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# The Use of Solar Energy for Produced Water Treatment

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**Abstract:** Water production is considered as one of the most common operational problems associated with oil production; it not only affects the economic benefits, it also has environmental impacts which affect human life. The huge volume of water is very difficult to be handled or managed; the large amounts complicate the process and more efforts are needed to reduce the expected risk which is constantly increasing as water production increases. Many efforts were done to reduce the environmental impacts of the produced water; including re-using (such as injection, irrigation or other disposal methods) which require specific costs for treatment. Through this work, solar energy was used to distillate the produced water for reusing in oil fields and evaluate its potential for irrigations. Samples were collected from the water injection station of Jake oilfield in the north east of Muglad basin in Sudan; the availability of the solar energy in the field offers a new source for the treatment with low cost. Series of laboratory experiments (pH, conductivity, total dissolved solid, salinity, total organic carbon (TOC) and the chemical oxygen demand (COD)) were conducted to estimate the properties of the produced water before and after distillation. A significant difference has been observed in the water properties before and after treating; the conductivity was decreased from 657 to 23.30  $\mu\text{S}/\text{cm}$ , the total dissolved solid was decreased from 393 to 14.19 mg/L. Sulfate was decreased from 7.0 to 0.7 mg/L; and the total organic carbon (TOC) was decreased from 135.8 to 50.49 mg/L, while the chemical oxygen demand (COD) was increased from 96.0 to 121.9 mg/L before and after treating respectively. An evaluation was presented with respect to irrigation and fracturing fluid uses; the properties of 0.4% guar gum solution with Borates under shear rate of  $170 \text{ S}^{-1}$  and different temperatures were evaluated to address the ability of the treated water to perform fracturing fluids; while corn seeds were used to evaluate the irrigation ability. Good germination performance was observed on corn seeds with the treated water; while the viscosity of the prepared fracturing fluid was increased randomly.

**Keywords:** Produced Water, Contaminants, Treatment, Solar Energy, Fracturing Fluid

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## 1. Introduction

In the oil and gas industry, produced water refers to the water trapped during subsurface formations and released as part of the co-production of oil and gas. It is the largest waste stream associated with oil and gas production; the amount varies with the location of the reservoir and the technology used to extract it. The American Petroleum Institute estimates 21 billion bbl of water was produced in 1985 and 18 billion bbl in 1995 while some authors presented that 210 million bbl of water is produced every day [1].

The Produced water is a very dangerous mixture

containing different amounts of materials with different concentrations according to the applied processes and the nature of the sources; this water is a mixture of soluble and insoluble organic compounds, Chlorides, and dissolved solids. It also contains produced chemicals such as Surface active agents, corrosion inhibitors, and various chemicals and chemical compounds added to the production line or separators during the production process. Besides that, the solid particles that result from the leaching of rocks and corrosion of pipelines also appear in this water [2, 3]. In addition, organic acids, dissolved hydrocarbons, dispersed oil, phenols, and metals, as well as residues of chemical

compounds added to the production line or purification process are complicated the chemical properties of the produced water [4].

The contaminants in produced water results from the concentration of the essential constituents in the water; worldwide the concentration of heavy metal vary from <0.005 (mg/l) for Zinc, Silver, and Beryllium as a minimum to value 97,000 (mg/l) for Sodium as a maximum value (mg/l). Other parameters, physical and chemical properties are presented in Table 1 [5, 6].

**Table 1.** Composition of Oilfield Produced Water (Fakhru -2009).

| Density (kg/m <sup>3</sup> ) | 1014 to 1140  |
|------------------------------|---------------|
| Surface tension (dyn/cm)     | 43 to 78      |
| Conductivity (μS/cm)         | 4200 to 58600 |
| TOC (mg/l)                   | 0 to 1500     |
| TSS (mg/l)                   | 1.2 to 1000   |
| Total oil (IR; mg/l)         | 2 to 565      |
| Volatile (BTX; mg/l)         | 0.39 to 35    |
| Base/neutrals (mg/l)         | Less than 140 |
| Chloride (mg/l)              | 80 to 200,000 |
| Bicarbonate (mg/l)           | 77 to 3990    |
| Sulphate (mg/l)              | <2 to 1650    |
| Ammoniacal nitrogen (mg/l)   | 10 to 300     |
| Sulphite (mg/l)              | 0 to 10       |
| Total polar (mg/L)           | 9.7 to 600    |
| Higher acids (mg/l)          | <1 to 63      |
| Phenol (mg/l)                | 0.009 to 23   |
| Volatile fatty acids (mg/l)  | 2 to 4900     |
| Density (kg/m <sup>3</sup> ) | 1014 to 1140  |
| Surface tension (dyn/cm)     | 43 to 78      |
| Conductivity (μS/cm)         | 4200 to 58600 |
| TOC (mg/l)                   | 0 to 1500     |
| TSS (mg/l)                   | 1.2 to 1000   |

Previously, to get rid of produced water, it is moved into large evaporation ponds without considering its environmental and social perspectives impact; although 250 million barrels of water are daily produced from fields, but more than 40% of it is discharged [7]. The common techniques to manage produced water are to reinject into the well for pressure maintenance, direct overboard discharge, or reused in different matter such as drilling, hydraulic fracturing (field development process), livestock water, irrigation and drinking; through which, re-injection it into disposal wells is the best method.

