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Review on Different Biomass Based Microbial Desalination Cell Catalyzed by Bacteria and Yeast

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Abbreviation and Acronyms

AEM	Anion-exchange membrane.
CEM	Cation-exchange membrane.
COD	Chemical oxygen demand
EC	Electrodialysis.
H	Height of microbial desalination cell.
L	Length of microbial desalination cell.
MDC	Microbial desalination cell.
MED	Multiple-effect distillation
MFC	Microbial fuel cell.
MSF	Multi-stage flash evaporation
MWW	Municipal wastewater
PMDC	Photosynthetic microbial desalination cell
RO	Reverse osmosis
SPMDC	Stacked photosynthetic microbial desalination cell
SS-AMDC	Algal MDC with stainless steel
TVC	Thermal vapor compression
W	Width of microbial desalination cell.
cm^2	Centimeter squared
E_{emf}	Overall cell electromotive force
E_o	Standard electrical potential
g	Gram
h	Hour
kg	Kilogram
kW	Kilowatt
L	Litter
m^3	Cubic meter
mA	Milliampere
mg	Milligram
min	Minute

ml	Millilitter
mS	Milli siemens
mW	Milliwatt
^{o}C	Degree Celsius
W	Watt
Ω	Ohm

Abstract

Existing desalination technologies require high amounts of power and electricity that accordingly produces high amounts of greenhouse gasses. Therefore, it is required to introduce a new technology that can produce electricity from organic sources as well as desalinate water at the same time. Microbial desalination cell (MDC) is the new technology that is composed of three chambers: anode, middle desalination chamber and cathode. The middle desalination chamber is isolated by anion exchange membrane (AEM) and a cation exchange membrane (CEM). The electron was produced in the anode by bacteria and transferred via an external circuit to the cathode thus producing current. When current is produced at the anode, ionic species in the desalination chamber were transferred into the two electrode chambers, so desalinating the water.

Different parameters affect the MDC's efficiency. Hence it is the aim of this project to test the effect of these parameters on the MDC efficiency. This includes: the kind and amount of biomass used, water salinity, and the optimum volume of desalination volume. The efficiency of MDC cell is observed through the output power in addition to the desalination rate.

Experimental work with the MDC was carried out using Fungi and bacteria microorganisms. When MDC was operated using fungi with glucose as the substrate, the maximum open circuit potential of cell operated fungi abstracted from mango was 800 mV and achieved 1.4% salt removal, while fungi abstracted from banana was more stable and was 450mV.

MDC operated using bacteria and acetate 1.6 g/L at ambient temperature to achieve a peak of open circuit potential at 500 mV and 20% salt removal. While the experiment was done using a 40% desalination chamber achieve a peak of closed-circuit potential, current and power values using 200 Ω as external resistance at 770mV, 3.8 mA/m^2, and 5.8 W/m^2, respectively. Also, the salinity of water for this experiment was decreased and the percentage of salt removal was found 65.4%. Effect of temperature was tested in one experiment and found that the maximum open circuit potential was of 954 mV at 50˚C.

Chapter One: Introduction

1.1 Background

Water is an essential substance for life on this planet and it covers approximately 70% of the planet's surface. Of this large amount saltwater accounts 97.5% and the rest is freshwater frozen in the icecap or combined as soil moisture (El-Dessouky & Ettouney, 2002). Most of the water available on earth in forms of oceans, seas and ice pole. Accordingly, only 1% of this water is fresh water either underground or surface water in lakes and rivers (Mohammadi & Kaviani, 2003). However, this 1% is not easily accessible for human use and not available in sufficient quantities either when or where it is needed (El-Dessouky & Ettouney, 2002).

Water is necessary for many purposes other than drinking, it is also important for households, agriculture, manufacturing goods, food processing and power generation (Singh, 2008). Fresh water scarcity is a growing problem. The Scarcity of freshwater resources is frequently the limiting factor for economic and social development (Singh, 2008). To overcome this water shortage, different desalination techniques have been developed to be effective especially in the middle east as it has the largest global desalination capacity (49.1%) (Anis *et al.*, 2019).

Desalination process refers to the removal of salt and other minerals from sea or brackish water to obtain clean water suitable for human consumption or industrial use (Qasim *et al.*, 2019). Mainly, desalination process involves the separation of salt from brackish water to produce fresh water, result in concentrated salt as rejected brine stream. The desalination processes can be classified as thermal or membrane separation methods (Qasim *et al.*, 2019).

The thermal separation method consists of phase change of water and leaving contaminants as solids, the first is evaporation of water followed by condensation in order to collect clean water. Common thermal processes include multi-stage flash evaporation

(MSF), multiple-effect distillation (MED), and thermal vapor compression (TVC) (El-Dessouky & Ettouney, 2002).

The second type of desalination is membrane processes that use membrane film as a physical barrier to separate pollutants from wastewater. Reverse Osmosis (RO) is the main membrane desalination process and is used as an alternative process to produce clean water by minimizing the desalination costs. The physical phenomena of osmosis are the penetration of water molecules through the membrane from low osmotic pressure into high osmotic pressure. The membrane is a semi-permeable membrane which rejects the solute and allows only the passage of water (Qasim *et al.*, 2019). Electrodialysis (EC) is another membrane process which the ions transfer through ion exchange membranes under the influence of an electrical feed (Sadrzadeh & Mohammadi, 2008).

Microbial desalination cell (MDC) is a new developed technology based on bio-electrochemical system. The MDC integrates the microbial fuel cell (MFC) and electrodialysis in order to treat wastewater, desalinate brackish water and produce renewable energy (Ashwaniy & Perumalsamy, 2019). This cell exploits the organic material in wastewater in order to produce energy which is used to desalinate brackish water. Desalinating water was accomplished by expending the electric potential gradient established by electro-active bacteria to allow the transfer of ions through ion exchange membranes (Pandit *et al.*, 2018).

The MDC is divided into three chambers anode, desalination and cathode isolated by anionic exchange membrane (AEM) and cationic exchange membrane (CEM) as shown in **Figure 1** below. In the anode chamber, exoelectrogenic microbe's oxides substrate producing electrons at the electrodes and releasing proton into solution. The electrons transfer through an external resistance to the terminal electron acceptor at the cathode. Oxygen is considered as an electron acceptor and combined with electron and proton to form water. The electron transfer created an electrical potential gradient. An AEM is placed next to the anode chamber while CEM is located next to the cathode chamber. The middle chamber has salt water containing cation and anion, these ions move to the cathodic and

the anodic chambers, respectively, due to the difference in cell voltage potential between the electrodes. As a result, water will be desalinated (Kim & Logan, 2013).

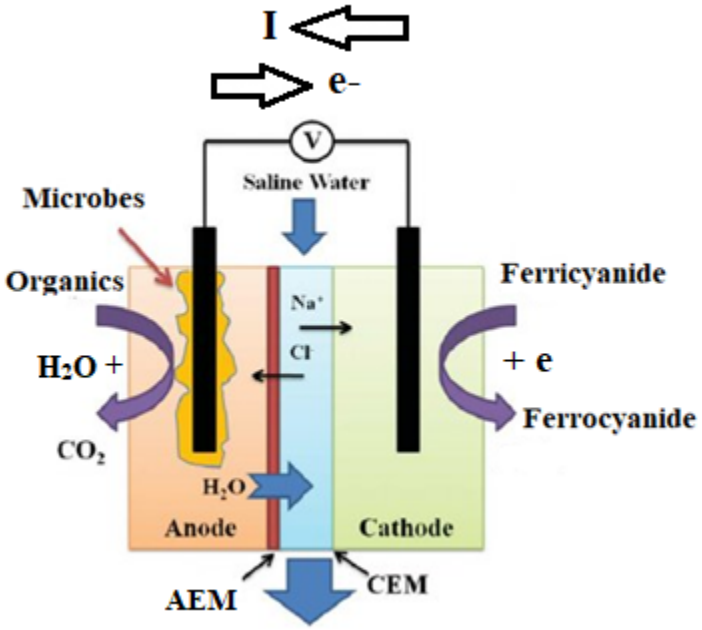

Figure 1: Typical scheme of microbial desalination cell(Saeed *et al.*, 2015)**.**

The microbes present in the anode chamber oxidize the organic matter which is present a source of energy in the absence of oxygen producing electrons, protons and carbon dioxide as shown in **Equation 1** below (Saeed *et al.*, 2015).

$$(CH_2O)_n + nH_2O \rightarrow nCO_2 + 4ne^- + 4nH^+ \quad (1)$$

In the case of using acetate as a substrate it will be broken down into bicarbonate according to **Equation 2** with standard electric potential (E_o) of 0.296 V (Mahdi, 2016)

$$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^- \quad (2)$$

Then the electrons move to the cathodic chamber by external wires where the electron acceptor will be waiting to complete the other half of the redox reaction as shown **in Equation 3** (Saeed *et al.*, 2015):

$$O_2 + 4ne^- + 4nH^+ \rightarrow 2H_2O \quad (3)$$

Usually oxygen with E_o of 1.229 is used as the electron acceptor but due to its need of expensive catalyst ferricyanide could be used with E_o of 0.361 V as shown in **Equation 4** below (Logan *et al.*, 2006):

$$Fe\ (CN)_6^{-3} + e^- \rightarrow Fe\ (CN)_6^{-4} \quad (4)$$

The overall cell electromotive force is calculated by **Equation 5** below (Logan *et al.*, 2006):

$$E_{emf} = E_{cathode} - E_{anode} \quad (5)$$

Thus, the overall electromotive force for a cell working with sodium acetate as the bacteria's substrate (E_{anode}= -0.296) in the anode and ferricyanide ($E_{cathode}$= 0.361) in the cathode will be 657 mV.

1.2 Statement of Problems

As population is in continuous increase, the demand for fresh water increase, hence there is a need to desalinate existing saline water to overcome the shortage of fresh water. Current desalination techniques require intensive energy or high pressure. The problem of high energy demand by desalination can be minimized using microbial desalination cell where it produces its own electricity through oxidation of substrate by bacteria and desalinate water. This cell also contributes to the utilization of disposed food waste by using it as a source of bacteria used in the cell.

1.3 Objective of the work

The objective of this work is of four folds:

1. Review of the use of bacteria microorganism and fungi in Microbial Desalination Fuel Cell (MDFC)
2. Construction of a MDFC.
3. Use of the microorganism presents in the sludge out of the wastewater treatment plant in the MDC.
4. Measurements of the electricity that can be generated and the efficiency of MDC in desalinating brackish water.

1.4 Scope

In recent days, the demand of fresh water increases while sources decrease, so MDC was developed to desalinate seawater or brackish water. In this work, microorganisms to be used in the cell can be bacteria taken from west Nablus wastewater treatment plant from anaerobic digester or fungi or mixture of food waste or mixture of them. These will be the basis of the oxidization reaction. They are used in the anode chamber to oxidize substrate in order to produce electrons and protons. In the cathode chamber, a reduction reaction will occur. Desalination occurs when there is a voltage difference between the anode and cathode.

1.5 Significance and importance of the work

As the available amount of fresh water is reduced, the demand for supply fresh water increases. Hence, the design of an MDC will be able to provide this supply of fresh water, where the MDC used for the desalination of brackish water by creating needed electricity. This cell incorporates the use of microorganisms from the wastewater treatment plant in the anode chamber of the cell in order to desalinate brackish water and generate electricity.

1.6 Organization of the report

This report consists of eight main chapters; the first chapter presents a background of microbial desalination cell and clarifies the problems that needs to be solved. The second chapter highlight the main constraints and standards used in this study. This will be followed by the third chapter which shows previous researches and studies related to the

project's filed published in the open literature. This includes a literature review of topics related to the fundamentals of the cell, microorganisms can be used in operating the cell, best materials used in cell and its main function. The methodology used in this work is presented in Chapter four. Consequently, experimental work, results, and discussion are discussed in Chapters 5, 6 and 7, respectively. The conclusion and future work are presented in Chapter 8.

Chapter Two: Constraints and Standards

The following constraints and standards are applicable to this project:

2.1 Constraints

- The size of the designed MDC is based on previous work carried out by (Cao *et al.*, 2009). Hence until now the work will use the cell as it is without any modifications to its size. (28 ml for desalination chamber, 14.3 ml for cathode and 12.5 ml for the anode.)
- Due to a shortage of financial support, Voltage is manually read in the first semester by a digital multimeter (UT-39) but in the second semester, potentiostat device was used in order to read voltage and it was more accurate and take voltage every 3 second. Reading will be carried out over 3 weeks, which is assumed as microorganism life. Acetate solution was used in the anodic chamber as a substrate for bacteria and glucose solution for fungi.
- The law of university prevented the keep of the cell in the water bath, and the voltage reading was not allowed to take at the all-time because of the cut off the electricity at the university.
- The planned experimental work was hindered from completion due to the pandemic COVID 19.

2.2 Standards

- Experimental work will be carried out according to standards, i.e. the anode holes must be closed properly because the microorganisms are used in anaerobic condition (absence of oxygen).
- Microorganisms which took from wastewater plant are grown at 37 ˚C, so the cell must be operated at this temperature in order to grow of microorganisms, this temperature was achieved by using water bath while yeast will grow at 40 ˚C (Mardiana *et al.*, 2016) .
- The microorganisms must be kept in the fridge at 4˚C to inhibit the death of the microorganism, and it will activate at desired temperature, 30 minute in water bath prior used in MDC (Mardiana *et al.*, 2016).

