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EVALUATION FOR RO-BRACKISH WATER DESALINATION: A CASE STUDY IN TOR SINAI - SOUTH SINAI GOVERNATE

M. S. Shalaby[1], H. H. Shaarawy[1], A. M. Shaban[2] and H. Abdallah[1]
[1]Department of Chemical Engineering and Pilot Plant, Dokki, Giza, Egypt
[2]Department of Water Pollution Research, National Research Centre, El buhouth St., Dokki, Giza, Egypt
E-Mail: marwashalaby14@gmail.com

ABSTRACT

The scarcity of water resources in Egypt especially in Sinai represents the most formidable challenge for the pursuit of our research for development as the available water resources is dropping below the threshold of water poverty especially with the rise in Egyptian populations. This research studied the establishment, monitoring and evaluate a prototype of an integrated system to desalinate brackish groundwater via high recovery low pressure reverse osmosis desalination unit and utilize the technique of electrochemical disinfection on-site as a new concern. The disinfection unit-preliminary evaluated within this work shows a promising optimized data for the electrolysis time to produce the selected disinfectant dose with the rate of inactivation of microorganisms present. The implemented desalination unit provided 96.8% salt rejection, 74%recovery which was suitable for irrigation system as salt rejection and first stage recovery.

Keywords: brackish water, RO- desalination, pretreatment technologies, performance evaluation, electrochemical disinfection.

1. INTRODUCTION

Whether brackish waters are used for drinking or agricultural use, salt concentrations have to be reduced. Desalination technologies are used for high recovery salt removal efficient processes equipped with either membrane separation or by thermal or freezing units.

Reverse osmosis (RO) was considered to be the leading technology for new desalination plants; with about 44% share in world desalting production capacity. Egypt especially in Sinai is among the countries that suffer from water scarcity [1]. The per capita share of water in Egypt has dropped to about 685 cubic meters per year in 2010, which is far below the international poverty line of 1000 cubic meters per year. In Sinai areas, ground-waters often contain higher levels of salinity and are considered brackish (2000- 8000 ppm) and are abundant in many aquifers throughout the western and eastern deserts of Egypt as well as in Sinai Peninsula. Together with the stringent governmental directions for Sinai development in Egypt nowadays, the search for cost effective development techniques in specially designed RO- brackish desalination pre- and post-treatment steps. Innovative pretreatment step as electrochemical disinfection will be highlighted in this work and its impact on desalinated water quality, and membrane lifetime. Such integrated systems are the aim of sustainable development for such remote areas holding the potential for addressing water scarcity issues and narrowing the ever-increasing food gap [2-5].In the previous decades, conventional disinfection techniques were applied in membrane desalination technologies to kill microorganisms causing biofilms clogging membrane pores (bio-fouling) decreasing permeability. This pre-treatment technique in turn increases the cost of permeate water produced depending on high chlorination cost; on the other hand, chlorine dissolve many polymers forming membranes as polyamide and others [6,7].Moreover, the formation of tri-halomethanes, haloacetic acids, free bromine with other carcinogenic products formed with chlorine disinfection was a strong pressing tools for environmental, cost effective healthy alternatives for water disinfection. The disinfection using UV radiations and ozonation were used till now but has serious problems of higher costs and limited usage in low cost - membrane desalination purposes especially those used for irrigation purposes [8-10].The effectiveness of electrochemical disinfection is dependent upon many parameters considering the cell configuration the material for electrode and type of deposited metals on it, electrolyte composition, microorganisms present, mass transfer conditions and current density/electrode potential [11].

In this field research, the process development and evaluation of RO desalination designed prototype unit in Abo-Kalam Farm located in Tor Sinai city -South Sinai Governorate, Egypt will be presented. The aim of this work is the design, implementation and evaluation of a prototype unit with integrated system for the utilization of reverse osmosis to desalinate brackish groundwater with innovative electrochemical disinfection unit with preliminary performance evaluation to produce irrigation water for different monitored saline-sensitive vegetables, aquaculture and so drinking water for animal production unit.

2. MATERIALS AND METHODS

Water samples were collected from Abo-Kalam well and subjected to full chemical analysis. This analysis was fulfilled by flame photometer (Jenway PFP7, ELE Instrument Co. Ltd.),UV double beam spectrophotometer Agilent- cary100, atomic absorption with an air-acetylene flame on a spectrometer (Varian 220, Varian Inc., Palo Alto, California), water salinity TDS ADWA model AD 32 EC/TDS, together with standard methods of examination of water and wastewater -APHA 1985using colorimetric methods and others.

