Integrated Pilot Scale System of

Nano Filtration with A Pulse Electrical Field to

Improve Water Quality

A Thesis

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بسم الله الرحمن الرحيم

((وفوق كل ذي علم عليم))

صدق الله العلي العظيم

سورة يوسف-الآية (76)

Dedication

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To my parents, may God give them long life,

and to everyone who participated in my

education through academic life.

Khamail

2021

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First of all, anything praise is to ALLAH HIS MAJESTY for all things. Then I want to thank with great gratitude my supervisor **Prof. Dr. Alaa Hussein Al-fatlawi,** for his appreciable guidance and useful suggestions throughout the course of this work.

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I

Abstract

The increasing consumer demand for safety drinking water has resulted in the development of processing technologies. Among these novel processes the use of Pulsed Electric Fields (PEF) technique, a physical technology based on power electronics. Pulsed electric fields (PEF) is a novel and very promising technology for drinking water treatment, the water enters the PEF, flows between two electrodes, and undergoes pulsing by electric fields. Microorganisms present in water are inactivated as a result. PEF treatment times are very short (microseconds), and processing temperatures are near room temperature or below. Energy savings using PEF are also important compared with conventional thermal treatment.

In this study, filtration and disinfection process were combined in one unit named Disinfectant Membrane (DM), as a part of water treatment process. A pilot scale system was used which is two meshes of silver (with dimensions of 30cm length and 3cm width) as electrodes placed between the layers of a reverse osmosis membrane. The important reason for this new design (DM) is to improve water quality and reduce chlorine dose. Tap and river water samples were treated in this system under different operating conditions (applied voltage, electrical pulse, pH, temperature and the flow rate of feed water). Physical, chemical and biological tests of these samples were tested in Directorate of Environment in Karbala/lab, and the results were written down for all samples. The experiments showed a complete elimination of the bacterial indicator at optimum conditions: V=12, 2pulse/second, Q=1L/min, P=10bar, and the

maximum removal efficiency of Tur, TDS, EC, Cl⁻ and TH was 48.5%, 94.8%, 95%, 59.2%, 84.8% for tap water respectively, and 90%, 87.8%, 87.7%, 62.6%, 87.5% for river water respectively, and 97% of TOC. These findings refer that DM is capable of removing indicator bacteria effectively and achieve high water quality.

Imaging by Field Emission Scanning Electron Microscopy (FESEM), was conducted to characterize of the membrane surface after applying Pulse Electric Field - Low Voltage (PEF-LV) technology.

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List of Abbreviations

Abbreviations	Description
APC	Aerobic Plate Count
AC	Alternating Current
APHA	American Public Health Association
AOC	Assimilable Organic Carbon
CA	Cellulose Acetate
Cl	Chloride
CFU	Colony Forming Unit
VC	Compression Vapour
DNA	Deoxyribonucleic Acid
DC	Direct Current
DBP_S	Disinfection By Products
DWTPS	Drinking Water Treatment Plants
EC	Electrical Conductivity
ED	Electrodialysis
EPA	Environmental Protection Agency
E.Coli	Escherichia Coli
EDTA	Ethylene Diamine Tetra Acetic Acid
EPS	Extracellular Poly Saccharides
FESEM	Field Emission Scanning Electrical Microscopy
FO	Forward Osmosis
HPC	Heterotrophic Plate Count
HDH	Humidification- Dehumidification
pH	Hydrogen Ion Exponential
LCD	Liquid Crystal Display

LPRO	Low Pressure Reverse Osmosis
MDF	Membrane Disinfectant Filter
MD	Membrane Distillation
MIB	Methlyisoborneol
MF	Microfiltration
MWCO	Molecular Weight Cut Off
MED	Multi Effect Distillation
MSF	Multi Stage Flash
NF	Nanofiltration
NOM	Natural Organic Matter
PEF	Pulse Electrical Field
POU	Point Of Use
PVC	Polyvinyl chloride
PEFLV	Pulse Electrical Field Low Voltage
RO	Reverse Osmosis
SEM	Scanning Electron Microscopy
SDI	Silt Density Index
Temp.	Temperature
TFC	Thin Film Composite
TDS	Total Dissolved Solid
TH	Total Hardness
TOC	Total Organic Carbone
THMS	Trihalomethanes
Tur.	Turbidity
ULPRO	Ultra low Pressure Reverse Osmosis
UF	Ultrafiltration
UV	Ultraviolet
US	United State

USB	Universal Serial Bus
WHO	World Health Organization
WWTPS	Waste Water Treatment Plants

List of Symbols

Symbol	Definition
mg/L	Milligram per liter
mL/min	Milliliter per minute
V	Voltage
Hz/sec	Hertz per second
L	Liter
nm	Nanometer
° C	Degrees Celsius
cm	Centimeter
m	Meter
g	Gram
%	Percent
hrs	hours
G/d	Gallon per day
NTU	Nephelometric Turbidity Unit
μs/cm	Micro-Siemens per Centimeter
ppm	Part per million
mm	Millimeter
m^2/m^3	Square meter per cubic meter
A	Ampere
mA	Milliampere
Ma	Micro ampere
L/min	Liter per minute
Kv	Kilovolt
M	Molarity

m^3/h	Cubic meter per hour
G/m	Gallon per minute
ms	Millisecond
H_2SO_4	Sulfuric acid
NaOH	Sodium hydroxide

Chapter One

Introduction

CHAPTER ONE

INTRODUCTION

1.1 Background

Pure drinking water supplies are considered a major public health milestone of our generation. However, waterborne diseases are still the third leading cause of death. The Word Health Organization (WHO) reported that diarrheal disease from unsafe water kills 1.5 million children each year and causes two billion cases of illness worldwide. The problem is expected to be exacerbated by climate change, [Levy et al., 2016].

Indeed, many waterborne pathogens are known to persist and reproduce in the drinking water distribution systems and are responsible for causing infections of gastrointestinal tract, skin and lymph nodes. *Legionellapneumophila, Pseudomonas aeruginosa, Aeromonas sp* and *Mycobacterium sp* are among the pathogens found in tap water in homes, public buildings and hospitals, [Bailey et al., 1970 and Kawai et al., 2004].

Microorganisms can colonize and form complex microbial ecosystems on all surfaces of drinking water distribution systems that are in contact with water, [Vaerewijck et al., 2005]. The age, construction and materials of the water distribution system affect biofilm formation and dynamics, [Lautenschlager et al., 2010; Bolton et al., 2010 and Moritz et al., 2010]. It has been shown that the diverse microbial community found in drinking water systems can increase microbial resistance to chemical disinfection.

Studies have clearly demonstrated that maintaining a residual level of chemical disinfectant in drinking water distribution systems is ineffective in controlling microbial growth, [Kilb et al., 2003;

Berry et al., 2006 and Wingender et al., 2011]. However, chlorination can produce unwanted byproducts such as chloromethane with its own health implications, [Sohn et al., 2004]. The same issue problem exists with ozone treatment in it produces byproducts, which byproducts as well as the ozone itself, have adverse health implications, [Galapate et al., 2001]. UV disinfection at point-of-use has been proposed, but at a significantly higher cost, and turbidity from gas bubbles can significantly reduce its effectiveness. Also, cellular repair mechanisms limit its efficiency as shown by a study that reports Gram-negative Enterobacteriaceae *(i.e.,* coliforms and enterococci) exhibit high rate of regrowth after UV disinfection, [Sommer et al., 2000]. A recent study also shows UV irradiation can induce competence in *Legionella pneumophila* allowing the bacteria to acquire and propagate foreign genes, contributing to its emergence as pathogen, [Charpentier et al., 2011].

Therefore, the conventional water treatment provides unsatisfactory results, because treatment facilities are not equipped to remove stable low-concentrated pollutants, [Kunduru et al., 2017].

1.2 Water Treatment by Membrane Filtration Techniques

The membrane filtration can be used as alternatives for flocculation, sediment purification techniques, adsorption (sand filters and active carbon filters, ion exchangers), extraction, and distillation. The selectivity and productivity (membrane dependent) determined the efficiency of a membrane filtration process. Selectivity is expressed as a parameter called retention or

separation factor while productivity is expressed as a parameter called flux, [Saravia et al., 2005].

The main membrane technology works without the addition of chemicals, with a relatively low-energy involvement. These are suitable for treating ground water, surface water and waste water. The membrane separation process is based on the presence of semipermeable membranes. The membrane acts as specific filter that will let water flow through, while it withholds suspended solids and other substances and these substances are forced to pass through the membrane by high pressure, the concentration gradient and electric potential are maintained on both sides of the membrane. Membranes are hold up in selective separation wall and some substances can pass through the membrane, while others are retained. All of the techniques have flaws such as significant increase of the operating costs; potential for membrane damage, [Le-Clech et al., 2006].

Application of membrane-based techniques for microbial decontamination has gained considerable momentum in water purification industries, the superiority of membrane-based techniques over conventional treatment methods can be expressed in terms of: [Torri et al., 2019 and Nemeth et al.,2019].

(i) Produced water with consistent characteristics.

(ii) Rapid and effective elimination of chemically resistant pathogens.

(iii) Inhibition of bacterial re-multiplication.

(iv) Negligible residual chemical hazard, and

(v) Promising efficacy to decontaminate the polluted water with the quality reaching at standard levels.

Point-of-use water filters are reported to be effective in reducing *Legionella pneumophila* and *Mycobacterium* in water fixtures, [Sheffer et al., 2004], but a more recent study shows that

water filters are also vulnerable to microbial colonization, [Chaidez et al., 2004]. Heterotrophic Plate Count (HPC) bacteria, Faecal Coliforms, acid-fast organisms (Mycobacteria spp.) as well as opportunistic pathogens such as *Aeromonas hydrophila,* *Plesiomonas shigelloides* and *Pseudomonas aeruginosa* are reported to thrive in filtered water samples.

1.3 Statement of The Problem

The high demand for pure water has led to the increasing development of membrane technology. Natural organic matter (NOM) present in water not only affects the odour, colour and taste of water, but it can form complexes with heavy metals and also can reacts with chlorine. Therefore, the sustainable manner should be considered to produce pure water and also protect the environment, [JEFFRI, 2017].

In Iraq, due to dams built in neighboring countries, and a lack of common management practices, peak flows in Iraq do not coincide with the country's water needs. This problem will become worse with time as demand increases due to rapid urbanization, population pressure, intermittent water supply due to fluctuation the electrical energy, unaccounted flow of water (leakages and unauthorized connections), old pipelines and frequent contaminations which lead to several health hazards, [Alwash and Al-Shibaany, 2018].

However, nowadays there are several methods for controlling the presence of microorganisms in tap water and provide a potable water, such as treatment by Pulse Electrical Field Technology.

Pulsed Electric Field Low Voltage PEF-LV Technology has been successfully used for water disinfection, [Espino-Cortes et al., 2006; Shimono et al., 2008; Riedel et al., 2008 and Duda, 2011]. This technology was first used for non-thermal sterilization

pharmaceuticals, [Goldberg and Rubinsky, 2010] and food products (e.g., fruit juices, milk and cream), [Wan et al., 2009].

1.4 Study Objectives

This technology consists of a household membrane system coupled with a device that releases silver ions into the water through generating pulse electrical current low voltage to a pair of electrodes, the overall objectives of this study are the following: -

1. Evaluating the custom designed model for purifying tap water for human consumption.

2. Assessing the modified membrane system's efficiency (lab scale), an integrated system that combines reverse osmosis membrane with applying Pulse Electrical Field-Low Voltage (PEF-LV) to remove microorganisms from tap and river water.

3. Evaluating PEF-LV technique as a suitable model for point-of-use (POU) disinfection of drinking water.

4. PEF-LV technique has many advantages such as improving and modifying treatment process, minimum required space, easy handling compared to other methods, no need to add chemicals in this system, less fouling production, reducing energy consumption and operational cost as well as minimizing the negative effect of direct current field on the safety of membrane, due to the low voltage needed to operate effectively.

1.5 Scope of The Study

This study consists of five chapters as follow: -

Chapter One: This introductory section, which has outlined the main objectives and motivation behind the study.

Chapter Two: Presents a basic concepts and literatures review of the main technologies existing which are relevant to this work.

Chapter Three: Which details the principal methods chosen for laboratory experiments and installing the scale plant, in addition to prepare materials and tools that are necessary for operation the system.

Chapter Four: Contains the results obtained for each case and presents a general discussion of the study as a whole.

Chapter Five: Presents overall conclusions of the study project and recommendations for future works.

Chapter Two

Literature Review and Theoretical Concepts

CHAPTER TWO

THEORETICAL CONCEPTS AND LITERATURES REVIEW

2.1 Introduction

Implementation for drinking water disinfection and filtration effectively reduced pathogen related waterborne diseases, such as typhoid fever and cholera, and therefore can be regarded as one of the most important public health advances of the last century, [Rosario-Ortiz et al., 2016]. However, the discovery of Disinfection By-Products (DBPs), formed by the reaction between chemical disinfectants and natural organic matter (NOM) as well as inorganic precursors (e.g., bromide) raised concerns due to their suspected adverse health effects, [Sedlak and Gunten, 2011]. Epidemiological studies suggested an increased risk of bladder cancer after life-long ingestion of chlorinated drinking water, [Hrudey and Farwell, 2015].

Point-of-use (POU) filtration devices may reduce potential risks posed by DBP exposure. POU filters should be considered as an end-of-pipe solution for distributions systems with chlorinous disinfectants. Preferably, in optimized drinking water systems, the use of chlorine can be minimized or avoided, [Rosario-Ortiz et al., 2016].

2.2 Theory of Filtration

2.2.1 Principal Mechanisms of Filtration

Filtration is a fundamental unit operation that separates suspended particles matter from water. Although industrial application of filtration varies significantly, all filtration equipment operates by passing the

solution or suspension through a porous medium, upon which solid particles are retained either on the surface of the medium or within the pore spaces of the medium. Conventional filtration processes are normally preceded by coagulation, flocculation and sedimentation. Direct filtration processes are preceded by coagulation and flocculation only; the floc is removed directly by the filters, [Tyagi and Reddy, 2010].

Slow sand filter is the first technique used for the treatment of surface water. It can eliminate up to 99.9% of the water born bacteria. It has been also used to prevent gastro intestinal diseases for the last 150 years, [Souter et al., 2003]. Slow sand filtration has several limitations; the most important of all requires large area, long time, as well as a great amount of filter material.

2.2.2 Types of Filtration Process

There are basically two types of filtration process, surface filtration and depth filtration, [Arndt and Wagner, 2004]: -

- **Surface filtration:** The suspended particles adhered only on the surface of the filtering media. Frequent Backwashing is required in such type of filtration process.

- **Depth filtration:** The suspended particles enter into the porous medium. In this case the medium provides the surface area for attachment and growth forms around the grains. Basically there are two types of depth filters, slow sand filters and rapid sand filters.

2.2.3 Transport Mechanism

The principal processes by which particles are brought into contact with the filter medium consist of the following, [Tyagi and Reddy, 2010]: -

- **Screening:** This is the process for the interception and retention particles too large to pass through the interstices

between the grains of sand. It takes place almost entirely at the surface of the filter.

- **Interception:** Occurs when particle motion along a streamline is close enough to the collector for contact to occur. Although interception has been considered a distinct transport mechanism, some researchers have incorporated it, as a boundary condition for attachment resulting from diffusion and sedimentation.

- **Sedimentation:** The settling action within the pores, whereby particulate suspended matter is precipitated onto the sand grains. The total upward facing surface area of all the grains is theoretically available for settling. The mechanism can only be significant for dp>1um, and plays an important role in filtration because of the large surface area on the grains available for deposition.

- **Inertial and Centrifugal forces:** The particles having specific gravity higher than the surrounding water, leave the flow lines due to the inertial and centrifugal forces acting upon them.

- **Diffusion:** It brings suspended particles into contact with the surface of the sand. This mechanism can only be significant for DP<1um.

- **Mass attraction:** Also known as Vander Walls force of attraction. This force acts universally and contributes to both the transport and the attachment mechanisms.

2.3 Fundamentals of Membranes for Water Treatment

Membrane can be defined as a barrier which can separates two phases and limits the transport of various chemicals components to pass through that membrane, [Soni et.al, 2009].

According to [Drahim, 2013], membrane is defined as a structure having lateral dimensions much greater than its thickness that mass transfer occurs under variety of driving forces.

Membrane filtration has gained particular attention for the removal of a broad spectrum of contaminants from water and wastewater since the 1990's despite the demonstration of their potential since early 1960s. The growing interest in the use of membrane technology for water and wastewater treatment can be explained by the increasing demand for high quality water, the introduction of more stringent regulations, and the increasing interest in wastewater reuse, [Visvanathan et al., 2000].

The extended application of membrane technology was also motivated by the improvement of membrane materials and the development of membranes with enhanced chemical, thermal and mechanical properties or better permeability and selectivity, as well as the decrease of operation costs, namely the membrane price due to enhanced use. Furthermore, membrane technologies present several advantages over conventional processes like it do not involve the addition of chemical additives, usually present reduced plant footprint, and may be easily up scaled and retrofit to an existing facility or combined with other treatment processes, [EPA, 2005; Fane et al., 2011].

2.3.1 Membrane Separation Process

Membrane separation processes are increasingly advanced methods for the treatment of water and wastewater. Membranes separate substances depend on pore and molecule size. It is a reliable and automated process for wastewater treatment, [Gehrke et al., 2015].

There are many different definitions of membrane which vary considerably in comprehensiveness and clarity. It can define

a membrane as: A material through which one type of substance can pass more readily than others, thus presenting the basis of a separation process. This definition identifies the property of the membrane to separate components of the water to be treated, and this is a property that is the key interest when selecting or designing membrane separation systems for water treatment. Membrane processes can achieve selective removal of contaminants across a wide range of sizes, with ultimate selectivity for ions over water as shown in Fig. (2.1).
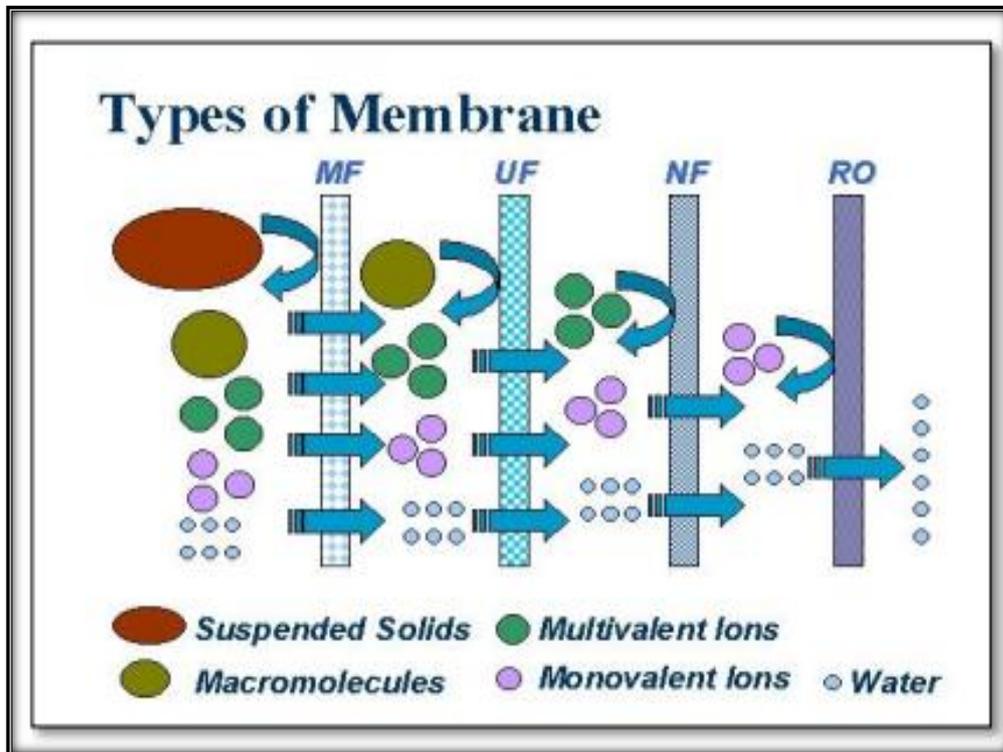
Fig.2.1: Types of Membrane Separation Process, (Drahim, 2013).

Good microbial and chemical quality of the water is also likely to be achieved by pressure-driven-membrane processes, as alternative to commonly rapid sand filtration, that will act as an effective barrier to organic compounds, [Yangali Quintanilla et al. 2009; Verliefde et al., 2009; Salvaterra et al., 2011] and natural organic matter (NOM),

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[Salvaterra et al., 2011] as well by constituting an extra barrier for bacteria and viruses, [Patterson et al., 2012].

2.3.2 Types of Membranes

Membrane performance is mostly dependent on the physicochemical properties of the membrane material such as surface chemistry, hydrophobicity, surface charge, thickness, chemical, biological and thermal stability, cost, chlorine tolerance, durability, porosity and surface roughness. Membranes are generally classified based on their pore size, molecular weight (MW), applied pressure and water affinity (hydrophobicity and hydrophilicity), [NWEDO, 2016].

The application of pressure-driven membrane processes to water treatment has become increasingly common over the last 20 years, as the quality of the technology has shown improvement and costs have shrunk. The basic properties of RO membrane are summarized in table 2.1 along with other types of pressure driven membranes such as Nanofiltration (NF), Ultrafiltration (UF), and Microfiltration (MF), which are categorized based on the pore size or operating pressure range. MF and UF membranes are the low-pressure membranes with relatively larger pores. They are also used as the support for fabricating TFC RO and NF membranes. RO membranes have the tightest surface "pores" (<2 nm (diameter), generally considered as non-porous membrane) and are able to retain dissolved ions (including monovalent ions Na^+ and Cl^-) and small organic molecules. RO membranes can be further divided into seawater RO (SWRO) and brackish water RO (BWRO) membranes, [Wang et al., 2019].

Table 2.1. Typical Properties of Pressure-Driven Membranes, (Wang et al.,2019).

	Microfiltration	Ultrafiltration	Nanofiltration	Reverse osmosis
Surface pore size (nm)	50–10,000	1–100	~2	<2
Operating pressure (bar)	0.1–2.0	1.0–5.0	2.0–10	10–100
Water permeability ($L/m^2h/bar$)	>500	20–500	5–50	0.5–10
MWCO (Da) *	Not applicable	1000–300,000	>100	>10
Targeted contaminants	Bacteria, algae, suspended solids, turbidity	Bacteria, virus, colloids, macromolecules	Di- and multi-valent ions, natural organic matter, small organic molecules	Dissolved ions, small molecules
Membrane materials	Polymeric, inorganic	Polymeric, inorganic	Thin-film composite polyamide, cellulose acetate, etc.	Thin-film composite polyamide, cellulose acetate

*MWCO: Molecular Weight Cut-Off., Da: Daltons.

Manufacturers have utilized several designs for cross flow membrane devices. Tubular, plate-and-frame, spiral-wound and hollow-fiber configurations are available, [Bergman, 2005]. Spiral wound membranes are made by attaching several membrane sheets to a cylindrical core, then winding the membranes into a compact cylinder. Hollow fiber designs feature a large number of thin, flexible membrane tubes glued together at one end. While hollow fiber membranes have greater surface area per unit volume, spiral-wound designs dominate the reverse

osmosis industry due to a lower propensity for fouling, [Ren, 2017].

2.3.3.   Membrane Characteristics

Membranes used in water treatment are composed of a permeable or semi-permeable material such as cellulose acetate derivatives, polysulphones, and polyvinyl derivatives. Water passes through the membrane material under an applied pressure while a fraction of contaminants are rejected or left behind. The rejection capabilities of a membrane depend on the size of the pores or molecular pores through which water passes, among other factors. porous membranes include Microfiltration (MF) and Ultrafiltration (UF), with pore diameters in the range 0.05 to 5 micron. Removal of particles by these processes is size-exclusion controlled and is a direct function of membrane pore diameter. These systems typically operate at low applied pressure (1–50 psi), Nanofiltration membranes which are more similar to RO membranes in that ionic species can be rejected. However, NF systems operate at lower pressures (50 − 150 psi) and have greater passage of solute through the membrane film, [Płatkowska-Siwiec and Bodzek, 2011].

In RO systems commonly used membrane materials are cellulose acetate (CA) membranes and thin film composite (TFC) membranes. Common membrane configurations are spiral wound and hollow fiber. The combination of membrane properties and configurations influence an RO system's effectiveness at removing impurities and passing the maximum amount of permeate through the system. RO membranes are designed for resistance to chemical and microbial damage, mechanical and structural stability over specified operating periods, and desired

filtration requirements. CA membranes are tolerant to oxidizing chemicals such as chlorine but can be vulnerable to compaction (where the membrane is compressed) at high pressures, which can reduce water flux. TFC membranes are not chlorine-tolerant but can tolerate harsh chemical environments and wide ranges in water temperature and pH, and are less vulnerable to compaction than CA membranes. TFC membranes generally have higher water flux than CA membranes because the layers are extremely thin, which creates more water transport through the membrane material, [Williams, 2003].

RO membranes are capable of rejecting ions species of a feed water such as sodium and chloride. High applied pressures (> 300 psi) are required. This type of membrane is typically referred to as "diffusion-controlled" since solute passage is dependent on Brownian motion and a concentration gradient through the membrane film, [Williams, 2003; Asadi et al., 2015].

Generally, thin film composite (TFC) membranes have a longer life than cellulose acetale (CA) membranes because of the CA membrane's tendency to compact. Important properties of CA and TFC membranes are summarized in table 2.2.

Besides production of water for human consumption and agriculture, RO technology has many different applications, such as in food processing, and use in the pharmaceutical, textile and paper industries, [Malaeb and Ayoub, 2011].

Table 2.2 Membrane Properties of RO, (Wang and Wang R., 2019).

