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Removal of Nitrate from Contaminated Groundwater Using Solar Membrane Distillation

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Abstract- *Nitrate contamination is worldwide water pollution posing a major health hazard to human and animal life. Challenges are being faced to get fresh water for the areas having a low amount of usable water. This study aims to asses and evaluates the feasibility of removing nitrate from groundwater by using cheap approaches. A pilot-scale solar distillation membrane filter, was designed and constructed for this study, the set up was designed into two partitions: i) water heater and ii) membrane distillation. The effect of several operating parameters such as feed and distillate temperature, nitrate concentration, and pH, on water flux and nitrate removal efficiency, was investigated. The results showed that 85 and 93 percent removal efficiencies for nitrate and total dissolved solids, respectively. The effect of important parameters of solar performance membrane filter distillation (SPMFD) process including solar collector efficiency (η_c), gained output ratio (GOR) and significant operating parameters containing feed and condensate temperature, feed nitrate concentration and pH were studied in this work and it could be concluded that water flux was increased exponentially with increasing feed temperature, and under the same operating conditions, average water flux changed from 9.52 to 34 kg/m2 per hour when temperature increased from 60 to 90 °C gradually. However, no significant effect was found by varying nitrate and TDS concentration and pH on water flux. It can be concluded that membrane distillation and solar desalination processes could be the efficient methodologies to exploit in the large nitrate-affected rural areas of Iraq and its surrounding with abundant sunlight, particularly during the critical dry season.*

Keywords- *nitrate removal, groundwater, jute membrane, distillation, solar energy.*

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1. Introduction

Increased demand for fresh water for diverse domestic, agricultural and industrial uses has raised many issues in economic development, population growth, and environmental pollution. The whole world is suffering a major shortage of fresh water, particularly arid and/or semi-arid regions due to the scarcity of available natural and traditional resources, emphasizing the necessity of well-articulated management approaches [1,2].
Nitrate (NO_3^-), the inorganic chemical is one of the potential groundwater contaminant posing significant threat to ground water quality and commonly being used as fertilizer. On the other hand, residential septic tanks can also be a source of nitrates in ground water. Nitrates, unlike other agricultural chemicals, do not chemically degrade with time and if their high amount is used, they can be absorbed by plant root systems results in the contamination of shallow ground water. WHO approved the amount of nitrate concentration in water is ranged as 45-50 mg-NO_3-/l as an excessive level of it create taste and odor problems and is a major health and environmental hazard [3,4]. Table 1 is showing nitrate concentration in drinking water according to WHO.

Table 1: Nitrate concentration in drinking water according to organizations

Organization/Country	Concentration of Nitrate (mg/l)	Reference
EPA	10	[11]
WHO	50	[6]

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Australia	50	[12]
Canada	45	[8]

Nitrates removal from contaminated water is one of the main requirement should be applied in the groundwater treatment to achieve the accepted level for safe drinking 50 mg/l NO_3^-. There are numerous technologies used for treating nitrate-contaminated water, including adsorption, ion exchange, catalytic reduction, biological denitrification, electrodialysis, nanofiltration, and reverse osmosis. However, all the methods mentioned above have some drawbacks, for example, the environmental impact due to the use of chemical compounds, need for regeneration and loss of adsorbent capacity with time, etc. [5,6,7]. Three primary factors, (1) discovery of new rarer contaminants, (2) the promulgation of new water quality standards and (3) cost, remained in discussion while in the development and implementation of groundwater treatment technologies. The natural fibers like jute have a high adsorption characteristic and might enjoy more favorable market conditions in the future because of increasing concern with environmental issues all over the world [8,9,10].

Considering the above-mentioned issues, i.e. economic, environmental and advancement of technique (solar membrane filter distillation), this work was aimed to manufacture a membrane filter from jute rope to remove nitrates from contaminated groundwater and to study the efficiency of this locally made membrane. In this work, a solar desalination process for brackish water treatment using membrane distillation technology was applied and the thermal efficiency of solar collectors as water heaters was evaluated. In addition, the feasibility of removing nitrate from ground water in the membrane distillation desalination process was also studied.