- Carbonaceous materials as the most common used as electrodes due to their high surface area, corrosion resistance, the ability to collect electrons and the conductivity properties (Slate *et al.*, 2019). carbon rod was used as electrodes in two chambers anode and cathode.
- The preparation of anolyte and catholyte and the concentration of materials that used was obtained from literature as illustrated in methodology chapter.
- Buffer solution is used in the anodic and cathodic cells to overcome the changing in pH also to maintain pH around 7 because it is the suitable value for the growth of microorganisms (Saeed *et al.*, 2015)
- Standard anionic and cationic membranes are used.

Chapter Three: Literature Review

3.1 Desalination Technology

Desalination techniques are categories into two groups: thermal and membrane desalination. The thermal process is generally defined as the addition or removal of energy to separate fresh water from saline water. The two most important thermal processes are multi-stage flash (MSF) and multiple effect desalination (MED) processes. In MSF seawater passes through a heat exchanger where it is heated above 100^{o}C and flashed into stream under pressure, then it is released into vacuum chamber where the vapor is condensed by cooling water and thus producing fresh water. Until the late 20th century, MSF has a market share close to 60% and widespread use in the Middle East due to its low temperature heat source, simple construction equipment and process reliability. In MED the water passes in different columns up to 8 or 16 effects with different pressures of heating and cooling to finally produce fresh water (He & Yan, 2009).

The most widely used technology of membrane based desalination process is reverse osmosis (RO) where it has been developed over the past 40 year to have 80% of all the desalination plants worldwide are based on it (Valavala *et al.*, 2011). In RO water is desalinated with no phase change through pressurizing water to pass through a semi permeable membrane (Kavitha *et al.*, 2019). Sea water is pretreated, pumped, and desalinated. Then the fresh water is mineralized and the concentrate is rejected back to the sea. But when the concentrate of high salinity up to 65,000-85,0000 mg/L is rejected back to sea it will increase the sea's salinity and thus affecting the marine life. It is expected that the salinity of the Arabian Gulf, Mediterranean Sea, and Red Sea, will be increased by some extra 2.24, 0.81 and 1.16 g/L by the year 2050 (Missimer & Maliva, 2018).

Many researches have been made to decrease the high energy consumption of both technologies mentioned above. The theoretical minimum energy required to desalinate 35 g/L dissolved solid is assumed to be 1.8-2.2 kWh/m^3. Moreover, when including energy required for pumping feed water and pretreatment total energy will be 3-4 kWh/m^3 (Kim & Logan, 2013). However, a new technology that decrease or eliminates the need of power

for desalination is microbial desalination cell (MDC). In MDC three goals can be achieved; energy production up to 1 kWh/m^3, water desalination more than 90% salinity removal and wastewater treatment (Al-Mamun *et al.*, 2018).

3.2 Microbial Fuel Cell

MDC is derived from microbial fuel cell (MFC), both are based on bio electrochemical system which produces energy from the direct oxidation of organic matter coupled to extracellular electron transfer by anode respiring bacteria (Al-Mamun *et al.*, 2018). In the other words, MFC is composed of anode and cathode, cation selective membrane (CEM) and wire as illustrated in **Figure 2** (Saeed *et al.*, 2015). Usually the Anode is fed with organically rich substrate such as acetate where the bacteria degrades the organic matter producing electrons and protons. Electrons moves through the anode then outer wire to the cathode. Simultaneously, the protons move through CEM to the cathode and reacts with electronic acceptors such as potassium ferricyanide and oxygen to produce water (Kumar *et al.*, 2019).

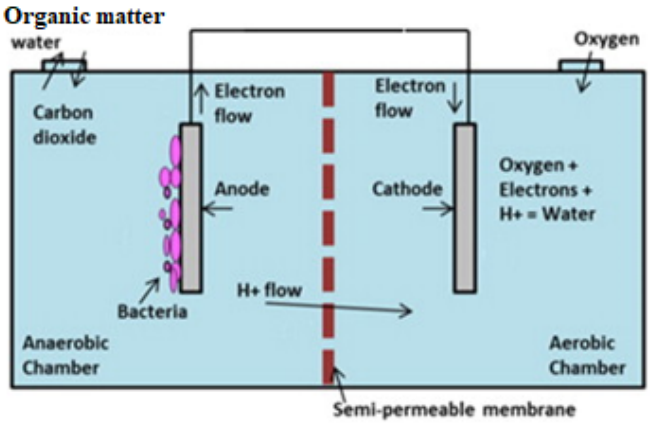

Figure 2: General scheme of microbial fuel cell (MFC) (Saeed *et al.*, 2015)

To convert MFC to MDC a middle chamber is introduced where the desalination process occurs between the two existing chambers separated by cation exchange membrane CEM and anion exchange membrane AEM. Cations produced in the desalination chamber moves to the cathodic chamber, while anions move to the anionic (Sevda *et al.*, 2015).

3.3 Microbial Desalination Cell

The first MDC was developed by Cao et al. in 2009, and there have been a variety of development on this technology since then. The anode chamber was filled with bacteria mixed culture from the anode of an active acetate laboratory MFC and using acetate (1.6 g/L) as the substrate, catholyte was prepared of ferricyanide (16.5 g/L). The water used at different salt concentration 5, 20 or 35 g/L. The MDC was achieved 88%, 94% and 93% removal of salt respectively in single cycle 24 hours, and produced maximum power density 2 W/m^2 (Cao *et al.*, 2009).

3.4 Factor Affecting on Microbial Desalination Cell Performance

Different parameters affect the MDC performance; the salt concentration in the desalination chamber, the substrate used, the configuration, the type of electrodes for anodic and cathodic chambers, the temperature and the catholyte used.

3.4.1 Salt concentration

Accordingly, the most important parameter is the salt concentration, since it affects the internal resistance. High salt concentration lowers the internal resistance, resulting in a high current density across the circuit and higher desalination rate (Saeed *et al.*, 2015).

3.4.2 Substrate

Consequently, different substrates could be used in MDC such as acetate, glucose, galactitol, sorbitol, starch etc. Which directly affects cell performance indigitated by current density produced as shown in the **Table 1**, hence different configurations and electrodes were used with each substrate (Pant *et al.*, 2010).

Table 1: Power density of different substrates used in MDC(Pant *et al.*, 2010).

Substrate	Acetate	Glucose	Galactitol	Sorbitol	Starch
Current density (mA/cm^2) at maximum power	0.8	0.7	0.78	0.62	1.3

3.4.3 Configurations of MDC

The configurations used for the MDC are various, starting with air cathode MDC where the oxygen is used as terminal electron acceptor resulting in 63% salt removal. Secondly, in stack structured MDC alternating AEMs and CEMs the desalination rate increased 1.4 times of a typical 3 chambers unit and the energy recovery increased as well. Third, recirculation MDC where catholyte and anolyte are recirculated consecutively in the cell. It showed an increase in the power and desalination efficiency (Saeed *et al.*, 2015).

Chen et al developed stack structured MDC by using alternating anionic and cationic exchange membranes creating alternating pairs of desalinating chambers (Chen *et al.*, 2011). This stacked cell had shown improvement in charge transfer efficiency and increase in energy recovery, pairs of ions separated and desalination rate was increased by 1.4 time compared to typical MDCs (Saeed *et al.*, 2015). In 2011, The effect of using more

than one desalination chambers and external resistance was studied. Results showed that the desalination rate increased by increasing the number of desalination chambers and reducing external resistance, a maximum desalination rate of 0.0252 g/h was obtained using two desalination- chambered with an external resistance of 10 Ω (Chen *et al.*, 2011).

3.4.4 Temperature

Moreover, the temperature has a dramatic effect on the MDC performance as Ragab concluded in his study. Where three similar MDCs operated at 12, 27 and 45°C for 600 hours. It was found that at higher temperature the current density was higher but more stable at ambient temperature. Also, the desalination rate was found to increase with temperature. Which was 23%, 18% and 10% for 45, 27 and 12°C, respectively. On the other hand, the power generation reached the highest value of 57.3 mW/m^2 at 27°C, while 51.6 mW/m^2 and 13.3 mW/m^2 for 45°C and 12°C, respectively (Ragab *et al.*, 2019).

3.4.5 Electron acceptor

Different electron acceptors could be used in MDC cell like oxygen, ferricyanide, nitrogen species, permanganate, mercury and iron. The most used electron acceptor is oxygen due to its high oxidation potential and the fact of production clean water after reduction. But most studies have shown that it has high energy consumption and it needs expensive catalyst like platinum. Ferricyanide is a great electron acceptor although it has lower electric potential than oxygen but it produces 50-80% higher power when used with carbon electrode. But the use of Ferricyanide is limited to laboratory study since it is toxic and requires difficult regenerating process. However, biocathodes made the use of nitrate as an electron acceptor usable by denitrification process. But nitrate has a low electric potential. Different electron acceptors with the substrate and power generated of each, is shown in **Table 2** below (Jadhav & Ghangrekar, 2009).

Table 2: Cathodic electron acceptor and the maximum density (Jadhav & Ghangrekar, 2009)

Type of substrate	Type of electron acceptor	Maximum power density
Acetate	Permanganate	115.6 mW/m^2
Glucose	Nitrate	7.2 W/m^3
Acetate	Potassium Ferricyanide	166.7 mW/m^2
Acetate	Mercury	433.1 mW/m^2
Potassium acetate	Ferric iron	0.86 W/m^2

3.4.5 External resistance

The External resistance have a major effect on the current density and desalination rate. It is important as it regulates the electron flux through the circuit. Jung and Regan (2011) has studied the effect of different external resistance 10, 50, 250 and 1000 Ω on MFC. The maximum power density was 2.16 w/m^2 obtained at 50 Ω. When the resistance was decreased to 10 Ω the power density was 1.25 w/m^2 while it was 0.93 w/m^2 for 1000 Ω (Jung & Regan, 2011b). When increasing the resistance, the voltage increases while the current density decreases and vice versa. Also, Jadhav in 2009 showed that it took 20 min for the increasing current to stabilize after a sharp drop when the resistance increased from 50 to 100 Ω while it took 2 hours for a decreasing current to stabilize when it was increased from 500 to 1000 Ω (Jadhav & Ghangrekar, 2009).

3.5 Microbial Fuel Cell Using Yeast

3.5.1 Yeast Microbial Fuel Cell

Yeast is also used to operate MDC's in order to produce electricity and desalinate water although it produces lower power output than bacterial fuel cell. Several studies have

proven that higher power values could be obtained by electrodes modification or mediator optimization (Christwardana *et al.*, 2018; Duarte *et al.*, 2019). Furthermore, yeast-based MDC provide a lower cost desalination process with substantial environmental benefits (Mardiana *et al.*, 2016).Baker's yeast, *Saccharomyces cerevisiae,* has been widely used in studies because it is nonpathogenic, fast growing, inexpensive, temperature resistant yeast, can be maintained for long time in dried state and can be easily mass cultivated (Christwardana *et al.*, 2018; Sayed *et al.*, 2012).

3.5.2 Yeast Preparation

A detailed way of preparing *S. cerevisiae* yeast was explained by Haslett in 2011 and used later by Sayed in 2012. Where yeast was prepared by mixing 2 g. dried yeast, 1.8 g peptone, 1.5 g. dextrose and 1 g. malt extract. Then the mixture was cultivated at 30˚C in 50 mL phosphate buffer at 7 pH for 24 hours. Then the cells were harvested by centrifugation at 5000 rpm for 5 minutes. After washing the extract twice by phosphate buffer, it was re-suspended in phosphate buffer. Then the mixture was kept at 4˚C. Prior to be used it was activated at 40 ˚C for 30 minutes (Haslett *et al.*, 2011; Sayed *et al.*, 2012).

3.5.3 Anode Material

The anode chamber prepared by Mardiana contained glucose monohydrate 0.1 M, 0.02 g/ml yeast, 0.1 mM methylene blue in phosphate buffer of pH 7. Where, phosphate buffer should campsite of 4.08 g/L Na_2HPO_4 and 3.28 g/L NaH_2PO_4 dissolved in ultrapure water, highly purified water, (Mardiana *et al.*, 2016).

3.5.4 Cathode Material

The cathode chamber could be fed by 0.02 M (6.58 g/L) potassium ferricyanide in phosphate buffer as prepared previously by Mardiana (Mardiana *et al.*, 2016). On the other hand, Sayed prepared an open-air cathode for the same type of yeast (Sayed *et al.*, 2012).

3.5.5 Influence of Temperature on Yeast

Yeast activity is affected by the temperature. In a study by Mardiana *et al* 2016, it was revealed that seven days operated yeast-based MFC showed a difference in the power density on temperatures ranged from ambient to 50˚C as shown in **Figure 3** where the power density was 1.2 $mW.m^{-2}$, 2.44 $mW.m^{-2}$, 4.75 $mW.m^{-2}$ and 2.32 $mW.m^{-2}$ at ambient, 30˚C, 40˚C and 50˚C, respectively (Mardiana *et al.*, 2016).