Feature	CA Membranes	TFC Membranes
Filtration of organic compounds	Low	High
Water flux	Medium	High
pH tolerance	4-8	2-11
Temperature stability	Max 35 °C	Max 45 °C
Oxidant tolerance	High	Low
Compaction tendency	High	Low
Cost	Low	High

2.3.4 Principle of Reverse Osmosis

The phenomenon of osmosis occurs when pure water flows from a dilute saline solution through a membrane into a higher concentrated saline solution. The phenomenon of osmosis is illustrated in Fig.2.1. A semipermeable membrane is placed between two compartments. "Semipermeable" means that the membrane is permeable to some species, and not permeable to others. Assume that this membrane is permeable to water, but not to salt. Then, place a salt solution in one compartment and pure water in the other compartment. The membrane will allow water to permeate through it to either side. But salt cannot pass through the membrane. As a fundamental rule of nature, this system will try to reach equilibrium. That is, it will try to reach the same concentration on both sides of the membrane. The only possible way to reach equilibrium is for water to pass from the pure water

compartment to the salt-containing compartment, to dilute the salt solution, [Mai**,** 2014]**.**
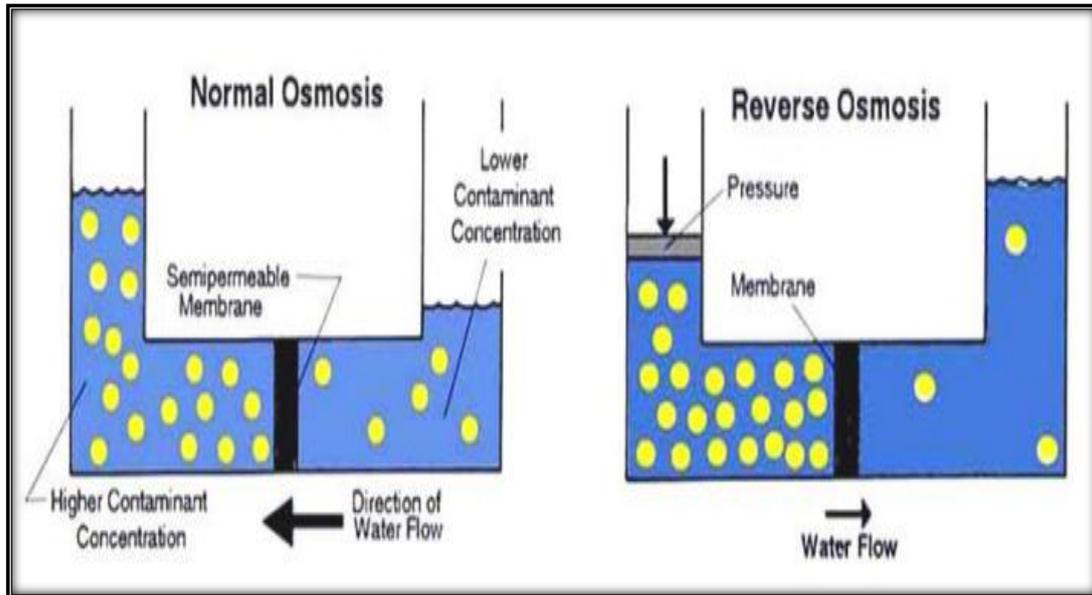
Fig.2.2.: Osmosis and reverse osmosis system, (Mai**, 2014).**

Osmosis can cause a rise in the height of the salt solution. This height will increase until the pressure of the column of water (salt solution) is so high that the force of this water column stops the water flow. The equilibrium point of this water column height in terms of water pressure against the membrane is called osmotic pressure.   In practice, reverse osmosis is applied as a crossflow filtration process. The simplified process is shown in Fig. 2.2.
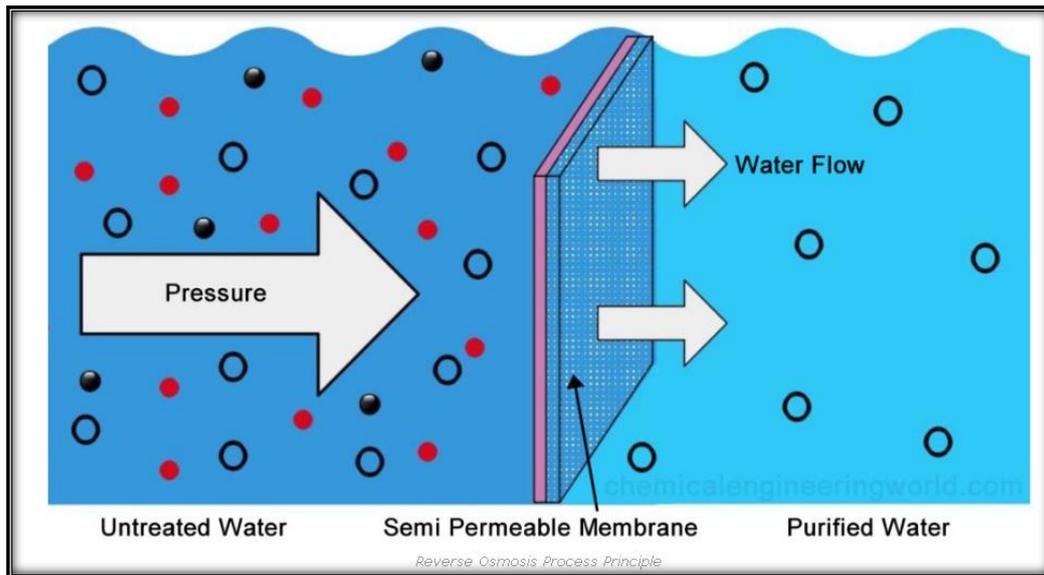
Fig.2.3: Reverse Osmosis process principle, (Chemical engineering world, 2020).

With a high-pressure pump, feed water is continuously pumped at elevated pressure to the membrane system. Within the membrane system, the feed water will be split into a low-saline and/or purified product, called permeate, and a high saline or concentrated brine, called concentrate or reject. A flow regulating valve, called a concentrate valve, controls the percentage of feed water that is going to the concentrate stream and the permeate which will be obtained from the feed, [www.complete water.com].

2.3.5 Advantages and Disadvantages of RO System:

Following are the advantages of the RO process that make it attractive for water treatment include: [www.chemical engineering world .com, 2020].

(1) It has a very compact design so it can fit it anywhere.

(2) It removes not only salts but also minerals, bacteria, viruses, and metal particles.

(3) The life of the membrane is more than 1.5 years.

(4) Parts are replaceable and easily available.

(5) It is efficient at atmospheric temperature only.

In addition, RO systems can replace or be used in conjunction with other treatment processes such as oxidation, adsorption, stripping, or biological treatment (as well as many others) to produce high quality product water that can be reused or discharged, [Garud et al., 2011].

Despite its effectiveness, RO has several well documented drawbacks, cited by [Adler, 2014]:

(1) It removes all the minerals so it will cause bone problems if we drink RO water for a long time.

(2) It also removes beneficial minerals.

(3) It rejects a high quantity of wastewater.

(4) It needs to replace filter after periodic time.

(5) It is not entirely efficient as a disinfection system, and thus, despite its high cost, compared to conventional POU filters, it still requires additional purification technology.

2.3.6 Membrane Fouling

Over time, membrane performance inevitably declines as indicated by higher pressure drop across the membrane, and/or reduced quality and quantity of producing water. All spiral-wound units experience some reduction in performance during the first few hours of operation due to compaction of the membrane surface. Compaction reduces the permeability of the membrane, resulting in decreased producing flux. However, as service lifetime progresses, membranes always experience reduced performance due to fouling, which is the accumulation of undesirable materials on the membrane surface. In addition to degrading performance, severe fouling can cut short the useful life of a membrane. There are many causes for fouling can be

categorized as being physical, chemical, or biological in nature, [Mareth et al., 2010].

☒ **Physical fouling:** Causes a defect in the performance of membrane due to the buildup of solid materials such as colloids, humic substances, oils, greases, rust, and other materials that can accumulate at the membrane surfaces, but that do not undergo chemical changes while in the membrane system. They may lodge in pores in the membrane surface, reducing membrane permeability. Larger particles may simply build up as a cake at the membrane surface, creating additional resistance to fluid flow as the cake thickens. Two feed water parameters commonly used to predict physical fouling are the silt density index (SDI) and turbidity. Typically, RO membrane manufacturers strongly recommend that feed water should SDI < 5 and/or turbidity < 1 NTU, [Mareth et al., 2010].

☒ **Chemical fouling:** Namely scaling. Scaling is the buildup of precipitated solids on surfaces in contact with water. In RO and Nanofiltration systems, mineral salts can precipitate out of solution when they exceed solubility limits as they are concentrated by the desalination process. These solids then can accumulate at the membrane surface, obstructing flow and perhaps physically damaging the membrane. The most common agents responsible for membrane scaling are calcium carbonate ($CaCO_3$), sulfate salts ($CaSO_4$, $BaSO_4$, $SrSO_4$), and silica (SiO_2.). Plant operating conditions such as feed water pH and recovery can be selected such that precipitation does not occur, and antiscalant chemicals are also commonly used to allow for

greater fresh water recovery while still avoiding scaling, [Bergman, 2005].

☒ **Biological fouling:** Perhaps the most challenging form of fouling is that caused by biological contaminants. Unlike other types of fouling, biofouling can not necessarily be controlled by reducing foulant concentration in the feed water. Biofouling can be destructive to membranes in two ways: 1) mechanically obstructing the flow of water across the membrane (in much the same way as physical fouling), and 2) chemically degrading the membrane itself. Biofouling generally begins with the growth of biofilm at the membrane surface. Biofilm is a layer of microorganisms, usually embedded in a protective layer of extracellular poly saccharides (EPS). As the film grows and begins to noticeably affect membrane performance, it is termed "biofouling." The bacteria presented in biofilm feed on organic compounds, so feed water assimilable organic carbon (AOC)is a key parameter for biofilm growth. Approaches to control of biofouling include reducing AOC and killing the microorganisms with biocides, cited by [Mareth et al., 2010].

2.4 Disinfection of Drinking Water

Disinfection is required after all the processes have been completed to remove all the bacteria from water. The goal of disinfection of public water supplies is the elimination of the pathogens that are responsible for waterborne diseases. The transmission of diseases such as typhoid and paratyphoid fevers, cholera, salmonellosis, and shigellosis can be controlled with treatments that substantially reduce the total number of viable microorganisms in water. While the concentration of organisms in drinking water after effective disinfection may be exceedingly

very little, sterilization (i.e., killing all the microbes present). The factors to be considered in choosing the disinfection treatment are: [Sorlini, 2004].

- The water characteristics (type and concentration of microorganisms).

- The effluent final quality required.

- The disinfectant agent toxicity.

- The disinfection by-products formation.

- Plants characteristics (WWTPs and DWTPs).

- The costs.

Disinfection is a method to inactivate pathogens, and there are three main categories of disinfectants when dealing with the disinfection of water:

- Chemical such as chlorine, Bromine and Ozone are three commonly used chemical disinfectants. All three have disinfection byproducts which are harmful to either human contact or to the atmosphere.

- Physical disinfection consists of boiling.

- Photochemical disinfection consists of UV disinfection or SODIS (solar disinfection).

2.4.1 Mechanisms of Microbial Inactivation by Disinfectants

Bacterial spores are much more resistant to disinfectants than the vegetative cells due to the protective spore structure and the state of low hydration. The target sites of disinfectants are believed to be within the spore, [Russell, 1990]. The structure of a "typical" bacteria spore includes core, plasma membrane, germ cell wall, cortex, inter and outer spore coat, and exosporium

(present in some spores, but may surround just one spore coat), from inside to outside, Fig. 2.3.
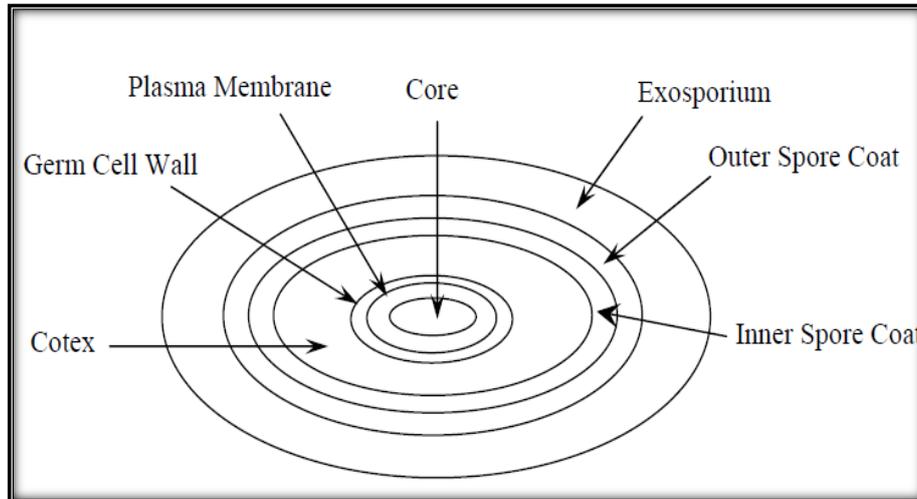
Fig. 2.4: Schematically Layered Diagram of a Bacterial Spore, (Russell 1990).

The spore coat comprises predominantly of protein with smaller amounts of complex carbohydrates and lipid. The spore coat plays an important role in disinfectant resistance by limiting penetration to the underlying protoplast.

Effective disinfection requires disinfectant uptake by bacteria, subsequent transport of the sorbed disinfectants to the target sites of bacteria, and accumulation of disinfectants to damaging levels. The effect of disinfectants can also be magnified by bacterial self-destruction (autocidal) due to free radical accumulation through metabolic imbalance and impaired ionic homeostasis, [Denyer and Stewart, 1998]. The targets of disinfectants include a range of cellular loci, such as the cytoplasmic membrane, respiratory function sites, enzymes and the genetic material, [Cloete, 2003]. According to [Denyer and Stewart, 1998], disinfection action can cause damages of different levels as:

❖ Disruption of the transmembrane proton motive force leading to an uncoupling of oxidative phosphorylation and inhibition of active transport across the membrane.

❖ Inhibition of respiration or catabolic/anabolic reactions.

❖ Disruption of replication.

❖ Loss of membrane integrity resulting in leakage of essential intracellular constituents such as potassium cation, inorganic phosphate, pentoses, nucleotides and nucleosides, and proteins.

❖ Lysis.

❖ Coagulation of intracellular material.

2.4.2 Current Disinfection Technologies

Conventional technologies are the most widely used processes for disinfection of water. They are classified into chemical processes, including chlorine, chlorine dioxide and ozone. In addition to chemical disinfectants, UV radiation has been used for many years for the treatment. Lastly Pulse Electrical Field (PEF) technology.

2.4.2.1 Chlorine

Chlorine has been widely used as the primary disinfectant for potable water treatment for over 100 years. Chlorine is highly soluble in water in the form of gaseous chlorine, chloramines and, sodium hypochlorite, and is very easy to apply. It can be easily measured, easily controlled, and is relatively inexpensive comparing with other disinfectants. These properties make chlorine a very useful disinfectant, [Qasim et al., 2000]. The influencing factors on disinfection process are temperature, pH and organic content in the water. When chlorine gas is dissolved

in water, it rapidly hydrolyzes to hydrochloric acid (HCl) and hypochlorous acid (HOCl), [Lin, 2014]:

$$Cl_2 + H_2O \longleftrightarrow H^+ + Cl^- + HOCl \quad \ldots\ldots \quad (2.1)$$
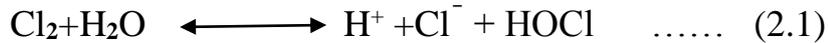
HOCl is a weak acid which is partially dissociated with the reaction

$$HOCl \Longleftrightarrow H^+ + OCl^- \ldots\ldots\ldots\ldots\ldots \quad (2.2)$$
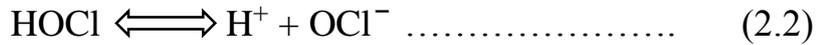
HOCl, OCl$^-$, and Cl$_2$ exist together in equilibrium as free available chlorine (FAC). Their relative proportions vary with pH, temperature, salinity, and the concentration of chlorine in solution. In natural water HOCl and OCl$^-$ are the predominant species.

Chlorine dioxide is characterized by high oxidizing power, which is the cause of its high germicidal potential. Due to the high oxidative power, possible bacterial elimination mechanisms may include inactivation of enzymatic systems or interruption of protein synthesis, [Kim et al., 2010].

Disinfection by-products (DBPs) are a major issue when chlorination is applied to water containing organic matter and nitrogen compounds. Trihalomethanes (chloroform or THMs) and Haloacetic acids will readily form when free chlorine (or bromide) is combined with natural organic matter, such as humic acids produced from decaying plant matter, [McDonald et al., 2013]. THMs have been linked to cancer, as well as spontaneous abortion, liver, kidney and central nervous problems, and are currently regulated by the EPA, [Xie, 2004]. Adding to the fact that actual disinfection is less efficient in the presence of high turbidity and/or particulate matter, it can be seen that chlorine should ideally be applied to relatively clear or filtered effluents, in order for it to be most effective, [Adler, 2014].

2.4.2.2 Ozone

Ozone is a faintly blue, pungent-smelling, and unstable gas with high oxidation potential. It must be generated at the point-of-use by applying energy to oxygen or dried air. High-energy electrical field caused oxygen to dissociate. Each dissociated oxygen molecule reacts with another oxygen to form an ozone molecule, [Qasim et al., 2000]. Ozone production can be done by electrolysis, photolytic reactions, and by radiochemical reaction induced by electric shocks. It is a highly unstable gas that, when produced, is rapidly discharged according to the reaction:

$$O_3 \longrightarrow O_2 + O \quad \text{……. (2.3)}$$

Ozone is an extremely reactive oxidizing agent characterized by disinfection efficiencies higher than the disinfection with chlorine. The bactericidal power is generally attributed to the ability to destroy the cell wall of the microorganisms. Ozonation also provides a significant reduction of UV absorbance and color, which can be an advantage for some reuse applications, [Mezzanotte et al., 2007].

Ozone is also not free from DBPs. Aldehydes and carboxylic acids, among other compounds, are formed when ozone reacts with dissolved organic matter in the water. Among these are formic, acetic and oxalic acid, which have been found in high concentrations following ozonation, [Xie, 2004]. As in the case of most disinfectants, ozone is more efficient in clear water with low turbidities, without heavy metals or compounds that react with it, leaving less substance free for bactericidal action. However, it can also be used as a form of pre-treatment, precisely to oxidize organic matter or remove certain contaminants before filtration or final disinfection, cited by [Alder, 2014].

2.4.2.3 The Ultraviolet Radiation (UV)

The Ultraviolet Radiation (UV) includes electromagnetic radiations between the X-rays and visible light in the range from 100 to 400 nm. The germicidal UV-ray portion falls in the range 220–320 nm. The generation of UV rays is carried out by means of lamps containing mercury vapors produced through an electric arc. The energy generated by the excitation of mercury vapors contained within the lamp results in the emission of UV radiation, [Bonomo, 2008].

Ultraviolet light was first used in the early 20th century in the USA. It has been gained increasing popularity as rapid, efficient and simple Pint of Use disinfection device, as well as in larger water purification plants. UV radiation, at around 260nm wavelength, attacks the DNA of microorganisms and virus. It can also eliminate hard to remove protozoan parasites such as *Giardia* and *Cryptosporidium*, although at higher doses. UV has also been found to be effective in the degradation of some hazardous chemicals by photolysis, notoriously NDMA. However, the dosages required for such removal are up to 10 times higher than what would be required for drinking water disinfection, [Mitch et al., 2003]. Among the drawbacks of UV treatment are: [Alder, 2014].

▪ Relative high cost of equipment and lamps, which need to be replaced periodically.

▪ Disposal of lamps may pose an environmental hazard issue where recycling is inadequate, since the UV is generated by a mercury vapour lamp.

▪ There is no residual, thus possibility of re-contamination in stored water.

- Constant supply of electricity required (lamps highly sensitive to voltage peaks).

- Turbidity or suspended particles will greatly reduce removal efficiency as bacteria will be more easily concealed from the UV radiation.

2.4.2.4 The Pulsed Electric Fields (PEF) Technology

Pulsed Electric Field (PEF) technology is viewed as one of the most promising non-thermal methods for inactivating microorganisms in foods. Electric fields generated by the application of short voltage pulses (μs) between two electrodes cause microbial inactivation at temperatures below those used in thermal processing; however, it is generally accepted that PEF leads to the penneabilization of microbial membranes.

The mechanism of PEF-induced pore formation in cell membrane is not yet fully elucidated. One of the most accepted theories about cell membrane permeabilizatio are based on molecular realignment within the lipid bilayer and protein channels which cause pore formation in cell membrane when subjecting a cell to an electric field. Based on studies with protoplasts as model systems, it has been suggested that PEF treatment cause alteration of membrane composition by reorientation of bipolar phospholipids and subsequent membrane permeabilization. These conformational changes cause destabilization with the loss of membrane semi permeability and thus the loss of cell vitality, [Sale & Hamilton, 1968; T song, 1991]. They described the presence of hydrophobic and hydrophilic pores in lipid matrix induced by the electric field and assumed that hydrophilic pores conduct electricity which causes

heating. Thus, increase of temperature might cause changes in membrane structure and affect its function as a barrier.

From Fig.2.4, membrane disintegration is believed to be caused by osmotic imbalances and swelling of permeabilized cells. Which means it can be seen as a result of the difference in the permeabilities of ions and macromolecules inside the cell, building up an osmotic pressure that press water into the cells and leads to cell elongation, [Kinosita & Tsong, 1977; Tsong, 1991].
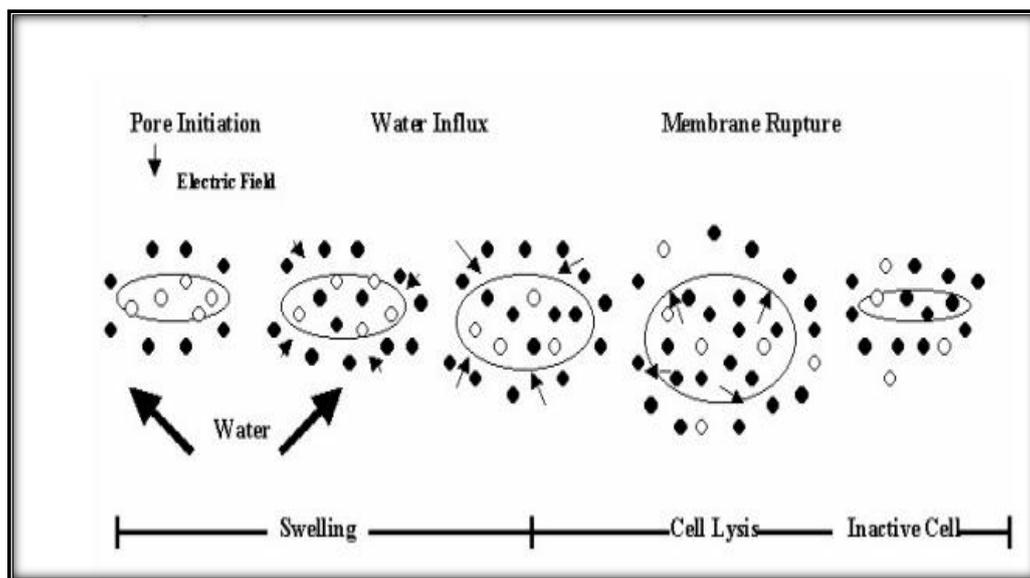
Fig.2.5: Electroporation of a cell membrane, (Tsong,1991).

Application of Pulsed Electric Field of high intensity and duration from microseconds to milliseconds may cause temporary or permanent permeabilization of cell membranes. The effects of PEF on biomembranes have been thoroughly studied since the use of PEF has attracted great interest in several scientific areas such as cell biology, biotechnology, medicine, or food technology, [Winter, 2011].

2.5 Bacteria Test

The cell wall is the first potential target of a disinfectant. Based on a staining procedure called the Gram's stain, bacteria can be divided into two basic cell wall types: Gram-positive and Gram-negative. The cell walls of Gram-positive and Gram-negative bacteria are structurally different (Fig. 2.5). The backbone material of both types is the peptidoglycan layer which is composed of layers of polysaccharide chains linked by short peptides, [Boyd and Hoerl,1991]
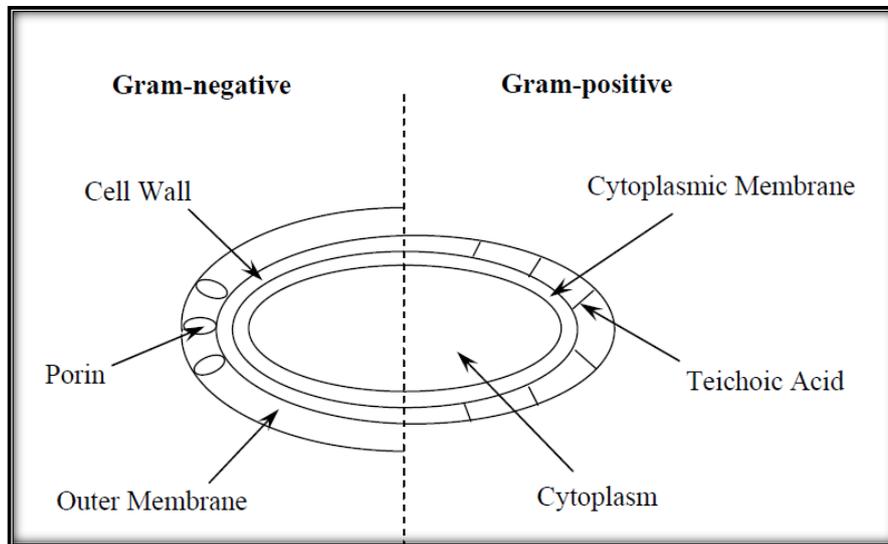
Fig. 2.6: Structural Differences between Gram-positive Cell and Gram- negative Cell, (Denyer and Stewart, 1998).

The cell wall of Gram-positive bacteria is made of peptidoglycan (over 90% of cell wall) and teichoic acids. The peptidoglycan layer of Gram-positive bacteria is very thick compared to the Gram-negative peptidoglycan layer and provides a strong protective layer that protects the plasma membrane form lysis by osmotic shock. Teichoic acids are acidic polysaccharides not only permeate the peptidoglycan but also appear on the surface of the cell wall. It makes the Gram-positive cell wall

acidic and is very important in regulating autolytic activity, cited by [Li, 2004].

Gram-negative cell walls are far more complex. The peptidoglycan layer of Gram-negative cells is very thin (only 5% to 10% of cell wall) and does not contain teichoic acids. Gram-negative cell walls also have other distinct structures called outer membranes which are semipermeable phospholipid bilayers. The outer membrane is attached to the peptidoglycan layer by lipoproteins and has channels made of proteins called porins which can pass small polar molecules freely. Very large molecules are blocked by the outer membrane. The cytoplasmic membrane is a phospholipid bilayer containing globular proteins. It provides a rich matrix of balanced interactions between phospholipid and enzymic/structural protein. The cytoplasmic membrane ensures a controlled impermeability and topological organization by which intracellular homeostasis and vectorial transport/metabolism are maintained, cited by [Li, 2004].

2.5.1 Indicator Bacteria

Indicator bacteria are types of bacteria used to detect and estimate the level of fecal contamination of water. They are not dangerous to human health but are used to indicate the presence of a health risk. These bacteria may include species of pathogenic bacteria, such as *Salmonella* or *Campylobacter*, associated with gastroenteritis. In addition, feces may contain pathogenic viruses, protozoa and parasites. Fecal material can enter the environment from many sources including waste water treatment plants, livestock or poultry manure, sanitary landfills, septic systems, sewage sludge, pets and wildlife. If sufficient quantities are ingested, fecal pathogens can cause

disease. The variety and often low concentrations of pathogens in environmental water makes them difficult to test for individually. Public agencies therefore use the presence of other more abundant and more easily detected fecal bacteria as indicators of the presence of fecal contamination, [Mushtaq et al., 2021].

2.5.2 Types of Indicator Organism

Commonly used indicator bacteria include Total Coliforms, or a subset of this group, Fecal coliforms. Perhaps the biggest drawback for using coliforms as indicators is that they can grow in water under simple conditions. *Escherichia Coli* (*E. coli*) and enterococci are also used as indicators.

-The Coliform Group had been chosen as an indicator organism over 100 years ago for many reason including (it is considered highly resistant pathogens, their ease of incubation and detection due to their ability to ferment lactose, low cost of modern standard tests). These organisms can be identified based on the fact that they all metabolize the sugar lactose, producing both acid and gas as byproducts. Which include species that are naturally found in plants and soil, [Adler, 2014].

