water sample

3.4.5Fecal coliform (FC) test

Fecal Coliforms can be defined as gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with the production of gas at 44.5ºC within 24 hr. Although the fecal coliform test is applicable to investigations of surface and ground water pollution, sewage treatment systems and general monitoring of natural waters for sanitary quality, including recreational and shellfish waters, it is so far not considered a substitute for the coliform test in the examination of potable waters. Coliform bacteria of any kind are not to be tolerated in a finished (treated) drinking water.

Procedures:

1- .Pair each positive presumptive fermentation tube with a fermentation tube containing EC broth. Mark each EC tube to match its paired presumptive tube.
2- Using a sterile transfer loop, transfer a portion of the liquid from each presumptive tube to its paired EC broth fermentation tube.
3- Discard the positive presumptive tubes after transferring using appropriate safety precautions.

4- Place all of the inoculated EC broth tubes in a water bath incubator maintained at 44.5° +/-0.2°C.

   NOTE: The tubes should be placed in the water bath within 30 minutes of inoculation.

5- Incubate the EC broth tubes for 24 (+/-2) hours.

6- Remove the tubes from the water bath, shake gently and inspect for gas production.

7- Record all fermentation tubes showing gas production as positive on the test data sheet.

8- Calculate the test results and record as Most Probable Number (MPN)/100 mL.

9- Discard the fermentation tube contents using appropriate safety precautions.

CHAPTER 4: RESULT AND DISCUSSION

This chapter show the result of all experiments , first show the result about ozone efficiency in COD removal and illustration the behavior of organic matter after ozonation cause the removal of COD.Then show the result about ozone efficiency in FC disinfection and illustration the behavior of FC after ozonation cause the disinfection for bacteria .Then show other result about ozone effect on pH , TDS , ammonia .

Compare all result with Palestinian standers for reuse wastewater treatment according to these parameters (COD,FC,pH,TDS,NH_3-N) .

4.1 Ozone efficiency in COD removal

Samples from influent and effluent wastewater for GWWTP were taken to find the influence of ozonation time and the initial concentration of COD on the COD removal. The range of influent COD concentration was (900 – 1350) mg/l with an average of 1154 mg/l. The removal efficiency was [28 % (1020 – 735) , 29 % (900- 635) , 46 % (1200 - 650), 64 % (1300- 473), 60 % (1350-539))] mg/l for Ozone injection time (30, 45, 60, 90 , 120) min. Respectively (Table 4-1) .

While the range of effluent COD concentration was (228-230) mg/l with an average of 229 mg/l. The removal efficiency was [9 % (230 – 210), 11 % (230- 205), 34 % (229- 150), 29 % (229 - 163) 51 % (228- 111)] mg/l for Ozone injection time (30, 45, 60, 90 , 120) min. Respectively (Table 4-1).

Table (4 -1) COD concentration from the influent and the effluent GWWTP and the COD removal efficiency in relation with the time of ozone dosage.

COD removal efficiency						
Time (min)	Influent			Effluent		
	Before	After	Reduction %	Before	After	Reduction %
30	1020	735	28%	230	210	9%
45	900	635	29%	230	205	11%
60	1200	650	46%	229	163	29%
90	1350	539	60%	229	150	34%
120	1300	473	64%	228	111	51%

The result shows that ozonation satisfy the Palestinian standard for wastewater reuse 150 mg/l, using ozonation for effluent 229 mg/l after 90 min the value of COD was low (150, 111 mg/l). Thus it could be used for irrigation like wet fodder irrigation, Gardens, Playgrounds, Recreational and Trees (Citrus and Olive), otherwise for Ozone injection time (30, 45,60) the value of COD (210 , 205 163) it’s compared with Palestinian standard which was higher than the stander 150 mg/l.

The result show that ozonation unsatisfied the Palestinian standard for wastewater reuse 200 mg/l, using ozonation for influent 229 mg/l the value of COD was high (473- 735). So it impossible event to discharge the wastewater to the sea according to the Palestinian standards. Therefore the removal efficiency of COD is not only depends on the ozone dosage or the time of dosage, but depends on the initial concentration of the COD. As shown in Figure (4-1), the removal efficiency is higher at higher COD (influent), while it is lower in case of the effluent.