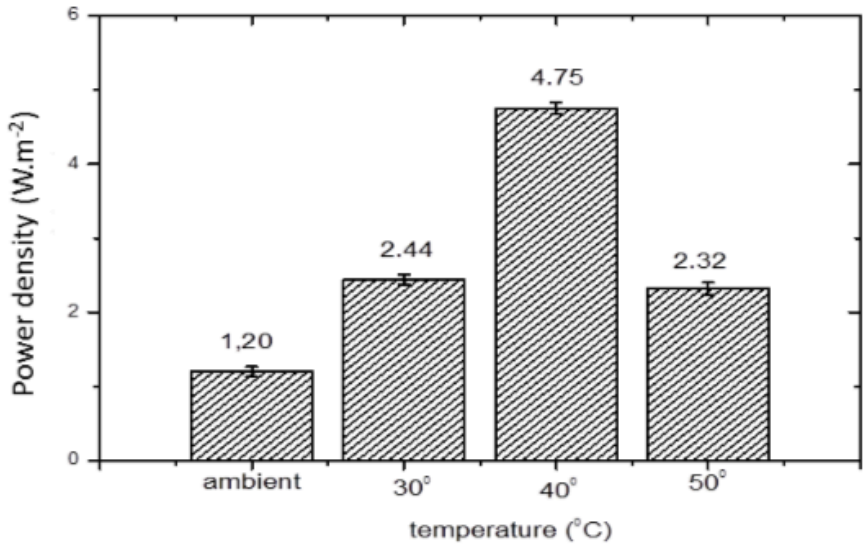

Figure 3: Power density as a function of temperature for a yeast-based MFC(Mardiana *et al.,* 2016).

3.5.6 Modifications for Electron Transfer

There are two mechanisms of electron transfer; direct and indirect. Direct electron transfer is when the microorganism develops nanowires to the anode, while indirect transfer is when electron mediator is used whether it is self-produced or externally added like methylene blue (Sayed *et al.*, 2012). Typically, the biocatalysts of a yeast operated cell can be found as floated biomass and/or deposited on the electrode. Thus, achieving direct electron transfer is difficult. Therefore, a combination of two strategies was studied by Christwardana to enhance electron transfer mechanism; attachment of yeast cell to the electrode by amine or hydrogen bonds and use of dissolved mediator to harvest electrons from floating cells (Christwardana *et al.*, 2018). Where carbon felt is used as electrode, a

polyethyleneimine (PEI) treatment is highly effective in linking carbon and biocatalysts together (Duarte *et al.*, 2019). While for the mediator, methylene blue was proved to be non-toxic for yeast and highly efficient benefits (Christwardana *et al.*, 2018; Mardiana *et al.*, 2016).

3.5.7 Power generation

Different MFC operated using yeast with different electrodes, volumes, substrates and power density are shown in **Table 3** below.

Table 3: Summery of different yeast types operated MFC.

Yeast type	Electrode Anode/Cathode	Substrate	Reference electrode	Cathode	Resistance (Ω)	Mediator	Power density ($mW.m^{-2}$)	Reference
Saccharomyces cerevisiae	Carbon rod	Glucose	n.a.	FC	100	yes	850	(Kaneshiro *et al.*, 2014)
Saccharomyces cerevisiae	Carbon paper/ carbon paper and platinum plate	Glucose	SCE	Air	n.a.	No	300	(Sayed *et al.*, 2012)
Saccharomyces cerevisiae	Carbon graphite/ Nickel	Glucose	SCE	FC	1000	yes	n.a.[1]	(Mardiana *et al.*, 2016)
Arxula adeninivorans	Carbon fiber clothe	Glucose	Ag/AgCl	FC	100	yes	1030	(Haslett *et al.*, 2011)
Candida melibiosica	Carbon felt	Fructose	Ag/AgCl	FC	1000	yes	640	(Babanova *et al.*, 2011)

n.a.: not applicable.

FC: potassium ferricyanide.

SCE: saturated calomel electrode.

1: power density was not applicable but current density was $88mA.m^{-2}$.

3.6 Comparison between bacterial and yeast operated MDC

A summarized comparison for substrate, preparation time and other properties are shown in **Table 4** below. In literature, both cells have been operated using different types of carbon source like: acetate, glucose, fructose. Where for yeast glucose is widely used as substrate as was shown in **Table 3**. For bacteria acetate had proven to give highest power (Pant *et al.*, 2010). Also, both cells operated efficiently using carbon-based electrodes especially carbon felt. Moreover, both cells need external resistance ranged from 100 Ω to1000 Ω to organize the electrons flow as it is operated by bioelectricity (Jung & Regan, 2011a). Furthermore, reference electrode has been used in both cells in order to stabilize the results while recording and plotting the curves such as Ag/AgCl and SCE (Babanova *et al.*, 2011; Cao *et al.*, 2009; Mardiana *et al.*, 2016). The optimum temperature for both cells is proven to be about 40 ˚C as the maximum power could be obtained at this temperature (Mardiana *et al.*, 2016; Ragab *et al.*, 2019).

However, the preparation of the biocatalysts takes longer time in bacterial based MFC in order to construct the biofilm in the electrode, while yeast doesn't need time to build the biofilm. Consequently, yeast needs mediator to enhance electron transfer as it floats on the surface, but bacteria could be operated without it (Cao *et al.*, 2009; Christwardana *et al.*, 2018).

Table 4: Comparison between bacterial and yeast-based MDC.

Properties	Bacteria	Yeast
Preparation time	Almost one month in order to grow biofilm	2 days
Temperature	45˚C	40˚C
Substrate	Acetate	Glucose
Maximum power ($mW.m^{-2}$)	2000	1030
Modifications	-	Mediators are required to enhance electron transfer
Cathode	Potassium Ferricyanide or Open-air	
Anode	Carbon felt	
Reference electrode	Ag/AgCl or SCE	
Resistance	100 - 1000 Ω	

Power generated from yeast is generally close to the value generated from bacteria as shown in **Table 5** below.

Table 5: Power density for different yeast and bacterial-based MFC's and MDC's.

Catalyst	Desalination efficiency (%)	Power density ($mW.m^{-2}$)	Reference
Yeast	n.a.[1]	850	(Kaneshiro *et al.*, 2014)
Yeast	n.a.[1]	1030	(Haslett *et al.*, 2011)
Yeast	64%	n.a.[2]	(Mardiana *et al.*, 2016)
Bacteria	94%	2000	(Cao *et al.*, 2009)
Bacteria	98%	800-1140	(Kim & Logan, 2011)
Bacteria	18%	57.3	(Ragab *et al.*, 2019)

1: cell is operated as MFC, so no desalination chamber presented.
2: Power density was not applicable but current density was 88 $mA.m^{-2}$.

3.7 Wasted food

Almost half of food and vegetables produced globally are wasted every year. Nearly one third of food produced worldwide for human consumption is wasted, which is almost 1.3 billion tons of food. However, fruits, vegetables, roots and tubers have the highest wastage rates. Also, these food wastes contribute to greenhouse emissions and climate change ("Worldwide food waste", 2020). Considering food waste in electricity generation has been considered by using leaves, wheat straw, boiled rice and vegetables has taken researchers' attention for further investigations (Chandrasekhar *et al.*, 2015; Shrestha *et al.*, 2016; Song *et al.*, 2014).

3.7.1 Leaves and wheat

In 2014 a study by Song *et al* 2014, showed that addition of different biomass waste in the microbial fuel cell could enhance the output power of a solid phase MFC because they contain high amounts of hydrocarbons which represent a nutrient for microorganisms. Where MFC operated without leaves generate 4.6 $mW.m^{-2}$ power, while adding of 3% of leaves a maximum power of 195 $mW.m^{-2}$ was generated. Also, a power of 167 $mW.m^{-2}$ was generated when 1% wheat straw was added.

3.7.2 Food waste

Furthermore, food waste comprises of boiled rice, vegetable peelings, cooked vegetables, spoiled un-cooked vegetables and cooking oil when added to solid state bio-electrochemical system (SBES) shown in **Figure 4** a power of 163 $mW.m^{-2}$ was reached with 72% COD removal (Chandrasekhar *et al.*, 2015). In other words, the food waste has been treated with power generated, but in this type of wasted food not show high output power due to the presence of cooked oil which will affected on the activity of microorganisms

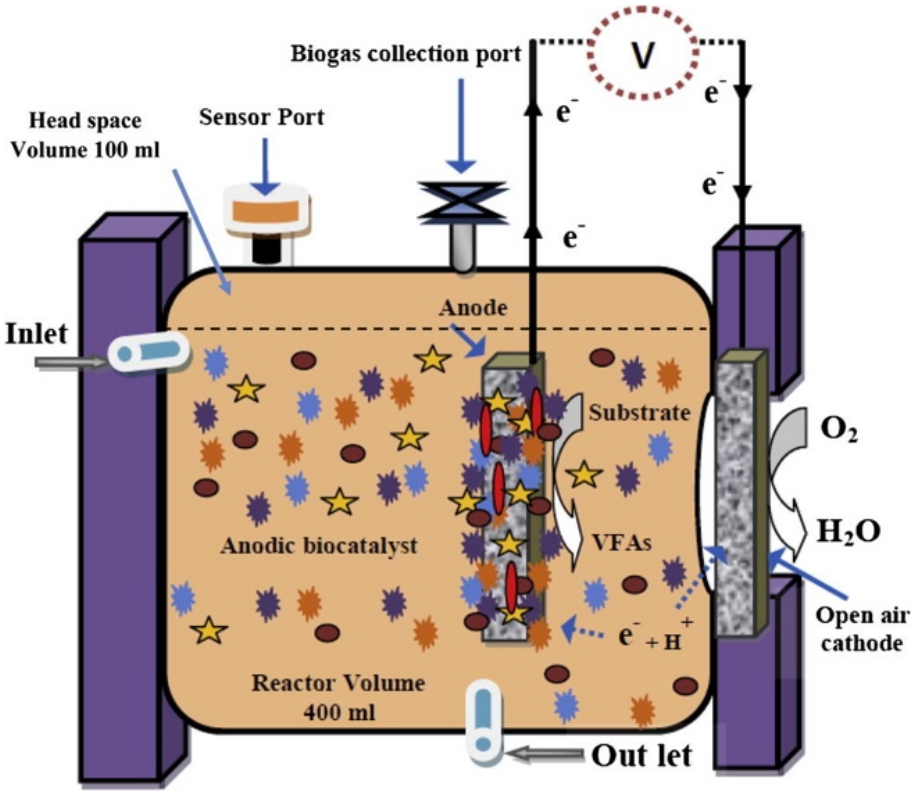

Figure 4: Solid phase bio-electrochemical system (Chandrasekhar *et al.*, 2015).

3.7.3 Wasted Tomato

Shrestha in 2016 proved that wasted tomatoes based MFC could produce power of 256 $mW.m^{-2}$ using tomato's cull, while it's seeds and skin could produce 132 $mW.m^{-2}$ compared to 134 $mW.m^{-2}$ generated from wastewater. Moreover, this cell could be operated without a mediator, since tomato contains different redox active mediators such as carotenoids, kampferol, malvin, myricetin, naringenin, naringin, petunidin, quercetin, and riboflavin. These mediators enhance electron transfer to the surface of electrode and thus power generation (Shrestha *et al.*, 2016).

Tomato's cull was prepared by Shrestha by boiling tomatoes for 5 minutes, then cooling them at 11˚C for 10 minutes. Then tomatoes were placed on an aluminum foil. Finally, they were dried by heating at 60˚C for 18 hours. This cell had operated Successfully for 125 days, almost 4 months with media replacement from 4 to 15 days range. Power density vs. current density of different operating days is shown in **Figure 5** below.

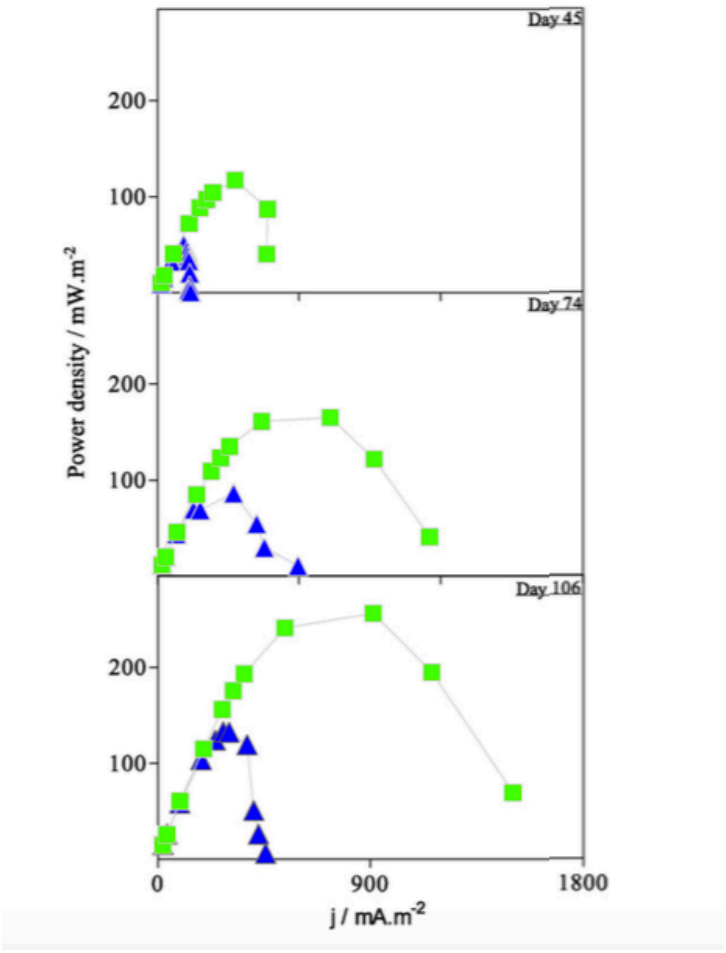

Figure 5: Power density and current density for culls (green squares) and peel and seed (blue triangles). Note: Media replacement were performed on day 12, 27, 43,47, 53, 60, 67, 74, 84, 89, 95, and 103 (Shrestha et al., 2016).