-**Fecal Coliforms bacteria** are one of total Coliform bacteria which grow in the intestines of warm-blooded animals, so their presence will usually denote fecal contamination. Fecal Coliforms are more useful as indicators in recreational water than Total Coliforms, [www.health.ny.gov].

- **E. coli bacteria** are a Gram-negative, non-spore-forming, rod-shaped, and facultative anaerobic bacterium. It is an abundant commensal found in the intestinal tract of humans and warm-blooded animals and has been employed widely in disinfection research as an indicator of fecal contamination in water for many

decades, clear indication of human sewage or animal waste, [Boyd and Hoerl, 1991; Haas, 1999; Morin et al., 2003].

2.5.3 Methods of Bacterial Analyses

One of the main aspects of coliform bacteria is their ability to produce acid and gas in lactose-based media. Both of the most well-known methods, multiple-tube fermentation (also known as Most Probable Number (M.P.N)) and Membrane Filtration (MF) rely on this ability. As knowing, that the coliforms are not a formal taxonomic unit, but are grouped together by detection characteristics such as these, which make them convenient as an indicator microorganism, [Adler, 2014]. There are two ways for bacterial analysis as follows: -

1. Most Probable Number

The method is based on the dilution of the sample into successive test tubes, observing gas production due to lactose fermentation in each one, until no more gas is produced (i.e. no bacteria detected). In this manner, a statistical estimate was achieved. This stage, called the presumptive test, was achieved by incubating at 37°C up to 48 hours in a lactose based medium. Positive tubes then need to be sub-cultured on an adequate medium in what is known as a confirmatory stage. A similar procedure exists for E. coli, [APHA, 2017].

2. Membrane Filtration

The preferred method for detecting bacteria is membrane filtration. It consists of filtering the sample through as filter with sufficiently small pore size so as to retain bacteria, and then aseptically transferring into a petri dish with a selective agar base or medium, depending on the type of microorganism sought, [Adler, 2014].

2.6 Literatures Review

Over the past years, reverse osmosis membrane technology has grown to 44% of the world's desalination capacity and 80% of the world's total number of desalination plants, [Fauzi and Jammel, 2021].

Historically, RO-membranes were designed for the production of drinking water by desalination of seawater and brackish water. Currently, RO is a popular technology for the production of highly purified water used in drinking water, dialysis, power generation, pharmaceuticals and medical devices, semiconductor manufacturing, the paper, sugar, beverage, horticulture industries as well as in the concentration and reclamation of wastewater, [Oki and Kanae, 2006]. Also, there has been an increase of about 40% in use of RO for purification of river water compared to the global installed capacity from 2002, [Eltawil et al., 2009]. The use of RO for seawater desalination is still dominating the RO market.
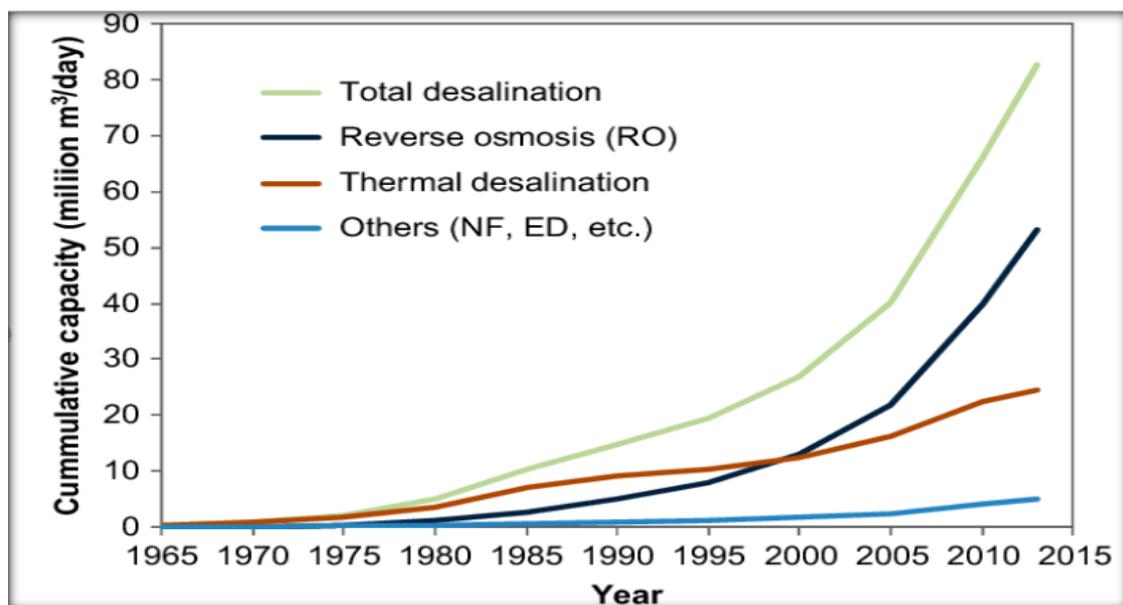

Fig.2.7: Cumulative installed worldwide desalination capacity in terms of applied technology, (Villacorte et al**., 2015).**

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The RO application for purification of river water happens primarily in parts of the world with rapid industrial growth and strict environmental policy. Given the environmental trends, the application of RO is projected to increase globally in the following years due to forthcoming environmental regulations in these areas and the influences that these measures would have on other parts around the world, [Haidari et al., 2018].

The records of articles and cumulative publications for the years 1970 until 2019 are shown in Fig.2.8.
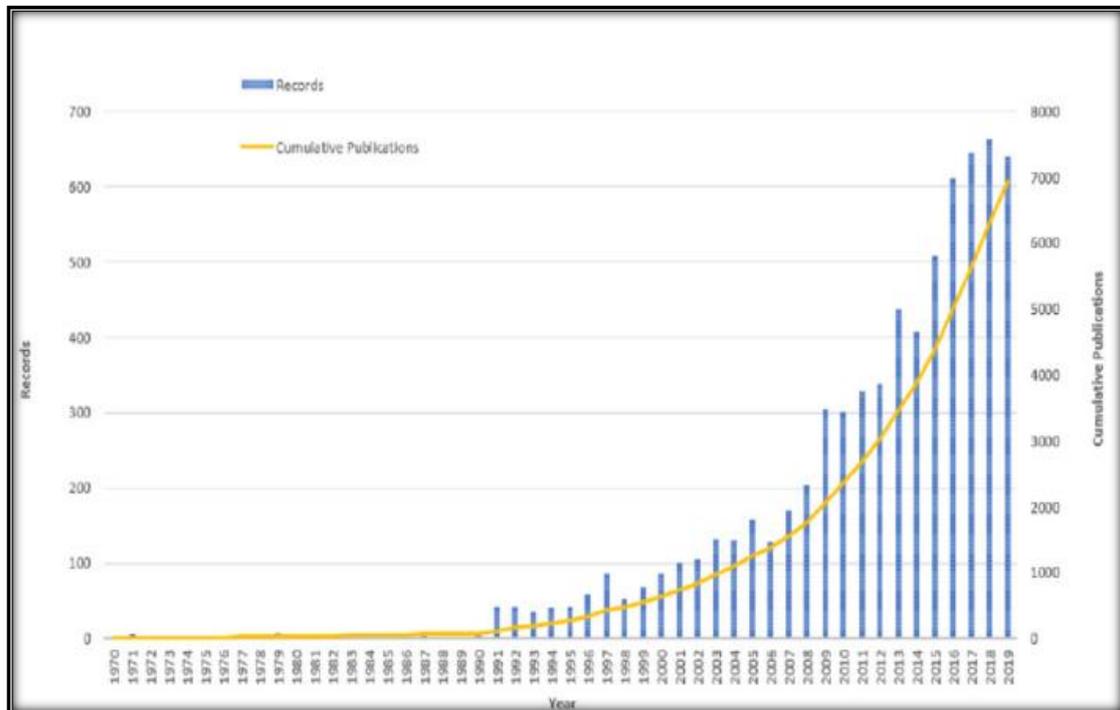
Fig.2.8: The records and cumulative publications of research articles on reverse osmosis in Web of Science from 1970 until 2019, [Fauzi and Jamil, 2021].

It shows that the number of articles increased rapidly from 1 to 6,939 and the increase started in the year 1991. The significant interest in reverse osmosis research has been proposed since 1990. Since then, annual publications have gradually risen, leading to a rapid rise in overall accumulated publications. The number of publications reached a peak in 2018, showing a gradual

increase from 1991 until 2002. Despite that, after 2003 onwards, the increase in the number of publications was 200 every six years. In that case, the annual publication will maintain to increase, [Fauzi and Jamil, 2021].

A short overview of some studies and research that used reverse osmosis systems RO in the field of drinking water treatment:

Rautenbach and Eilers, [2000] used a new concept of integrated membranes consisting of RO/NF/ high-pressure RO. The integration can achieve water recovery rates of more than 95% in the case of dumpsite leachate, which promises an almost zero discharge process.

Molinari and Romeo, [2001] compared rejection of several pollutants such as silica, nitrate, manganese and humic acids by means of RO and NF membranes. At a pH of 8, RO rejected silica, NO_3, Mn_2, and humic acid in a rate equal to 98%, 94%, 99% and 95.5%, respectively, while NF had a much lower rejection, i.e., 35%, 6%, 80% and 35%, respectively. The results showed that the NF membranes effectively rejected SO_4 up to 95% in concentrated brines.

Baruth, [2005] used bench-scale NF and RO system to evaluate taste and odor compounds removal such as MIB (2-methlyisoborneol) and geosmin removal from the surface source for the Yuciapa Valley Regional Water Filtration Facility. Seven NF and RO membranes were tested, and geosmin and MIB removals from 50% to 90% were reported. No formation on influent or finished water geosmin and MIB concentrations or challenge testing was reported.

Shamel and Chung, [2006] used a pilot scale membrane separation system coupled with another pilot scale plate heat exchanger to investigate the possibilities of sweetening seawater from Telok Kalong Beach, Terengganu, Malaysia. The experiments were conducted to get the optimum operating parameters to produce drinking water from desalination of seawater using reverse osmosis system. The best operating conditions to produce drinking water with the Na^+ concentration of 79 ppm which is below the WHO were identified for feed TDS concentration of 34929 ppm. For a production rate of 413 l/m. day with 8 operating hours per day, these optimum operating conditions are found to be feed temperature of 40C, cross flow velocity of 1.77m/s, transmembrane pressure of 53.5 bar.

Belkacem and Bensadok, [2007] studied ground water treatment in which two stage RO module was used in the beverage industry. The results of the physicochemical analysis showed that the raw water taken from the groundwater contained significant amounts of solutes and suspended solids (TDS ranging from 757 mg/L to 964 mg/L). The Feed water composition shows that the raw water was rich in sulphate, chloride and calcium and highly furring. The quality of water produced from the pre-treatment demonstrates that turbidity reduced from 1.3 NTU to 0.167 NTU. The rejection rate varied between 97% and 98% and remained stable during the RO operation which signified that the permeate quality was constant with total conductivity decreased from 1070 μs/cm to 33 μs/cm with larger rejection of 95% ions. The bacteria removal efficiency of microorganisms decreased from 90 CFU/100 ml to 50 CFU/100 ml. However, the rejection

of nitrate was lowest i.e about 88.18%. Hence the obtained results showed applicability of RO for the ground water treatment.

Gurtler, et al., [2008] used combining reverse osmosis system (RO) and pulsed electrical current electrodialysis for improved recovery of dissolved organic matter from seawater and achieve recoveries of 64% – 93% of marine DOM. The level of residual salts in the concentrated samples, however, still precluded the haracterization of marine DOM by solid-state, mass spectrometry, or even elemental analysis. This paper describes a major improvement to the RO/ED method, in which pulsed electrodialysis is used (at sea) to reach roughly 100-fold greater removal of salts compared to not pulsed ED while maintaining comparable recoveries of DOM.

Bellona et al., [2008] investigated the use of Ultra–Low-Pressure Reverse Osmosis (ULPRO) and Nanofiltration (NF) membranes for water reuse applications where lower operating pressures and a high permeate quality are desired. A laboratory scale investigation was performed to compare the rejection and operational performance of RO, ULPRO, and NF membranes and to select two membranes for testing at a California Water Facility. An ULPRO membrane and a NF membrane were then tested at a pilot and full scale in a water recycling plant and monitored for operational performance and rejection of total organic carbon, total nitrogen, and regulated and unregulated organic micro-pollutants. Pilot and full scale testing of the best performing membranes demonstrated that both ULPRO and a NF membrane could be used to meet potable water quality requirements. The presumed advantage of using ULPRO and a NF membranes diminished as fouling occurred, resulting in operating pressures

only slightly lower than or similar to those found for traditional RO membranes.

Radjenovic et al., [2008] investigated the removal of a broad range of pharmaceuticals during Nanofiltration (NF) and Reverse Osmosis (RO) applied in a full-scale drinking water treatment plant (DWTP) using groundwater. Pharmaceutical residues detected in groundwater used as feed water in all five sampling campaigns were analgesics and anti-inflammatory drugs. Excellent overall performance of both NF and RO was noted, with high rejection percentages for almost all of the pharmaceuticals investigated (>85%). Deteriorations in retentions on NF and RO membranes were observed for acetaminophen (44.8–73 %), gemfibrozil (50–70 %) and mefenamic acid (30–50%). Furthermore, since several pharmaceutical residues were detected in the brine stream of NF and RO processes at concentrations of several hundred nanogram per liter, its disposal to a near-by river can represent a possible risk implication of this type of treatment.

Choi et al., [2009] constructed small-scale RO (reverse osmosis) desalination systems, which size ranges from 10 m3 /day to 1000 m3 /day, have been constructed to produce potable water from brackish or seawater. The major issue of these systems is the optimization of system design to minimize capital cost and energy consumption, which is likely to be difficult for small-scale systems. The RO system consists of four units and 16 vessels. Each vessel has six 8-in. The recovery ratio ranges from 40% to 50%. An additional mineralization process is applied as a post-treatment. TDS and hardness of product water are 30 mg/L and 3 mg/ L as CaCO3, respectively. The rejections for major ions were

over 99.5%, allowing the production of high quality water from this feed water. For all water quality parameters, the permeate quality satisfied the drinking water standard of Korea.

johir et al., [2009] evaluated the performance of single and dual media filters with in-line flocculation. They have been examined as pretreatment to seawater reverse osmosis (SWRO). A comparison of filter performance was made between single medium filter (80 cm) consisting of sand or anthracite, and dual media filter consisting of sand (40 cm at the bottom) and anthracite (40 cm on top). Short term (6 hours) experiments were conducted with in-line coagulation followed by direct filtration. Filtration velocities of 5m/h and 10m/h were used. The performances of these filters were assessed in terms of turbidity removal, head loss build-up, and organic compound removal in terms of molecular weight distribution (MWD). The efficiency of the filter as pretreatment was evaluated in terms of silt density index (SDI) and modified fouling index (MFI). It was found that the turbidity removal was high and all the filters produced more or less same quality water. There was a slower buildup of head loss for coarser filter medium. A post treatment of reverse osmosis after an inline-flocculation-dual media filtration showed lower normalized flux decline (J/J_0) (0.35 to 0.22 during the first 20 hours' operation) while, seawater without any pretreatment showed steeper flux decline (0.18 to 0.11 at first 20 hours' operation) in RO.

Diawara et al., [2011] conducted a study on a membrane filtration plant constructed by Pall Corporation which improved through Nanofltration (NF) and Low Pressure Reverse Osmosis (LPRO). Both NF and LPRO membranes were shown applicable

for salinity and fluoride ions removal from brackish and high fluorinated drinking water in a remote community. The NF membrane has given a fluorine retention rate varying between 63.3% and 71% while the LPRO membrane allow to reach 97% to 89.9% for fluorine rejection.

Albergamo et al., [2019] investigated in pilot-scale drinking water treatment, the robustness of reverse osmosis (RO) against polar organic micropollutants (MPs). Experiments were carried in hypoxic conditions to treat a raw anaerobic riverbank filtrate spiked with a mixture of thirty model compounds. The chemicals were selected from scientific literature data for their relevance for the quality of freshwater systems, RO permeate and drinking water. RO proved to be a robust barrier against most polar MPs. Overall, the passage figures observed for the investigated set compounds ranged from less than 1% to 25% in standard conditions. Statistical analysis showed significant influence of physicochemical properties on compound passage. Compound size and passage were highly correlated for neutral MPs, and charge for anionic MPs. Determining key factors were also membrane chemistry and feed water properties.

Jiang et al., [2019] investigated the effects of an electromagnetic field (EMF) on control of membrane fouling and scaling during desalination of brackish groundwater using a pilot reverse osmosis (RO) skid. The groundwater was primarily CaSO4 type with a total dissolved solids concentration of 5850 mg/L and hardness of 2500 mg/L as CaCO3. Two EMF devices were installed in the pipeline before a cartridge filter and in the RO feed inlet to induce an electric signal of 150kHz to the groundwater. The effects of EMF on membrane scaling were

evaluated under accelerated conditions, i.e., without pH adjustment and addition of antiscalant. Two-phase experiments were conducted: Phase 1 (376 h) with the EMF devices turned on after 150h baseline operation; and Phase 2 (753h) with the EMF devices turned on from the beginning of testing. The EMF significantly reduced membrane scaling and improved RO performance by 38.3% and 14.3% in terms of normalized water permeability decline rate after 150h and 370h operation, respectively. Membrane autopsy results indicated that the fouling layer formed under the influence of EMF was loose with a low density and was easily removed by hydraulic flushing.

The distinguishing feature of the current study from the previous studies is the use of Pulsed Electrical Field-Low Voltage (PEF-LV) technique as a purification mean with the Reverse Osmosis system for the first time in Iraq and the boundary area, because of its many advantages including: don't use chemicals, less fouling production, reduce energy consumption and operational cost. Hopefully, this study is useful in providing good information for further research into membrane technology applications in the field of drinking water treatment.

Chapter Three

Experimental Works and Procedures

CHAPTER THREE
EXPERMINTAL WORK

3.1 Introduction

This chapter includes the description of the experimental system in order to study and measure the experimental data by using Reverse Osmosis system with Pulse Electrical Field Low Voltage (PEF-LV) as a purification method, (scale plant).

The experimental work was carried out for investigating the effect of different operating conditions such as (electrical pulse, applied voltage, pH, temperature and water flow rate) on the removal efficiency of the unit. This was achieved by keeping some operating parameters fixed, and changing one of them, each time.

River and tap water samples were collected from the Euphrates river and distribution network of Karbala city / Iraq. Some parameters of river and tap water were tested at the Directorate of Environment Lab/Karbala, while total organic carbon test was done at the Ministry of Science and Technology/Lab. These parameters were Turbidity (Tur.), Temperature (T), Electrical Conductivity (EC), Hydrogen Ion Concentration (pH), Total Hardness (TH), Chloride (Cl^-), Total Dissolved Solids (TDS), Total Organic Carbon (TOC), Aerobic Bacteria, Total Coliform, Fecal Coliform, and Escherichia Coli (E. coli).

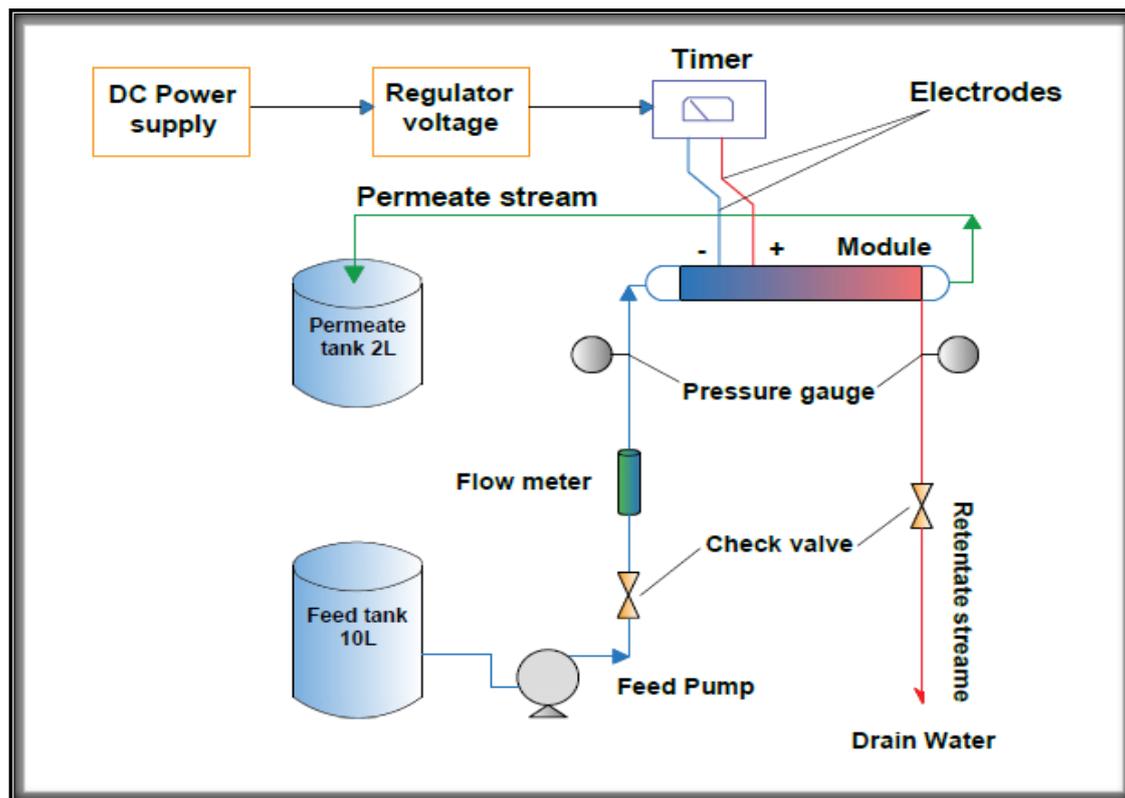The experimental setup was depicted schematically in Fig. 3.1.

Fig. 3.1: The schematic diagram of RO experimental setup

3.2 Materials and Equipment

3.2.1 The module

The module consists of reverse osmosis membrane and membrane housing (pressure vessel). Reverse osmosis membrane used in this experiments was a thin-film composite membranes packed in a spiral-wound configuration and made of synthetic organic polymers. Spiral-wound designs offer many advantages for most of the reverse osmosis applications in water treatment compared to other module designs, such as tubular, plate-and-frame and hollow-fiber module. Typically, a spiral-wound configuration offers significantly lower replacement costs, simpler plumbing systems, easier maintenance and greater design freedom than other configurations, making it the industry standard

for reverse osmosis and Nano-filtration membranes in water treatment.

The spiral-wound module uses flat sheets wound around a centre pipe. The membranes are glued along three sides to form membrane leaves attached to a permeate channel (centre pipe) placed along the unsealed edge of the membrane leaf. The internal side of the leaf contains a permeate spacer designed to support the membrane sheet without collapsing under pressure.

This permeate spacer is porous and conducts permeate to the centre pipe. A feed channel spacer (a net-like sheet) is placed between the leaves to define the feed channel height (typically round 1 mm) and provide mass transfer benefits. The membrane leaves are wound around the centre pipe and given an outer casing. This design provides a high packing density (300-1000 m^2 /m^3).

A pair of electrodes in the form of mesh (with dimensions 3cm $\times$ 30cm) were placed between the layers of the membrane. These electrodes were made of conductive material to deliver an electrical pulse to the water for disinfection. In this work, meshes of silver were used, because of silver has high conductivity and corrosion resistance, as shown in Fig. 3.2.
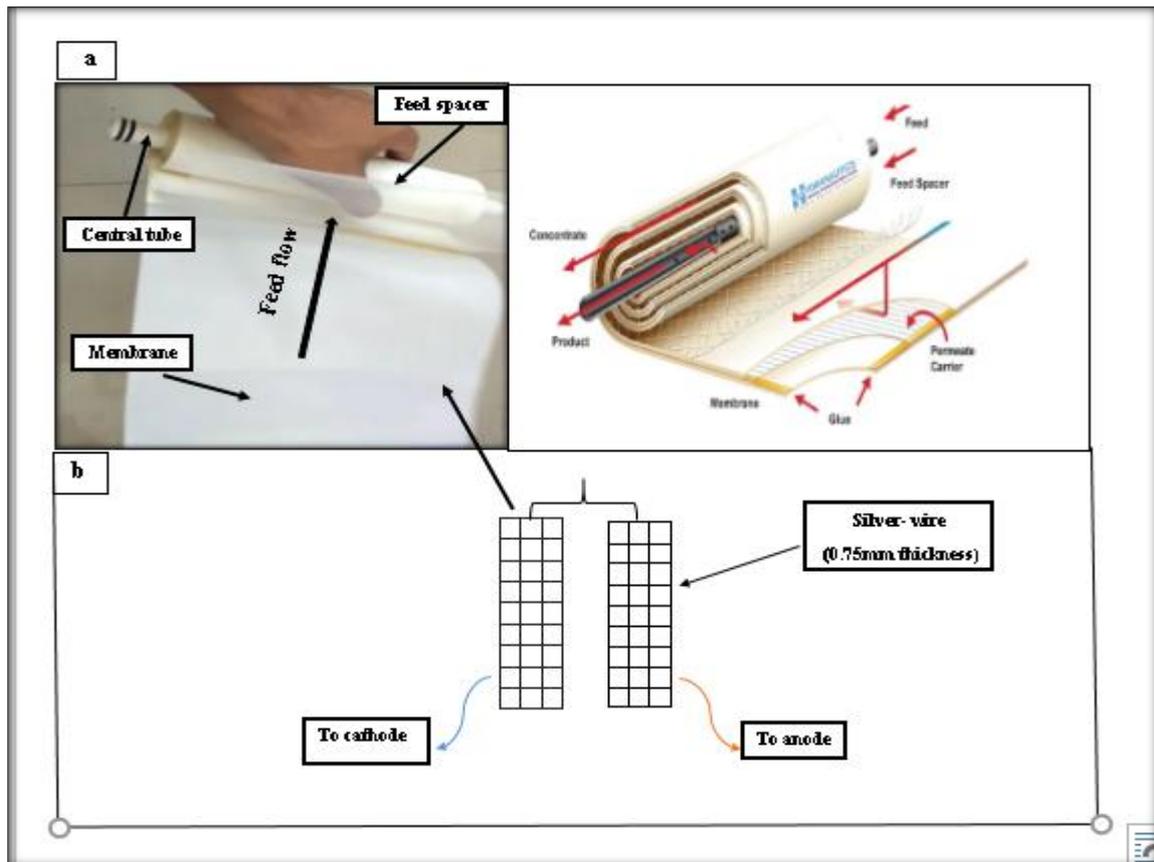
Fig. 3.2: RO membrane (a) Spiral wound configuration;(b) Silver mesh

The RO membrane housing was in the form as shown in Fig. 3.3, it was made of polyethylene material with O-rings for helping seal it, and contain inlet/outlet ports with 8mm diameter. The RO element used in the study was 30cm long and 4.6cm in diameter to fit into nominal 6cm diameter membrane housing.
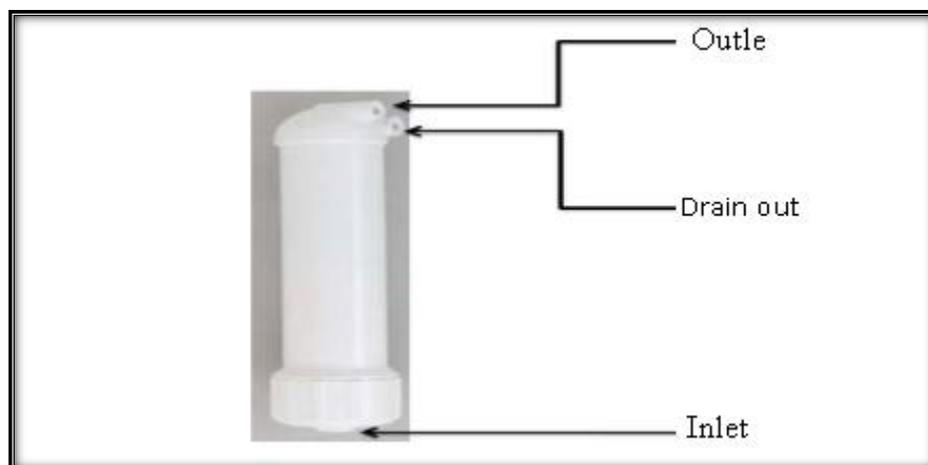

Fig. 3.3: RO Membrane Housing.