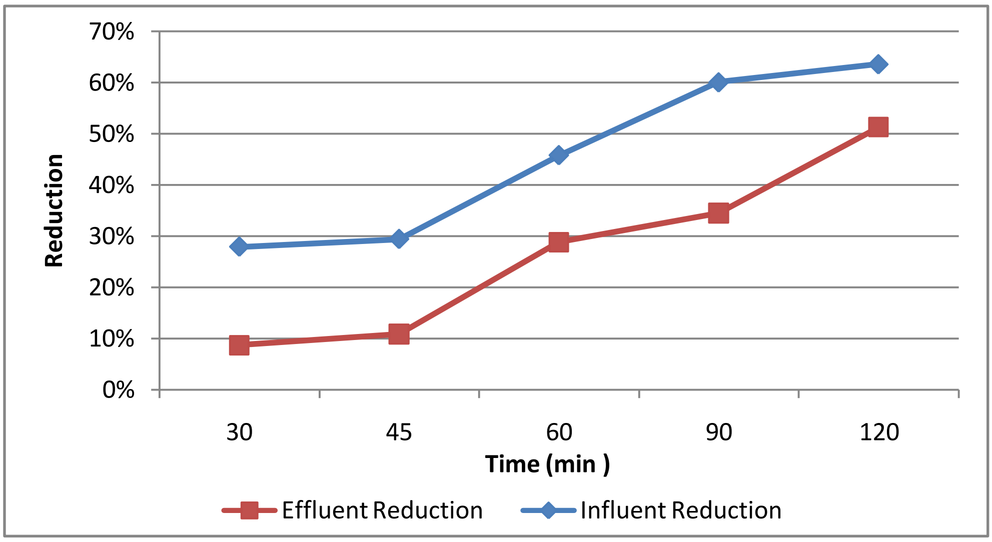

Figure (4-1) the removal efficiency of COD from the(influent , effluent) wastewater in relation to the time of the ozonation dosage

It is noticeable that in the influent wastewater where COD is not treated the ozonation process gives higher removal efficiency. The higher the influent COD the higher removal. This trend is not clear in case of effluent COD where the ozonation efficiency is not high compared with the effluent.

Ozonation process show higher efficiency on the influent due to the characteristics of the organic matter. The higher COD contains the higher amount of easily degradable organic matter, while the effluent lost the easily degradable organic matter during the biological process in the treatment plant.

The treatment process at GWWTP depends mainly on the aeration ponds and trickling filter. Table (4-2) shows the COD removal efficiency of the treatment process by aeration process in both the ponds and the trickling filter. The COD removal efficiency exceeds 78% by normal aeration process, while ozonation process within 120 minutes reduced the COD by 64%. (Ghannam, 2006) in his study collected data over 5 years for COD reduction between influent and effluent for GWWTP (91.3,92.7,90.3,84.2,86.6)% for years (2000, 2001, 2002, 2003 and 2004) respectively, which indicates a poor performance of GWWTP COD removal efficiency is less than the BOD because of the non-removal of the non-degradable fraction of the COD.

Table (4-2) The influent and effluent wastewater COD of Sheikh Ajleen Wastewater. (CMWU, 2013)

GWWTP	COD		
	Influent (mg/l)	Effluent (mg/l)	%removal
July, 2013	1020	220	78
August, 2013	1160	255	78
Sept, 2013	1090	213	80
October, 2013	980	209	79

The observed percentage removal efficiencies varied between 9% and 64 % for COD in the current experiment. The removal efficiency of COD using ozonation process was fluctuated between 5-75 based on ozone dosage .as As shown in Table (2-11) . Several researchers have conducted studies on the treatment of wastewater effluent using ozone. The amount of ozone in the current research is 48 mg O_3/l/hr. is used in the experiment. From the literature the behavior of ozonation process is studied at different concentrations as well Table (2-11).