2. Materials and Methods

I. Experimental Setup

A pilot-scaled solar membrane filter distillation process was designed and constructed for this study as shown in schematic Figure 1. (a) This set up was designed into two partitions i) water heater and ii) membrane distillation and was composed of seven components as (1) a membrane filter distillation, (2) solar energy collector (glazed liquid flat-plate collector and concentrators), (3) heater electrical, (4) pump, (5) tightly closed tank for feeding, (6) temperature and pressure gages and (7) distillate tank. (b) The plot of the system set up.

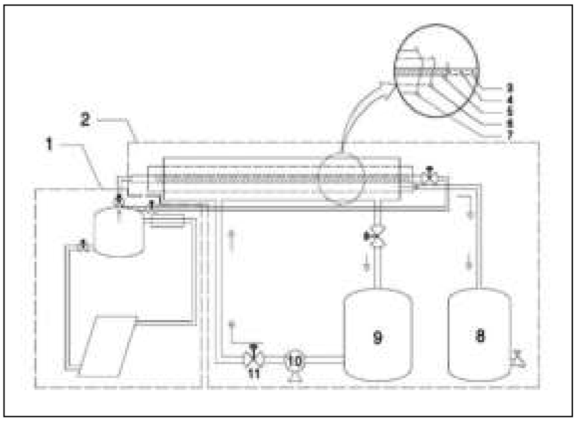

Figure 1(a): schematic diagram for the experimental setup. (1) Solar water heater partition (2) Nitrate removal partition. (3) Perforated polyethylene pipe. (4) Holes 5mm at 25mm. (5) Jute rope. (6) Aluminum pipe. (7) Plastic cover. (8) Cold water tank. (9) Distillate water tank. (10) Pump. (11)Valve.

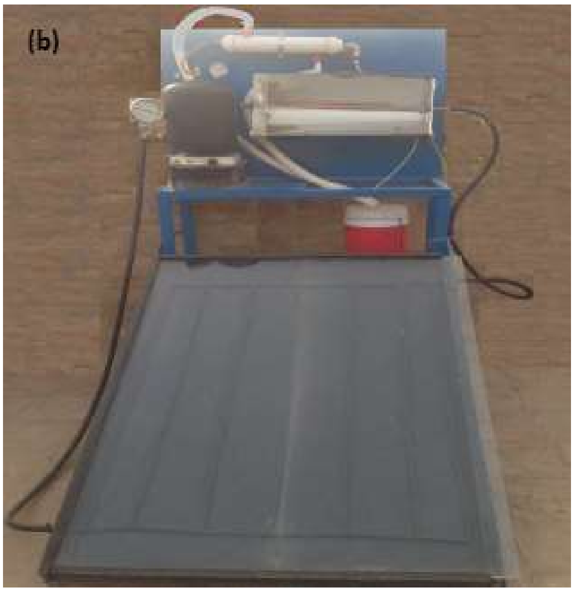

Figure 1(b): Plot of the system set up.

a. Solar Water Heater Partition

The solar water heater partition has been designed in such a way that it consists of three major components; (1) a solar energy collector (a flat-plate absorber), (2) parabolic solar concentrator and (3) a (20 L) solar collector storage tank.

The solar energy collector (a flat-plate absorber) was made from aluminum metal with 1m × 1.5 m dimension. This plate was placed in a wood frame between a single layer of glass with 4mm thickness from the front side and isolation panel from the back. This technique prevents escaping of solar rays and high reflection through the cell (greenhouse effect) causing increased temperature leading to heat the raw water coming from the storage tank through network copper pipes (12 mm diameter, 10 m length) fixed to the cell in front of the plate. The plate and outer wall of the pipes were coated with selective absorbing material (black color and endothermic). This system absorbs solar radiation and transfers the heat to the water flowing inside the pipes.

Parabolic solar concentrator (50cm $\times$30cm as a project area) was made from chrome metal to concentrate a large area of sunlight onto a small area (50cm and 12mm diameter pipe existing at the focus of the parabola) for enhancing water temperature [7]. Raw water circulates between storage tank, solar water collector and parabolic solar concentrator continuously by natural convection and gravity (difference in density of liquid) until the sunset. Iraq locates in the northern hemisphere so, in this study, the solar panel was directed to true south and installed with the tilt angle of 30degrees according to yearly optimum tilt angle for Babylon province. Figure 2 illustrates the schematic diagram of the solar heater partition.