3.8 Application of Microbial Desalination Cell

One of the applications of MDC is to softening water which was developed by Brastad and He in 2013. They used continuous mode by pumping acetate at a rate 0.042 ml/min and the anode was containing a mixture of aerobic and anaerobic sludge, while hardwater was fed into the middle chamber in batch model also it was fed with heavy metal such as arsenic 13 mg/l, copper 391 mg/l, nickel 357 mg/l and mercury 11 mg/l. They achieved removed 90% of the hardness, also it was found that cell removed 89% of the arsenic, 97% of the copper, 95% of the nickel and 99% of the mercury (Brastad & He, 2013).

In 2018, Ebrahimi et al. developed MDC in order to use it in treatment of municipal wastewater (MWW). They designed a quadripartite microbial desalination cell which constructed with a symmetric structure of cubic Plexiglas chambers, it consists a central anode chamber, 4 desalination compartments and 4 cathodes which located at each side of anode. Anode was inoculated with a mixture of MWW and septage sample in ration 10:1, MWW contain 1106.78 mg/L of chemical oxygen demand (COD) while septage sample contain 4911.6 mg/l. The cell was operated for 120 day, and at end of cycle, 58.4%, 72.8% removal of COD from septage and MWW, respectively. Also, power density was found 8.16 W/m^3 (Ebrahimi *et al.*, 2018).

Al Mamun et al 2018 have shown that MDC have various applications besides desalination. It could be used in remediation of polluted ground water where it was subjected to remove Nitrate (NO_3) and it removed 90.5% with power generation of 101.1 mW/m^2. Also, it could be used ammonia removal where it removed 88% of ammonia. Moreover, it could be used to remove copper (Cu) from waste water by 73% removal efficiency Additionally, Henna Saeed suggested of implementing three desalination cell in series to increase the desalination rate, then the partially desalinated water moves to RO for further desalination, or to MFS unit (Saeed *et al.*, 2015).

3.9 Scaling up of MDC

One of the challenges face MDC is scaling up of the cell Saeed et al 2015 reported that the cell takes 200 ml of artificial water to desalinate only 3 ml of salt water. This challenge was studied and improved by Zhang and He 2015. They developed MDC with 105 L volume of liquid and investigated the performance of it. They found that by applying external voltage, the current density increases from 670 mA to 2000 mA with increasing salt removal rate from 3.7 to 9.2 kg / m^3.day (Zhang & He, 2015).

3.10 Use of MDC in Palestine

The first study on MDC in Palestine was carried out by Mahdi 2016. She tried to find a solution for drinking water scarcity in Gaza by desalinating seawater in order to use for human uses. She studied the efficiency of desalination process by using four

configurations of MDC: air-cathode MDC, Photosynthetic MDC (PMDC), Stacked Photosynthetic MDC (SPMDC) and Algal MDC with stainless steel electrodes (SS-AMDC). She prepared wastewater using algal and fed to the anode chamber of the cell. As a result of her study, she found that PMDC has the best desalination efficiency and electricity generation where the desalination rate reached 94% by the end of the 11 days, and produced power generation equal to 1.1 W/m^3 (Mahdi, 2016).

Up to the researchers' knowledge the use of MDC for desalination of water and production of electricity is the first project to be carried out in the West bank tackling MDC project, and second in Palestine.

Chapter Four: Methodology

4.1 Materials and Equipment

The following materials have been used in the experimental work:

- Potassium Ferricyanide ($K_3Fe(CN)_6$).
- Sodium Acetate (CH_3COONa).
- Dipotassium phosphate (K_2HPO_4).
- Potassium Dihydrogen Phosphate (KH_2PO_4).
- Ammonium chloride (NH_4Cl).
- Magnesium chloride hexahydrate ($MgCl_2.6H_2O$).
- Calcium chloride dihydrate ($CaCl_2•2H_2O$).
- Potassium chloride (KCl).
- Iron (II) sulfate heptahydrate ($FeSO_4.7H_2O$).
- Manganese (II) chloride tetrahydrate ($MnCl_2.4H_2O$).
- Boric acid (H_3BO_3).
- Zinc sulfate ($ZnSO_4$).
- Copper (II) chloride dihydrate ($CuCl_2.2H_2O$).
- Nickel (II) chloride hexahydrate ($NiCl_2.6H_2O$).
- Cobalt (II) chloride hexahydrate ($CoCl_2.6H_2O$).

In addition, the following apparatus were used:

- Digital Multimeter (UNI-T).
- Electrical Conductivity (JENWAY 4310).
- pH meter.

4.2 MDC Construction

The MDC design was based on a cubic-shaped MFC made of acrylic sheets with dimensions (6×6×5) centimeter (W×H×L) for cell number 1 and (5×5×4) centimeter for cell number 2. Both MDC's consisted of three chambers anode, middle desalination and the cathode, isolated with ion-exchange membranes: anion-exchange membrane which adjusted to the anode chamber and a cation exchange membrane that is on the cathode side

as shown in **Figure 6** (Cao *et al.*, 2009). Holes were drilled for filling, and taking samples in each chamber. The volumes of chambers were changed to make the desalination chamber smaller than the cathodic and anodic chamber to increase desalination efficiency as concluded by Arana (Arana & Gude, 2018). The change in volumes were made by moving the AEM one piece of acrylic sheet. The new and old volumes of all chambers for both cells are shown in **Table 6** below. Carbon rod was used as electrode in the anode and cathode chambers, and electrode has 3 mm in diameter and 4 cm in length which gives 3.3 cm^2 was considered as the working surface area of electrodes. Therefore, the length of electrode must be measured every experiment because the surface area depends on the length of electrode that contact with sludge

Membranes used in the MFC were left in 5% NaCl solution for 24 hours then washed with deionized water before using them to increase hydration and expansion (Ragab *et al.*, 2019) as shown in **Figure 7** below.

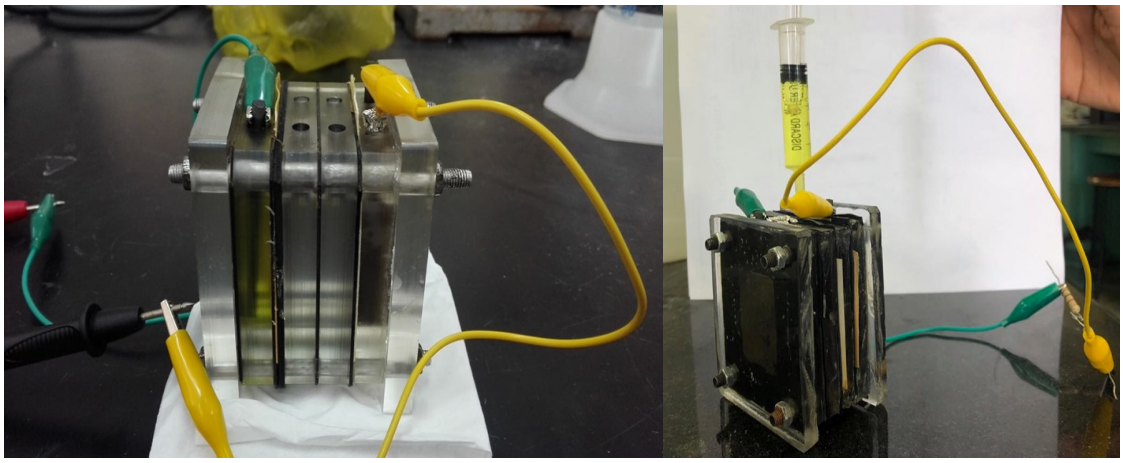

Figure 6: MDC design and photograph on experimental setup.

Table 6: New volume of MDC chambers.

Cell		Chamber volume (ml)		
		Anode	**Desalination**	**Cathode**
1	Old	12.5	28	14.3
	New	28.6	14	12.6

2	Old	12.9	18	12.3
	New	21	13	9.9

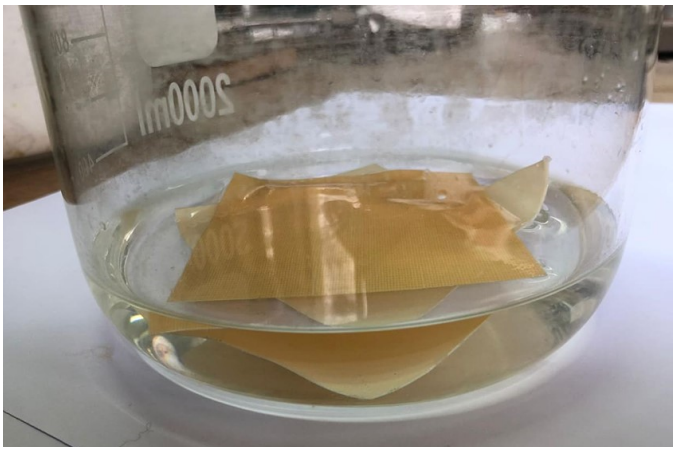

Figure 7: Membrane in NaCl solution.

4.3 Trace Minerals preparation.

In one liter deionized water, the following materials shown in **Table 7** below were dissolved according to Rabaey *et al* to prepare trace minerals solution which consider as the minor nutrients for microorganisms.

Table 7: Composition of trace minerals (Rabaey et al., 2005).

Materials	Concentration (mg/L)
$FeSO_4.7H_2O$	1000
$ZnSO_4$	70
$MnCl_2.4H_2O$	100
H_3BO_3	6
$CaCl_2.6H_2O$	130
$CuCl_2.2H_2O$	2
$NiCl_2.6H_2O$	24
$CoCl_2.6H_2O$	238

4.4 Medium

Anode compartment was inoculated with anaerobic sludge, which is semi-solid material containing suspended solid and mixed culture of microorganisms and its produced in wastewater treatment, from west Nablus wastewater treatment plant. An anode chamber was fed with an anode solution which was prepared by dissolving (in one litter deionized water) sodium acetate 1.6 g, with buffer solution of K_2HPO_4 3.4g, and KH_2PO_4 4.4g, ,and nutrient which include NH_4Cl 1.5g, $MgCl_2.6H_2O$ 0.1g, $CaCl_2 \cdot 2H_2O$ 0.1g, KCl 0.1g and 10ml trace minerals. Catholyte solution was prepared by dissolving 16.5g/l potassium which used as acceptor of electrons in cathode chamber in one liter of deionized water. Also, buffer solution of 8g K_2HPO_4 and 9g KH_2PO_4 was added to the catholyte solution. The middle chamber was filled with saline water of 20g/l concentration. It was prepared by dissolving 20g of salt in one liter of distilled water and all chambers were operating in batch mode and the cell was operated at 37 ˚C and neutral pH approximately 7 (Cao *et al.*, 2009). pH was checked every day by pH-meter in order to maintain the pH value around 7 which consider as the best value for the growth of microorganism. Electrodes were left in distilled water 24 hours prior to each experiment (Ragab *et al.*, 2019).

4.5 Famiralization with the MDC

Prelaminar experimental work: several experiments were carried out to make sure that all experimental set up are working. The first set of experiments were the measurement of the conductivity of the saline water under open circuit potential of the MDC. Therefore, in experiments 1 to 4 the electrodes in anode and cathode chamber were connected by copper wires with a digital multimeter to observe the voltage of the cell as shown in **Figure 8Error! Reference source not found.**. No external resistance was used. The open circuit potential of MDC was recorded every 5 min. The conductivity of the saline water was measured with a manual conductivity meter. pH also was measured for the cycle using pH meter or litmus paper.

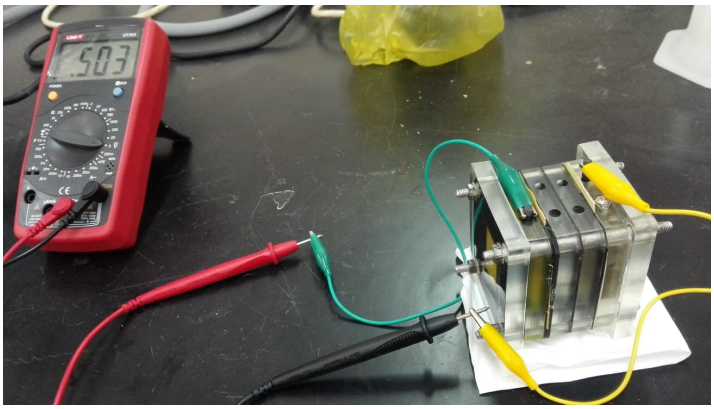

Figure 8: Connection of MDC with digital multimeter.