3.2.2 Equipment

The equipment used in the pilot scale setup were as follows and shown in Fig. 3.4: -

A- **Feed tank:** Plastic cylindrical feeding tank with capacity 10L was used to store tap and raw (river) water,

B- **Permeate tank**: Used to store the purified water with capacity 2L.

C- **Feed pump (booster pump):** The purpose of a booster pump is to increase water pressure going into the RO unit and water with specific features are provided to the filter. Features of this pump were listed in table 3.1,

Table 3.1: Characteristics of feed pump

Characteristic (as labeled)	Value
Flow rate, m^3/d	0.34
Head, m	1.5
Working pressure, psi	72
Current rate, A	<1.2

D- **Flow meter:** To control the inlet flow to the system, the flow meter of type (LZT) was used, with flow rate range of 0.2-1 L/min. The flow rate can be adjusted according to the required operating conditions.

G- **A pressure gauge:** Is a mechanical instrument with a dial that is used to measure water pressure in a variety of applications, and used for monitoring the work and control flow.

H- **Pipe fittings:** Join the system's tubing. They are in PVC form which include: elbows, connectors, valves. All valves are hand operated and used to regulate a flow in the system.

E- **Adapter power regulated (model 002):** The power source was utilized during the work included: the low voltage DC

generator transforms voltage from a high voltage AC utility line (220 V, 50-60Hz) to a low voltage DC, (designed to 24V DC). The specifications of this device are: -

- This power adapter has a wide input voltage range of 110V to 240V AC.

- The output voltage is adjustable between 9V and 24V DC, with 95% high accuracy.

- Designed with a knob and voltage display so, it can easily adjust and check voltage.

- It supports over-voltage, over-current and over-load short circuit protection.

F- Electrical pulse regulator (Micro USB Digital LCD Display):

Used to determine the number of pulses per time as required, with the following specifications: -

- The product has two LCD screens, that can display parameters directly,

- Very strong and clear,

- Simple and easy to use,

- Power supply: 6- 30V, also supports micro USB 5V,

- Parameters can be modified,

- DC 30V 5A and AC 220V 5A are maximum output loads,

- Static current: 15mA,

- Operating current: 50 mA,

- Working temperature ranges from 40 to 85 °C,

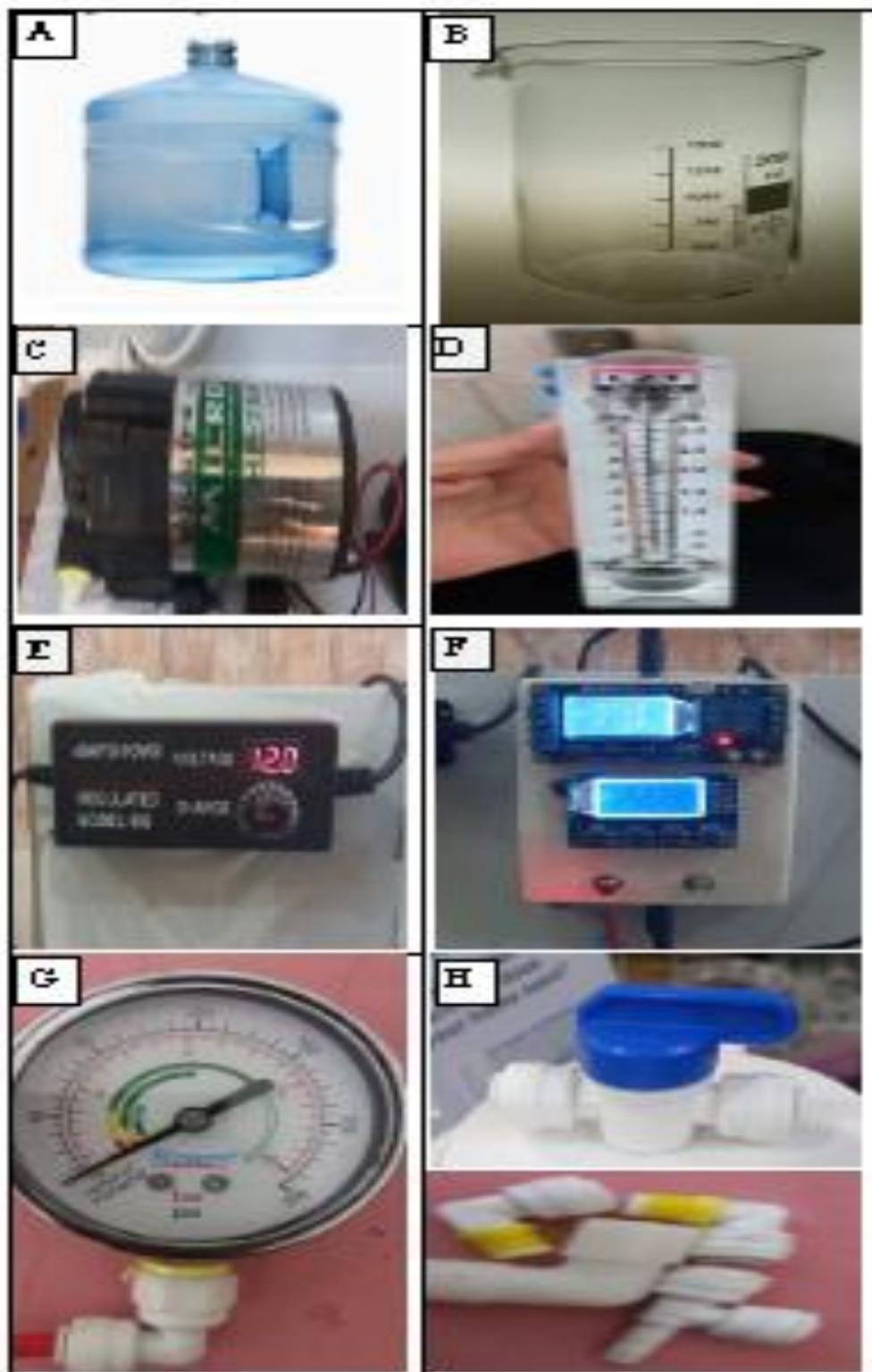- Size: 8cm length ×3.8cm width ×1.9 cm height.

Fig. 3.4: Pilot scale equipment. A) feed tank, B) permeate tank, C) feed pump, D) flow meter, E) voltage regulator, F) electrical pulse regulator, G) pressure gauge, H) pipe fittings.

I- Electrodes

Silver has been used as an antimicrobial agent since times immemorial. Beside medical uses, silver is also employed in water treatment plants. Most heavy metals are significantly more hazardous to humans than silver and its derivatives. Silver, on the other hand, may kill bacteria in even minute levels. In the body, reactive silver ions quickly convert to insoluble forms like silver chloride. Silver bio-accumulates and manifests as Argyria, a skin pigmentation disorder, only after long-term exposure to large doses, such as continual intake of silver salt or colloids, [Landau, 2007].

In this study, two meshes which are composed of a set of fine silver wires with 3m length and a 0.75 mm diameter and a purity of 99 percent (meaning at least 0.99 silver with the most likely impurity being trace amounts of copper). These meshes served as a pair of electrodes in cells.

The silver meshes (rectangular shape 30cm length and 3cm width) were inserted within a reverse osmosis membrane and connected to the anode and cathode of a low voltage electrical pulse device, and subsequently to the power source, through conductive wires, (Fig. 3.5), combining RO filtration and disinfection process in one unit (Disinfectant Membrane DM) as a part of water treatment system.

The effect of some operation conditions like applied voltage, number of electrical pulse, pH of feed water, variation in temperature and flow rate on RO membrane disinfectant efficiency, were investigated.
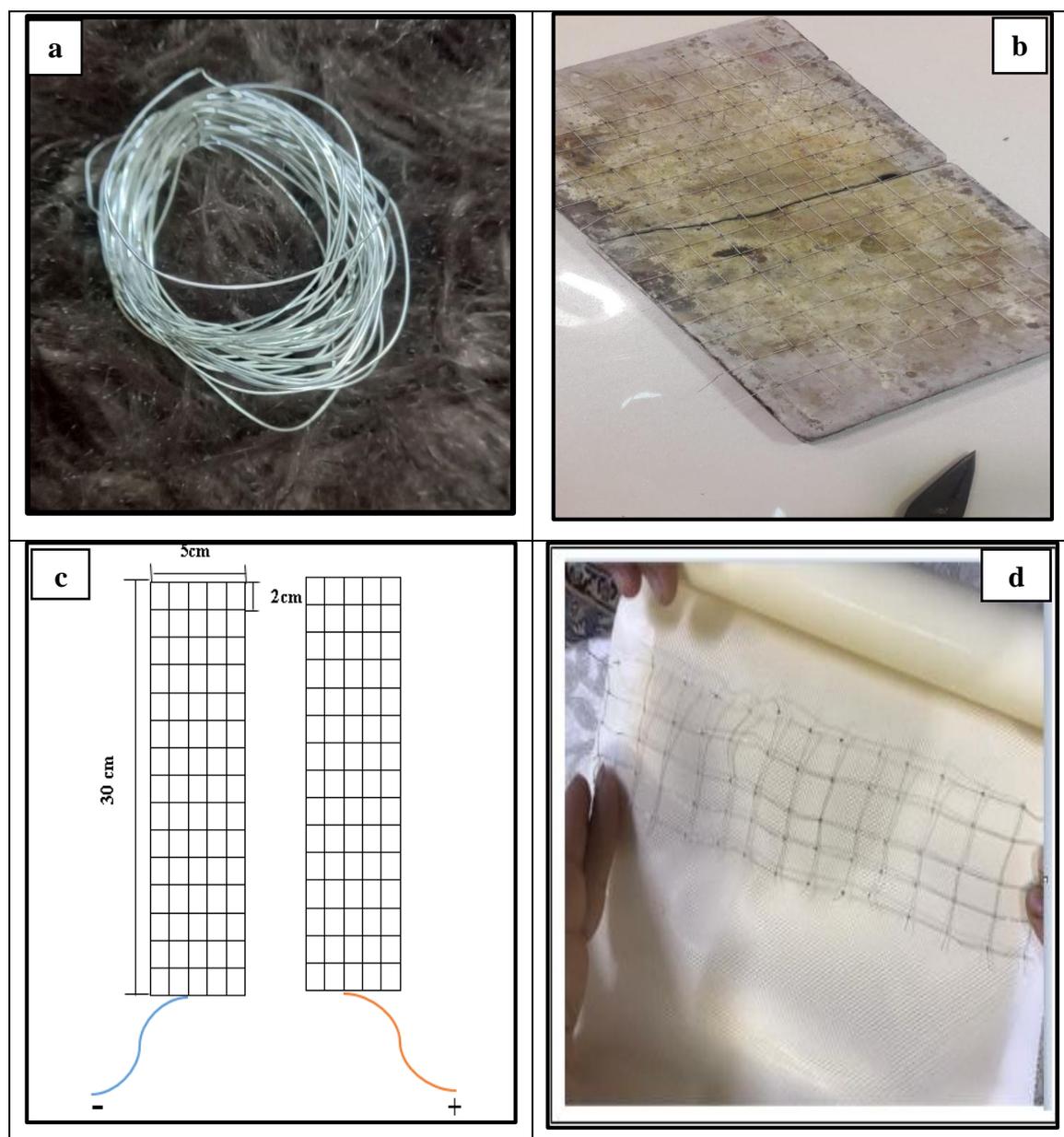
Fig. 3.5: Silver electrodes: (a)Silver wire, (b) Silver mesh, (c) Mesh dimensions, (d) Silver mesh (electrode) in a RO membrane.

J- Measuring devices

Table 3.2 shows the instruments utilized in this work for chemical, physical and biological analyses for samples which were collected from feed water (tap, and raw).

Table 3.2: Devices used for lab measurements.

Test	Device
Hydrogen Ion Concentration, Temperature, Total Dissolved Solid, Electrical Conductivity .	Multi (350i WTW).
Turbidity, Tur.	Turbid Meter (HANNA /LP2000).
Total Hardness, TH	Titration by EDTA
Chloride, Cl^-	Argentometric titration
Total Organic Carbon, TOC	Color meter (DRs5000, Hach).
Sterilize glass materials (Petri dishes, test tubes and pipettes).	Oven (Memmert 4913).
Incubate cell cultures.	Incubator(BINDER)
Growing bacteria(E.coli).	Water Bath (Memmert).
Sterilize all solutions, media, and glassware.	Autoclave (H1CLAVE,HVA-110).
Chlorine.	Spectrophotometer(LaMotte OCTA-SLIDE).
Membrane characteristics(Inspect F 50).	Scanning Electron Microscope.
Weighting and prepare the media.	Analytical Balance(FA2204B).
Counted the colonies after incubation.	Colony Counter (FUNKE GERBER).
Measure density of bacteria in the medium.	Densitometer (DEN-1).

3.3 Experimental Work

Set of experiments were carried out to examine the important influences of varying operational parameters on modified membrane performance, in particular applied voltage, number of electrical pulses, pH, temperature and feed water flow rate. This was done by keeping some the operational parameters constant and varying only one of them each time. Water used for these experiments collected from two different sources, drinking water (tap) and raw (river) water, chosen for their differences in physicochemical and biological characteristics.

As shown in Fig. 3.6, the system starts with the main storage tank (feed vessel) made of plastic material with a maximum capacity of 10L. Stirring was provided to the feed water during the experiments to ensure the homogeneity of water and to prevent particles settling. When the system is running, the feed water flows by the feed pump to the cell. Two manual check valves were used, one located with the outlet line of the feed pump to regulate the inlet flow and thereby the inlet pressure to the module, and the other with the outlet of RO membrane housing to prevent backflow of treated water. Three feed pumps were connected in series to produce a pressure up to 10 bar. The desirable pressure can be adjusted by the pressure regulator setting in the feed pump line at the inlet and outlet the module.

Part of the feed water passes through the membrane and going into the outlet hose (permeate). The remaining portion (concentrate) leaves the cell to drain. Both permeate tank and feed tank were protected from dust and microbiological

contamination. At the end of each experiment, the system was rinsed with distilled water through backwash.

AC is the power supply to the system which was converted to DC power through the converter unit. A control system was used to control the ON/OFF of the pulse generated, and then transmitted to the electrodes.
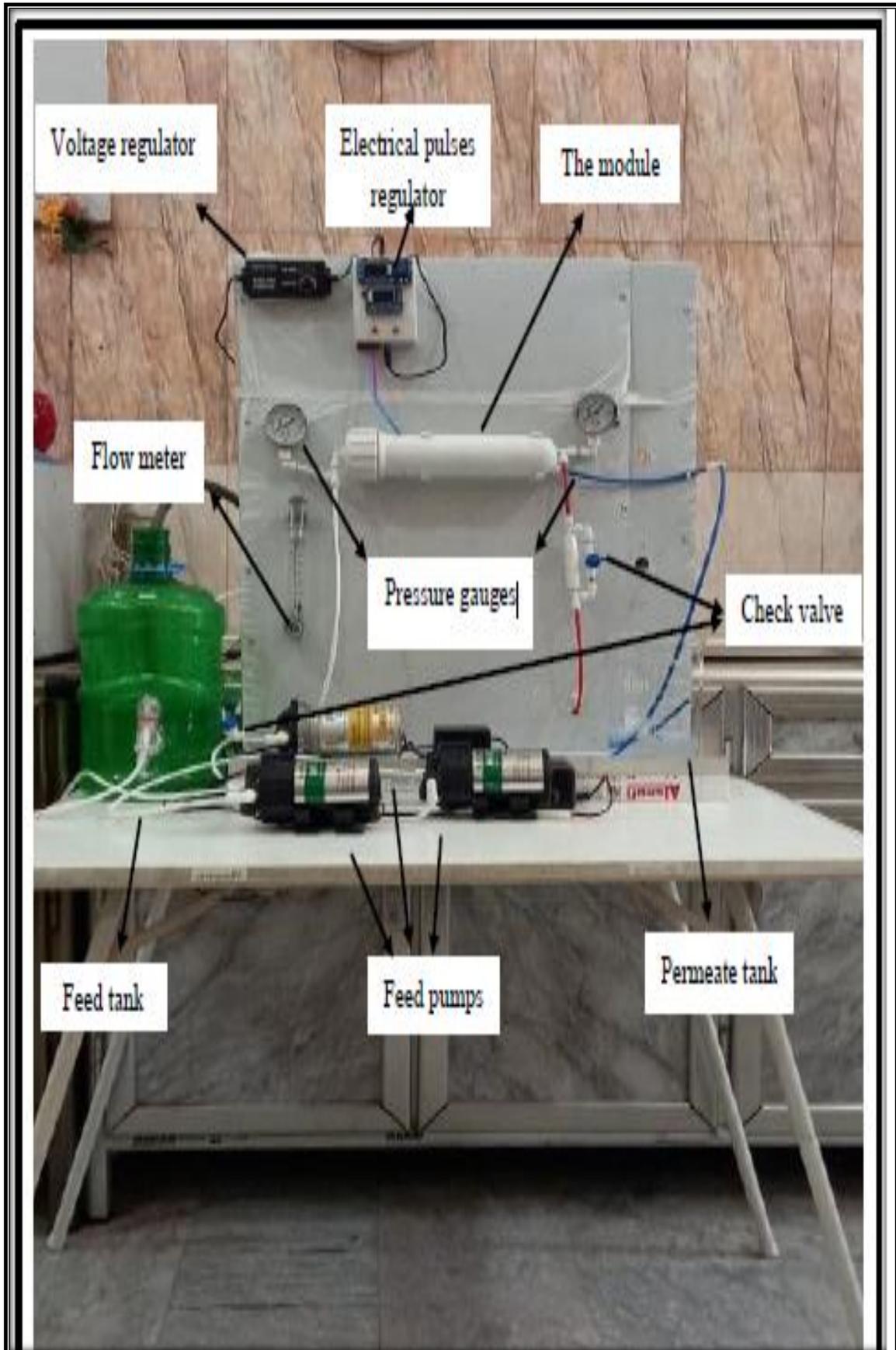
Fig. 3.6: The pilot scale system

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3.4 Bacterial Contaminant

Chlorine kills pathogens such as bacteria by breaking the chemical bonds in their molecules. When enzymes in bacteria cells come in contact with chlorine, one or more of the hydrogen atoms in the molecule are replaced by chlorine. This causes the entire molecule to change shape or fall apart, and enzymes do not function properly, so a cell or bacterium will die, [Baker et al., 2002].

The disinfection process in the system is performed by generating silver ions in water, whereby positive Ag^+ ions are attracted and absorbed into the negatively charged cell membranes of microorganisms once they are released into the water.

The permeability of the cell wall is thus damaged, impairing the organism's capacity to absorb nutrients. Metal ions may form complexes with other ions at higher concentrations.

3.5 Microbiological Analysis

All the sampling and analyses were performed at Holy Karbala Environment/Lab based on the standard procedures mentioned in (Standard Method for Examination of water and Waste Water (AWWA), APHA, 2017), the following biological tests were performed: -

3.5.1 Aerobic Plate Count (APC) Test, was done by pour plate method, as follow**:**

1. Culture media is Nutrient agar; it was prepared by dissolving 34g of Nutrient agar in 1 L of distilled water.

2. The buffer solution is a stock phosphate buffer solution that was prepared previously.

3. Successive dilutions of the test sample until a colony count of 15 to 300 colonies per plate is reached.

4. Taken 1L of each dilution for each plate and by a sterile pipette also for each plate and it pours in the dish, the pipette is placed at an angle of 45 degrees, Fig. 3.7.
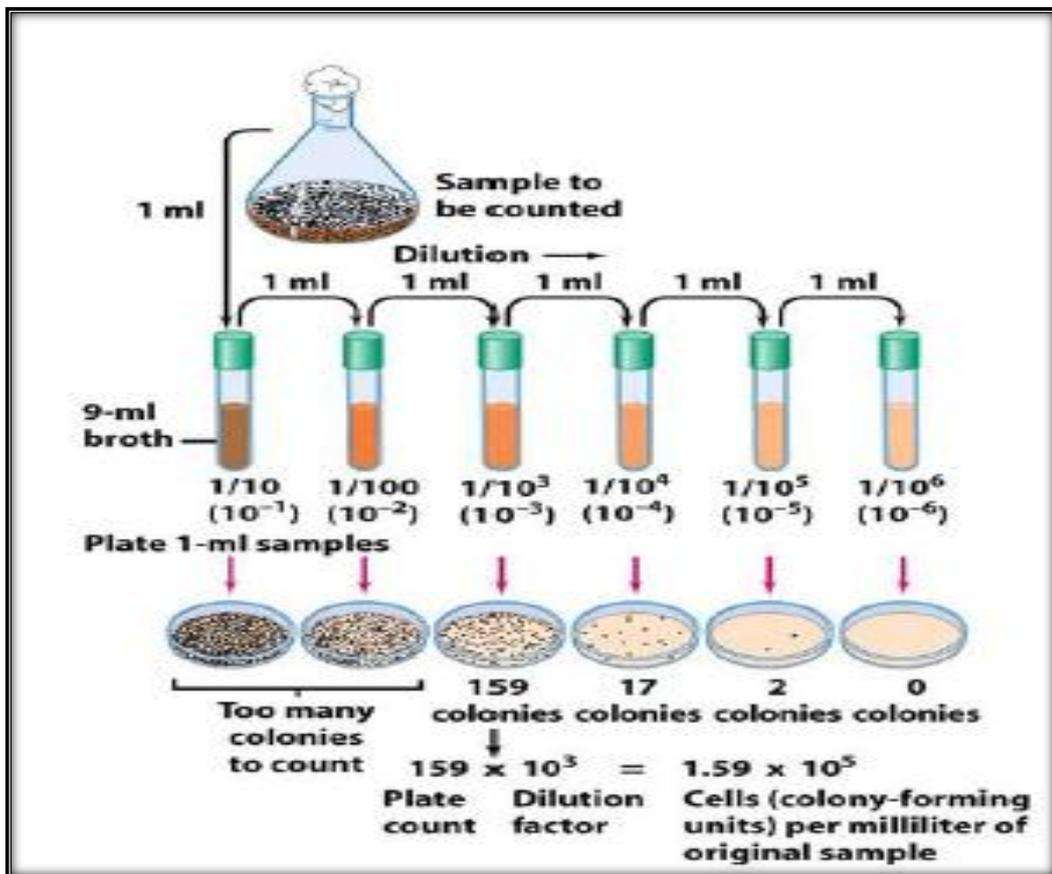

Fig. 3.7: Serial dilutions of the test sample, (acebiolab, 2019).

5. The culture medium is poured over the plates, then left to solidify for 10 minutes, and then placed in the incubator upside down at a temperature of 35°C for 48±3 hrs, Fig. 3.8.

6. At the end of the incubation period, the growth colonies that give from 30-300 colonies per dish are counted in the

Colony Counter, which represents the number of bacteria in 1mL and through:

$$\text{Colony Forming Unit (CFU/m L)} = \frac{\text{No. of colonies} \times \text{dilution}}{\text{Volume of culture plate}} \quad\quad ..... \; 3.1$$
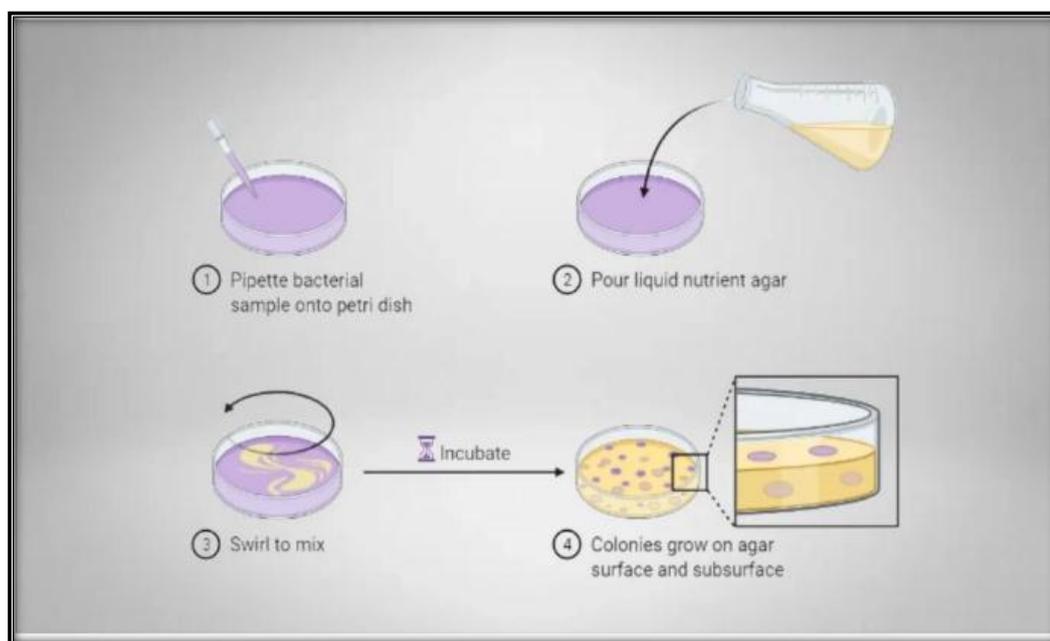

Fig. 3.8 : Pour plate method procedure, (Sourava, 2021).

3.5.2 Total Coliform Test, was done by Multiple Tube Fermentation Method, this technique is a three stages procedure in which the results are statically expressed in terms of the Most Probable Number (MPN). These stages are presumptive stage, confirmed stage, and completed test, as follow:

1. Lauryl Tryptose broth was used as the culture media, and it was prepared by dissolving 70g of Lauryl Tryptose broth in   1L of distilled water.

2. Added 10mL of the sample to be tested to each of the ten tubes containing Lauryl Tryptose broth liquid medium (dual

concentration). Then shake the tubes slowly to distribute the sample homogeneously in the culture medium.

3. The injected tubes were incubated in the incubator at $35\pm0.5°C$ for 24 ± 2 hrs.

4. The confirmed test was performed using the previously prepared Brilliant green lactose bile broth culture medium at the end of each incubation period for tubes that indicated a positive result, and repeated steps 2 and 3.