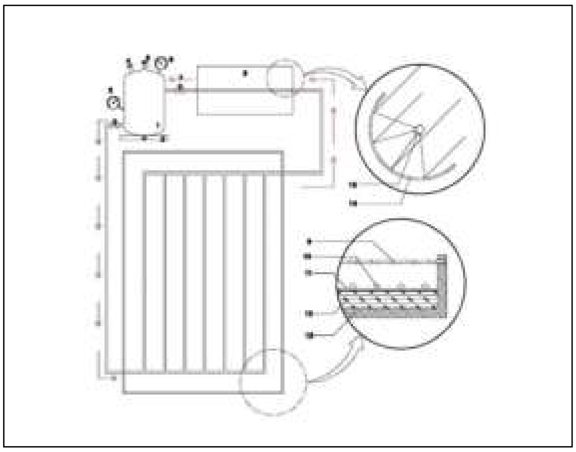

Figure 2: Schematic diagram of the solar water heater partition showing its components and flow. (1) Feed tank. (2) Heater electrics. (3) Temperature gage. (4) Groundwater feed. (5) Water vapor outlet. (6) Pressure gage. (7) Valve. (8) Parabolic trough solar concentrator. (9) Glass sheet. (10) Copper pipe (11) Aluminum plate. (12) Insulation 50 mm. (13) wood panel. (14) Chrome plate.

b. Nitrate Removal Partition

The nitrate removal partition was composed of the water circulation pump (temperature: 20–30 $^{\circ}$C) for cooling the aluminum pipe. It was hypothesized that when the water temperature reaches 60°C or more, the water will vaporize and then drive from partition 1 (solar water heater) to enter a perforated polyethylene pipe of diameter 12.5 mm and length 50 cm. The diameter of the holes was made 5 mm at 25 mm at both sides of the pipe. A string of natural jute rope was wrapped on this pipe to function as surface adsorption of nitrate and other salts. This perforated pipe was put inside another pipe of aluminum to get heat exchange and water vapor condensation, which will result in the production of distilled water.

II. Experimental Procedure

Experiments were carried out using groundwater collected from three wells of Babylon province, Iraq during the period of three months (April, May and June) of the year 2017. The characteristics of this groundwater are listed in Table 2.

The membrane filter distillation model was made from initial cost-effective and environmentally friendly materials. The feed temperature from the feed tank was varied between 60 to 90 $^{\circ}$C with and without electrical power assistance (using assistant when the temperature dose does not reach 90 $^{\circ}$C). Membrane filter module was run after heating feed water to 60 $^{\circ}$C for 30 minutes. Temperature/pressure gages and valves controlled the feed side, while the distillate side was managed to circulate cold water using a pump and all experimental measurements were done for three interval feed temperatures, 1) 60-70, 2) 70-80 and 3) 80-90 $^{\circ}$C. The water vapors entered the perforated tube and out to find the string of jute where nitrate and other salts were supposed to accrue at the jute surface. It was hypothesized that the vapors would attach to the cold surface of the aluminum tube and condense to produce distillate water.

Table 2: characteristics of groundwater for the study area

Parameters	Range	Parameters	Range
NO_3^- (mg/l)	18-150	Na^+ (mg/l)	189-312
TDS (mg/l)	960-2800	Cl^- (mg/l)	170-1013
EC (μScm^{-1})	1500-4180	SO_4^{-2} (mg/l)	540-1013
Temperature (^{0}C)	20-25	K^+ (mg/l)	9.5-14
Mg^{+2} (mg/l)	136-212	pH	5-8.5

III. Measurements

Samples of distillate collected at the definite interval were analyzed for measurement of nitrate concentration by an atomic absorption spectrophotometer (68 Series UV/Visible Double Beam Spectrophotometer). Other parameters such as total dissolved solid (TDS), EC, pH and temperature for groundwater and distillate water were done by the HM Digital COM80 Hydro Quality Tester Meter EC/TDS, pH meter (HI 110 series) and Digital Pen Thermometer respectively.