4.2Ozone efficiency in FC disinfection

Samples from influent and effluent GWWTP were taken to find the influence of ozonation time and the initial concentration of FC on the FC disinfection. The range of influent FC concentration was (17000 – 20000) CFU/100 ml with an average of 18500 CFU/100 ml the reduction was [25 % (20000 – 15000), 46 % (18500- 10000) , 53 % (19000 - 9000), 64 % (18000- 6530) 71 % (17000- 5000)] mg/l for Ozone injection time (30, 45, 60, 90 120) min. respectively .

The range of effluent FC concentration was (5100-6020) CFU/100ml with an average of 5484 CFU/100ml the reduction was [35 % (5500 – 3570) , 42 % (5500- 3200), 57 % (6020 - 2560) , 75 % (5300- 1350) , 83 % (5100- 850)] mg/l for Ozone disinfection time (30, 45, 60, 90 and 120) min. respectively. Table (4-3).

The result shows that ozonation satisfy the Palestinian standard for wastewater reuse 1000 CFU/100 ml, for effluent 5100 CFU/100 ml after 120 min. By disinfection the value of FC was low 850 CFU/100 ml so we can use the wastewater for reuse application like fodder irrigation, Gardens, Playgrounds, Recreational and Trees (Citrus , Olive) and Industrial Crops, otherwise for Ozone injection time (30,45,60 ,90) the value of FC (3570, 3200, 2560 and 1350) it's compared with Palestinian standard which was higher than the stander 1000 CFU/100 ml .

Table (4-3) Samples of wastewater from influent and effluent showing FC before and after disinfection by ozone at different time intervals.

F.C Reduction by ozone						
Time (min)	Influent			Effluent		
	Before	After	Reduction %	Before	After	Reduction %
30	20000	15000	25%	5500	3570	35%
45	18500	10000	46%	5500	3200	42%
60	19000	9000	53%	6020	2560	57%
90	18000	6530	64%	5300	1350	75%
120	17000	5000	71%	5100	850	83%

The result show that ozonation unsatisfied the Palestinian standard for wastewater reuse 20000 CFU/100 ml, for influent 20000 CFU/100 ml by disinfection the value of FC was high (5000- 15000) so we can't discharge the wastewater to the sea .

It is noticeable that in the effluent wastewater where FC treated the ozonation process gives higher removal efficiency. There is change at removal efficiency between influent and effluent under the same injection time that cause FC behavior, to avoid the change removal efficiency between influent and effluent force samples to the same condition (temperature, day of experiment, container sample)

Ozonation process show higher efficiency on the effluent due to the characteristics of the samples as shown in Figure (4-2) . For effluent most organic matter have been removed during the biological process in the treatment plant so the ozonation process work on the bacteria and the amount of bacteria in the effluent is less than the influent .

The FC removal efficiency of treatment process by aeration process in both the ponds and the trickling filter exceeds 0.99% by normal aeration process, while ozonation process within 120 minutes reduced the FC by 83%.

Nebal et al. (1973) obtained 99% removal for FC, (Ghannam 2006) collected data over 5 years for FC reduction between the GWWTP influent and effluent (0.99,0.99,0.99,0.98,0.98) % for years (2000,2001,2002,2003,2004) respectively .which indicates a very low microbiological removal efficiency of GWWTP. The plant is equipped with a chlorination station with dosing pumps and the sodium hypochlorite should be used for disinfection. Due to lack of financial resources, the chlorination unit had been stopped since the summer of 1999 and this is the main reason of having the high values of the Fecal Coliform in the effluent.