A design of a special RO brackish desalination unit- multimedia pre-treatment, scalable system will be built according to feed water analysis and permeate water concentration and flow rate for aqua-agriculture and drinking requirements. The innovative pre-treatment technology of electrochemical disinfection system was introduced for elongated lifetime for RO cartridge with inhibited bio-fouling, and stabilized permeate flux. Electrochemical disinfection system was subjected to preliminary evaluation experiments to govern their efficiency in RO brackish water desalination. Generally; the electrochemical disinfectants can be injected through the system on site via a compact electrochemical cell composed of electrode array, power supply, circulating pump, and salt solution tank. In this work, the system with selected electrode material was calibrated and optimized for mixed disinfectant dose with different current densities and the population of present microorganisms. Rhodium/Rhodium oxide thermally treated electrode [7] was used as a modified mixed electrode. The current density was varied from 5mA/cm2 to 250 mA/cm^2 in a cylindrical shape- PVC cell with graphite electrode as a cathode and the modified mixed electrode as an anode. The power consumption of electrochemical disinfection cell was correlated with the DC-power supply consumed by the cell with varied current densities showing different efficiencies as logarithmic decrease in microorganisms' population and inactivation rate.

Commercially- grade chemicals for cleaning, and antifouling agents were purchased and synthesized for operation and maintenance facilities.

Feed salinity was recorded and several composite samples were taken and subjected to full chemical analysis which were then averaged and presented in Table-1.

Table-1. Analysis of feed water through averaging composite samples.

Parameters	Unit	Average Result
pH	---	7.35
TDS	mg/l (ppm)	5950
EC	dSm^{-1}	7.43
Calcium	mg /l	1165
Magnesium	mg/l	238
Sodium	mg/l	1591.6
Potassium	mg/l	7.92
HCO3-	mg/l	159
Cl-	mg/l	1902
SO4--	mg/l	2436
Iron	mg/l	0.12
Manganese	mg/l	0.06

For us to work on such concentration of feed saline brackish water containing remains of agriculture drainage, a special design for a brackish- desalination plant was built with a special disinfection unit for powerful removal of living organisms saving RO-membrane system and decreasing bio-fouling and so extending its life time [11-12].

Monitoring steps will be carried out prior to the installation of the reverse osmosis desalination plant and so through complete periodical analysis of feed, permeate, and concentrate streams for plant evaluation. The analysis of total mixed disinfectants produced on-site were processed by N,N-diethyl-p-phenylenediamine (DPD) colorimetric method using double-beam UV/VIS spectrophotometer Agilent cary100. A blank sample of E-coli and streptococci in water was measured using HPLC-Agilent 1200 using methanol :water (50:50 v/v)as mobile phase, and stationary phase Eclipse XDB-C18- reversed phase -5μm- 4.6*150 mm.Samples were taken over time intervals and incubated for 24h and then survived population was counted as **m** at each disinfection dose, which was initially$\mathbf{m_0}$.

The evaluation of the reverse osmosis system efficiency for RO system, electrochemical disinfection pre-treatment system under the actual operating conditions with the applied maintenance strategy and the modified dosing system will be presented.

3. RESULTS AND DISCUSSIONS

3.1 Design and development of plan components for specially integrated system

The identification of water characteristics from a well of depth of 28 m for feed brackish water was considered in the design; this includes the minimum number of independently operable membrane banks and the minimum capacity of the banks was determined. The output required salinity required by different activities in Abou-Kalam instructive farm. The Engineering design schedule was run on manual basis to avoid any over-design commercial norms for the proposed Brackish water desalination plant.

3.1.1 Special design of electrochemical disinfection unit

Both of the R.O feed water and the desalinated water was onsite disinfected using the electrochemical mixed oxidant generator. The following diagram is showing the composition of the proposed cell. The electrochemical cell is formed from PVC housing in cylindrical shape of 10cm diameter and of 30cm length. Inside this housing a set of modified electrodes is fixed. These electrodes contain one cathode in midway position between two anodes. Both the cathode and the anodes have dimensions of 3cm width and 20cm length with 0.1cm thickness. The electrode materials are of rhodium-rhodium oxide coated titanium substrate. The method of electrodes fabrication was formerly described briefly [13].