3.5.3 Fecal Coliform Test, was carried out by Multiple Tube Fermentation Method, as follow:

1. Culture media was prepared by dissolving 37g of EC medium in 1Lof distilled water.

2. The tubes that gave a positive result were shaken, and one or more loopfuls were transferred from the culture to the tubes holding the sterile EC Medium.

3. At $44.5\pm0.2°C$, the injected tubes were incubated in a water bath for 24 ± 2 hrs and within 30 min. after culturing.

4. Examine the tubes that showed growth (the appearance of turbidity and gas) and the results are recorded and read from the table of drinking water on the basis of the most likely for each 100mL of the water sample. as shown in Fig. (3.9)
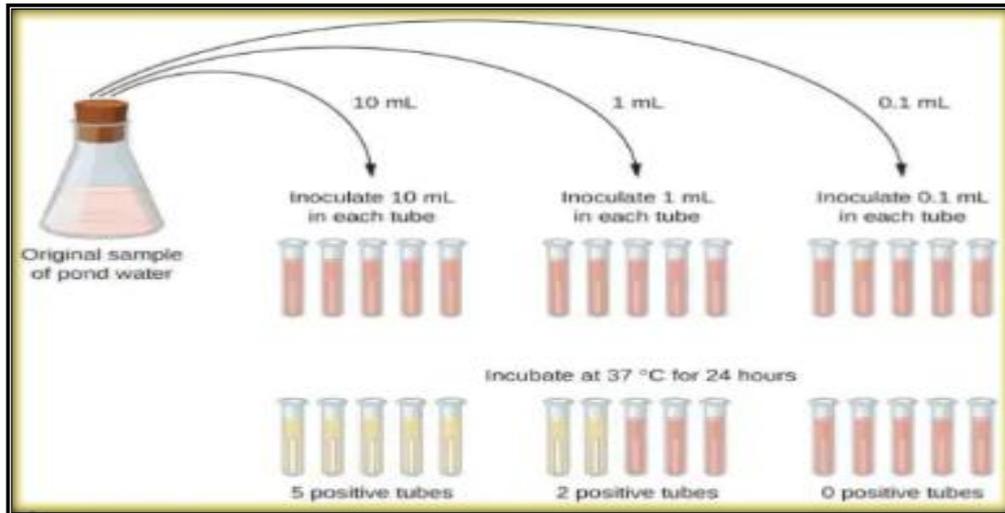
Fig. 3.9: Multiple tube fermentation method, (SamsuDeen , 2019)

3.5.4 Escherichia Coli (E. coli) Test, was examined by Multiple Tube Fermentation Method, as follows:

1. The culture media was prepared by dissolving 37g of EC Mug   in 1L of distilled water.

2. The tubes that indicated a positive result during the confirmatory examination is shaken, and one or more (loopfuls) are transferred from the implant to the tubes holding the previously prepared sterile EC Mug culture material through a sterile conveyor.

3. The injected tubes are incubated in a water bath at $44.5\pm 0.2°C$ for 24 ± 2 hrs and within 30 min. after culture.

4. The tubes that showed growth (the appearance of turbidity and of gas) were examined using UV lump device with a wavelength of 365 nm, where the positive results appeared in a radioactive blue-green color. The results were recorded and read from the drinking water table on the basis of the most likely count/ 100 mL of sample.

Chapter Four
Results and Discussion

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results and discussion of the experiments are given. The experiments were carried out with the scale plant (an integrated system that combines reverse osmosis membrane with applying Pulse Electrical Field-Low Voltage, (PEF-LV)) to kill microorganisms from tap and river water. Samples of feed and permeate water were taken throughout the experiments for physical, chemical and biological tests, such as Turbidity (Tur), Hydrogen Ion Concentration (pH), Temperature (T), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Hardness (TH), Chloride (Cl^-), Total Organic Carbon (TOC), Aerobic Bacteria, Total Coliform, Fecal Coliform and Escherichia Coli (E. Coli).

The important influences of varying operational parameters such as applied voltage, number of electrical pulses, temperature, flow rate and pH of feed water were studied.

The present work is generally related to the field of a Point-of-use (POU) disinfection of drinking water by generating a Pulsed Electric Field-Low Voltage (PEF-LV), between two electrodes placed inside reverse osmosis membrane, to avoid excessive use of chemicals, as well as reduce energy consumption and operational costs.

4.2 Reverse Osmosis Membrane

A filter unit equipped with a commercial spiral-wound RO membrane (Dow Film Tec FE1812-4021, The Dow Chemical Company). The RO element is a thin-film composite membrane consisting of three layers: a polyester support web, a microporous polysulfone interlayer, and an ultra-thin aromatic polyamide barrier layer on the top surface with an active area of $1.5m^2$, and it is housed in a plastic pressure vessel. Three booster pumps were used to supply 1 L/min of water to the module at a pressure of 10bar. Polyvinyl chloride (PVC) tubing and fittings were used to construct the RO system, and it was connected to the permeate water collection tank.

Influent and effluent water quality parameters were tested during the experiments for both water (tap and river) without any disinfectant. These parameters were summarized in table 4.1 at operating conditions (Pressure=10 bar, flow rate=1L/min, Temp=25-30°C). This table shows a significant difference between tap and river water regarding turbidity test before and after treatment, these differences likely due to the tap water was treated before being supplied to households. However, these parameters are in compliance with Iraqi Drinking Water Guidelines, 2010.

Table 4.1: Physicochemical characteristics of influent and effluent water (river and tap).

Parameters	River water		Tap water		Iraqi Drinking Water Guidelines, 2010
	Influent	Effluent	Influent	Effluent	
pH	8.85	7. 92	7.82	7.5	6.5-8.5
Temp, °C	24.5	25	23.8	24	25
Tur, NTU	10.2	3.76	2.45	0.83	5
TDS, mg/L	704	85	670	35	1000
EC, µs/cm	1078	130.2	1031	60.8	2000
TH as (CaCo3),mg/L	363.9	50.18	255.7	50	500
Cl,⁻ mg/L	60.73	23.36	56.06	23.36	350

4.3 Disinfectant Membrane (DM)

Once the water passes through the filter unit of RO membrane, a large percentage of the original particles have been removed, but there is still a potential that microorganisms remain in the water. So, in this case the disinfection process is necessary.

The process of disinfection is to treat the water in a way that kills or inactivates the remaining microorganisms in the water.

Application of (PEF-LV) as a disinfection process in reverse osmosis systems was the first attempt and the first time in

Iraq and boundary area. It has many advantages such as improve and modify treatment process.

The effectiveness of (PEF-LV) technique depends on several factors which can be classified in technical and chemical process conditions as well as in biological product characteristics. Besides technical factors, including (PEF-LV) process parameters such as electric field intensity, treatment time, pulse shape and applied energy, as well as chemical and physical characteristics of treated water, the biological aspects like species, cell size, shape or physiological state influence the degree of membrane permeabilization additionally. Small microorganism's cells were found to be less sensitive against the external electric field, whereas membrane disintegration of larger plant cells occurs in markedly higher percentage by applying same PEF treatment conditions, cited by [Winter, 2011; Abu khanafer et al., 2021].

4.4   Factors Affecting on The Performance of Disinfectant Membrane (DM)

In the present work, Disinfectant Reverse Osmosis Membrane was tested as an alternative way to conventional methods for removal of turbidity and natural organic matter from tap and river water. The effect of different operating conditions such as applied voltage, number of electrical pulses, temperature, flow rate and pH of feed water, which are considered the most important factors that affecting on the performance of the Disinfectant Membrane (DM) were studied in detail, as follows: -

4.4.1 Applied Voltage

Operating voltage and electric current are critical parameters in disinfection process. Disinfection "is defined as at least 90 % reduction of the number of microorganisms (e.g., the number of Colony Forming Units (CFU) of bacteria) in a sample of water". In this work the disinfection of microorganisms was generally achieved by application of a pulse electrical field to the cell wall of microorganisms captured within the electric field.

Besides the voltage, the electric field strength depends on the treatment unit configuration and design. For a parallel plate electrode configuration, the electric field was homogeneous and the field strength was calculated depending on the electrode distance Eq. (4. 1), [Töpfl, 2006]:

$$E=V/d \qquad\qquad … \ 4.1$$

Where,

E: electric field strength, (Kv/cm).

V: voltage, (Kv).

d: electrode distance, (cm).

Effect of applied voltage on the main characteristics, physical (Tur, pH, Temp, TDS, EC and TOC) and chemical (TH and Cl^-) of tap and river water were compared and demonstrated separately: -

A-Turbidity (Tur)

Turbidity removal is one of the main aims of water and wastewater treatment. It is a measure of clarity of water and used as an indicator of water quality.

In order to study the effect of voltage on removal efficiency of turbidity in the system, experiments were performed at five different voltage levels: 12, 15, 18, 21 and 24V respectively at

room temperature (25-30) °C, and the results are presented in Fig. 4.1.
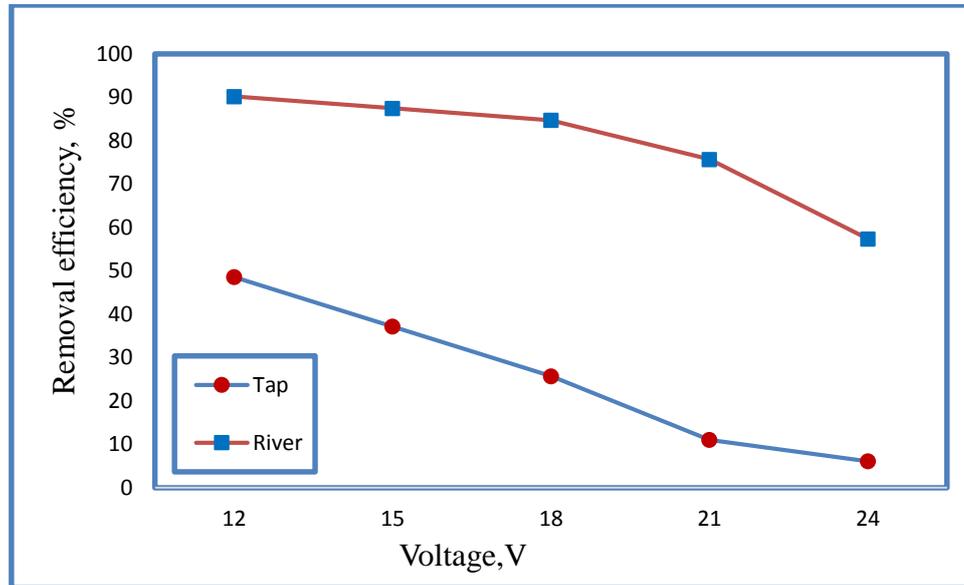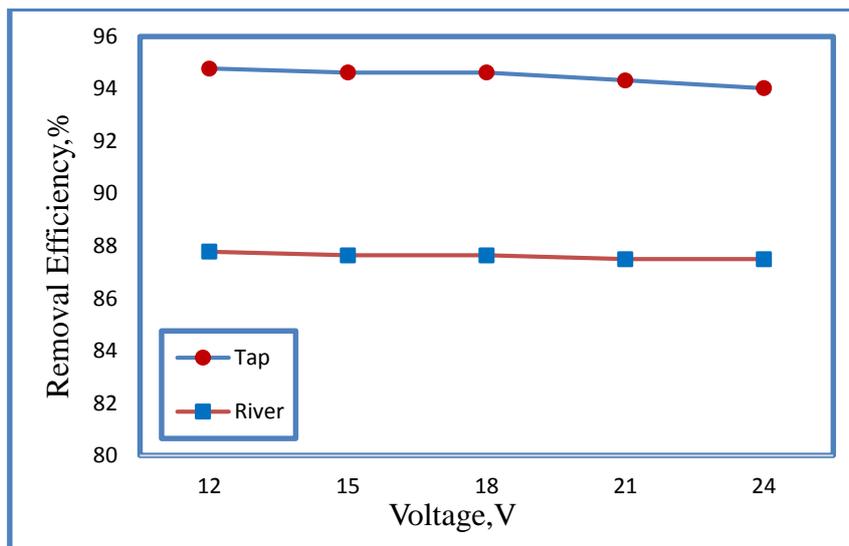

Fig. 4.1: Effect of applied voltage on removal efficiency of turbidity for tap and river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

From Fig. 4.1, results show a significant increase in turbidity levels with rising applied voltage which is directly proportional to the electric current passing through the electrodes, (Ohm's law) leading to a greater release of silver ions.

The maximum removal efficiency of turbidity for tap and river water was 48.5% and 90%, respectively, at voltage =12V, while the minimum at 24V. Therefore, 12V was selected as the best voltage level for all experiments of Disinfectant Membrane (DM) performance. The same finding was conducted by [Racyte, 2013] which confirmed that the electric field induces an increase in cell permeability (e.g., pore formation) of the cell wall of the microorganism, and thus causes an irreversible damage to the microorganism through a combination of cell wall collapse,

osmotic stress and enhanced transport of residual disinfectants (e.g., chlorine) in water.

B- Total Dissolved Solid (TDS)

Total dissolved solid (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions. TDS in water supplies originate from natural sources, sewage, urban and agricultural run-off, and industrial wastewater. Fig. 4.2 appears the effect of applied voltage on removal efficiency of TDS.

Fig. 4.2: Effect of applied voltage on removal efficiency of TDS for tap and river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

It can be seen from Fig. 4.2 that the concentration of TDS was tended to remain nearly constant throughout the treatment process, where the removal efficiency of tap water ranged between 94% to 94.8%, and for river water ranged between 87.5% to 87.8 %.

C- Electrical Conductivity (EC)

The Electrical Conductivity of water is defined as a numerical value that indicates to the ability of water to carry an electric current. Most acids, bases and inorganic salts dissolved in water are good conductors of electric current, while organic salts and acids are considered poor materials for electrical conductivity because they are low ionization. Fig. 4.3 explains the effect of applied voltage on EC.
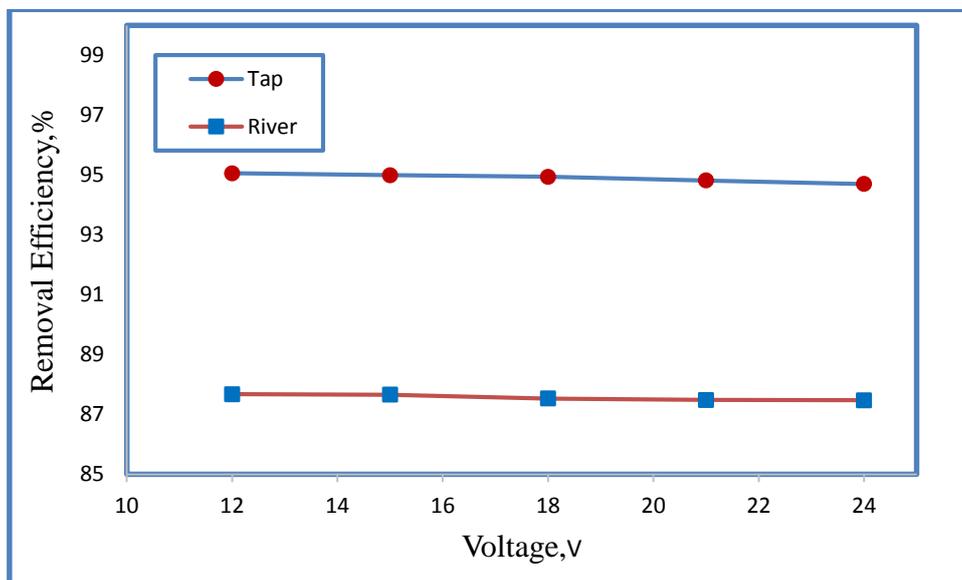

Fig. 4.3: Effect of applied voltage on removal efficiency of EC for tap and river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

From Fig. 4.3, it can be observed that EC did not vary significantly after applying (PEF-LV), where the removal efficiency for tap water ranged from 94.7% to 95 %, and for river water ranged from 87.4% to 87.7%. This value depends on the concentration and equivalence of the dissolved ions present in water and on the temperature of the water during the measurement because they have a direct effect on the movement and direction of the different ions in which silver ions was distributed through water.

D- Hydrogen Ion Concentration(pH)

pH is a measure of how acidic/basic the water is. The range goes from 0 to 14, with 7 being neutral. The pH meter measures the difference in electrical potential between a pH electrode and a reference electrode. Figs. 4.4 and 4.5 explain the effect of applied voltage on pH for tap and river water.
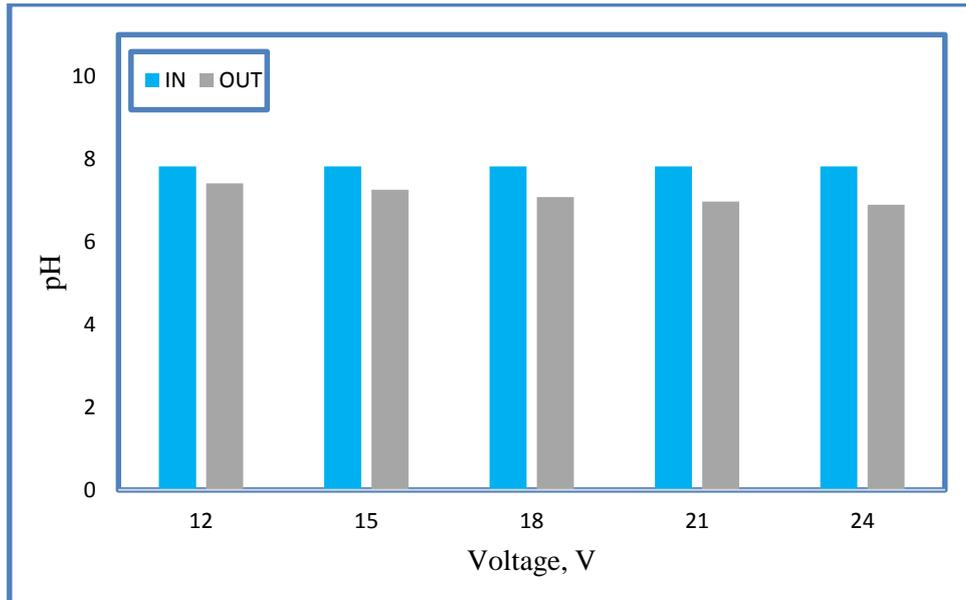

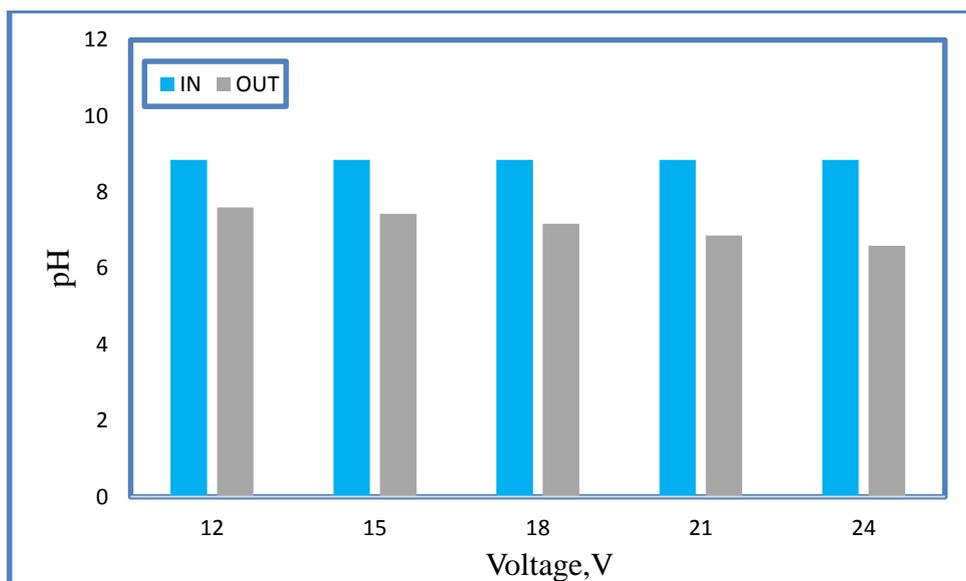**Fig. 4.4: Variation in pH for tap water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).**

Fig. 4.5: Variation in pH for river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

By comparing Fig. 4.4 and 4.5, pH was close to neutral, and showed no significant variation before and after treatment process, this was due to no additives of chemicals in water samples. The pH value for tap water was found to be up to 7, which is in compliance with Iraqi Drinking Water Guidelines, 2010.

E- Total Hardness (TH)

Hard water is water that has high mineral content. Calcium is the most common mineral associated with water hardness. Total Hardness (temporary: caused by bicarbonates and carbonates of calcium and magnesium cations, and permanent: caused by sulphates and chlorides of calcium and magnesium) of water reflects the sum total of alkaline metal cations present in it. Fig. 4.6 shows the effect of applied voltage on TH.
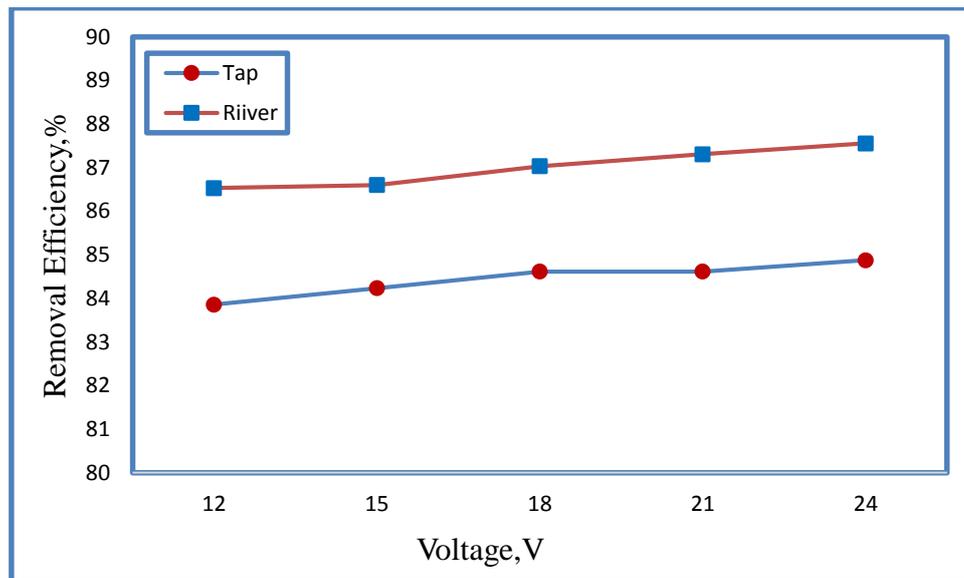

Fig. 4.6: Effect of applied voltage on removal efficiency of TH for tap and river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

From Fig. 4.6, the change in resulting concentrations of TH is slightly noticeable after treatment process. The removal efficiency of TH for filtered water ranged between 83.8% to 84.8% for tap water, and from 86.5% to 87.5% for river water.

These results can be explained by the fact that, by increasing the electrical volt, the oxidized silver increases and generate more hydroxyl ion which makes hardness concentration reduce fast by precipitation. These findings were in line with the results of [Malakootian and Yousefi, 2009].

F – Chloride (Cl⁻)

Chloride is an important negative ion found in a natural water as well as in a domestic and industrial waste water. It also causes a corrosive effect on pipes and metal structures and also affects implants. Fig. 4.7 refers to the effects of applied voltage on Cl^- ions.
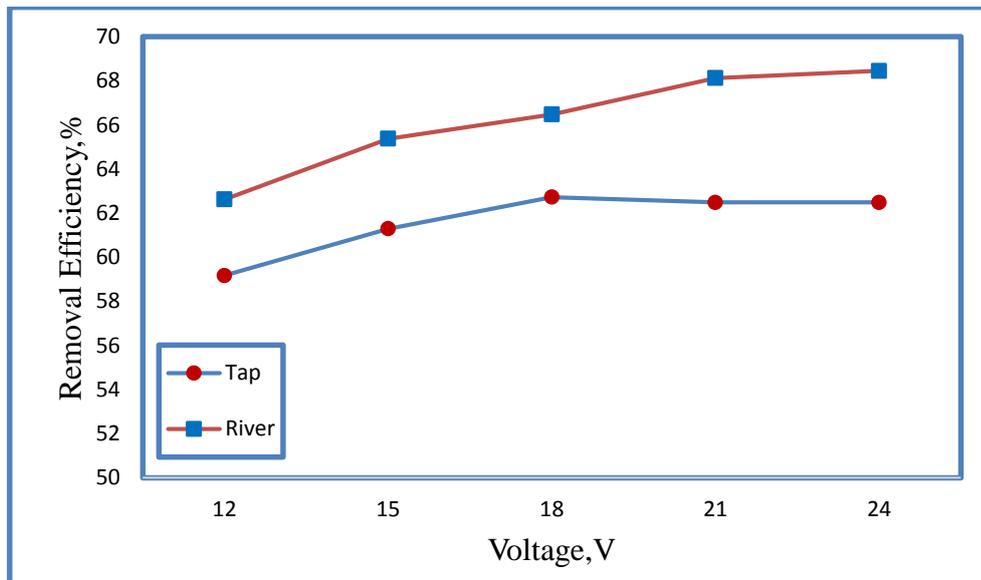

Fig. 4.7: Effect of applied voltage on removal efficiency of Cl⁻ for tap and river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

From Fig. 4.7, the maximum removal efficiency of chloride ions for tap and river water was 62.48% and 68.4%, respectively, at 24V. With increasing the applied voltage from 12V to 24V, silver ions in the water increases which, in turn, react with chloride ions to form silver chloride .

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Through laboratory tests, it was found that Cl^- concentration in tap water is slightly more than in river water, that is attributed to the use of chlorine in drinking water treatment plant for disinfection processes, that was confirmed by [WHO, 2003].

G-Total Organic Carbon (TOC)

Total organic carbon (TOC) is the amount of carbon found in an organic compound and is often used as a non – specific indicator of water quality. TOC detection is an important measurement because of the effects on the environment, human health, and manufacturing processes. It is also of interest in the field of potable water purification due to byproducts of disinfection.

It can be clearly seen from Fig. 4.8, that the TOC levels were decreased significantly after using (PEF-LV) technology. The results obtained showed that the removal efficiency of TOC ranged from 91.9% to 94.9% at 12V and 24V, respectively.
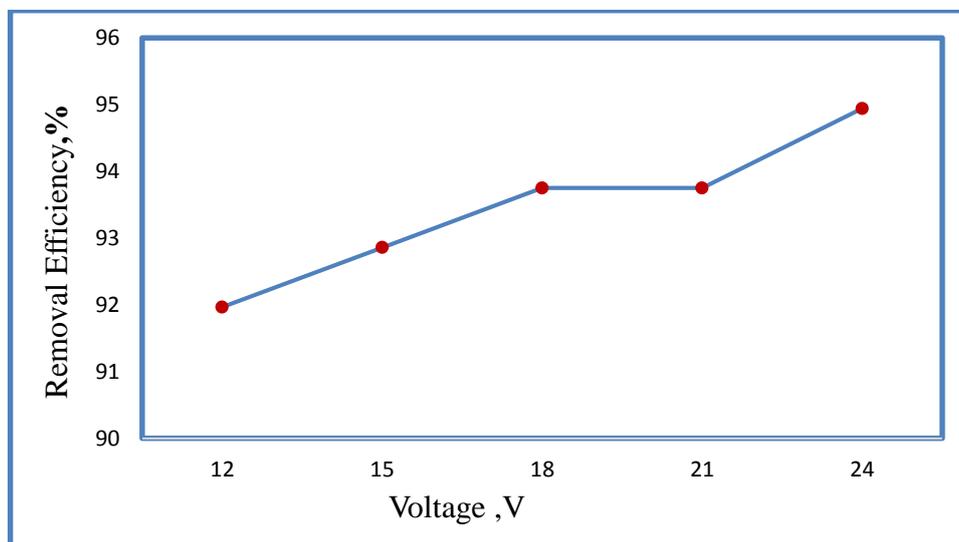

Fig. 4.8: Effect of applied voltage on removal efficiency of TOC for river water (electrical pulse= 2pulse /sec., Q= 1 L/min, P=10 bar).