These experiments were followed by another two experiments where the MDC's was immersed in water bath to ensure operating the cell at 37˚C. The cell voltage across an external resistance was recorded by PGP 201 Potentiostat shown in **Figure 9** (VoltaLab, 2020). Copper wires were used for connection. Due to lab safety instruction, the electricity of the lab where the apparatus exist is shut down at 3pm, therefore, the data was collected for 2 to 3 hours every day then the cell was taken to another lab where it is kept in an incubator at 37˚C to ensure temperature stability. Electrical conductivity of saline water and acidity of three chambers' solution was checked every day to ensure pH stability and thus bacterial and operational stability.

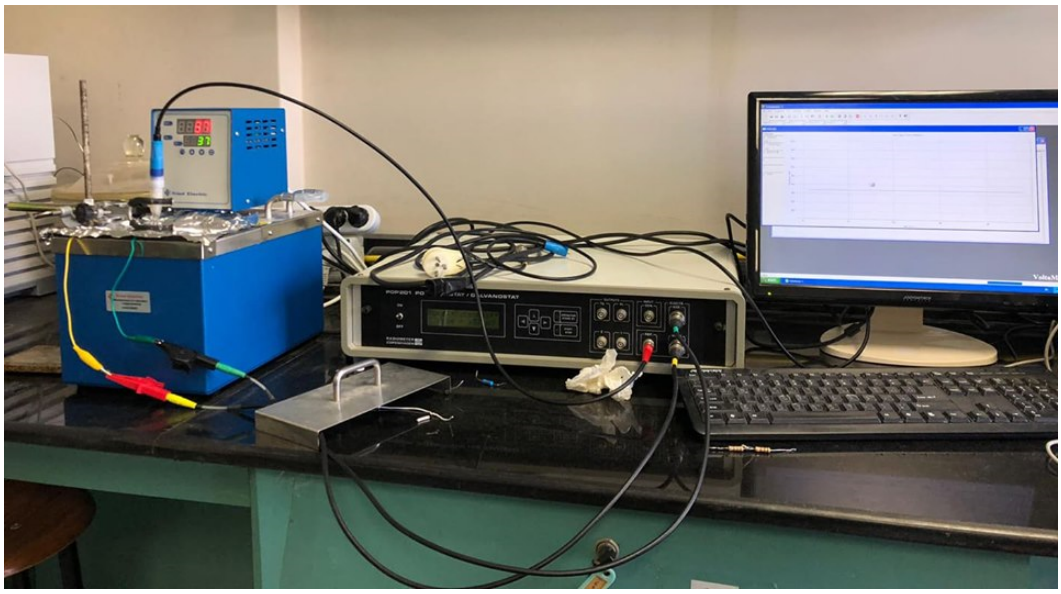

Figure 9: Potentiostat device PGP 201.

All above experiments were essential to make sure that the MDC's is operating.

4.6 Data Analysis:

Using potentiostat, open circuit potential was recorded until the voltage become stable. Then external resistance was connected with cell for the purpose of measuring closed circuit potential. Data were collected for two to three hours daily then further analysis using Excel was carried out. For each experiment, a reference voltage was taken and recorded in the startup time at the beginning of operation. This is considered as the voltage difference between solutions in the MDC and not the voltage resulted from the bacteria in the cell.

The Current density was calculated using ohm's law $\left(I = {}^{V}/_{A.R}\right)$, where I ($mA/m^2$) is the current, V (mV) is the voltage and R (Ω) is the resistance. Hence power density per the surface area of electrodes was then calculated using $\left(P = {}^{I.V}/_{A}\right)$, where A ($m^2$) is the working surface area of electrode.

The Impedance of the cell indicates the losses occurred caused by anodic activation, ohmic electrolyte and cathodic activation. In another words, Impedance give an indication of the internal resistance of the cell. Cyclic voltammetry is another important parameter that can be measured to indicate the reaction kinetics of anode and cathode, where a voltage is applied to specify the oxidation-reduction reaction (O'hayre *et al.*, 2016).

Chapter Five: Experimental Work

The experimental works is divided into two parts: the first one where Bacteria is used as substrate and the second part is when fungi is used.

5.1 Fungi Experiments

5.1.1 Experiment 1 "Fungi Abstracted from Mango"

This experiment was conducted to check if the MDC works. Fungi was abstracted from mango fruit which was prepared for two weeks at ambient temperature. Then the results were taken for almost 40 minutes using digital multi meter without using any external resistance, but this period of time wasn't enough for fungi to produce electron, it will need at the minimum two days to operate properly. Two graphite rods were taken from batteries, washed with distilled water and conducted for the experiment. The two electrodes were connected externally by copper wires.

The MDC cell was prepared with two essential holes in cathodic and anodic chambers separated by CEM and AEM, respectively. One is used for feeding and taking samples, the other hole was used for connecting wires with electrodes. The desalination chamber was prepared with one essential hole for feeding and sampling. Rubber gaskets were placed between the chambers to ensure the system is air tight and prevent leakage.

The cathode chamber was injected with 12 ml Potassium Ferricyanide of 16.5 mg/L solution. Then the anode chamber was injected with 14 ml solution of 2 g Fungi dissolved in 1 Liter distilled water. And sugar 3 g/L was used as a substrate for Fungi. The desalination chamber was fed with 28 ml of 20g/L NaCl solution. Also, salinity was measured at the beginning and at the end of experiment.

5.1.2 Experiment 2 "Fungi Abstracted from Banana"

Another experiment using Fungi was conducted, following the same procedure described in experiment one, using different Fungi. The Fungi was taken from banana fruit

that was prepared for three weeks at ambient temperature. The results were taken along 240 minutes.

5.2 Bacteria Experiments

5.2.1 Experiment 1 "Bacteria"

The carbon rod was washed with distilled water before placing it in the anode and cathode chamber to remove any impurities. The electrodes are connected externally by copper wire with digital multimeter.

Anaerobic bacteria were brought from the West Nablus Waste Water Treatment Plant (WNWWTP) and keep in the fridge in order to stop the activity of microorganism without death and when it use activate the microbes by put I water bath at 37 ˚C for 30 minutes, this temperature was consider as the operating temperature for this bacteria according to the WNWWTP. The anolyte solution was prepared by dissolving 1.6 g sodium acetate, K_2HPO_4 3.4g, and KH_2PO4 4.4g in one-liter of deionized water for the anolyte solution. The catholyte solution was prepared by dissolving 16.5 g/L of ferricyanide, 8g K_2HPO_4 and 9g KH_2PO_4 in one-liter deionized water. To mimic the saline water, Salt solution, 2 g of salt was dissolved in in 100 ml of deionized water. Catholyte solution and saltwater were injected into the cathode and desalination chamber. 20% (V/V) of bacteria was inoculated in the anode chamber and filling with the anolyte solution and then closed the anode holes with aluminum foil. The cell was operated at ambient temperature and without using external resistance. The open circuit potential of the cell and the electrical conductivity were measured approximately every 5 minutes, value of the electrical conductivity gives an indication how salt concentration varies. Reading voltage and electrical conductivity was continued for six-day.

5.2.2 Experiment 2 "Bacteria with different temperatures"

Using same procedure carried out in experiment one, another experiment was carried out but with some extra materials added to anolyte solution and operating the cell at different temperatures. These materials are: NH_4Cl 1.5g, $MgCl_2.6H_2O$ 0.1g, $CaCl_2•2H_2O$

0.1g, KCl 0.1g and 10ml trace minerals which consider as nutrient for microorganisms. In addition, trace minerals of $FeCl_3$ (0.194g), $MnCl_2$ (0.082g), and $ZnCl_2$ (0.005g) were dissolved in one-liter deionized water and magnetic stirrer was used to dissolve the materials. The cell was filled with these solutions and was placed in the oven 30 minutes prior to injection to raise the temperature to the desired-on 40˚C. Then when their temperature elevated to 40 ˚C, the solutions of anolyte, catholyte and salt were injected to the cell and placed in the oven. The open circuit voltage reading was taken every 3 minutes. The cell was conducted at different operational temperature ranging from 38 ˚C to 65 ˚C.

5.2.3 Experiment 3 "100% Desalination chamber"

To conduct this experiment, MDC number 2 was used where the working volume was modified to 2:1:1 volume ratio of anode, desalination and cathode chamber, respectively. Carbon rod electrodes of 3-millimeter diameter and 3.3 cm^2 working area were used. 200 Ω external resistance was connected. Anaerobic bacteria were brought from WNWWT to fill the anodic chamber with sludge (50% V/V) and anolyte solution then all holes in the cell was sealed with aluminum foil and the cell was put in water bath at 37 ˚C. Potentiostat was used in order to record changing in potential with time and Ag/AgCl was used as reference electrode. This experiment was conducted for two days only as to ensure that the MDC is operating efficiently. Results show a high jump in the voltage from 304mV to 567mV. But the electrical conductivity increased as well from 20.3 mS to 28 mS which reflected an increase in the salinity of water This increase is a surprise for us and cannot be explained.

5.2.4 Experiment 4 "40% (V/V) Desalination chamber"

A new experiment was conducted following the same procedure mentioned in experiment 3 previously except for the desalination chamber and the sludge volume ratio which was 30% instead of 50%, the percent was taken from literature and working in this percent. In this experiment the desalination chamber was filled with only 5 ml of 20g/l saline water which represent 40% (V/V) of the salt solution in the desalination chamber. This experiment was conducted for almost one month (700 hours). The anodic and cathodic

chambers were batch-circulated every two days by changing 5 ml of the anodic chamber and 4 ml of the cathodic chamber.

Chapter Six: Results and Analysis

The Results for the experiment which operated using fungi abstracted from mango, the cell was filled with fungi and glucose solution in anode and ferricyanide in cathode with using any buffer solution. The experiment was done at ambient temperature and without using any external resistance, the electrical conductivity an=t the beaning of experiment was 21.2 mS and at the end was found 20.9, which represent 1.4% salt removal after working two days are shown In **Figure 10**.

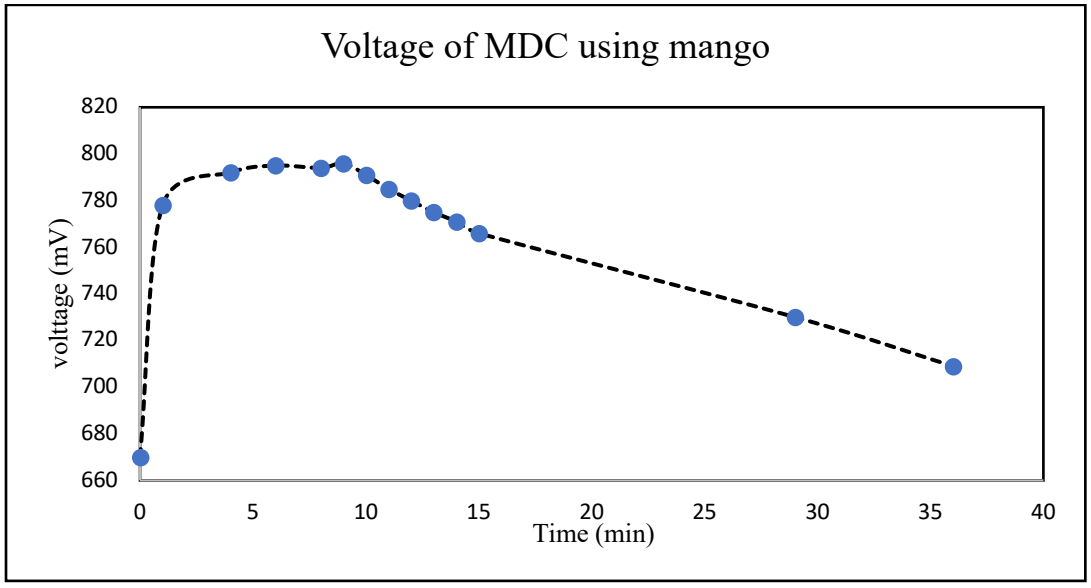

Figure 10: Voltage profile during operating MDC using mango fungi. The experiment which was used fungi from banana was conducted at the same way of the experimnt using mango, but the result of open curcuit potential was taken for six days while electrecal conductivity wasn't taken. The result of this experiment are shown in the **Figure 11** below.

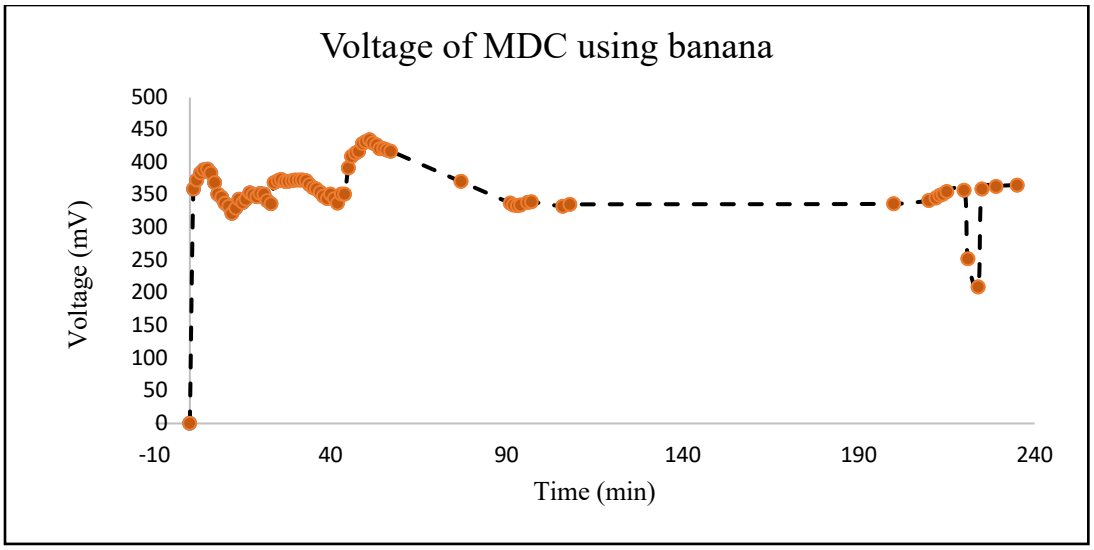

Figure 11: Voltage profile during operating MDC using banana fungi.