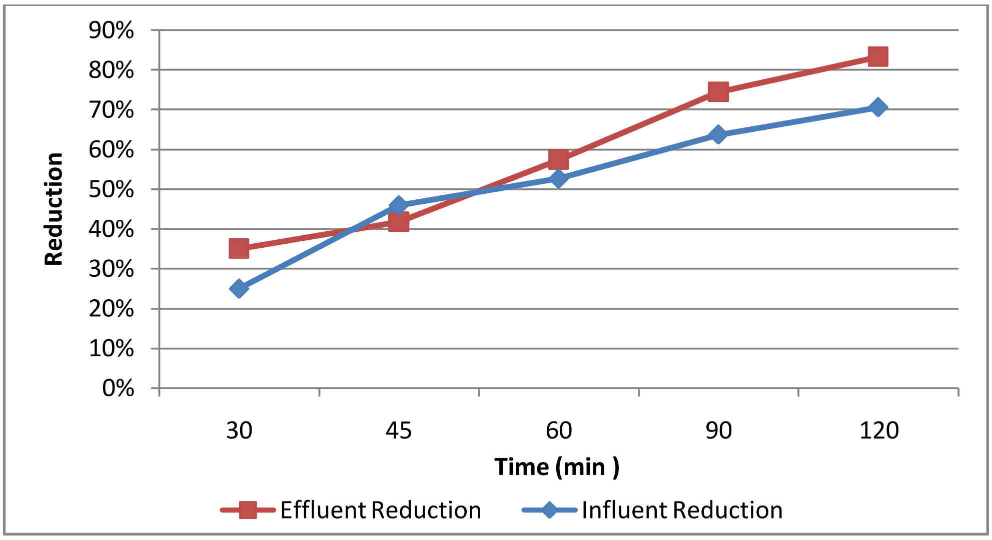

Figure (4-2) ozone disinfection efficiency with time for FC values at influent and effluent

The removal efficiency of the Fecal Coliform is very minor limited only to two logs and the effluent content of the Fecal Coliform is considered to be high putting in mind that this effluent will be discharged to the sea or sometimes used for agriculture which will cause bad environmental impact on man. In addition, the plant is not designed for nutrient removal. The effluent wastewater discharged to the sea or to the infiltration basins will have a bad environmental impact on the aquifer and bathing sea water quality.

4.3The effect of Ozonation on pH

The range of influent pH concentration was 7.8 the reduction was 5 % (7.8 – 7.4) for Ozone injection time (30, 45) min. and was 6 % (7.8 – 7.3 for Ozone injection time (60 , 90 and 120) min.

The range of effluent pH concentration was 8 the reduction was 6 % (8 – 7.5) for Ozone injection time (30, 45) min. and was 5 % (8 – 7.63 for Ozone injection time (, 60 ,120) min. the reduction was 7 % (8 – 7.46) for Ozone injection time (90) min. shown table (4-4) .

Table (4-4) Data and result for pH taken from (influent and effluent) before and after change by ozone

PH Reduction by ozone						
Time (min)	Influent			Effluent		
	Before	After	change %	Before	After	change %
30	7.8	7.4	5%	8	7.5	6%
45	7.8	7.4	5%	8	7.55	6%
60	7.8	7.3	6%	8	7.63	5%
90	7.8	7.3	6%	8	7.46	7%
120	7.8	7.3	6%	8	7.59	5%

The result show that ozonation satisfy the Palestinian standard for wastewater reuse (6-9) the value for pH (7.3-7.63) so we can use the wastewater for reuse application like fodder irrigation, Gardens, Playgrounds, Recreational and Trees (Citrus and Olive) and Industrial .

In an acidic solution (pH low) , ozone gaze oxidize the organic matter. Mean while, when the solution is nutrient (pH = 7) ,Hydroxide Radicals OH^* will be more powerfull of oxidizing organic matter and hence the hydrogen ions (H^+) will be reliezed and hence the pH of the solution will be reduced .

That’s most of COD removal was due to settling instead of oxidizing where the final pH very close to the initial pH of the solution .

There is no major effect of Ozone for pH value. On the other hand, it has been reported that permeability of the outer membrane, which is the main shelter of the cell against oxidant species, increases at alkaline pH values. It could be expected that at pH 9.0 the cells turned more sensitive than at pH 7.0, that behavior was observed from the experiments and was rationalized by the ionization grade of sugars on the lip polysaccharide (LPS) of the bacteria. LPS is considered the main component in the outer membrane of E. coli and it is known that this molecule has a net charge of -1.5 at neutral pH, when pH decreases, this net charge turns the cell membrane into a less hydrophilic conformation less permeable to polar species including the oxidant species at pH 9.0 .

Figure (4-3) show the change percentage of the pH in the (influent, effluent) after ozonation with the contact time.