4.4.2 Number of Electrical Pulses

The basic principle of the PEF technology is the application of short pulses of low electric fields with duration of micro- to milliseconds. The processing time is calculated by multiplying the number of pulses times with effective pulse duration. The process is based on pulsed electrical currents delivered to a water placed between two electrodes; the distance between electrodes is termed as the treatment gap of the PEF unit, the applied low voltage results in an electric field that causes microbial inactivation, as conducted by [Mohamed and Eissa, 2012; Abo khanafer et al., 2021]. For continuous flow-through PEF application, the number of pulses applied to a given amount of water depends on the residence time of the water in the treatment unit and the pulse frequency.

With pulsed electric fields, the energy input was reduced in comparison to a constant field of the same field strength. The effect of Pulse Electrical Field (PEF) on removal efficiency of the RO unit as follow: -

A- Turbidity (Tur)

Typical sources of turbidity include suspended solids such as soil particles, sand, clay and suspended inorganic materials. It can be also due to bacteria, microorganisms. Fig. 4.9 explains the effect of number of electrical pulse on removal efficiency of turbidity for treated water. This Figure shows that the maximum removal efficiency of turbidity for tap and river water was 75% and 83.4%, respectively, at 2pulse/sec, while the minimum is at 5pulse/sec. The reason for this is attributed to the pulse that speeds up detachment and fluctuate of particles inside the cake layer, which is formed on membrane of the filter, so the fouling is

affected by the strength of electrical field, this findings were consistent with [Mostafazadeh et al., 2016]. Therefore, 2pulse/second (pulse frequency 2Hz/sec, pulse width 250millisecond) was selected as the optimal value for treatment process in this work.
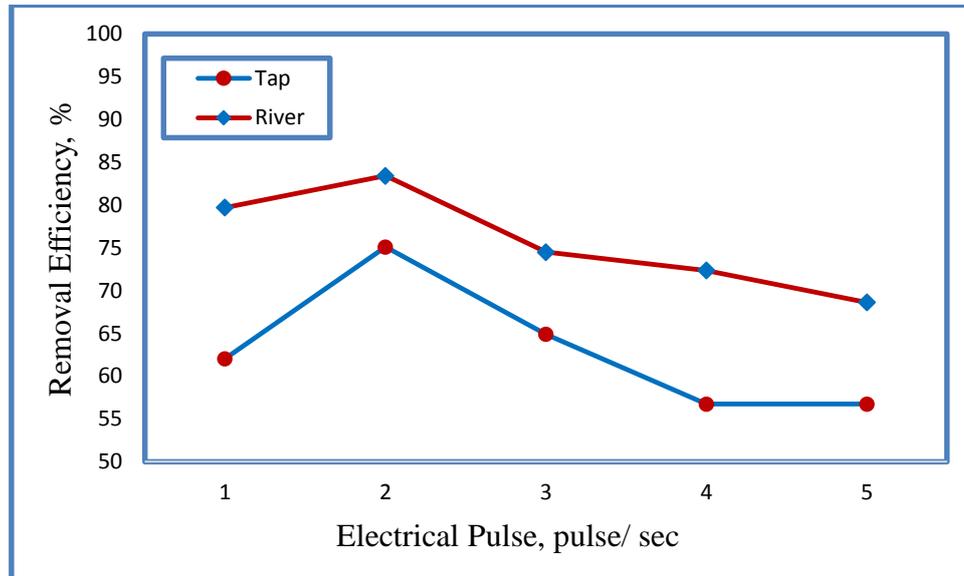

Fig. 4.9: Effect of electrical pulse on removal efficiency of turbidity for tap and river water (Voltage =12V, Q= 1 L/min, P= 10 bar).

Turbidity can be used as an operational parameter to assess the likely effectiveness of disinfection, and as a basis for setting disinfectant doses and modifying contact times. Turbidity has potentially shielding microorganisms from inactivation.

Therefore, the optimal conditions for best removal efficiency of turbidity was (voltage = 12V, electrical pulse = 2pulse /sec, pressure = 10 bar), and during each run these optimal conditions were kept constant.

B- Total Dissolved Solids (TDS)

Fig. 4.10 shows the effect of electrical pulse frequency on removal efficiency of TDS. It appears that applied voltage and the

number of electrical pulses in the treatment system does not have a big effect on TDS removal. The removal efficiency of TDS for tap water ranged from 94% to 94.6%, and for river water from 86.3% to 87.3%.
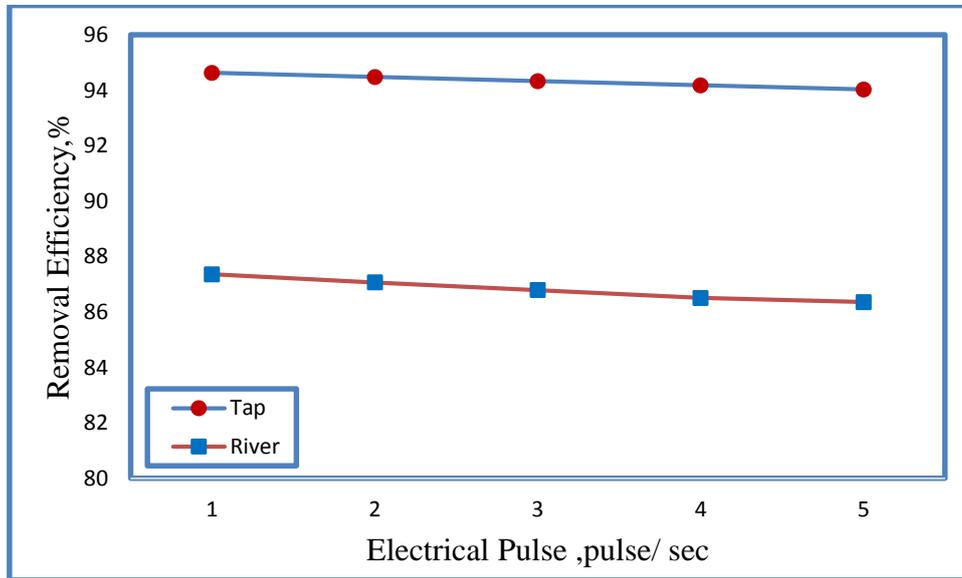

Fig. 4.10: Effect of electrical pulse on removal efficiency of TDS for tap and river water (voltage=12V, Q= 1 L/min, P=10 bar).

C- Electrical Conductivity (EC)

The conductivity is the most important parameters influencing the inactivation of a microorganism through applying (PEF-LV). Fig. 4.11 illustrates the effect of number of electrical pulses on EC removed by the RO unit. The removal efficiency of EC for tap water ranged from 93.9% to 94.2 %, and for river water from 86.3% to 87.3%. That is possibly due to the effect of silver ionization.
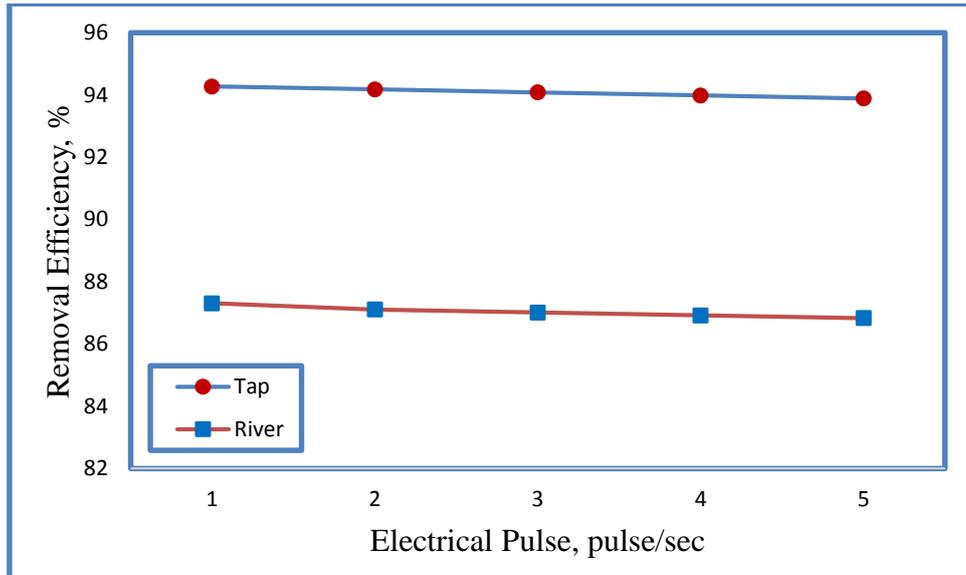
Fig. 4.11: Effect of electrical pulse on removal efficiency of EC for

tap and river water (voltage=12V, Q= 1 L/min, P=10 bar).

D- Total Hardness (TH)

Fig. 4.12 shows the effect of electrical pulse on removal efficiency of total hardness for both tap and river water.
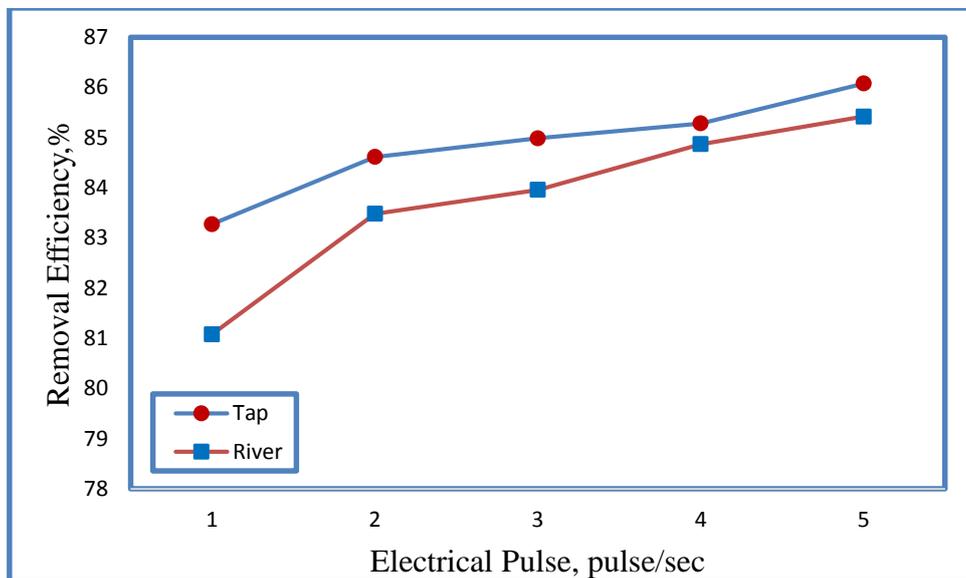

Fig 4.12: Effect of electrical pulse on removal efficiency of TH for

tap and river water (voltage =12V, Q= 1 L/min, P=10 bar).

The maximum removal efficiency of TH is 86% and 85% for tap and river water, respectively, at 5pulse/sec, while the minimum is at 1pulse/sec. The output values of TH are decreased

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with increasing (PEF). The reason is due to that the electrical current is altering the calcium and magnesium ions in the water and makes them attracted to itself, which is similar to the results reported by [Apell and Boyer, 2010], who used PEF as a healthier way for softening water.

E- Chloride (Cl$^-$)

Fig. 4.13 demonstrates the effect of electrical pulse on Cl$^-$ ions for treated water, where the maximum removal efficiency of Cl$^-$ is 66.7% and 72% for tap and river water, respectively, at 5pulse/sec, while the minimum is at 1pulse/sec. A small drop occurs in chloride concentration, presumably due to the formation and precipitation of silver chlorides, due to the relatively low amount of silver present.
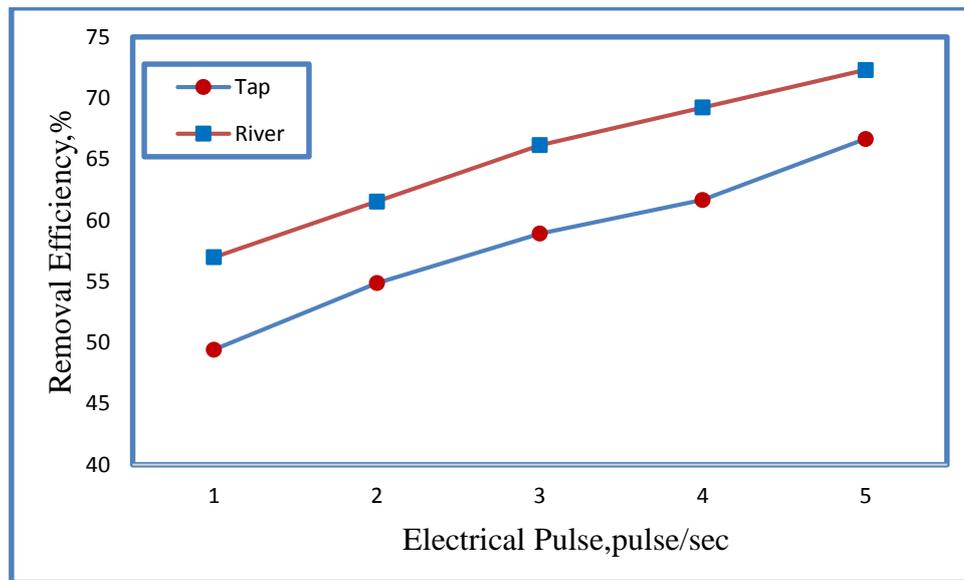

Fig. 4.13: Effect of electrical pulse on removal efficiency of Cl $^-$ for tap and river water (voltage=12V, Q= 1 L/min, P=10 bar).

F- Total Organic Carbone (TOC)

Fig. 4.14 explains the effect of electrical pulse on removal efficiency of TOC for river water.
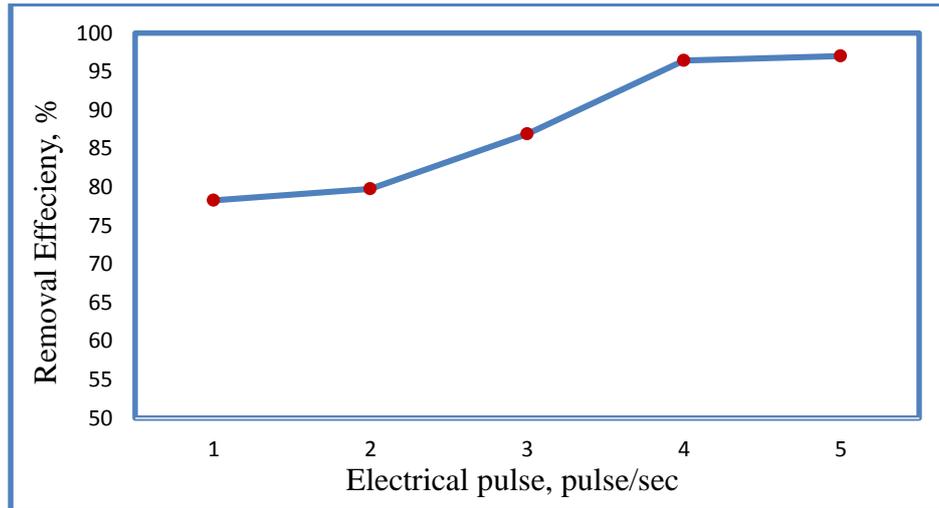
Fig. 4.14: Effect of electrical pulse on removal efficiency of TOC for river water (voltage = 12 V, Q= 1 L/min, and P=10 bar).

The maximum removal efficiency of TOC is 97% at 5pulse/sec, while the minimum is 78.2% at 1pulse /sec.

The pulse width is defined as the time where the peak field is maintained for square wave pulses or the time until decay to 37% for exponential decay pulses. Typically, increasing the number of pulses causes an increase in treatment time, as the pulse width is fixed by the impulse generation setup. Fig. 4.15, shows the effect of the ratio of pulse time to break time duty cycle) (25% :25%, 50%:50%, 25%:75%), respectively, on removal efficiency of TOC. This figure shows that the change in pulse time to break time had no effect on removal efficiency of TOC at the same operation conditions.
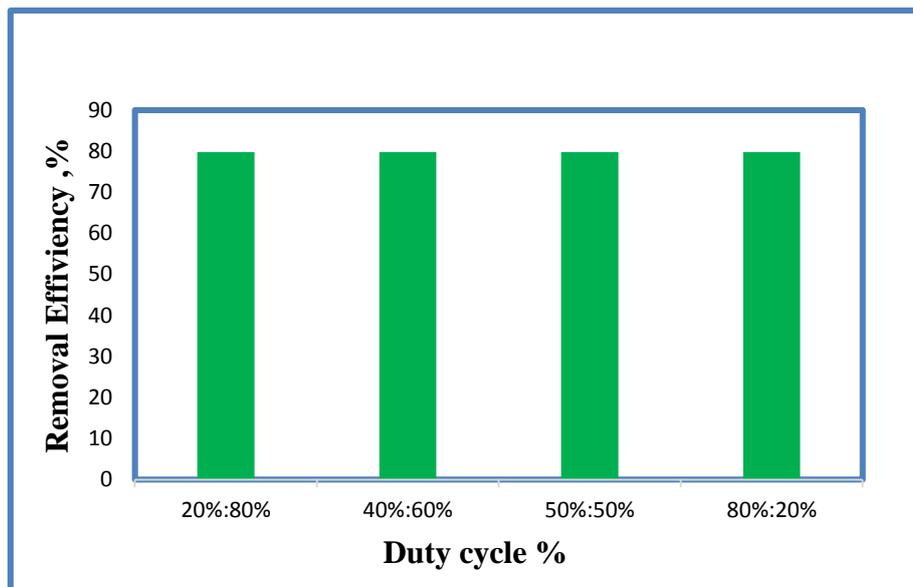
Fig. 4.15: Effect of pulse width on removal efficiency of TOC for River water (voltage = 12 V, Q= 1 L/min, P=10 bar).

4.4.3 Feed Flow pH

The pH tolerance of various types of RO membranes can vary widely. Thin-film composite (TFC)membranes are typically stable over a broader pH range than cellulose acetate (CA) membranes and, therefore, offer greater operating latitude.

Most thin-film composite (TFC) RO membranes have negatively charged active surfaces at neutral pH, due to the presence of ⁻COOH functional groups on the poly-amide (PA) layer. On the other hand, the membrane surface charge plays an important role in fouling. The attractive force between oppositely charged foulants and membrane surface has a strong tendency to induce foulant deposition.

The value of experimental pH in this study ranges between 3.5 to 11.5. These values are adjusted with two synthetic solutions NaOH (normality= 1M) and H_2SO_4 (Dilution ratio 1:25), which are prepared previously. At the first, the experiments are carried out with 2L of acidic solution, pH of the feed phase is monitored

by adding sulphuric acid drops wise gradually and very slowly to reduce the solution pH and ensure a good estimation.

The feed water is pumped from the feed tank passing through the module to the permeate tank with a flow rate of 1L/min and pressure 10 bar. At the beginning, water runs at normal pH 7.5 ± 0.5 for 30 minutes, then is replaced with adjusted water at experimental pH. Fresh water is used to wash and clean the membrane, after each experiment. The samples of permeate from each experiment are collected at every 15 min and stored for analysis. All the experiments are carried out at room temperature of $(25 \pm 5)°C$.

The change in parameters rejection is monitored and interpreted in terms of the membrane surface charge and the Donnan theory of dielectric exclusion. The effect of pH on the performance of the system is illustrated in appendix A.

4.4.4 Feed Water Temperature

Temperature exerts a major influence on biological activity and growth that has been correlated with microbial inactivation, and although (PEF) application is strictly a non-thermal processing technology. In this study, the temperature is chosen within the range from 15°C (minimum temperature for water in winter season) to 35°C (maximum temperature for water in summer season), [Holy Karbala Environment Directorate, 2021], because of temperature in this range is mild and does not have much impact on substances other than microorganisms. The temperature of water is controlled by using an electrical heater inserted in the feed tank and pieces of ice for water cooling purposes, and that is monitored by a thermometer.

A critical aspect to consider related to the optimum temperature to be applied is the membrane life "deterioration rate" as at certain temperature the effective life of the membrane may be affected. This is normally informed by the supplier or the manufacturer.

The effect of temperature on the removal efficiency of RO unit for different physical, chemical and biological parameters were shown in Figs. from A.6 to A.10 in appendix A.

In general, the lethality of PEF treatments increases with an increase in processing temperature.

4.4.5 Feed Flow Rate

In RO system there are three streams. The feed water stream is separated by RO membrane into two main streams; permeate and reject streams. The feed flow rate is defined as the rate of flow entering the RO system. Permeate flow rate is defined as the rate of flow passing through the RO membrane, and the concentrate flow rate is defined as the rate of flow which has not passed through the RO membrane, and comes out from the RO system with rejected ions. The flow rate of feed stream remains constant as it is a function of feed pumps, but permeate streams can be fluctuated in their flow as a result of fouling or scaling factors. The flow of the salt (salt passage) depends on the salt concentration difference.

It is necessary to know the characteristics of the feed water and whether it needs a pre-treatment or not. It is observed that properties of feed water have vital impact on the properties of the permeate water, while temperature and pressure of feed water have a dominant impact on the recovery, salt passage and rejection percentage. In order to study the effect of feed flow rate

on performance of the system, experiments were conducted in the flow range from 200 mL/min to 1000 mL/min at room temperature. The results are presented in Figs. from A.11 to A.15 in appendix A.

4.5 Bacterial Analysis

Table 4.2 illustrates the bacterial analysis for the six points of river water which was conducted for both cases before and after applying (PEF-LV). The results show no bacterial indicator in the effluent samples without applying (PEF-LV), except a small concentration of aerobic bacteria which indicates presence of bacterial pollution, the locations of sampling points were shown in Fig. 4.16.

Table 4.2: Bacterial analyses of river water in reverse osmosis system without applying PEF-LV.

Sampling[*] Location	Aerobic Bacteria		Total Coliform		Fecal Coliform		E.coli	
	Before	After	Before	After	Before	After	Before	After
Ehs1	Full	300	1600	zero	1600	zero	1600	zero
Ehs2	Full	20	1600	zero	920	zero	1600	zero
Ehs3	Full	30	1600	zero	920	zero	1600	zero
Ehs4	Full	200	1600	zero	1600	zero	1600	zero
Ejb	Full	30	1600	zero	1600	zero	1600	zero
E8K	Full	20	1600	zero	920	zero	1600	zero

[*]Stationary monitoring points on Euphrates and AL-Husayniah rivers in Karbala Government by Iraqi Ministry of Environment.
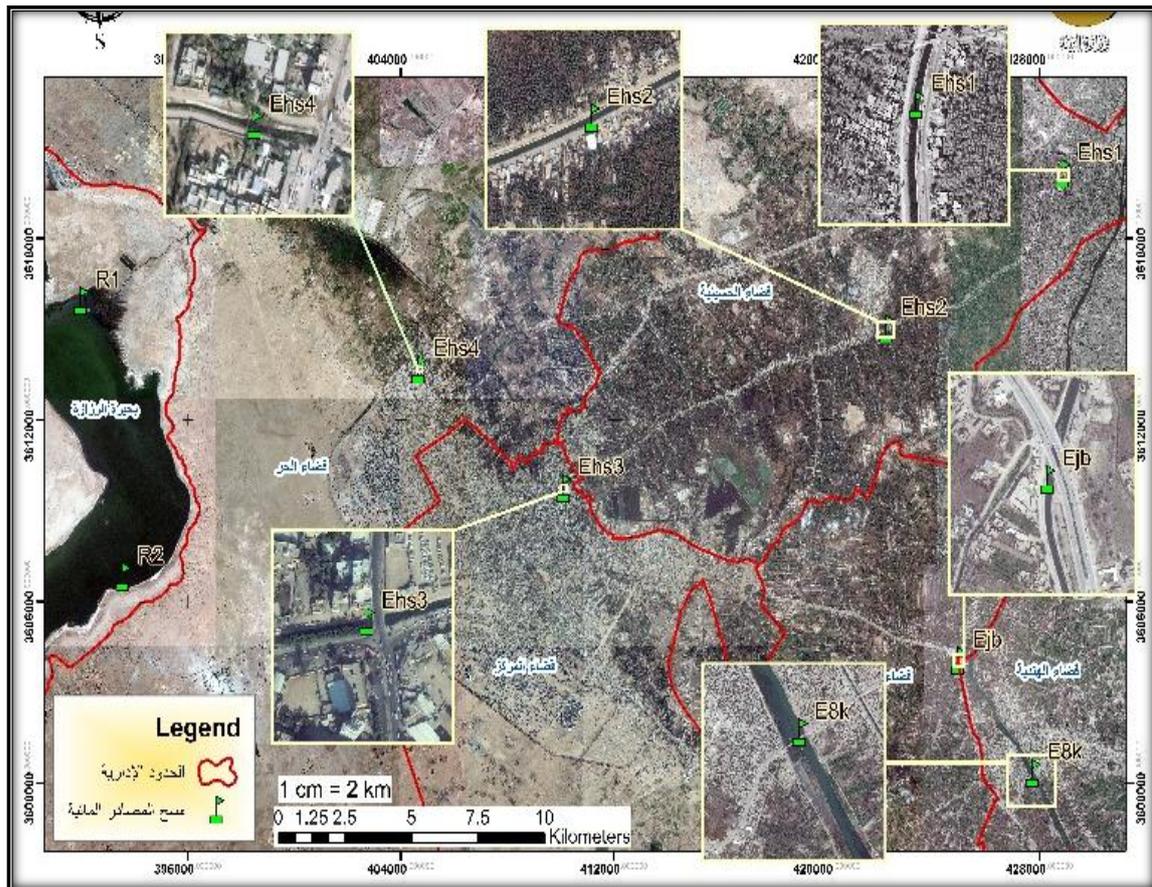
Fig. 4.16: Locations of sampling points in Karbala Government, (Karbala Environment Directorate, 2021).

Table 4.3, shows a complete elimination of the bacterial indicators that can be observed for river water samples after treatment with (PEF-LV) technique. The results obtained confirm the effectiveness of this technology as a whole in removing bacterial indicators from polluted water, as well as generally improving water quality.

Table 4.3: Bacterial analyses of river water in reverse osmosis system with applying PEF-LV.