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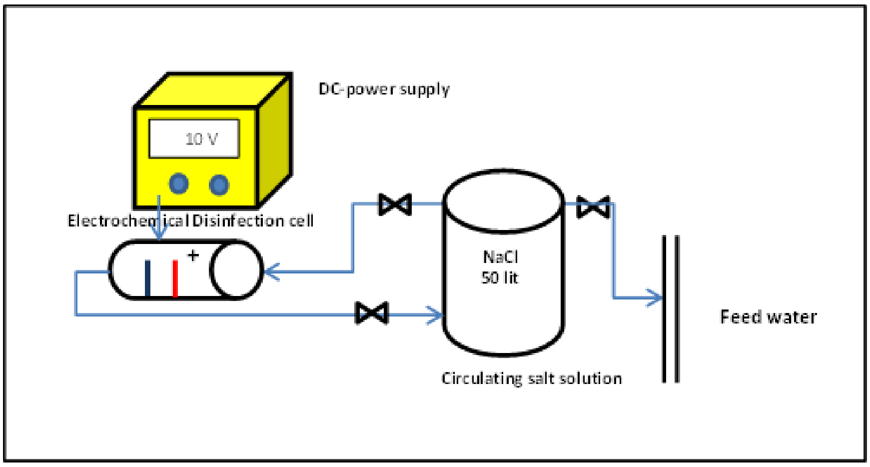

Figure-1. A schematic diagram for the electrochemical disinfectant generating system.

As shown in Figure-1, the circulating solution-tank containing NaCl solution of concentration 35 g/l which was used as an electrolytic solution for the generation of mixed disinfectants and has been proposed as illustrated in the following mechanism.During the electrolysis of sodium chloride solution mixed disinfectants active species were produced electrochemically such as Cl_2, $OH^{\bullet}$, ClO^-, O_3 and H_2O_2 which was formed with the following proposed mechanism [12].

$H_2O \longrightarrow H^+ + OH^{\bullet} + e^-$
$OH^{\bullet} O^{\bullet} + H^+ + e^- \longrightarrow$
$2O\bullet \longrightarrow O_2$
$O_2 + O\bullet \longrightarrow O_3$
$OH^{\bullet} + OH^{\bullet} H_2O_2 \longrightarrow$
$NaCl \longrightarrow Na^+ + Cl^-$
$Cl^- + Cl^- Cl_2 \longrightarrow$
$Cl_2 + 2\ OH^- ClO^- + Cl^- \longrightarrow + H_2O$

The concentration of mixed disinfectants generated through different electrochemical operation time (electrolysis time) was recorded with different current densities and shown in Figure-2.The applied potential through the cell was stabilized using a DC-power supply at 10 volt, using a circulating sodium chloride solution (35g/l) of volume 0.05 m^3.

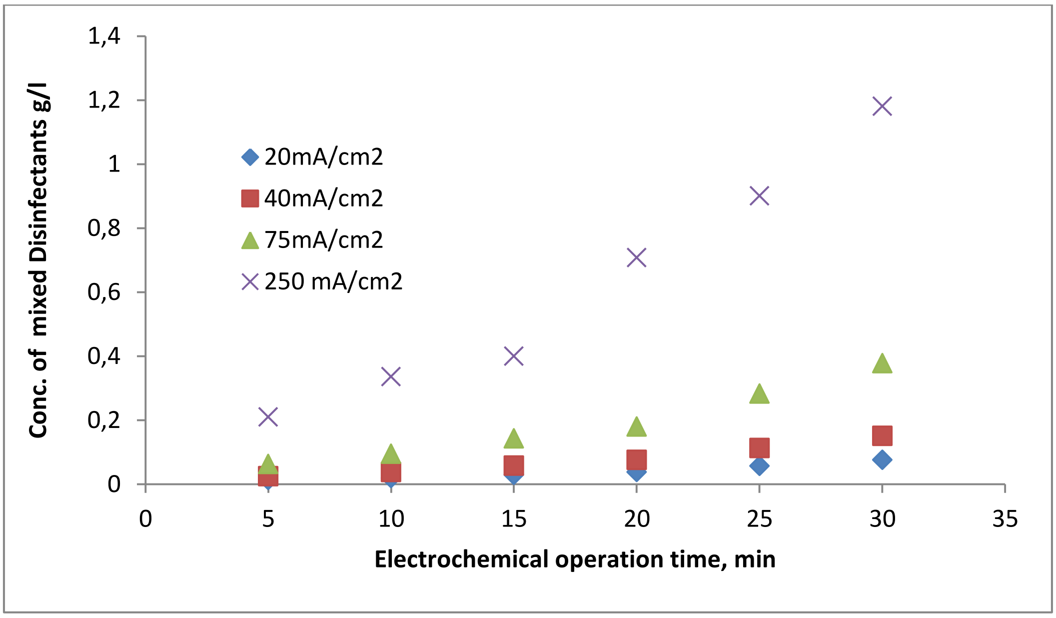

Figure-2. The effect of electrochemical operation time (electrolysis) on conc. of produced mixed disinfectants at different current densities.

It was concluded from Figure-2 that a gradual increase of mixed disinfectants concentration was presented in the 1st three current densities and their linear increase with the increase in time were also logically interpreted. Moreover, the triplication of current density to reach 250mA/cm2 shows a higher value of magnitude for

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its value especially at electrolysis time of 30 min, the conc. of disinfectants reaches about 1.2 g/l compared with only 0.2 g/l at 75mA/cm^2.