Results of the first experiments operated using anaerobic bacteria microorganisms 20% (V/V) in the anode chamber with buffer solution, no any external resistance was used and the experiment was done at the ambient conditions, the open circuit potential was measured using digital meter every 5 minute and the electrical conductivity was measured from time to time. The results of open circuit potential and electrical conductivity was shown in the figures below. This experiment achieved 20% salt removal and 500mV as peak of voltage.

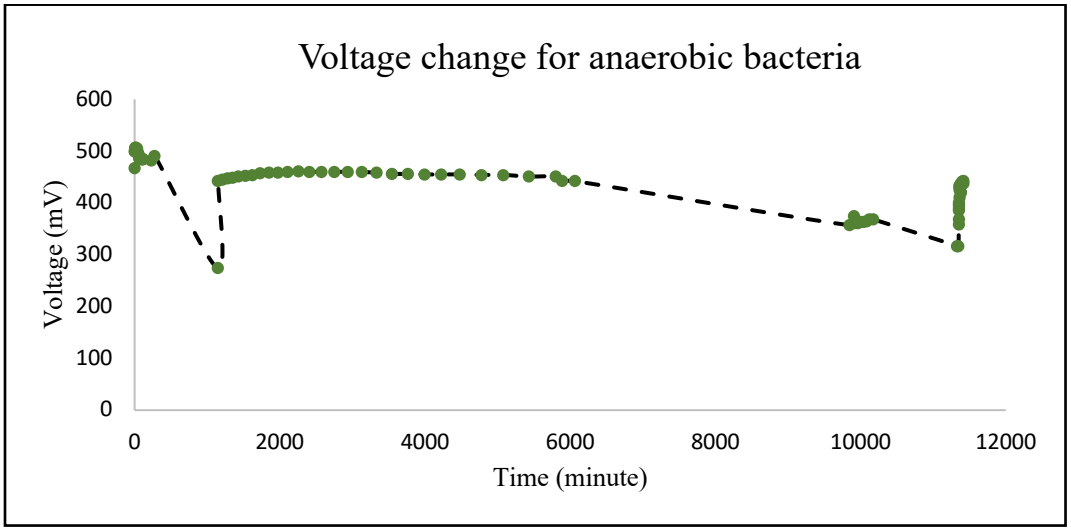

Figure 12: Voltage profile during operating MDC using anaerobic bacteria.

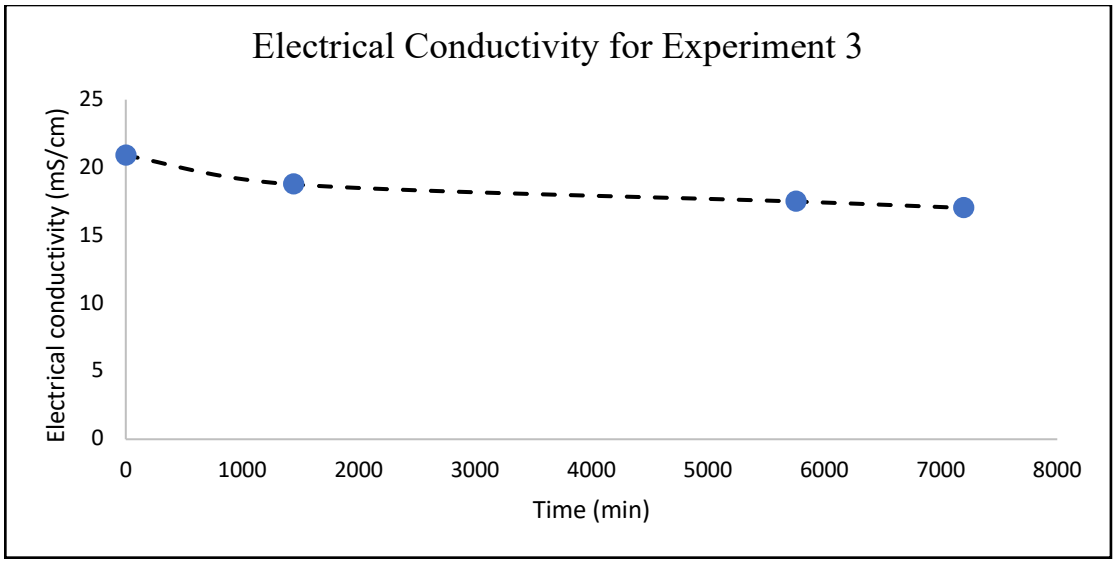

Figure 13: Electrical conductivity during operating the cell using anaerobic bacteria.

Second experiment was made by using bacteria but at different temperatures ranging from 38˚C to 65˚C using oven and the voltage was measured using digital multimeter without using external resistance. The voltage reached a peak at 954 mV at 50˚C as illustrated in **Figure 14**.

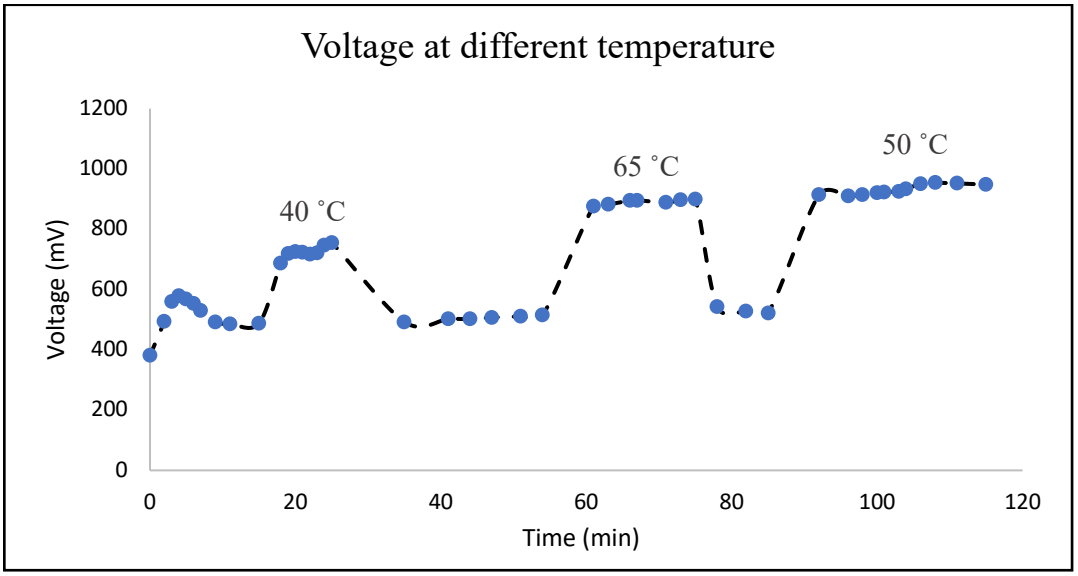

Figure 14: Voltage profile during operating MDC at different temperature.

The results of potential of third experiment which conducted using full volume of desalination chamber at 37 ˚C and using sludge 50% (V/V) were not taken, While the result

of fourth experiment which using bacteria 30% (V/V) and 5 ml salt volume and operated at 37 ˚C for one month potential, current and power change along with desalination efficiency is shown in figures below respectively. The efficiency of salt removal was found 65.4% and reach a peak potential at 770 mV.

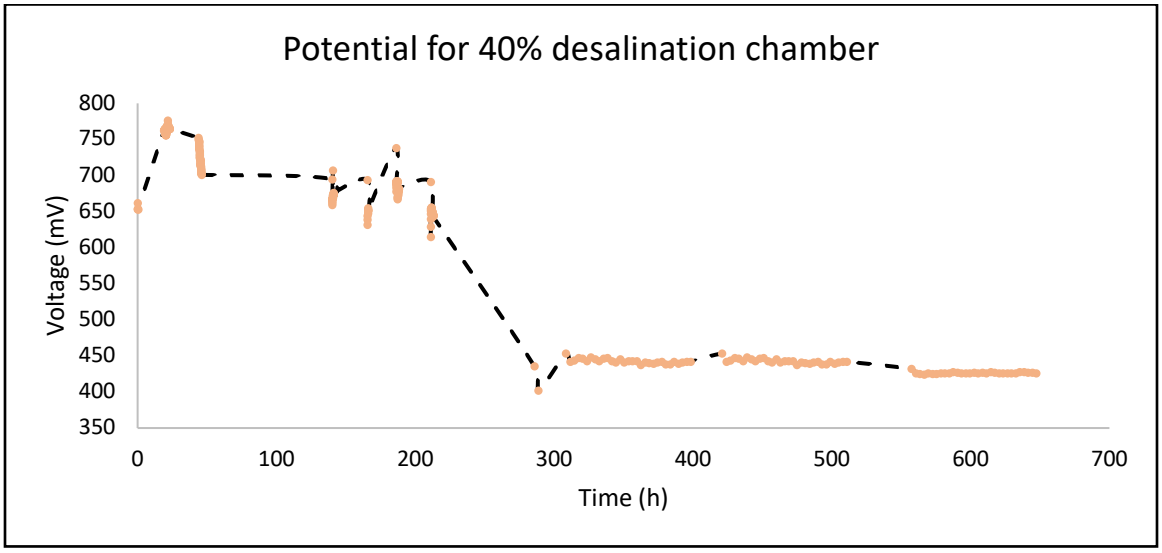

Figure 15: Potential versus time for using 40% (V/V) desalination chamber.

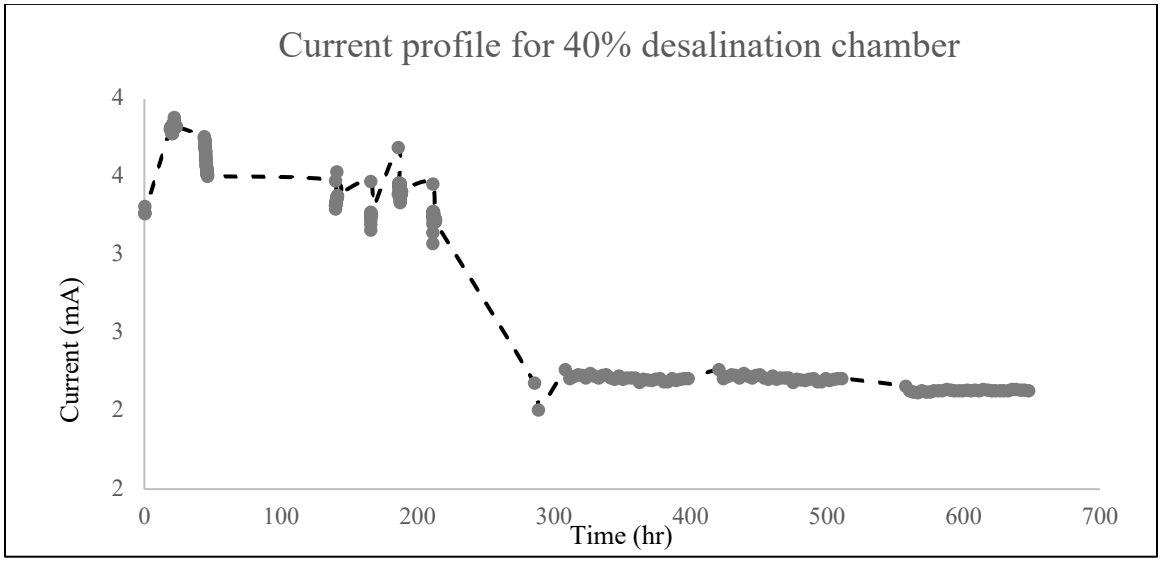

Figure 16: Changing of current with time for using 40% (V/V) desalination chamber.