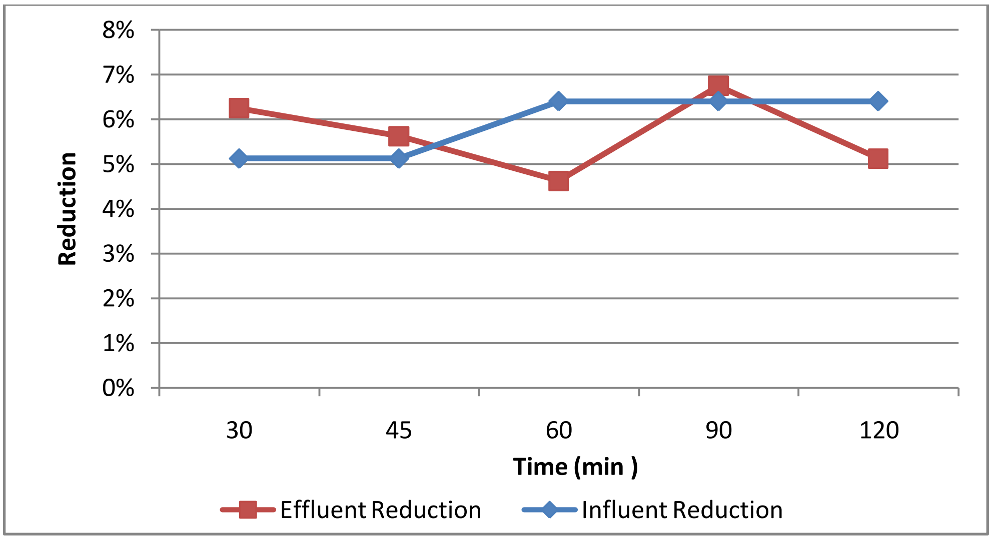

Figure (4-3) compare the values for pH before ozonation and after in the influent ozone change efficiency with time for pH values in the influent

4.4 The effect of Ozonation on TDS

The range of influent TDS concentration was (1700 – 1750) mg/l with an average of 1725 mg/l. the reduction was 3 % (1750 – 1690) , 2 % (1707- 1677) , 2 % (1742 - 1710) , -1 % (1700- 1710) , 2 % (1730- 1700)] mg/l for Ozone injection time (30, 45, 60, 90 and 120) min. respectively .

The range of effluent TDS concentration was (1700-1750) mg/l with an average of 1725 mg/l. the reduction was [6 % (1750 – 1650) , 2 % (1707- 1670) , 6 % (1742 - 1632) , 4 % (1700- 1630) ,3 % (1730- 1677)] mg/l for Ozone injection time (30, 45, 60, 90 and 120) min. respectively . Shown table (4-5) .

The results show that for effluent 1750 mg/l ozone effect satisfied the Palestinian standard for discharge the wastewater to the sea . majed m. ghannam ,2006 , collected data over 5 years for TDS reduction between the GWWTP influent and effluent (1.4,5.3,-3,-7.41,-4.9) for years (2000,2001,2002,2003,2004) respectively .

Considering the period from the year 2000 to 2004, the values of the effluent TDS are increasing with time and this is mainly due to the deterioration of water quality of the aquifer, which is reflected on the incoming influent to GWWTP . The values of TDS increased a little when passing through the treatment process due to evaporation which is clear in summer months. This was reflected clearly after the year 2002 as the effluent TDS average values were higher than the influent values ,The difference between total and dissolved COD behaviors could be related to the global decrease of turbidity observed during the tests , some particles and high weight organic compounds would be destroyed by ozone and converted into dissolved compounds

Table (4-5) Data and result for TDS taken from (influent and effluent) before and after removal by ozone

TDS Reduction by ozone						
Time (min)	Influent			Effluent		
	Before	After	Reduction %	Before	After	Reduction %
30	1750	1690	3%	1750	1650	6%
45	1707	1677	2%	1707	1670	2%
60	1742	1710	2%	1742	1632	6%
90	1700	1710	-1%	1700	1630	4%
120	1730	1700	2%	1730	1677	3%

Figure (4-4). shows the change in the TDS value of the (influent , effluent) wastewater after ozonation .