A kinetic model for the rate of inactivation of microorganisms in water was studied by plotting the variation of logarithmic inactivation versus disinfection time. In general electrochemical treatments, first order, pseudo-first order, and second order kinetics have been usually used [13, 14].

$$\frac{dC}{dt} = -K\,C + \text{constant}$$

where
C = Concentration of mixed disinfectant at time t;
t = time of electrolysis, min;
k = first order kinetic coefficient.

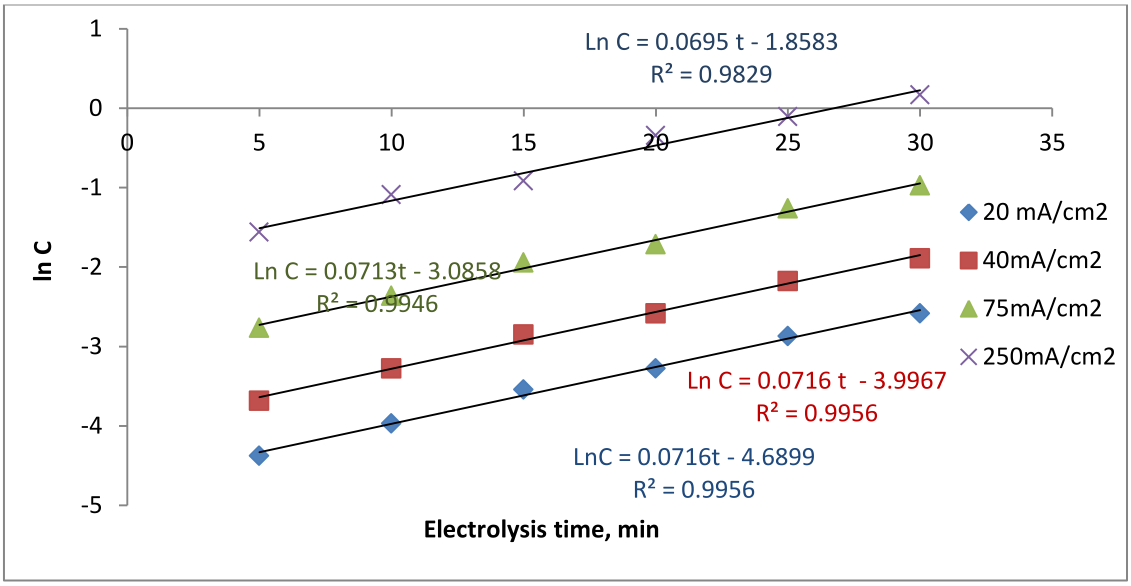

Figure-3. The kinetic rate equations and rate coefficients for the rate of disinfectants concentration varied with electrolysis time.

The rate of change of disinfectant concentration versus electrolysis time shown in figure 3 obeys first order kinetic model for all covered current densities; the correlation factor R^2 tends to reach 0.996≈1as the experimental data are fitting well to first order kinetic model. The kinetic rate coefficient shows a slight decrease from 0.0716 to 0.0695 min^{-1} with the increase in applied current density from 20 to 250 mA/cm2, which was clear in Figure-4.

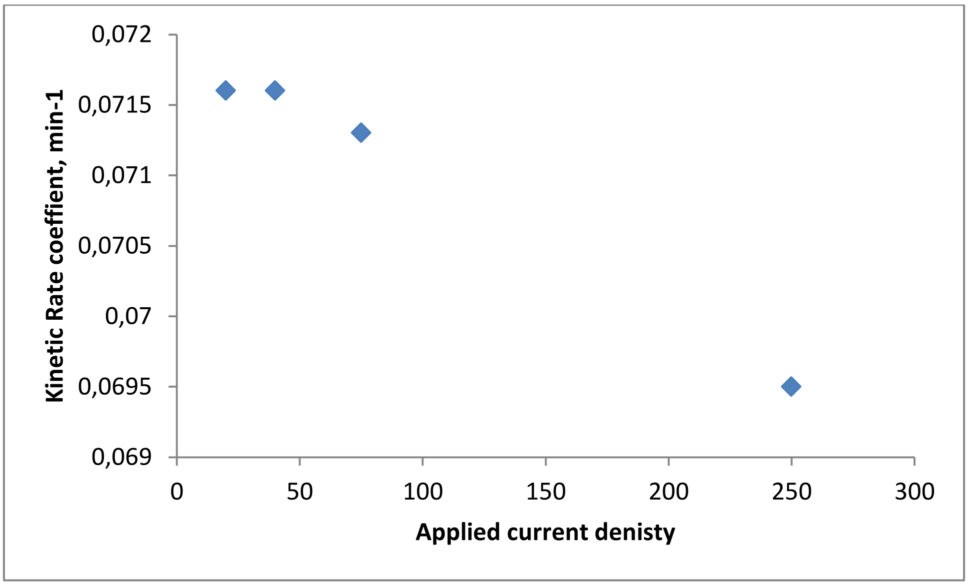

Figure-4. The variation in current density and its effect on kinetic rate coefficient.