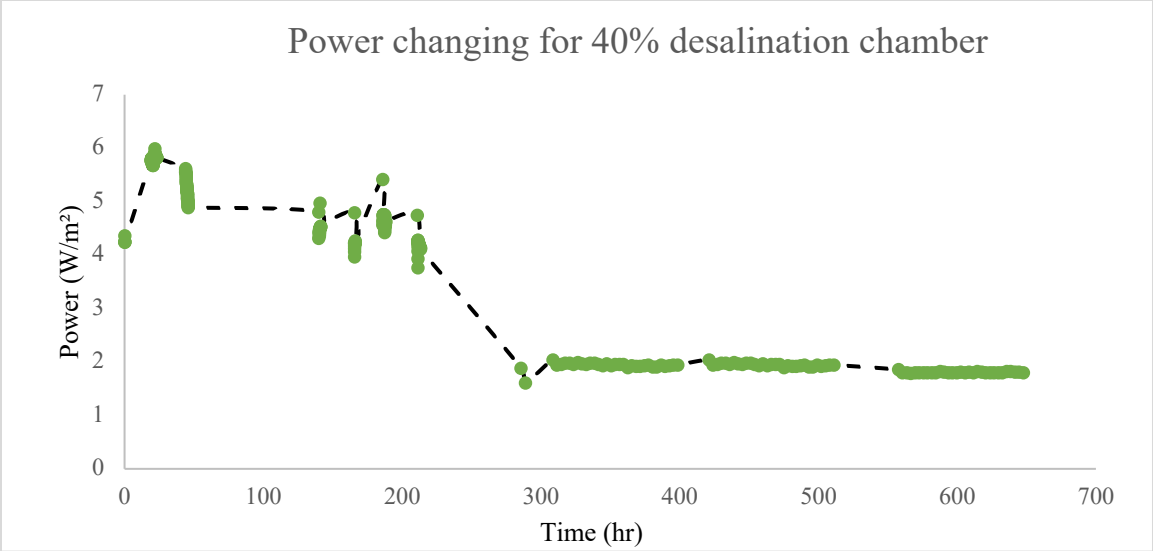

Figure 17: Power changing for experiment using 40% (V/V) desalination chamber.

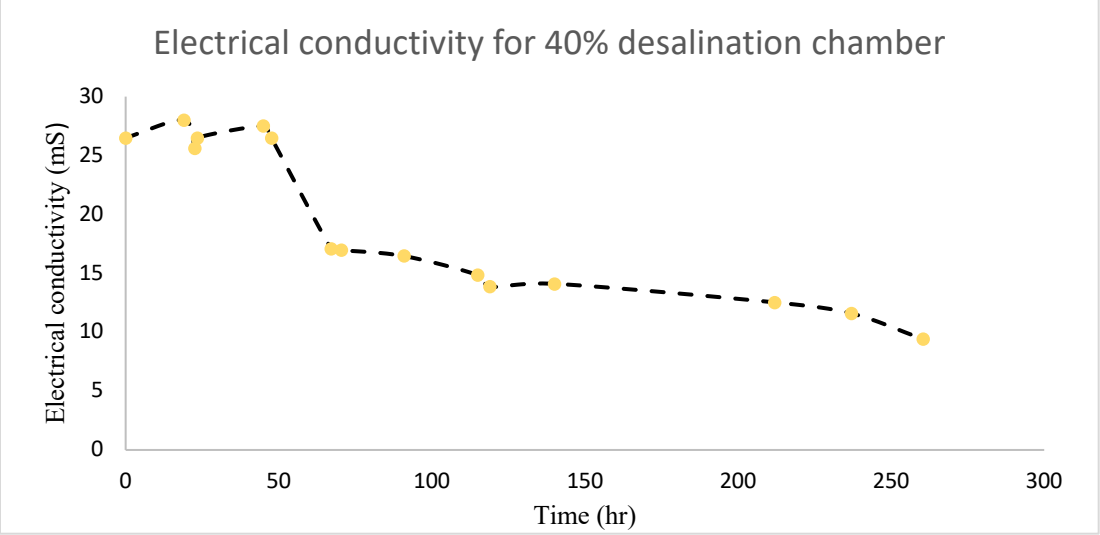

Figure 18: Behavior of salt removal for experiment using 40% (V/V) desalination chamber.

Chapter Seven: Discussion

This project aimed to study the voltage production and desalination rate of MDC using various type of microorganisms. For fungi experiments, initial results were taken from experiment using mango Fungi. The results reached a peak open circuit voltage of 796 mV. But the period for taking the results was very short, due to constrains in the laboratory timing. So, there was a need to conduct the experiment for extra time to determine it is stability since the period recorded could be considered as a startup time. Moreover, this experiment achieved 1.4% salt removal in this short period of operation.

Then the same conditions were repeated using banana Fungi. The results were stable and showed a fixed value of almost 340 mV. Therefore, it was thought that there is a need to use a reference cell such as Ag/AgCl. The process startup was slow which took almost 90 minutes. There was a need to investigate the operating conditions more precisely in order to get more accurate results.

Experiments carried out using the bacteria taken from WNWWTP resulted in a salt removal of 20% during six days period when the cell operated at ambient temperature. The electrical conductivity was decreased from 20 to 17 mS/cm which means that salt decrease while the voltage still keeps decreasing. The decrease in voltage means that the decrease of electrons produced by the bacteria could be due the death of microorganisms and/or decrease in salt concentration leads to increase internal resistance increase so decrease current density and voltage (Saeed *et al.*, 2015). These results indicate that the MDC is working in principles.

Increasing the operating temperature from room temperature to 50 ˚C resulted in an increase in the produced open circuit voltage from 0.58 volt to 0.954 volt. This may be due to the increase in electrolyte conductivity (Fondriest, 2020) and/or the presence of thermophilic bacteria. Therefore, it is concluded that raising the temperature resulted in is better results, so water bath must be used to maintain the temperature to nearly 37 ˚C which is the optimum temperature for working anaerobic bacteria according to the instruction of WNWWTP.

Electromotive force for the cell was calculated as 657 mV and the closed-circuit voltage was found in the range 567 to 304 mV which is closed to electromotive force. The increase in the electrical conductivity could be due to evaporation since the cell operated and kept at 37 ˚C or from membrane which left in 5% NaCl solution

On the other hand, experiment using 40% desalination chamber showed a higher jump in the cell's voltage where a peak of 776 mV was reached. This is higher than the cell's electromotive force, which could be explained by the presence of different bacterial types in the sludge. The volume of salt decreased almost one milliliter every week, as a result at the end of the experiment almost 1 milliliter of salt was left with a smell like sodium acetate solution smell. This could be due to high evaporation rate and the osmotic pressure to reach an equilibrium. This claim was also confirmed by Arana (Arana & Gude, 2018) while the desalination chamber in this experiment increased. The desalination efficiency reached 64.5% by the end of the experiment. Which is a high desalination efficiency that ensures the desalination chamber volume is very important and does affect many parameters like the voltage and removal efficiency which are considered a key parameter in out experiment. They key factors that raised the MDC operational efficiency in this experiment are the temperature 37 ˚C and the desalination chamber volume.

Chapter Eight: Conclusions and Recommendation

8.1 Conclusion

The microbial desalination cell is a promising and environmentally friendly technology to desalinate water with the use of biochemical energy. While other techniques require high energy consumption, MDC produces energy. A small-scale laboratory MDC was successfully constructed to further widen the study on MDC performance.

It was found that the MDC electrical production of voltage were more stable when operated using bacteria rather than Fungi. Due to time limitation and constrained faced, no clear trend for the voltage production could be predicted. On the other hand, the MDC performance improved dramatically when the operating temperature was 37 ˚C and 1:4 volume ratio of anode and desalination chamber, respectively. A removal efficiency of 64.5% was reached after operating the cell for one month. Many challenges occurred when conducting MDC experiment:

1- Inability to leave the device running throughout the day in order to take potential value due to university laws and cut off electricity in the region.
2- Nablus wastewater treatment plant was far away from university, so we couldn't take a new sample of sludge in each experiment.
3- After conducting the first experiment using $AgCl_2$ as a reference electrode. It was broken, and when it was fixed it didn’t give the stability in the results as usual. Also, when another electrode was used the ferricyanide penetrate through it is membrane and thus the result were not correct.
4- The incubator used to keep the cell in was in another faculty. So, the cell was moved every day for almost five minutes in the ambient temperature which could affect the temperature stability in the cell.

8.2 Recommendations

Based on what we have revealed from the literature then using food waste as a substrate for MFC produces considerable power density. Further studies could take into consideration food waste specially spoiled fruits due to its wide availability to operate MDC in order to desalinate water beside power generation and waste treatment. Nevertheless, analyzed spoiled fruit showed that it's mold commonly contains yeast, which was previously investigated and proven that it generates high power densities (Tournas & Katsoudas, 2005).

Wasted fruits could be prepared in the same way of tomato was prepared as described previously and used as substrate for yeast, which is suggested to use further more than bacteria because of short preparation time, fast growth and give high power. Anodic chamber should comprise phosphate buffer as well to prevent pH change due proton release from fruit degradation. Accordingly, potassium ferricyanide and phosphate buffer could be used in cathode chamber. Both SCE or Ag/AgCl can be used as a reference electrode,200 Ω external resistance is suggested to be used, where higher resistance could give high voltage values but low current values. However, no need for a mediator, because fruits could contain different redox active mediators as Shrestha proved for tomatoes.

Comprising both of food waste operated MDC which already contains yeast, could lead to significant results. Since up to the researcher's knowledge, no study has been done considering food waste as a substrate for yeast-based MDC.

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Appendices

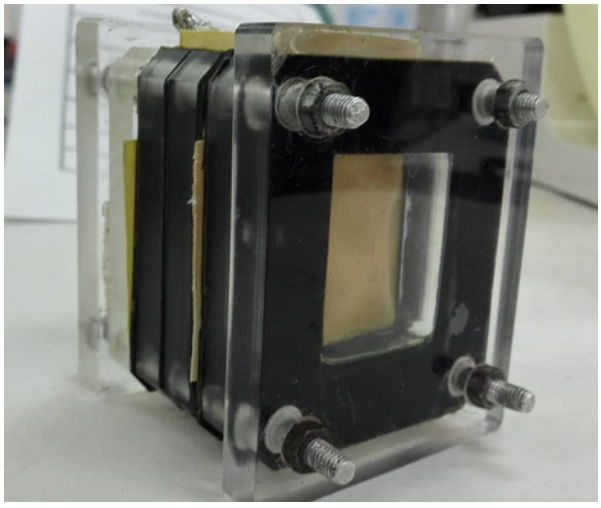

Figure A 1: Microbial desalination cell.

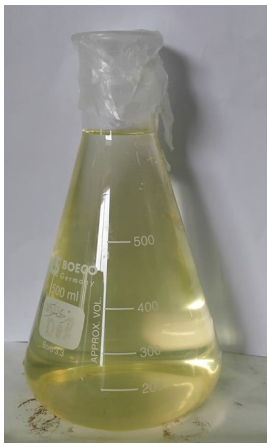

Figure A 2: Trace minerals.

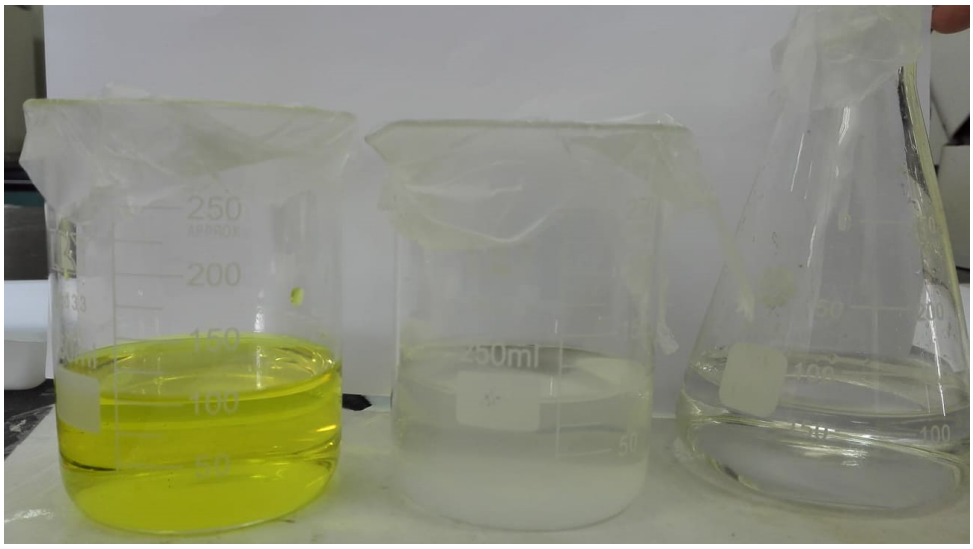

Figure A 3: Cathodic, anodic and salt solutions.

Figure A 4: Carbon rod electrodes.

MATERIAL SAFETY DATA SHEET

POTASSIUM FERROCYANIDE TRIHYDRATE

Revision : 00	Date: 15.02.2019	MSDS Number : 168

Section 1 - Chemical Product and Company Identification

1.1 Product Name : **POTASSIUM FERROCYANIDE**
Synonyms : Potassium hexacyanoferrate(II) trihydrate
CAS No. : 14459-95-1
HS Code : 2837 20 00
Molecular Weight : 422.39 g/mol
Chemical Formula : $K_4[Fe(CN)_6].3H_2O$
Product Code : A 2163
Brand : SMART-LAB
1.2 Manufacturer :**PT.Smart-Lab Indonesia**
Address : Ruko Boulevard Taman Tekno Blok E No.10-11,BSD Sektor XI Serpong, Tangerang - Indonesia
Website :www.smartlab.co.id
Email :sales@smartlab.co.id
For information :Telp: +62-21- 7588 0205(Hunting) , fax:+62-21-7588 0198
1.3 Application : General Chemical reagent
Emergency Telephone: +62-21-7588 0205(Hunting)

Section 2 - Hazards Identification

2.1 Classification of the substance or mixture
Classification according to Regulation (EC) No 1272/2008
Chronic aquatic toxicity (Category 3), H412

For the full text of the H-Statements mentioned in this Section, see Section 16

2.2 Label elements

Labelling according Regulation (EC) No 1272/2008

Pictogram	none
Signal word	none
Hazard statement(s)	
H412	Harmful to aquatic life with long lasting effects
Precautionary statement(s)	
P273	Avoid release to the environment.
Supplemental Hazard Statements	
EUH032	Contact with acids liberates very toxic gas.