3. Results and Discussion

I. The Solar Collector Efficiency (η_c)

The solar collector is an essential component in the solar performance membrane filter distillation unit (SPMFD). The energy efficiency of the solar collector is the ratio of useful energy obtained in the collector to solar radiation in coming to the collector. Equation 1 was used to compute the collector efficiency [10,11,12,13].

$$\eta_c = \frac{m_c \, C_p \, (T_{co} - T_{ci})}{AI} \quad (1)$$

where η_c is the average solar collector efficiency, m_c is the mass flow rate of feed (kg/s), T_{co} and T_{ci} are the feed temperature at the collector outlet and inlet ($^\circ$k), C_p is the feed specific heat (J/kg.$^\circ$k), A is the solar collector area (m^2) and I is the global irradiation (W/m^2).

II. Gained Output Ratio (GOR) of the System

Gained output ratio (GOR) is a measure of how much thermal energy is consumed in the desalination process. It is generally defined as the heat of evaporation (Q_{evp}) to the heating energy (Q_h), (theoretical energy required to produce distillate divided by the actual thermal energy consumed in feed side of the module). The GOR of the membrane module was calculated using equation 2 [13,14].

$$GOR = \frac{m_{evp} \, \lambda_{evp}}{m_h \, C_{ph} \, (T_{hi} - T_{ho})} \quad (2)$$

where m_{evp} is the mass flow rate through the membrane (kg/h), λ_{evp} is the latent heat of vaporization (J/kg), m_h is the feed flow rate (kg/h), T_{hi} and T_{ho} are the inlet and outlet feed temperatures ($^\circ$K). GOR of this work was found to be 0.36 at 60 $^\circ$C feed temperature whereas for feed temperature 70 $^\circ$C, it was calculated as 0.43, which is consistent with the findings of [13,15]. The standard GOR value is ranged between 0.3–0.9. Table 3 is showing the obtained results for GOR value.

Table 3: Performance parameters of the solar energy collector and membrane module

T_{hi} ($^\circ$C)	$^*T_{di}$ ($^\circ$C)	$\boldsymbol{\eta_c}$ (%)	GOR
60	20	68	0.36
70	26	72	0.43

$^*T_{di}$ is distillation temperature

III. Effects of Operating Parameters on Flux and Membrane Filter Efficiency

a. Effect of Feed Temperature: Figure 3 shows the effect of feed temperature on water flux. This figure illustrated that water flux increased significantly from 9.52 to 34 kg/m^2.h with increasing feed temperature. Obtained results were found consistent with the findings of [16,17].

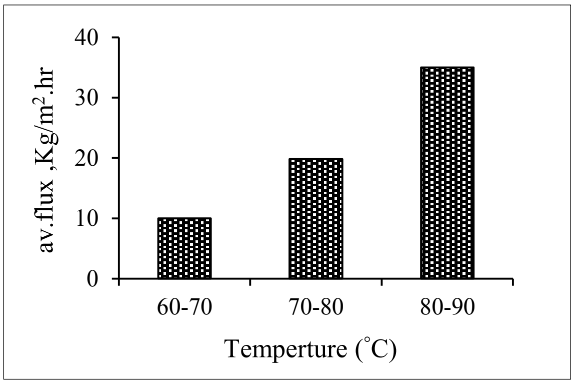

Figure 3: Effect of feed temperature on water flux

b. Effect of Nitrate Concentration: The effect of nitrate concentration on water flux has been explained in Figure 4. It was observed that increasing feed nitrate concentration leads to a slight decrease in permeate flux. It was also observed that the influence of feed nitrate on water flux was not as significant as that of feed temperature or distillate temperature in the studied range.

c. Effect of pH: pH of groundwater was in the overall range of 6–8.5, and no noticeable effect was observed on water flux, as shown in Table 4.

d. Effect of Condensate Temperature: A strong negative correlation between the condensate temperatures was observed. It was noticed that the amount of water flux decreased with increased water temperature, as shown in Figure 5.

e. Effect of Feed Temperature on the Nitrate, TDS Removal Efficiency: The concentrations of nitrate (NO_3^-) and total dissolve solid (TDS) were tested and then efficiencies of nitrate removal in three intervals of the temperature 60-70, 70-80 and 80-90 $^\circ$C were calculated as explained in Figure 6. It was concluded that increasing temperature does not have an important effect on the efficiencies of nitrate removal.