Sampling Location	Aerobic Bacteria		Total Coliform		Fecal Coliform		E. coli	
	Before	After	Before	After	Before	After	Before	After
Ehs1	Full	zero	1600	zero	1600	zero	1600	zero
Ehs2	Full	zero	1600	zero	920	zero	1600	zero
Ehs3	Full	zero	1600	zero	920	zero	1600	zero
Ehs4	Full	zero	1600	zero	1600	zero	1600	zero
Ejb	Full	zero	1600	zero	1600	zero	1600	zero
E8k	Full	zero	1600	zero	920	zero	1600	zero

4.6 Characterizing of Disinfectant Membrane with Field Emission Scanning Electrical Microscope (FESEM).

Reverse Osmosis (RO) membranes are the most used technology for water treatment in recent years. Despite their widespread use, RO membranes have some important problems like fouling. Fouling is the accumulation of unwanted material on the membrane and cause decrease of permeate flux and a reduction of ionic rejection. There are four types of fouling:

(1) Inorganic (produced by precipitation of salts).

(2) Organic (composed by humic acid).

(3) Colloidal (suspended particles), and

(4) Biofouling (generated by microorganism such as bacteria, fungi, algae that usually form biofilms on the membrane). Biofouling affects more than one-third of RO membranes. Over time, the properties of the

membrane surface can change due to the accumulation of foulants.

Therefore, a proper understanding of the membrane surface properties is essential to assess how these can change over time. Scanning Electron Microscopy (SEM) and High Resolution SEM (HRSEM), also known as Field Emission SEM (FESEM) imaging, have been extensively used to characterize the membrane surface properties, Fig.4.17.

Three samples preparation of polyamide membrane RO were prepared and coated with gold to facilitate the conduction required for imaging (gold commonly used range for coating thickness is 2–5 nm). Three membranes were used in different disinfection processes previously: In Pulse Electrical Field Low Voltage (PEF-LV) technology for (membrane A), Ultraviolet Radiation UV for (membrane B) vs Control membrane (membrane C) for comparison.

In membrane A (Fig. 4.18), shows the intact cells may be of *E. coli* with the rod shape, smooth surface and its characteristics size (around 870.9nm long and 290.6nm diameter). The polyamide surface is covered by groups of crystalline and round morphology particles. These structures have a heterogeneous distribution. Although inorganic fouling is the main one in this sample, there are also microorganisms which could be seen between the compact crystals of the fouling. This distribution is somewhat irregular, and microorganisms are not very abundant.

In membrane B (Fig. 4.19), fouling is composed of a thick layer of crystals which are homogeny distributed throughout the membrane. The size of each of these crystals is much greater than

in the case of membrane A. This could be due to the fact that the membrane has been used for a long period of time in a Point of Use filtration system at home. In the case of microorganisms, the few microorganisms that could be visualized are settled on the salt crystals. Also, some microorganisms grew in the spacer and not only in the polyamide layer.

The visualization of control membrane (membrane C) in Fig. 4.20 shows the normal appearance of an unused RO membrane surface. The surface had a morphology of ridge-and-valley structures due to the two monomers constituting the layer of polyamide 1-4- benzenediamine bound to terephthaloyl chloride.
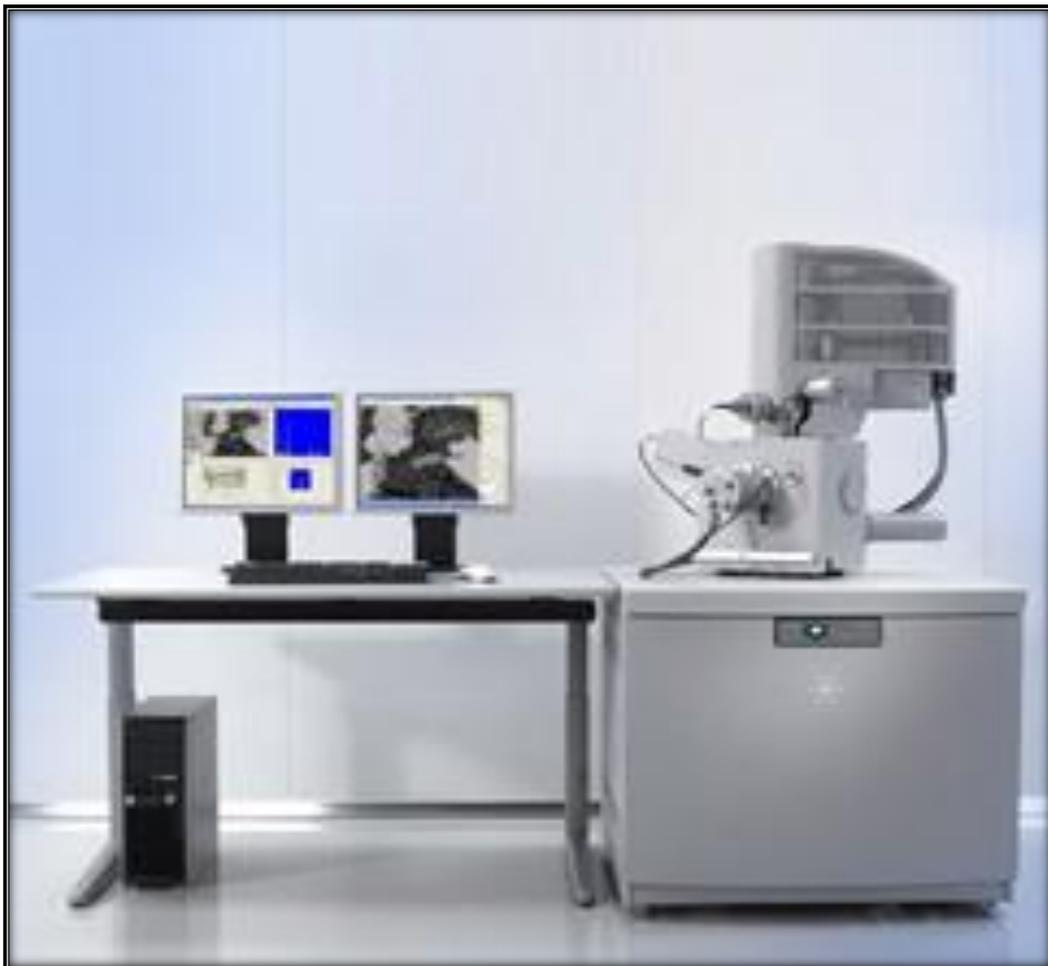

Fig. 4.17: Scanning Electron Microscopy, (Schottky Field Emission FESE).
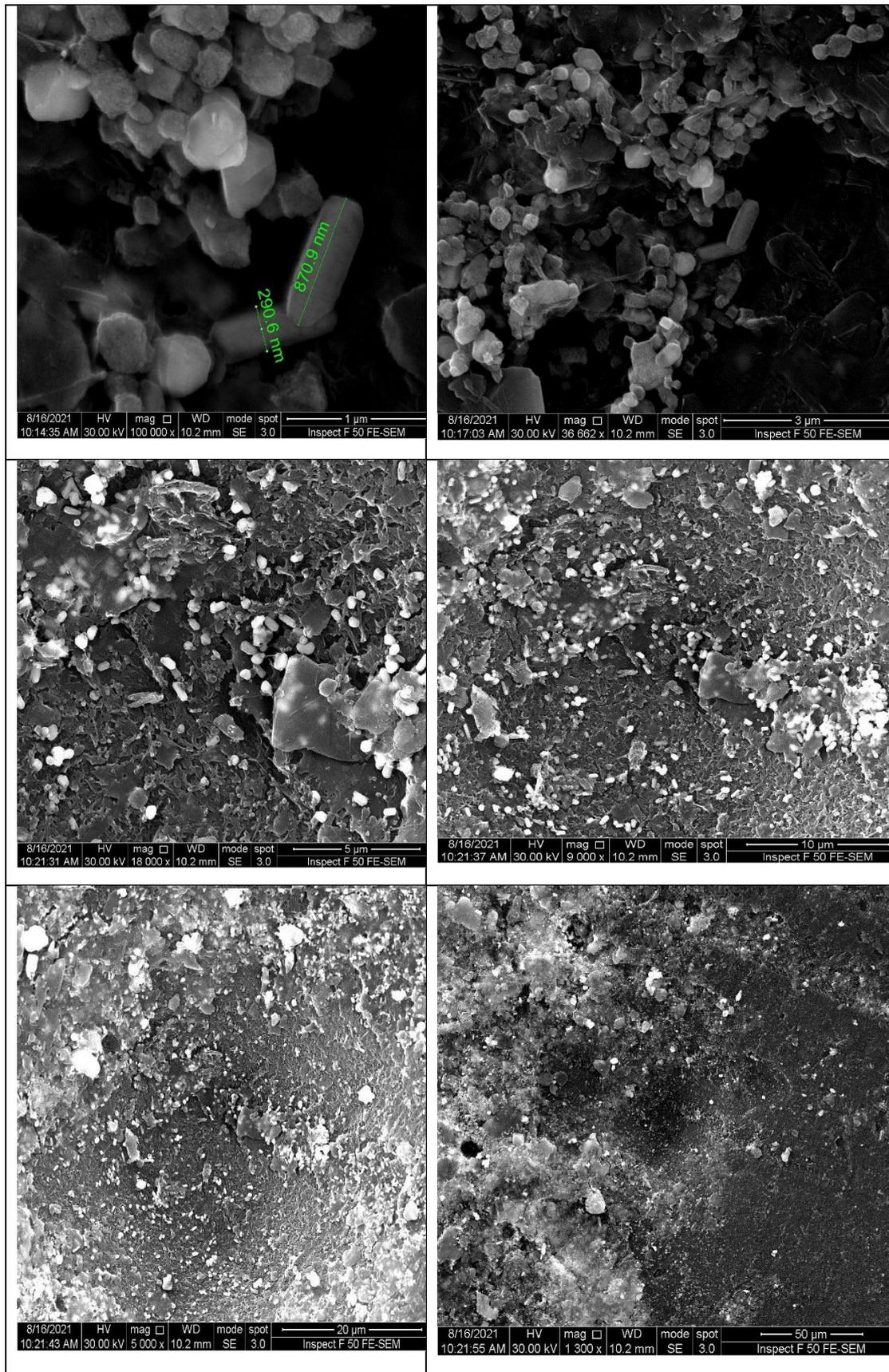
-Membrane (A)

Fig. 4.18: SEM images of reverse osmosis membrane(A) after applying PEF-LV.
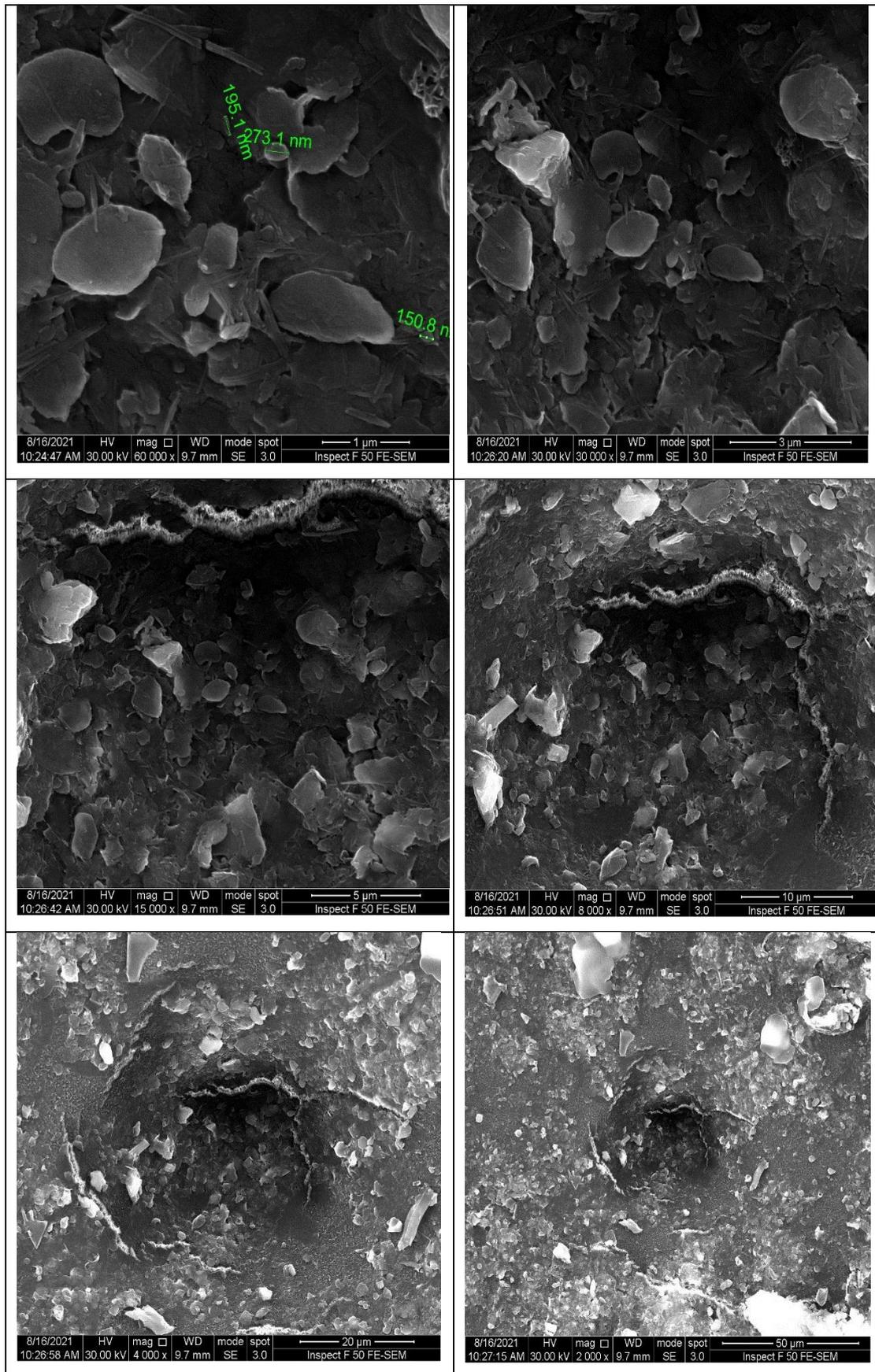
- **Membrane (B)**

Fig. 4.19: SEM images of reverse osmosis membrane (B) after applying UV.
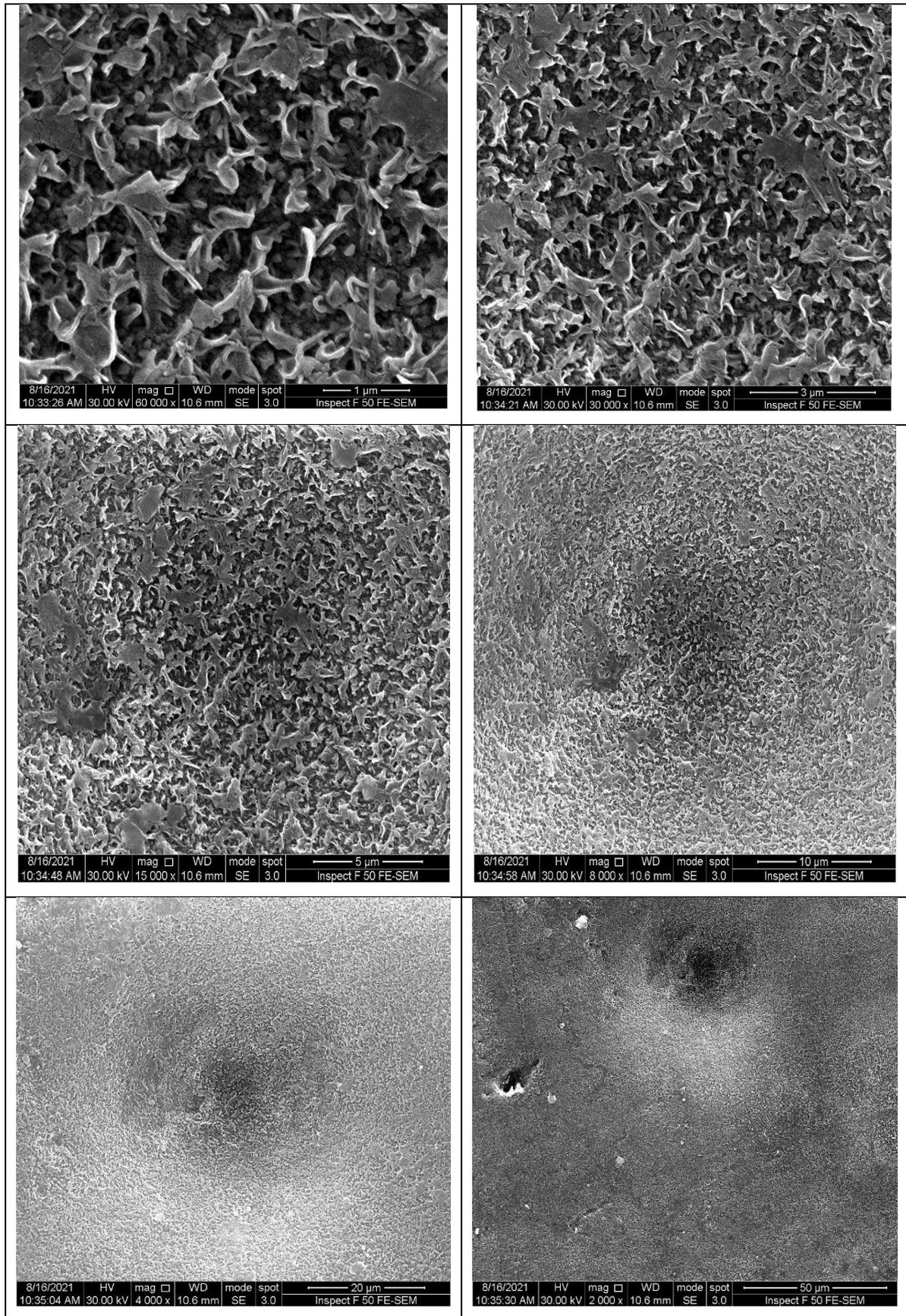
- **Membrane (C)**

Fig. 4.20: SEM images of control reverse osmosis membrane (C).

Chapter Five

Conclusions and Recommendations

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter contains the main concluding remarks obtained from this study. It also provides recommended suggestions, which may be useful for future work.

5.2 Conclusions

Based on the results obtained, the following conclusions are drawn:

1. The results show the effect of applied voltage on maximum removal efficiency of Turbidity, Total Dissolved Solids, Electrical Conductivity, Total Hardness and Chloride is 48.5%, 94.8%, 95%, 84.8% and 62.5% for tap water respectively, and 90%, 87.8%, 87.7%, 87.5% and 68.5% for river water respectively, and 94.9% of TOC, at operation conditions (2pulse/sec, P=10 bar, Q =1L/min, and room temperature (25-30) Cº).

2. Based on the results obtained, the effect of number of electrical pulse on removal efficiency of Turbidity, Total Dissolved Solids, Electrical Conductivity, Total Hardness and Chloride is 75%, 94.6%, 94.2%, 86% and 66.7% for tap water respectively, and 83.4%, 87.3%, 87.3%, 85% and 72% for river water respectively, and 78.2% of TOC, at operation conditions (12V, P=10 bar, Q =1L/min, and room temperature).

3. The experiments show the effect of feed flow pH on maximum removal efficiency of Turbidity, Total Dissolved Solids, Electrical Conductivity, Total Hardness and Chloride is 93.2%,

74%, 79%, 74.4% and 66.3% for tap water respectively, and 95.7%, 78%, 79.3%, 79.5% and 75% for river water respectively, at operation conditions (12V, 2pulse/sec, P=10 bar, Q =1L/min, and room temperature).

4. Based on the results obtained, the effect of feed water temperature on removal efficiency of Turbidity, Total Dissolved Solids, Electrical Conductivity, Total Hardness and Chloride is 73%, 89.9%, 87.8%, 80.8% and 50% for tap water respectively, and 89.9%, 87%, 86.9%, 74% and 67.7% for river water respectively, at operation conditions (12V, 2pulse/sec, P=10 bar, Q =1L/min, and room temperature).

5. Based on the results obtained, the effect of feed flow rate on removal efficiency of Turbidity, Total Dissolved Solids, Electrical Conductivity, Total Hardness and Chloride is 62%, 90%, 90%, 87.3% and 59% for tap water respectively, and 92.8%, 93.6%, 93.8%, 89.4% and 62% for river water respectively, at operation conditions (12V, 2pulse/sec, P=10 bar, Q =1L/min, and room temperature).

6. Bacteriological analysis show a complete elimination of the bacterial indicators that investigate in river water samples after applying (PEF-LV) technique.

7. PEF-LV has a slight effect on physicochemical characteristics of water (pH, Temperature, Total Dissolved Solids, Electrical Conductivity, Total Hardness and Chloride) after treatment.

8. The final pH of the treated water (tap and river) is within the standard range (6.5-8.5).

5.3 Recommendations

The following recommendations can be helpful for future studies:

1. Future work is needed to test the long-term performance of the Disinfectant Membrane (DM) and the possibility of its applying not only in a domestic situation, but also in public commercial and industrial premises where safe drinking water is paramount

2. An economical evaluation should be carried out to the integrated treatment (PEF-LV technology with RO system), and comparison of the scientific advantages and costs in terms of operating related with energy consumption and membrane cleaning/replacement with other treatment methods.

3. Future works should focus on the inactivation of gram positive bacteria throughout treatment systems.

4. Further research are necessary to understand the applicability of PEF-LV to treat a variety of wastewater.

5. Studying the possibility of applying different pulsed frequencies and widths for different disinfection environments.

6. As fouling and high energy demand remain a major issue in RO system, continuous research is needed to find a lasting solution to them, either through introduction of rigorous but cheap pre-treatment processes or through development of fouling resistant membranes.

7. Greater awareness by manufacturers and users to utilization this advance technology in treatment of drinking water and avoid the adverse health effects that resulted from the conventional methods.