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The Kinetic rate coefficient illustrated in the above figure shows a decrease in this coefficient with increased current densities with the increase in produced mixed disinfectants concentration due to presence of system linearity. In this preliminary evaluation, one can conclude that the higher the current density (250mA/cm2), and electrolysis time (30 min), the greater the concentration of produced mixed disinfectants (1.18 g/l), and the lowest the rate coefficient (0.069 min^{-1}).

The on-site electrochemical disinfection doses varied with different current densities which were then optimized through varying concentration of mixed disinfectants analyzed in g/l in feed water with the inactivation of microorganisms population expressed as log m/m_0.

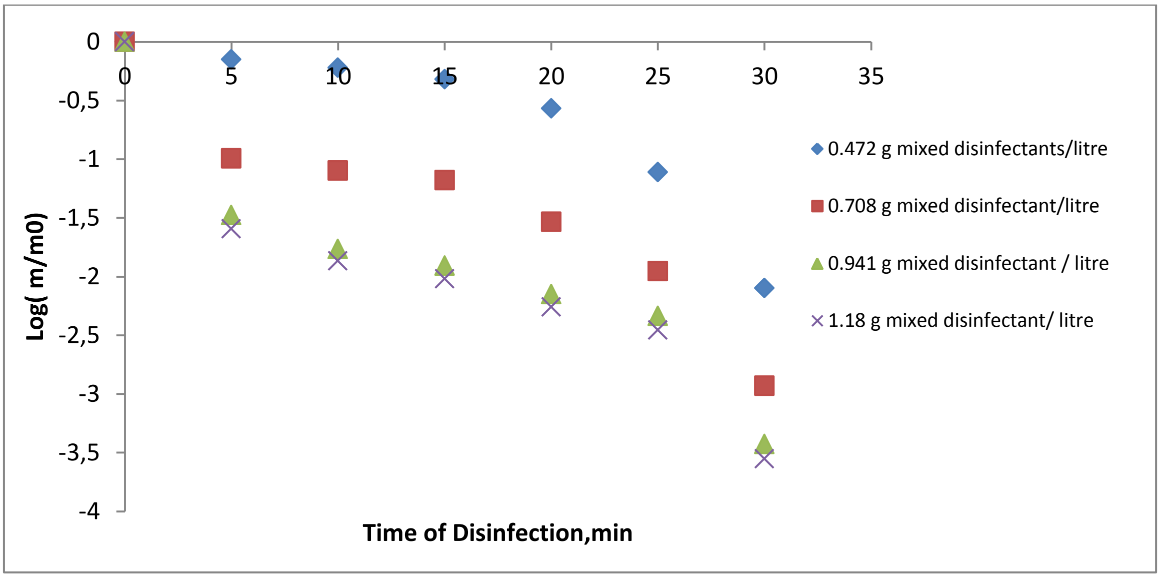

Figure-5. The variation in disinfection dose and its effect on inactivation rate of microorganisms.

The rate of inactivation of microorganisms expressed as the logarithmic ratio of survived microorganisms to the initial population found and shown in figure 5 was highly affected by the time of disinfection and so the dose of injected active disinfectants. 30 minutes disinfecting time and 0.941 g/l disinfecting dose were selected as the optimum disinfection parameters in batch evaluation experiments as the inactivation rate was decreased from $10^{-3.47}$ to $10^{-3.55}$corresponding to 0.941 to 1.18 g/l concentration of mixed disinfectants respectively at 30 minutes of disinfecting time. The same can be seen in comparing the observed decrease in disinfection time from 30 minutes to 25 minutes which shows an adverse effect on the inactivation rate of recorded microorganisms.

The mixed disinfectant solution was allowed to diffuse through the bulk solution of feed water stream in water desalination unit by means of a calculated flow rate of injected disinfectant rate according to optimized data reached using the dosing injection flow system.

3.1.2 Design consideration for the whole integrated RO system

The desalination unit was designed, fabricated, and implemented to produce $50m^3/h$ as a minimum output flow rate from saline brackish water from beer abou-kalam- El-tor is shown in Figure-6. The salinity of well is showing a variable norms from about 5100 - 6800 ppm due to possible mixing with agriculture drainage water due to the nature of the case study- well found which is an aggregate shallow well with a depth of only 28 meters.