2.3 Other hazards
This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher. Contact with acids liberates very toxic gas.

Section 3 - Composition, Information on Ingredients

MATERIAL SAFETY DATA SHEET		
POTASSIUM FERROCYANIDE TRIHYDRATE		
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3.1 Substances

Synonyms : Potassium hexacyanoferrate(II) trihydrate
Formula : $K_4[Fe(CN)_6].3H_2O$
Molecular weight : 422.39 g/mol
CAS-No. : 14459-95-1
EC-No. : 237-722-2

Hazardous ingredients according to Regulation (EC) No 1272/2008

Component	Classification	Concentration
Tetrapotassium hexacyanoferrate CAS-No. 14459-95-1 EC-No. 237-722-2	Aquatic Chronic 3; H412	<=100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

Section 4 - First Aid Measures

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

Section 5 - Firefighting Measures

5.1 Extinguishing media

Suitable extinguishing media
Dry powder

5.2 Special hazards arising from the substance or mixture
Carbon oxides, Nitrogen oxides (NOx), Potassium oxides, Iron oxides, Hydrogen cyanide (hydrocyanic acid)

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

Section 6 - Accidental Release Measures

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Avoid breathing dust. For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Do not flush with water. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

Section 7 - Handling and Storage

7.1 Precautions for safe handling
Avoid formation of dust and aerosols. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Store in cool place. Keep container tightly closed in a dry and well-ventilated place. Never allow product to get in contact with water during storage. Do not store near acids. Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

Section 8 - Exposure Controls, Personal Protection

8.1 Control parameters
8.2 Exposure controls
Appropriat engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.
Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.
The selected protective gloves have to satisfy the specifications of EU Directive 89/686/EEC and the standard EN 374 derived from it.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740, Size M)

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use (EN 143) respirator cartridges as a backup to engineering controls. If th full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

Section 9 - Physical and Chemical Properties

9.1 Information on basic physical and chemical properties

Appearance	Form: crystalline Colour: light yellow
Odour	No data available
Odour Threshold	No data available
pH	8.0 - 10 at 211 g/l at 25 °C
Melting point/freezingpoint	Melting point/range: 70 °C - lit.
Initial boiling point and boiling range	No data available
Flash point	No data available
Evaporation rate	No data available
Flammability (solid, gas)	No data available
Upper/lower flammability or	No data available
explosive limits	No data available
Vapour pressure	No data available
Vapour density	No data available
Relative density	1.850 g/cm^3

Water solubility	211 g/l at 20 °C
Partition coefficient: noctanol/water	log Pow: 1,645
Auto-ignition temperature	No data available
Decomposition temperature	No data available
Viscosity	No data available
Explosive properties	No data available
Oxidizing properties	No data available

9.2 Other safety information

Bulk density 1,200 kg/m^3

Section 10 - Stability and Reactivity

10.1 Reactivity

No data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

No data available

10.4 Conditions to avoid

Avoid temperatures above 60°C, direct sunlight and contact with sources of heat. Contact with acids liberates very toxic gas.

10.5 Incompatible materials

Acids, Strong oxidizing agents

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Carbon oxides, Nitrogen oxides (NOx), Potassium oxides, Iron oxides, Hydrogen cyanide (hydrocyanic acid) Other decomposition products - No data available In the event of fire: see section 5

Section 11 - Toxicological Information

11.1 Information on toxicological effects

Acute toxicity

LD50 Oral - Rat - 3,613 mg/kg(Tetrapotassium hexacyanoferrate)

Skin corrosion/irritation

Skin - Rabbit(Tetrapotassium hexacyanoferrate)
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation

Eyes - Rabbit(Tetrapotassium hexacyanoferrate)
Result: Mild eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation

Guinea pig(Tetrapotassium hexacyanoferrate)

Result: Did not cause sensitisation on laboratory animals.

Germ cell mutagenicity
No data available(Tetrapotassium hexacyanoferrate)

Carcinogenicity
Did not show carcinogenic effects in animal experiments.(Tetrapotassium hexacyanoferrate)
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

Reproductive toxicity
No data available(Tetrapotassium hexacyanoferrate)

Specific target organ toxicity - single exposure
No data available(Tetrapotassium hexacyanoferrate)

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available(Tetrapotassium hexacyanoferrate)

Additional Information
RTECS: Not available May cause cyanosis.(Tetrapotassium hexacyanoferrate)

Section 12 - Ecological Information

12.1 Toxicity
No data available

Toxicity to daphnia and other aquatic invertebrates
EC50 - Daphnia (water flea) - 32 mg/l - 48 h(Tetrapotassium hexacyanoferrate) Remarks: anhydrous

12.2 Persistence and degradability
Biodegradability
Result: - Not readily biodegradable. No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

12.6 Other adverse effects
Harmful to aquatic life with long lasting effects.
No data available

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Section 13 - Disposal Considerations

13.1 Waste treatment methods

Product

Offer surplus and non-recyclable solutions to a licensed disposal company. Dissolve or mix the material with a combustible solvent and burn in a chem scrubber.

Contaminated packaging

Dispose of as unused product.

Section 14 - Transport Information

14.1 UN number

ADR/RID: - IMDG: - IATA: -

14.2 UN proper shipping name

ADR/RID: Not dangerous goods
IMDG: Not dangerous goods
IATA: Not dangerous goods

14.3 Transport hazard class(es)

ADR/RID: - IMDG: - IATA: -

14.4 Packaging group

ADR/RID: - IMDG: - IATA: -

14.5 Environmental hazards

ADR/RID: no IMDG Marine pollutant: no IATA: no

14.6 Special precautions for user

Further information

No data available

Section 15 - Regulatory Information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

This safety datasheet complies with the requirements of Regulation (EC) No. 1907/2006.

15.2 Chemical safety assessment

For this product a chemical safety assessment was not carried out

Section 16 - Additional Information

Full text of H-Statements referred to under sections 2 and 3.

EUH032	Contact with acids liberates very toxic gas.
H412	Harmful to aquatic life with long lasting effects.

HMIS (U.S.A.):

Health Hazard: 1
Fire Hazard: 0
Reactivity: 0
Personal Protection: -

No: F/QCL/008 Rev.01

MATERIAL SAFETY DATA SHEET POTASSIUM FERROCYANIDE TRIHYDRATE		
Revision : 00	Date: 15.02.2019	MSDS Number : 168

National Fire Protection Association (U.S.A.):
Health: 1
Flammability: 0
Reactivity: 0

Further information
The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. PT. Smartlab Indonesia Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigmaaldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Figure A 5: Material safety data sheet of potassium ferricyanide (Smartlab, 2006).

ISO9001:2000 Certified

Material Safety Data Sheet
Sodium acetate, ACS

Section 1 - Chemical Product and Company Identification

MSDS Name:
Sodium acetate, ACS
Catalog Numbers:
LC22820
Synonyms:
Acetic acid, sodium salt, trihydrate
Company Identification:
LabChem, Inc.
200 William Pitt Way
Pittsburgh, PA 15238
Company Phone Number:
(412) 826-5230
Emergency Phone Number:
(800) 424-9300
CHEMTREC Phone Number:
(800) 424-9300

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name:	Percent
6131-90-4	Sodium acetate trihydrate	100%

Section 3 - Hazards Identification

Emergency Overview

Appearance: *White crystals*
Caution! May cause eye and skin irritation. May cause respiratory tract irritation. Hygroscopic (absorbs moisture from the air).
Target Organs: None.

Potential Health Effects

Eye:
May cause eye irritation.
Skin:
May cause skin irritation.
Ingestion:
Ingestion of large amounts may cause gastrointestinal irritation.
Inhalation:
No hazard expected in normal industrial use.
Chronic:
No information found.

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Section 4 - First Aid Measures

Eyes:
Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

Skin:
Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse.

Ingestion:
If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid immediately.

Inhalation:
Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

Section 5 - Fire Fighting Measures

General Information:
As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Combustion generates toxic fumes.

Extinguishing Media:
For small fires, use dry chemical, carbon dioxide, water spray or alcohol-resistant foam.

Autoignition Temperature:
599 deg C (1,110.20 deg F)

Flash Point:
No information found.

NFPA Rating:
Health-1; flammability-1; reactivity-0

Explosion Limits:
Lower: n/a Upper: n/a

Section 6 - Accidental Release Measures

General Information:
Use proper personal protective equipment as indicated in Section 8.

Spills/Leaks:
Vacuum or sweep up material and place into a suitable disposal container. Clean up spills immediately, observing precautions in the Protective Equipment section. Avoid generating dusty conditions. Provide ventilation. Place under an inert atmosphere. Do not get water inside containers.

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Section 7 - Handling and Storage

Handling:
Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Use with adequate ventilation. Avoid contact with eyes, skin, and clothing. Avoid breathing dust.

Storage:
Keep from contact with oxidizing materials. Store in a cool, dry, well-ventilated area away from incompatible substances. Store protected from moisture.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls:
Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.

Exposure Limits:

Chemical Name:	ACGIH	NIOSH	OSHA
Sodium acetate trihydrate	none listed	none listed	none listed

OSHA Vacated PELs:
Sodium acetate trihydrate: No OSHA Vacated PELs are listed for this chemical.

Personal Protective Equipment

Eyes:
Do not wear contact lenses when working with chemicals. An eye wash fountain should be available in the immediate work area. Wear appropriate protective eyeglasses or chemical safety goggles as described in 29 CFR 1910.133.

Skin:
Wear appropriate protective gloves to prevent skin exposure.

Clothing:
Wear appropriate protective clothing to prevent skin exposure.

Respirators:
Follow the OSHA respirator regulations found in 29 CFR 1910.134. Use a NIOSH/MSHA approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Section 9 - Physical and Chemical Properties

Physical State:	Crystalline powder
Color:	White
Odor:	Odorless
pH:	8.9 (1M aq soln)
Vapor Pressure:	Not available
Vapor Density:	Not available
Evaporation Rate:	Not available

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Viscosity:	Not available
Boiling Point:	253°F
Freezing/Melting Point:	136°F
Decomposition Temperature:	Not available
Solubility in water:	Soluble
Specific Gravity/Density:	1.45
Molecular Formula:	C2H3O2Na.3H2O
Molecular Weight:	136.08

Section 10 - Stability and Reactivity

Chemical Stability:
Stable at room temperature in closed containers under normal storage and handling conditions.
Conditions to Avoid:
Exposure to moist air or water.
Incompatibilities with Other Materials:
Strong oxidizing agents.
Hazardous Decomposition Products:
Carbon monoxide, carbon dioxide.
Hazardous Polymerization:
Has not been reported.

Section 11 - Toxicological Information

RTECS:
CAS# 6131-90-4: AJ4580000
LD50/LC50:
CAS# 6131-90-4: Not available
Carcinogenicity:
CAS# 6131-90-4: Not listed by ACGIH, IARC, NTP, or CA Proposition 65.
Epidemiology:
No information available.
Teratogenicity:
No information available.
Reproductive:
No information available.
Mutagenicity:
Mutagenic effects have occurred in experimental animals.
Neurotoxicity:
No information available.

Section 12 - Ecological Information

Ecotoxicity:
No data available. Acute aquatic effects (for anhydrous sodium acetate)96-hour LC50; Fathead minnow: GT 100 mg/L 96-hour LC50; Water flea: GT 1000 mg/L. This chemical has a high biological oxygen demand, and it is expected to cause significant oxygen depletion in aquatic systems. It has a low

potential to affect aquatic organisms.

Environmental:

This chemical is readily biodegradable and is not likely to bioconcentrate.

Physical:

None reported

Section 13 - Disposal Considerations

Dispose of in accordance with Federal, State, and local regulations.

Section 14 - Transport Information

US DOT

Shipping Name: Not regulated.
Hazard Class:
UN Number:
Packing Group:

Section 15 - Regulatory Information

US Federal

TSCA:

CAS# 6131-90-4 is not on the TSCA Inventory because it is a hydrate. It is considered to be listed if the CAS number for the anhydrous form is on the inventory (40CFR720.3(u)(2)).

SARA Reportable Quantities (RQ):

CAS# 6131-90-4 does not have a RQ.

CERCLA/SARA Section 313:

Not reportable under Section 313.

OSHA - Highly Hazardous:

Not considered highly hazardous by OSHA.

US State

State Right to Know:

CAS# 6131-90-4 is not listed on the following state right to know lists: California, Florida, New Jersey, Pennsylvania, Minnesota, and Massachusetts.

California Regulations:

Not listed.

European/International Regulations

Canadian DSL/NDSL:

CAS# 6131-90-4 is listed on Canada's DSL List.

Canada Ingredient Disclosure List:

CAS# 6131-90-4 is not listed on the Ingredient Disclosure List.

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Section 16 - Other Information

MSDS Creation Date: August 31, 2006
Revision Date: None

Information in this MSDS is from available published sources and is believed to be accurate. No warranty, express or implied, is made and LabChem Inc. assumes no liability resulting from the use of this MSDS. The user must determine suitability of this information for his application.

Figure A 6: Material safety data sheet of sodium acetate (labchem, 2019).