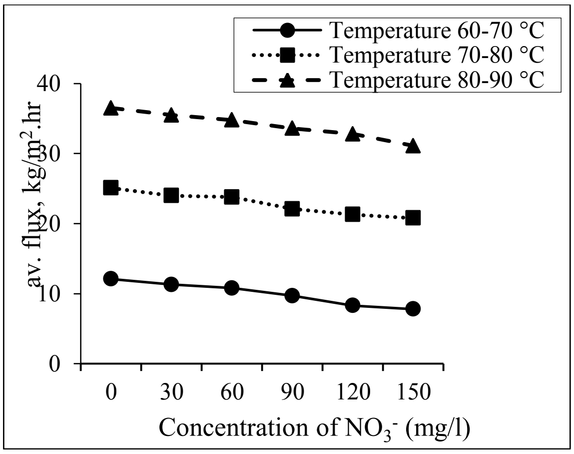

Figure 4: Effect of nitrate concentration on water flux

Table 4: Effect of pH on water flux

		pH				
	Temperature (°C)	6.5	7	7.5	8	8.5
Av. water flux (kg/m^2.hr)	60-70	9.51	9.49	9.51	9.50	9.48
	70- 80	21.71	21.68	21.72	21.69	21.70
	80-90	34.13	33.92	34.19	34.10	33.89

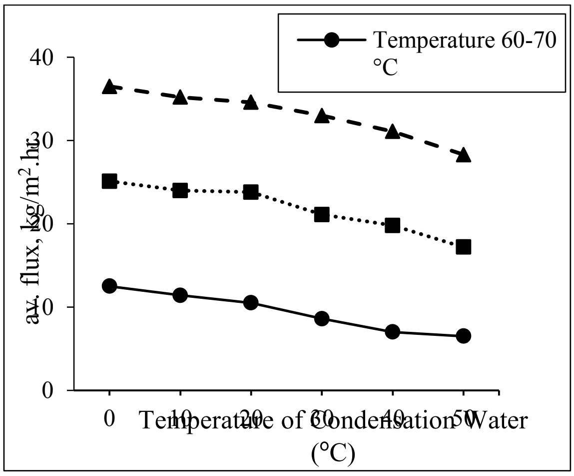

Figure 5: Effect of condensate temperature on water flux

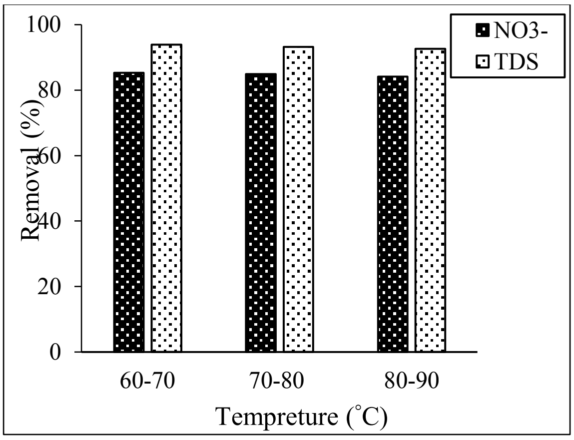

Figure 6: Effect of feed temperature on NO3- and TDS removal efficiency

4. Conclusion

Nitrate removal is the most common groundwater contamination issue in the world as it is a necessity to keep nitrate concentration below the maximum permissible level, which is 50 mg/L. In this work, an environment-friendly and economical technique has been studied, which can be applied in remote areas suffering from fresh water shortage. Results have shown 85 and 93 percent removal efficiencies for nitrate and total dissolved solids, respectively. The effect of important parameters of (SPMFD) process including solar collector efficiency (η_c), gained output ratio (GOR) and significant operating parameters containing feed and condensate temperature, feed nitrate concentration and pH were studied in this work and it could be concluded that water flux was increased exponentially with increasing feed temperature, and under the same operating conditions, average water flux changed from 9.52 to 34 kg/m^2 per hour when temperature increased from 60 to 90 °C gradually. However, no significant effect was found by varying nitrate and TDS concentration and pH on water flux.

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