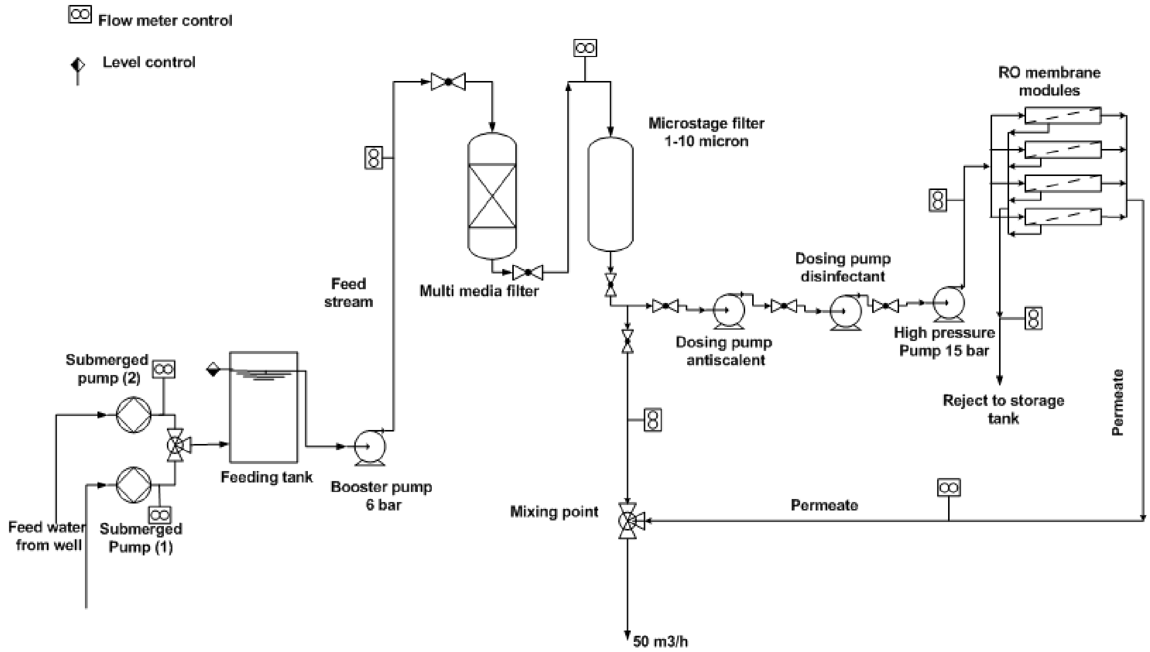

Figure-6. Typical process flow diagram for brackish water desalination system.

Engineering design basis depends on the feed flow rate 5 m^3/hr, with nominal product flow 50 m^3/Day. The feed TDS is 5100-6800 ppm. The maximum incoming feed from deep well with raw water turbidity <1.5NTU (Normal turbidity unit) (without pre-treatment) and feed water turbidity < 1NTU (after multimedia filter). Feed water Silt index (SDI)< 5 Maximum. The capacity design basis is 24 hours. The desalted water quality < 250 ppm (TDS).To design the desalination plant, suggested system was divided to three units; feeding unit, pretreatment unit, and RO unit. Each unit was designed to contain required equipment's with suitable material of constructions. The unit consists of two submerged pumps (304 stainless steel) to raise the feed brackish water from well to the desalination unit by means of a separate control unit to switch between lead and lag pumps for continuous operation over 24 hours. The pump will withdraw the feed water from the well to a 1m^3 equalizing tank, which has level controller to automatically control the feeding pumps after complete filling.

The feeding water is drawn by booster pump with pressure 6 bar to the multimedia filter to remove any suspended solid materials like organics or inorganics in the feed water after disinfecting agent's injection through a dosing system. This classical disinfecting system which depend on locally produced and fabricated chemical disinfection will be compared with another locally fabricated on-site disinfecting device with a lower fixed and operating cost together with a green impact on environment [11], in addition to complete absence of common globally banded disinfecting agents which can't be adsorbed in the coming multimedia adsorption step to protect RO system utilizes a vertical multi-stage centrifugal pump, stainless steel 316 l with a flow rate of 5 m^3/hr. Antifouling chemicals shall be dosed to prevent fouling and scaling in the membranes.. After that, the permeate water from this filter is drawn to the micro-stage filters having pores size in range from 1 to 10 microns. These filters are used to remove bacteria, algae or any suspended solids escaping from multistage filter. The previous steps were the primary steps in the pre-treatment process to protect RO units from any traces or contaminations and so prevent RO membranes fouling.