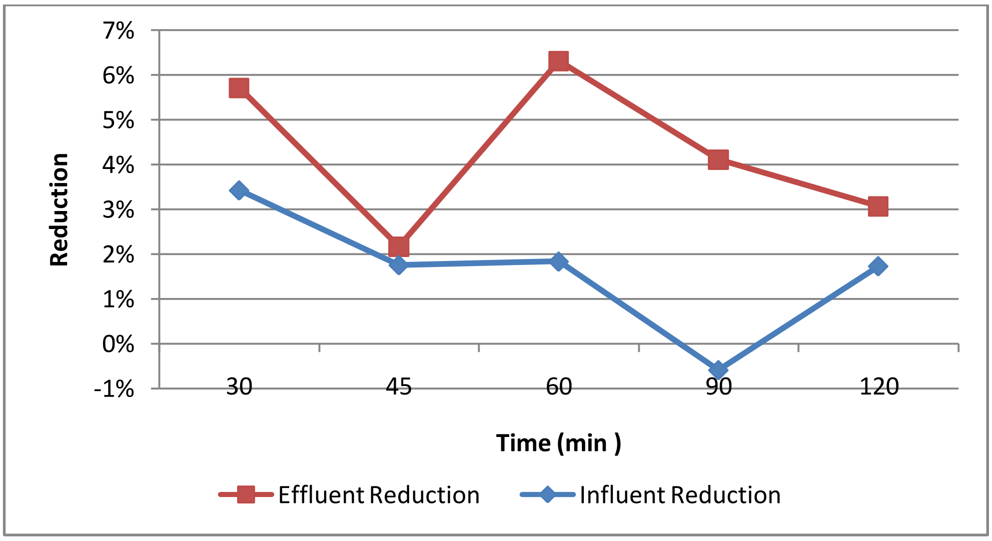

Figure (4-4) compare the values for TDS before and after removal at influent and effluent source

4.5 The effect of ozonation on Ammonium

The range of effluent NH3-N concentration was 73 mg/l . there is no effect at time (30, 45) min . the reduction was 1 % (73 - 72) mg/l for Ozone injection time (60) min. the reduction was 2 % (73- 71.5 mg/l for Ozone injection time (90) min. the reduction was 4 % (73- 70) mg/l for Ozone disinfection time (120) min shown table (4-6) .

The result show that ozone removal unsatisfied the Palestinian standard for wastewater reuse 200 mg/l , for effluent 73 mg/l by ozone removal the value of NH3-N was high (70 -73) so we can't use the wastewater for reuse application .

The observed percentage removal efficiencies varied between 0–4% for NH3–N (majed m. ghannam 2006) collected data over 5 years for N-kjd reduction between the GWWTP influent and effluent (23.5,25.5,13.5,28.5,21.5) for years (2000,2001,2002,2003,2004) respectively .The removal efficiency of GWWTP for the TKN is not related to temperature or to hydraulic load of the plant. There is no clear trend for the removal efficiency in winter when the temperature and flow decrease, or in summer when the flow and temperature increase. The GWWTP was not upgraded to nutrients removal, this is explained as follows; a soluble BOD5as low as 20 mg/l is required before sufficient oxygen is available to permit nitrification (Horan, 1991) and this value of the BOD5can never be achieved by the existing trickling filters according to the upgrading design. The nutrient removal is highlighted in this research as part of the evaluation of GWWTP for this aspect.

It is thought that the presence of organic materials may have protected $NH_3$from oxidation Results of a comparison study showed that if alum were substituted for $FeCl_3$in the treatment process at the GWWTP, ozone disinfection efficiency would be enhanced. Ozone disinfection itself was did not cause any increased toxicity in the wastewater

When increase the dosage and reaction time , the NH3-N removal will be enhanced . further more, the increase of pH solution to be base will enhance the removal efficiency of NH3-N espiacally if the ozonation system is close system .

Table (4-6) Data and result for NH_3-N taken from effluent, before and after disinfection by ozone

NH3-N Reduction by ozone			
Time (min)	Effluent		
	Before	After	Reduction %
30	73	73	0
45	73	72.9	0
60	73	72	1
90	73	71.5	2
120	73	70	4

Figure(4-5). shows the change in the NH3-N value of the (influent, effluent) wastewater and after ozonation.