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APPENDIX A

EXPERIMENTAL RESULTS
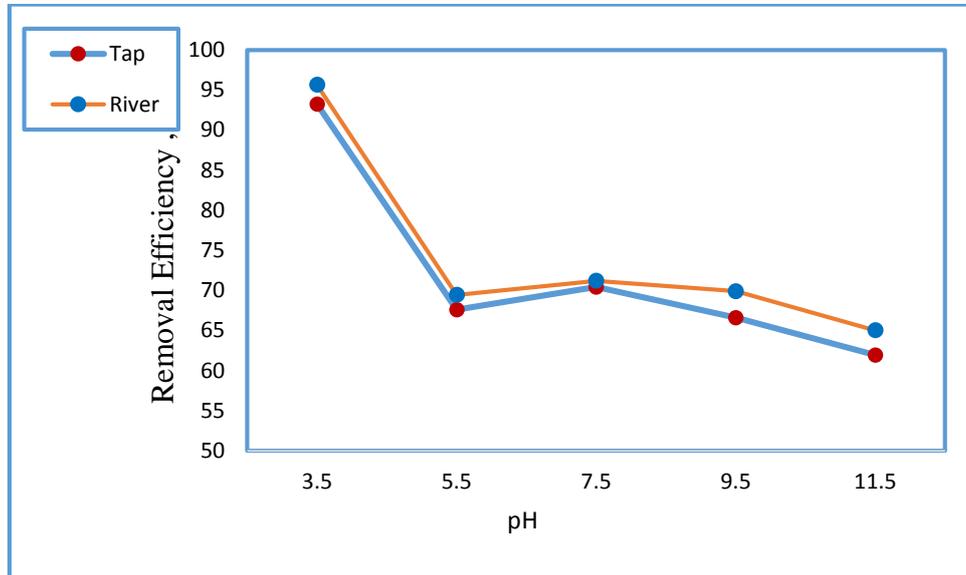
Fig. A1: Influence of pH on removal efficiency of turbidity for tap and river water (P=10, Q=1L/min, electrical pulse=2pulse/sec., voltage =12V).
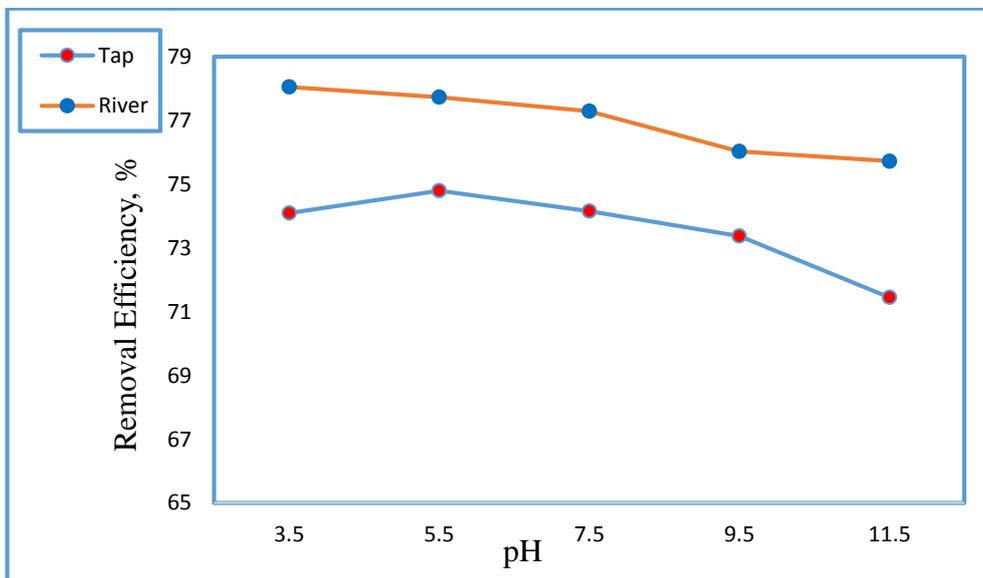
Fig. A2: Influence of pH on removal efficiency of TDS for tap and river water (P=10, Q=1L/min, electrical pulse=2pulse/sec, voltage =12V).
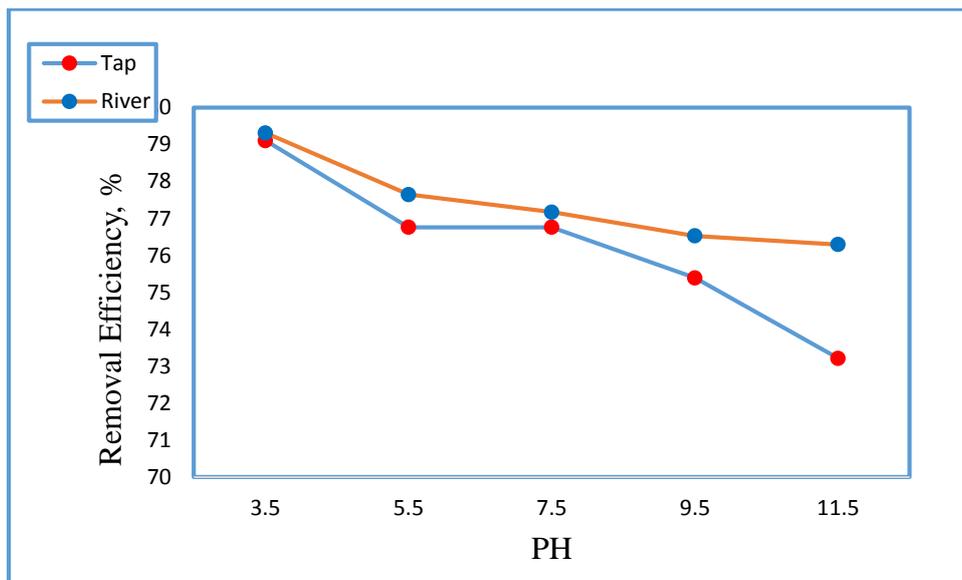
Fig. A3: Influence of pH on removal efficiency of EC for tap and river water (P=10, Q=1L/min, electrical pulse=2pulse/sec., voltage =12V).
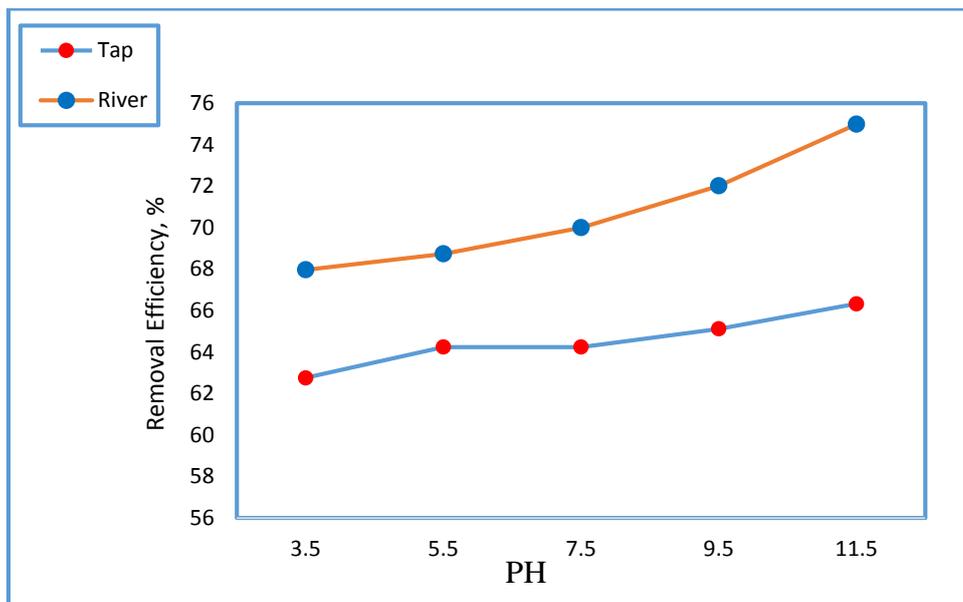
Fig. A4: Influence of pH on removal efficiency of Cl⁻ for tap and river water (P=10, Q=1L/min, electrical pulse=2pulse/sec., voltage =12V).
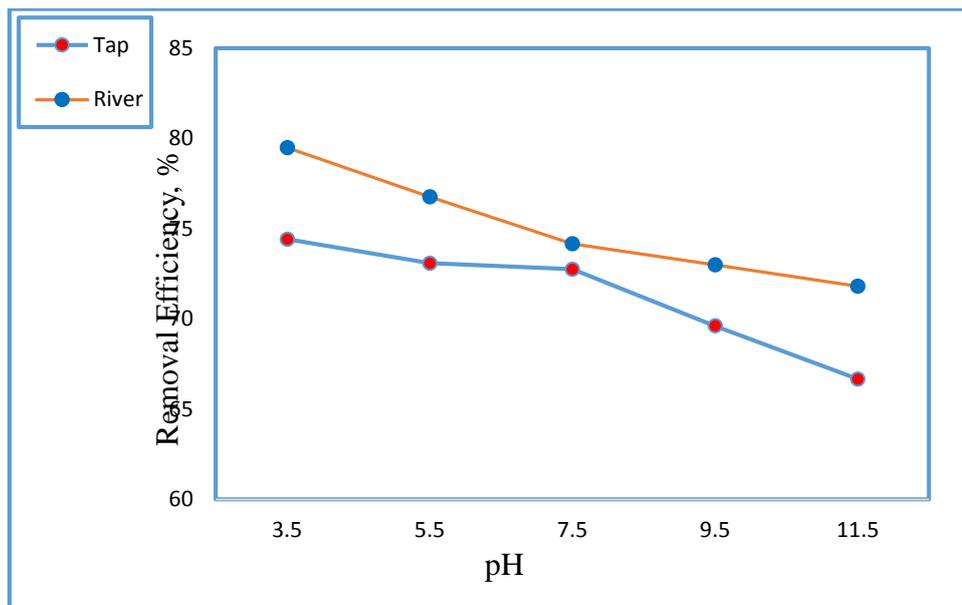
Fig. A5: Influence of pH on removal efficiency of TH for tap and river water (P=10, Q=1L/min, electrical pulse=2pulse /sec., voltage =12V).
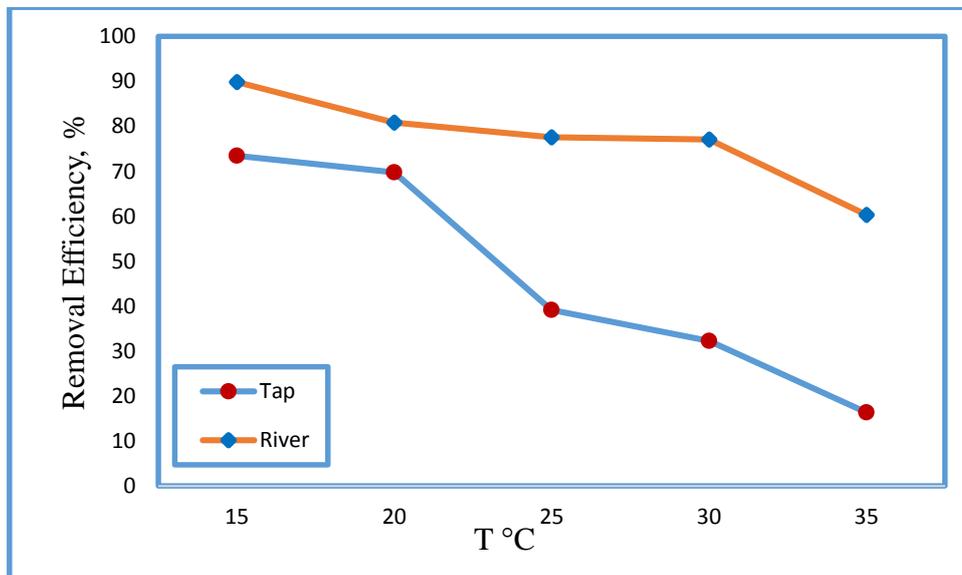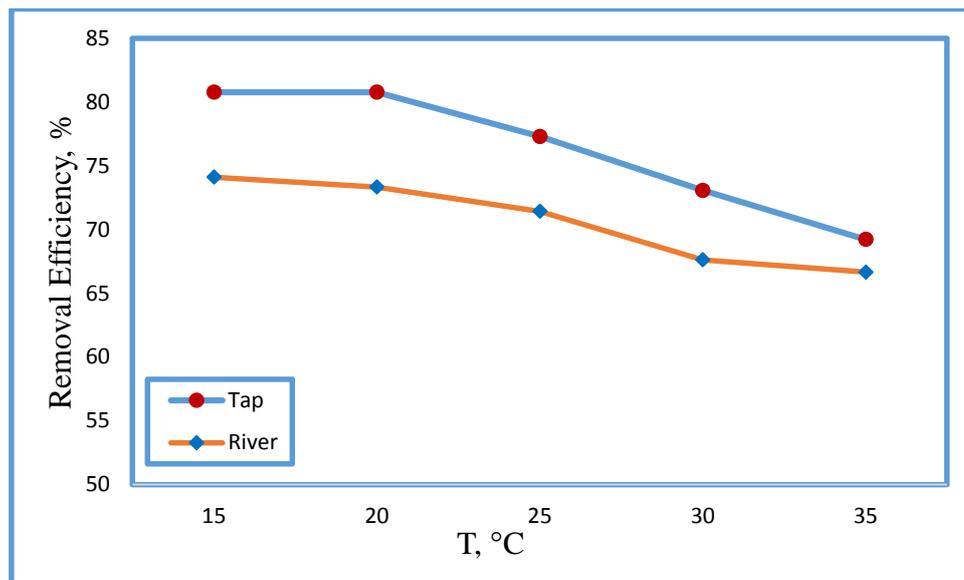

Fig. A6: Effect of temperature on removal efficiency of turbidity for tap and river water (electrical pulse= 2pulse /sec, Q = 1 L/min, P=10 bar, voltage =12V).
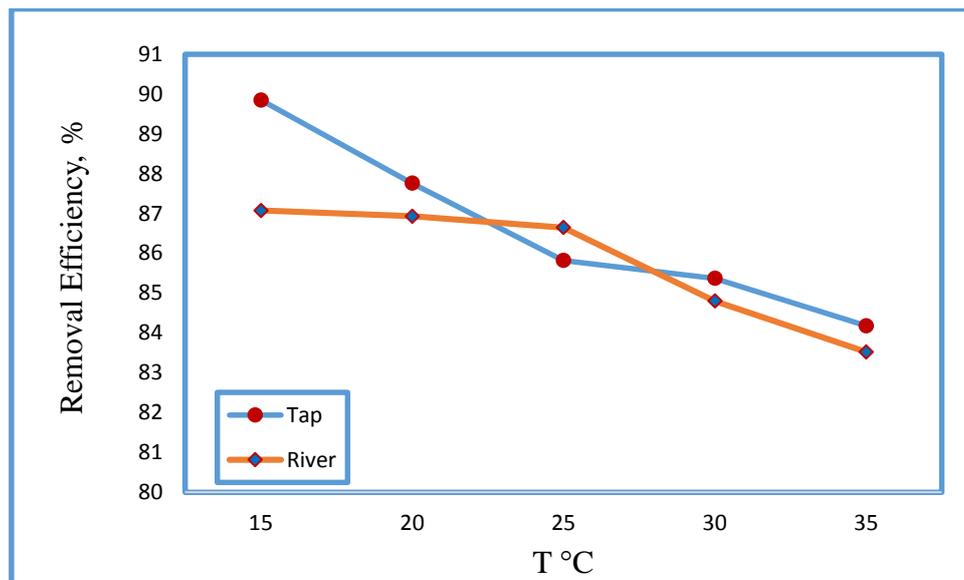
Fig. A7: Effect of temperature on removal efficiency of TDS for tap and river water (electrical pulse = 2pulse /sec, Q= 1L/min, P=10 bar, voltage =12V).
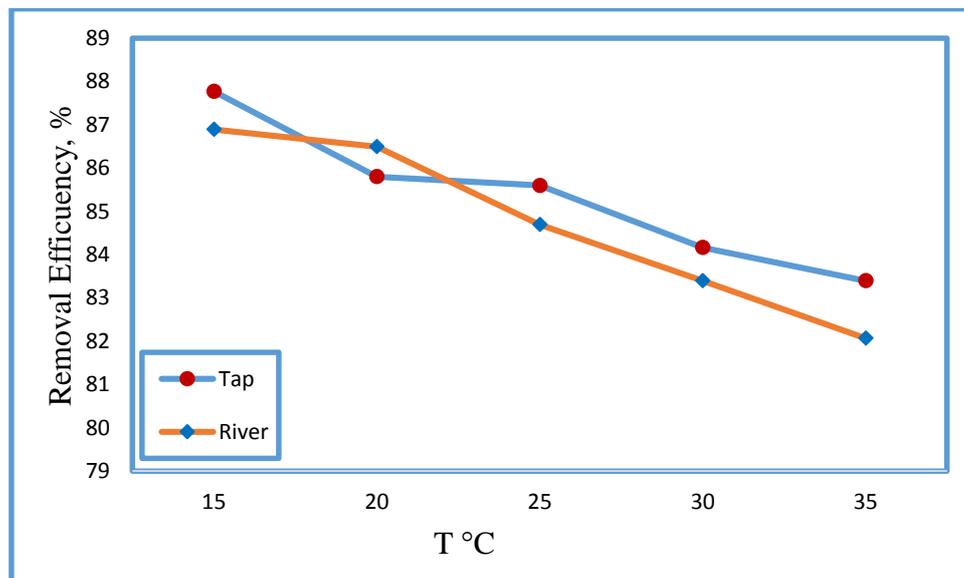
Fig. A8: Effect of temperature on removal efficiency of EC for tap and river water (electrical pulse= 2pulse /sec, Q = 1 L/min, P= 10 bar, voltage =12V).
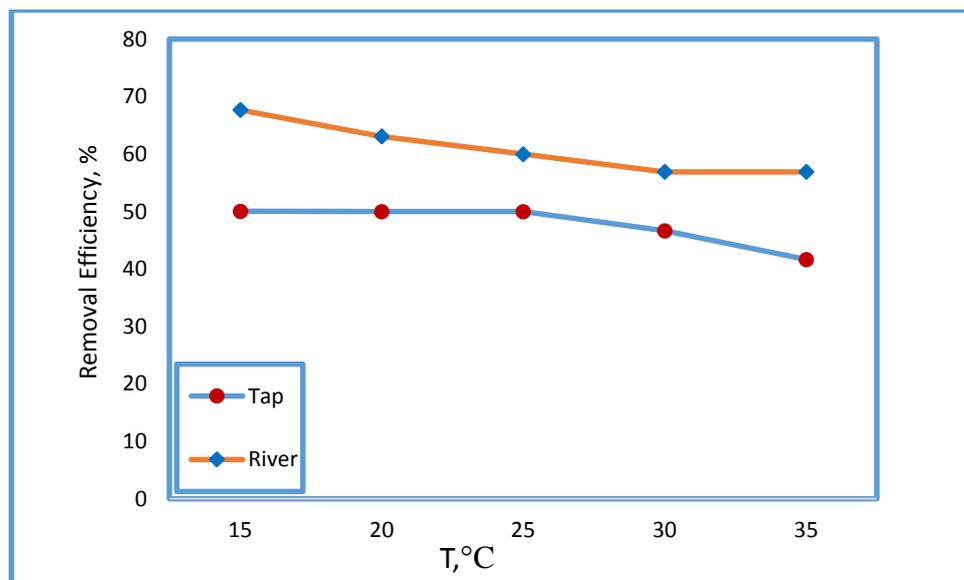
Fig. A9: Effect of temperature on removal efficiency of TH for tap and river water (electrical pulse= 2pulse /sec, Q = 1 L/min, P=10 bar, Voltage e =12V).

Fig. A10: Effect of temperature on removal efficiency of Cl⁻ for tap and river water (electrical pulse =2 pulse/sec, Q = 1 L/min, P= 10 bar, voltage =12V).
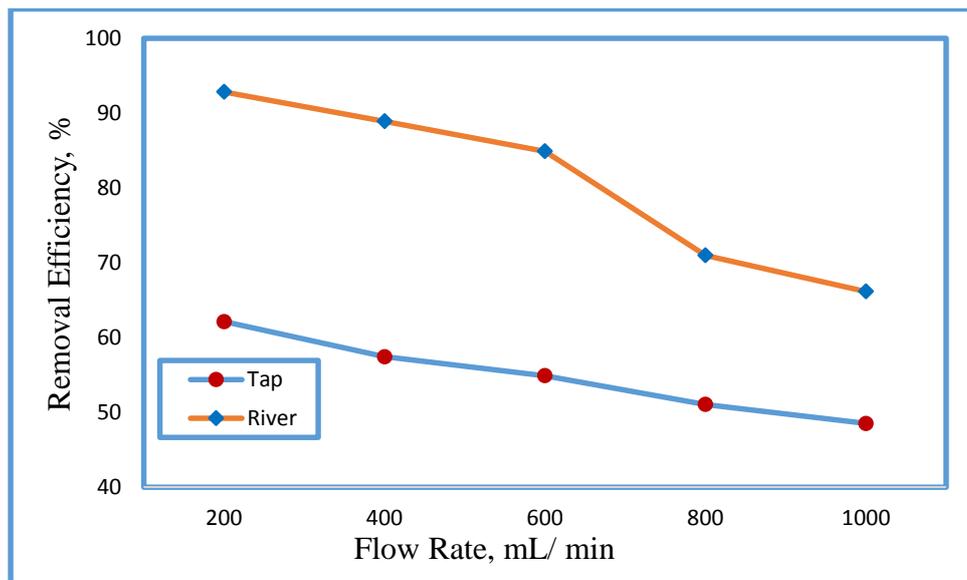
Fig. A11: Effect of feed flow rate on removal efficiency of turbidity for tap and river water (P=7 bar, voltage =12V, electrical pulse =2pulse /sec)
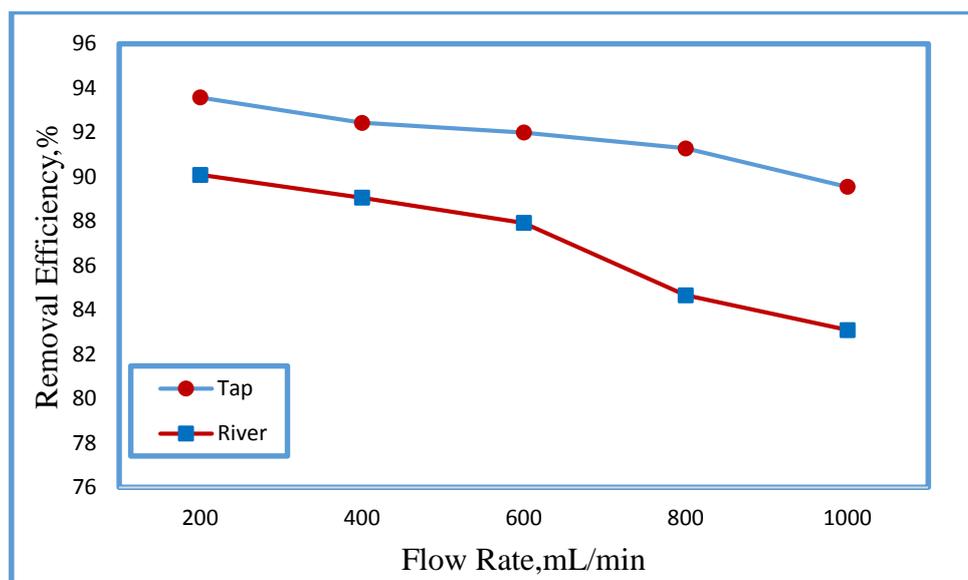

Fig. A12: Effect of feed flow rate on removal efficiency of TDS for tap and river water (P=7bar, electrical pulse=2pulse /sec, voltage=12V).
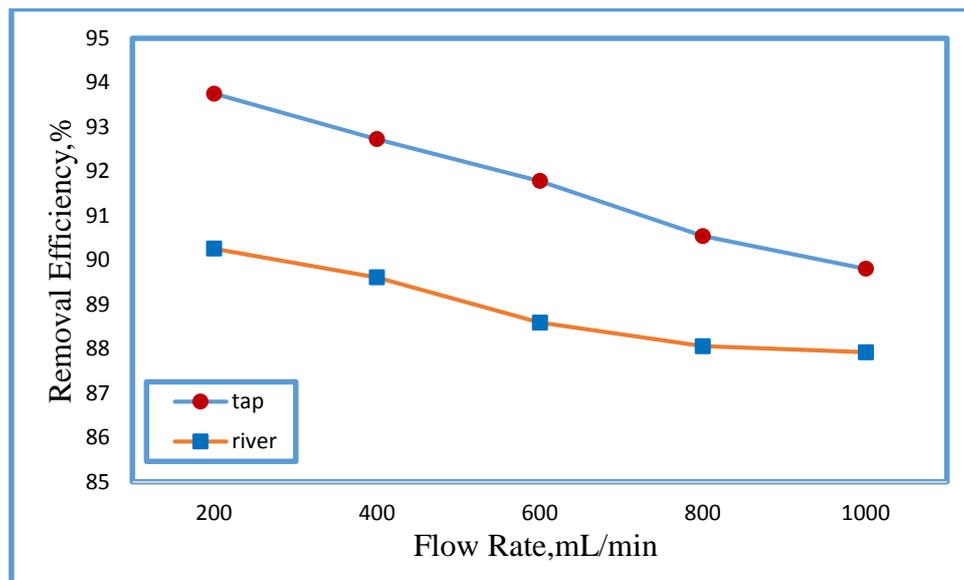
Fig. A13: Effect of feed flow rate on removal efficiency of EC for tap and river water (P=7bar, electrical pulse=2pulse /sec, voltage =12V).
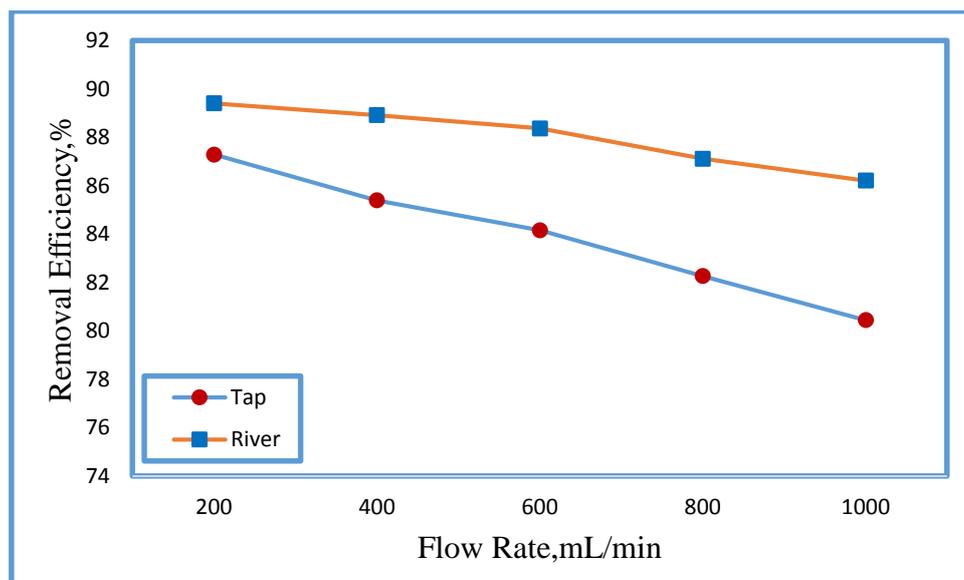

Fig. A14: Effect of feed flow rate on removal efficiency of TH for tap and river water (P=7 bar, electrical pulse=2pulse /sec, voltage =12V).
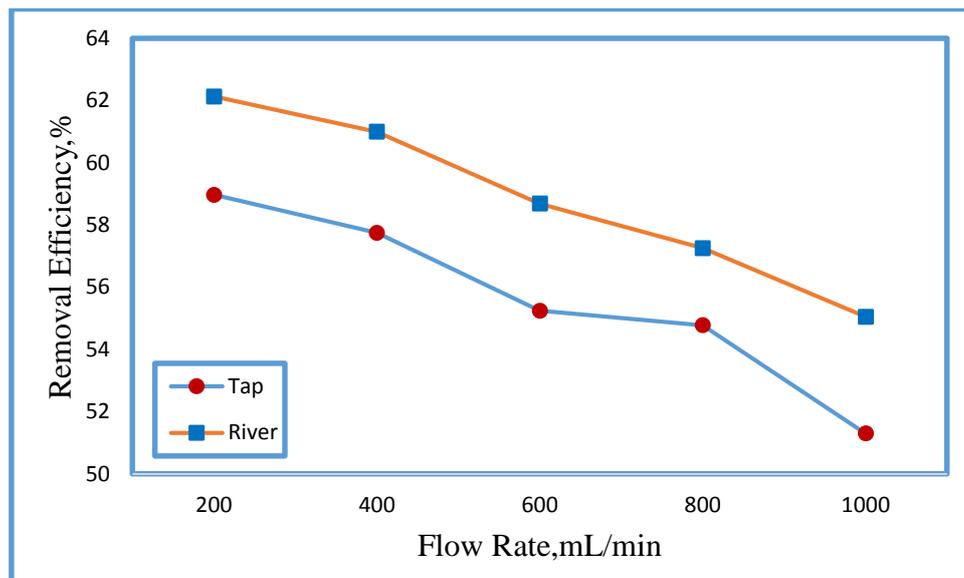
Fig. A15: Effect of feed flow rate on removal efficiency of Cl⁻ for tap and river water (P=7bar, electrical pulse=2pulse/sec, voltage=12V).

Appendix B

Tests Procedures

1- Total Organic Carbone

☒ Add 10 mL of sample to a 50 mL Erienmeyer flask that contains a stir bar.

☒ Add 0.4 mL of Buffer Solution pH= 2. Use pH paper to make sure the sample pH = 2.

☒ Place the flask on a stir at a moderate speed for 10 minutes.

☒ Label two high range acid digestion vials sample and reagent blank.

☒ Use a funnel to add the contents of one TOC Persulfate powder pillow to each acid digestion vial.

☒ Use tensette pipet to add 0.3 m L of organic free water to the reagent blank vial and 0.3 m L of prepared sample to the sample vial to mix.

☒ Lower one unopened ampule into each acid digestion vial. When the score mark on the ampule is level with the top of the acid digestion vial, snap the top off the ampule and allow it to drop into the acid digestion vial.

☒ Cap the vial assemblies tightly and insert them in the DRB 5000 reactor for 2 hours at 105°C.

☒ Carefully remove the vial assemblies from the reactor. Insert them in a test tube rack.

☒ Allow the vials cool for one hour for accurate results. The liquid in the reagent blank vial should be dark blue and select the test.

☒ Wipe the reagent blank vial assembly and insert it into the 16 mm round cell holder and press zero.

☒ Wipe the reagent vial assembly and insert it into the 16 mm round cell holder, and press read.

Fig.1: DRB5000 Reactor

Fig.2: Spectrophotometer

Fig.3: Stirrer

2- Total Hardness

a) Dilute 25mL volume of the sample to 50 mL with distilled water, or take 50 mL of the sample if its hardness is low.

b) 2mL of buffer ammonia is added to make the pH of the sample =10.

c) Add a little amount of dry Erio- chrome black T.

d) The titration process is done by adding EDTA solution slowly with shaking until the solution color changes from purple to blue.

e) After titration, the volume of EDTA solution is recorded, and then the calculations are as follows:

$$\text{Total hardness (EDTA) as mg of CaCO}_3/\text{L} = \frac{[A*B*1000]}{\text{Sample volume (ml)}} \quad \text{.....} \quad \textbf{B-1}$$

Where:

A: ml testing sample titration

B: mg of CaCO3 which equivalent to 1ml EDTA titrant.

3- Chloride

a) Dilute 25mL volume of the sample to 50 mL with distilled water, or take 50 mL of the sample if its chloride is low.

b) A few drops of potassium dichromate solution as a reagent are added, and the yellow color is observed.

c) The sample is titrated with silver nitrate solution until the end
of the reaction point at which a reddish- brown color appears.

d) The volume of silver nitrate solution is recorded, and then the calculations are as follows:

$$\text{Chloride mg/L} = \frac{(A\text{-}B) \times C \times 35450}{\text{Sample volume (mL)}} \quad \text{.......} \quad \text{B-2}$$

Where:

A: mL testing sample titration.

B: mL testing distilled water titration.

C: Molarity of silver nitrate.

نظام تجريبي متكامل باستخدام تقنية الترشيح النانوي والاشعة الكهربائية النبضية لتحسين نوعية المياه

رسالة

مقدمة إلى كلية الهندسة في جامعة بابل كجزء من متطلبات نيل درجة الماجستير في الهندسة/ الهندسة البيئية

من قِبل

خمائل لطيف مكي روضان

بكالوريوس هندسة بيئية/2002

إشراف

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