Before the feeding water follow to RO units, it passes to anti-scalant dosing pump, disinfectant dosing pump as a final pre-treatment step. The water then flows to high pressure pump raising its pressure to 15 bars to feed inlet in RO system modules. The RO unit has four modules each one has entrance for feeding and two out lets, one for concentrate and the second one for permeate. The membrane module length was 8 in and the system can be scaled up to four modules with water permeate flow rate of 100 m^3/day, but it was implemented with only two modules with a minimum capacity of 50 m^3/day. Also, each pressure vessel (membrane modules) should be manifold with rigid pipes or 316 St.St tubing connected to the raw water inlet and the concentrate ports. A sampling cock shall be installed on the permeate side of each vessel. The concentrated stream (reject) is pumped through a piping system and collected in a storage area for further treatment and Salt production. The permeate stream is mixed with treated desalinated water after micro-stage filters to adjust the salinity of pure irrigation water with the required ranges from (800-1000 ppm).

3.1.3 Evaluation of implemented RO- Desalination unit

The operating parameters of brackish- RO system are mainly function of feed water salinity and temperature. For example, for feedwater of about 7000 ppm TDS salinity and water temperature in the range of 18–38°C, the RO systems are designed to operate at a recovery rate in the range of 59–74% as 1st recovery stage and other compared designed and observed parameters as shown in Table-2.

The desalination experiments were performed on the designed implemented desalination plant. The salinity of brackish water in Abo-kalam well was tested before and after desalination. Table-3 indicates the analysis of saline brackish water in Abo-kalam well before and after using desalination system together with the concentrate reject analysis which shows good beginning step. The results indicates the salt rejection % reached to 94.6% after using desalination unit, where the TDS before desalination was 5950 ppm and reached to 187.6ppm as pure permeate, which mean the rejection % was reached to 96.8%. The rejected salt water (concentrate) was stored in tank to be used in mixed salt precipitation by means of solar power in future work.

Table-2. Performance evaluation data for the first 400 days- operation for the implemented brackish water desalination unit.

Parameter	Design value	Average observed value
Feed brackish input rate, $m^3\ h^{-1}$	3.2- 5.76	5.53
Product Water production, $m^3\ h^{-1}$	2.1- 3.75	3.6
Reject water output before treatment, $m^3\ h^{-1}$	1.1- 2.01	1.93
Product 1st recovery, %	65%	69-74%
Feed water TDS, mg L^{-1}	6000	5000-6000
Product water TDS, mg L^{-1}	50-70	85+ blending
RO Inlet pressure range , Kg Cm^{-2}	15-18 bar	
Plant utilization (mean of 15 months), h/d	24	24
Product water production (mean of 15 months), m^3/d	5085	

Table-3. Physico chemical characteristics of Beer Abo-Kalam Feed water, permeate and reject.

Parameters		Permeate water	Reject concentrate water
pH	**---**	**7.26**	**7.8**
TDS	mg/l (ppm)	187.6	11208
EC	dSm-1	0.59	14.01
Calcium	mg /l	49	61.5
Magnesium	mg/l	19.2	168
Sodium	mg/l	87	3606
Potassium	mg/l	0.39	10.53
HCO3-	mg/l	31.1	398.35
Cl-	mg/l	66.5	4790
SO4--	mg/l	66.56	8248
Iron	mg/l	< 0.01	0.8
Manganese	mg/l	< 0.01	0.17

It was clear from Figure-7 that the maximum reached recovery % was 74% and this can be considered as a high record to be treated with the solar concentrator technique and so reach to an economic treatment system for precipitated blend salts with pure water condensate for drinking and irrigation purposes.

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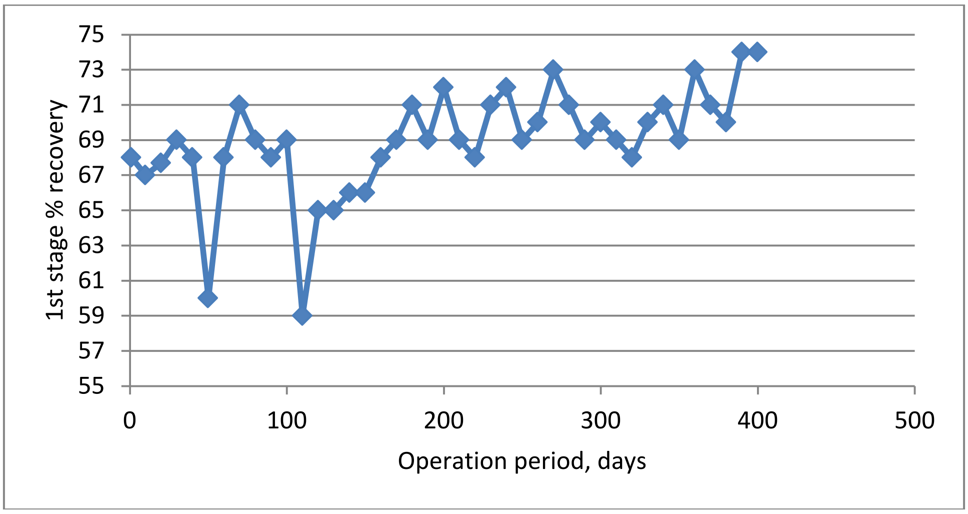

Figure-7. The 1st stage % recovery as a function of operation days.