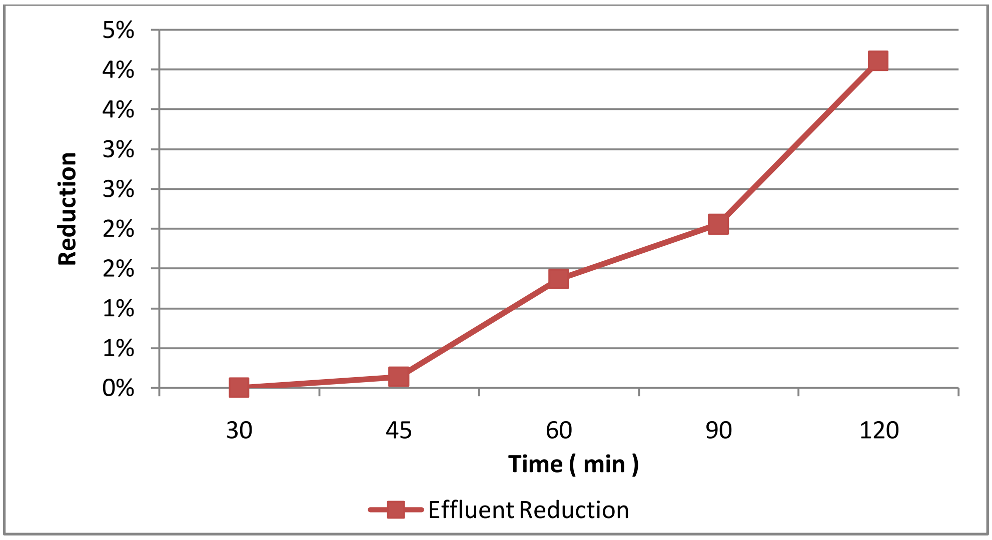

Figure (4-5) ozonation efficiency with time for NH3-N values at effluent source

CHAPTER 5 : CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

The use of ozone for wastewater disinfection has received a considerable attention in the last 20 years. Interest in the disinfection of ozone is likely to increase in the future, particularly where wastewater effluents are to be reused and a high degree of treatment is required.

Ozone emerges as a very versatile solution offering the highest efficiency in the treatment of effluents. It allows the production of an effluent with no micro-organisms, no odors, low COD level and suitable for discharge into the environment use in agriculture.

Combined with biofiltration, ozone provides an optimized chemical and biochemical oxidation. Unlike systems that only displace pollution by producing large amounts of sludge (e.g. precipitation with salts and flocculation with lymers) or by producing a concentrate of this pollution (e.g. with membranes), ozone eliminates the pollution and produces only a small amount of biological sludge

- The disinfection of wastewater by ozone treatment for COD parameter (influent , effluent) respectively has minimum reduction achieved (28% , 9%) for time interval 30 minutes and maximum reduction achieved (64% ,51%) for time interval 120 minutes which is the optimum , ozone flow 48 mg O3 / h . for effluent source 229 mg/l ozone disinfection satisfy the Palestinian standard for wastewater reuse , but influent source unsatisfied with standers to discharge the wastewater to the sea.
- The disinfection of wastewater by ozone treatment for FC parameter (influent , effluent) respectively has minimum reduction achieved (25% , 35%) for time interval 30 minutes and maximum reduction achieved (71% ,83%) for time interval 120 minutes which is the optimum , ozone flow 48 mg O3 / h , for effluent source 5100 CFU/100 ml ozone disinfection satisfy the Palestinian standard for wastewater reuse , but influent source unsatisfied with standers to discharge the wastewater to the sea.
- There is no observed systematic change for PH, NH_3-N and TDS parameters

5.2 RECOMMENDATIONS

- Study efficiency of ozonation process on a continuous flow column of wastewater .
- Make ozone device using pure oxygen to study ozone effect on the same parameters .
- Test other parameters to inject the treated wastewater in the groundwater to avoid negative effect on the groundwater quality .
- Use advanced oxidation material with ozone because ozone alone is weak (such as , Persulfate, Fenton) .
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CHAPTER 6 : REFERANCES

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Appendices

Limits and standards for the re-use of treated sewage water for -different purposes