The minimum reached recovery was then attributed to mal-maintenance routines to reach about 59-60% in the 1st 100 days of operation. Due to successive shut-down in operation and maintenance in the first operation period (before 50 days) the recovery percentage shows a sharp minimum point.

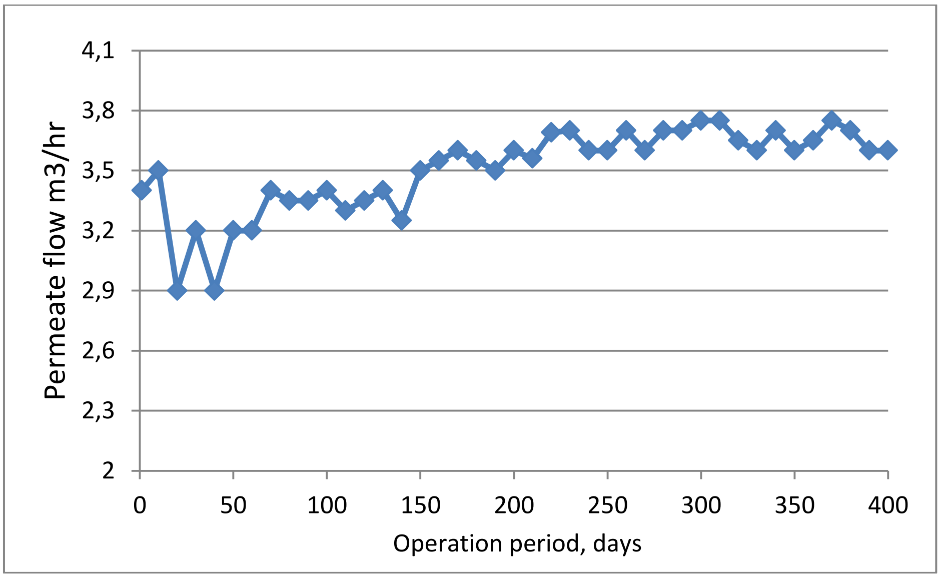

Figure-8. Variation of permeate flow rate, m^3/hr with operation period in days.

The change of permeate flow rate with operation time over evaluation period was presented in Figure-8 to show a slight fluctuation above the designed value to have a mean value of 3.6 m^3/hr. A certain exception was found at the 1st- 50 days operation period showing a slight minimum point reached to give a permeate flow rate of 2.9 m^3/hr. Minor fluctuations for permeate flow rate was attributed to change in feed water salinity together with the presence of clay deposits due to nature of aggregate well-brackish water causing pre-treatment stages clogging and shut down for maintenance facilities.

4. CONCLUSIONS

a) Implementation of desalination plant with all its components, connections with start-up for examining all of these successive parts with a comparison between designed and observed parameters were presented and illustrated.

b) The optimum reached evaluated data for the on-site disinfection system that 30 minutes electrolysis time, 10 volts at 250 mA/cm^2 were proved to give a concentration of mixed disinfectant solution which is able to reach the inactivation rate of survived microorganism to less than $10^{-3.5}$ as a logarithmic value of survived population / the total population existing before disinfecting at only 30 minutes as disinfecting time.

c) The rate of producing mixed disinfectants C, electrochemically with the optimized parameters were found a good fit with the first -order kinetic model, with accepted rate correlation, Knowing that the kinetic rate constant shows a slight decrease with the increase in the applied current density.

d) The reached 1st stage recovery percentage reaches 74% with a salt rejection of 96.8%, averaged permeate flow rate over evaluation operating period of 3.6 m3/hr.
e) The reached preliminary study for disinfection step electrochemically proves its excellence as efficient health effective technique for feed and permeates water.
f) The ease of operation with a cost effective - environmentally friendlier adsorbent BVB-1100 for iron and manganese removal was presented with a promising preliminary study for extended studies in future work.
g) The reject water was collected to be fed to a low cost-salt recovery designed and implemented unit with a compared solar evaporation pond in a coming work.
h) The preliminary reached data for 2nd stage recovery exceeds 65% % recovery, which then will give an overall recovery percentage from 87-90% with almost 99% overall salt rejection.

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