Property Mg/L Unless otherwise stated	Discharge to the sea	recharging the aquifer by filtration	Irrigation of dry feed	Irrigation of green feed	Irrigation of parks and playgrounds	Irrigation of Industrial crops and grains	Irrigation of Forest trees and forests	Irrigation of Citrus trees	Irrigation of olive trees	Irrigation of Almond trees
Biochemical oxygen demand BOD5	40	20	60	45	40	60	60	45	45	45
Chemical oxygen demand COD	100	50	120	90	80	120	120	90	90	90
Dissolved Oxygen DO	More than 1	More than 2	More than 0.5	More than 0.5	More than 0.5	More than 0.5	More than 0.5	More than 0.5	More than 0.5	More than 0.5
Total Dissolved Solids TDS	-	1000	1200	1200	1500	1500	1500	1000	1500	1000
Total Suspended Solids TSS	60	50	50	40	30	50	50	40	40	40
Hydrogenous PH	6-9	6-9	6-9	6-9	6-9	6-9	6-9	6-9	6-9	6-9
Color (PCU)	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Turbidity (NTU)	-	2	5	5	5	5	5	5	5	5

Fat Oil and Grease	8	0	5	5	5	5	5	5	5	5
Phenol	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Detergents (MBAS)	25	5	15	15	15	15	15	15	15	15
Nitrates NO3	45	30	50	50	50	50	50	50	50	50
Total Nitrogen TKN	50	25	100	100	45	100	100	100	100	100
Phosphate-Phosphorus P-PO4	10	15	30	30	30	30	30	30	30	30
Chlorides CL-	-	350	500	500	500	500	500	400	600	400
Sulphates SO4	300	300	500	500	500	500	500	500	500	500
Sodium Na	200	200	200	200	200	200	200	200	200	200
Magnesium Mg	60	60	60	60	60	60	60	60	60	60
Calcium Ca	200	200	400	400	400	400	400	400	400	400
SAR	6	6	9	9	10	9	9	9	9	9
Aluminium Al	2	2	5	5	5	5	5	5	5	5
Arsenic Ar	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Copper Cu	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Iron Fe	5	5	5	5	5	5	5	5	5	5
Manganese Mn	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Nickel Ni	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Lead Pb	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Selenium Se	0.02	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Cadmium Cd	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zinc Zn	5	5	2	2	2	2	2	2	2	2
Cyanide CN	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Carbon Cr	0.02	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mercury Hg	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cobalt Co	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Boron B	1	1	2	2	2	2	2	2	2	2
Faecal Coliform (CFU /100 ml)	500	200	200	200	200	200	200	200	200	200
E.coli (CFU / 100 ml)	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Pathogens	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Amoeba and Gardia (Cyst/L)	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Nematodes (Eggs/L)	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1

(-): Non specific

Table 2: response values for different experimental conditions (ozone oxidation).

Run no.	Factors			Response			
	A	B	C	1	2	3	4
	Ozone dosage (g/m^3)	COD concentration (mg/l)	Reaction time (min)	COD removal (%)	NH_3-N removal (%)	Colour removal (%)	OC (Kg O_3/Kg COD)
1	80	250	60	27.2	8.5	90	19.40
2	55	1125	35	18.8	1.1	31.8	3.62
3	30	250	10	16	0.0	25	3.44
4	55	2000	35	21	0.0	24	1.80
5	80	2000	10	10	0.0	18.5	2.04
6	55	250	35	24	6.5	72	7.72
7	55	1125	35	17.5	1.2	32.5	3.41
8	80	2000	60	15	0.0	27.3	6.96
9	55	1125	35	18	1.1	33	3.33
10	55	1125	35	18.5	1.2	32	3.41
11	30	2000	10	4	0.0	11	1.80
12	55	1125	35	17.6	0.9	31	3.70
13	30	2000	60	11	0.0	23	2.09
14	55	1125	10	15.5	0.0	16	1.60
15	30	1125	35	12.5	1.0	38	5.15
16	80	250	10	15	4.7	45	9.47
17	55	1125	35	17.5	1.2	33.6	4.50
18	30	250	60	20.8	2.0	88	4.72
19	55	1125	60	22	1.4	58	3.18
20	80	1125	35	19	2.2	31	6.09