Recently, many studies were conducted to utilize the produced water in different manners considering the recent regulations and restrictions regarding keeping the environment safe for all human beings [8, 9]. Surfaces, groundwater, and soil may be polluted and the environmental impact will be very high if the concentration of the above-mentioned materials was not reduced or totally removed.

Water management cost in oil and gas field varies widely from field to other as it depends on the quantity and quality of the Produced water; the quality depending on the extraction method, reservoir properties, formation location and geochemistry [3].

Reusing water is oilfield development become the best solution for produced water management due to the depletion of usable water resources around the world and the

required amount of water for wells development. A variety of factors prevents produced water from reusing outside of the energy sector. Based on volumetric calculations, reusing produced water would eliminate half of the plays as fracturing water demand exceeds produced water demand. There are several limitations for produced water reuse other than energy, from the perspective of water quality: inadequate knowledge of water chemistry, difficulties measuring water quality due to high salinity matrix and interference issues, lack of acceptable measurement techniques, lack of appropriate standards, and lack of regulations across various sectors [5].

The required water may need transportation to well site or can be offered from the field itself. Therefore, it is requires specific treatment to ensure its priority of any materials affect the reservoir productivity or any contaminants that lead to environmental disasters; then, a favorable treatment methods and techniques are required for a good management system [10]. The transportation, treatment and disposal fees are the major elements of produced water management cost; normally many successive operations are required with different cost deepens on the original or raw water properties [11, 12]. Due to the contaminants in the produced water, using produced water outside the energy sector comes with high risks; and additional information are required before considering reuse in other sectors.

The produced water treatment techniques vary from simple to very complicated processes depending on the water compositions. However, the process mainly categorized into three stages; the first stage is to reduce pollutants of the major particles of the oil droplets, gas bubbles, and solid particles. The second stage involved two steps primary step and secondary step; The primary step remove small droplets and small solid using the common surface facilities and gravity effect such as separators, skim tanks, and Plate coalescers. The secondary step abstract the very small droplets and solid particles using gas flotation units, De-oiling hydro-cyclones, and centrifuges. The third stage membranes use to remove hydrocarbons that are less than 10 mg/l and the ultra-small oil droplets and solid. Extra treatment can be used to removes dissolved matter, gases, and dispersed hydrocarbons less than 5 mg/l; which require additional processes. For this reason physical, chemical, biological and membrane treatment processes [13]. Additional treatment techniques, such as distillation, are costly and require high energy.

Distilling water using the solar energy is called solar distillation was presented as an effective tools to distill the seawater or saline water; it is involves the use of the sun's energy directly to evaporate water; it is became more prominent after World War II. [14, 15] There are two scientific principles that govern a solar system: evaporation of the raw water and condensation of this vapor; the formed condensates gathered as produced water while it is not possible for minerals, salts and most pollutants to evaporate or produced with the water [16, 17].

In the distillation system, there are external and internal

modes of heat transfer; Radiation and convection are independent processes drives the external heat transfer mode, and they are reside outside the still. Alternatively, internal heat transfer mode occurs inside the solar distillation system as a result of radiation, convection, and evaporation. On the other hand, internal heat transfer mode occurs inside the solar distillation system due to radiation, convection, and evaporation. [18].

## 2. Methodology

Water samples were collected from the water injection station of Jake oilfield in the north east of Muglad basin in Sudan.

### 2.1. Water Properties Measurements

#### *pH Measurement*

The water pH values were measured directly using Toledo Seven 2 Go Portable pH Meter.

#### *Salinity*

The term salinity refers to the total amount or concentration of dissolved particles and ions in water; Electrical Conductivity (EC) was used to estimate the Salinity of the two samples directly using Pro30 Conductivity meter.

#### *Samples Conductivity and Total Dissolved Solids (TDS)*

Electric Conductivity is an indicator of the concentration of dissolved ions in water, and it is expressed as micromhos per centimeter ( $\mu\text{mhos/cm}$ ) or micro Siemens per centimeter ( $*\text{S/cm}$ ). Water's ability to conduct electricity is proportional to how many dissolved salts are present - particularly the amount of charged (ionic) particles in the water. The conductivity was measured directly using Pro30 Conductivity meter.

#### *Total Suspended Solid*

The total suspended Solids (TSS) in a mixture refers to the measured amount of dry particles weight trapped in a filter. First, a filter of a particular pore size was weighed; then a one-liter volume of the water poured through the filter and the filter was dried for two hours at 100 degrees Celsius (100 CO). The filter is weighed repeatedly in order to ensure that all water droplets have evaporated from the filter; the final filter weight is the filter weight with suspended solids.

#### *Turbidity*

After Five grams of sample is placed in the sample cell, distilled water is used to fill the cell; the cell are capped and shaken vigorously for 30 seconds; then, loaded into turbidity meters for measurement.

#### *Total Organic Carbon (TOC) and the Chemical Oxygen Demand (COD)*

Organic pollutants contents are the measurement of the total organic carbon (TOC) and chemical oxygen demand (COD); TOC is defined as the amount of carbon contents to organic compounds, while the Chemical Oxygen Demand is defined as the total measurement of organics and inorganics chemicals in the water.

Prior to analyzing the sample for organic carbon content, all inorganic carbon (IC) must be removed. The inorganic carbon interference is removed through converting the mineralized inorganic carbon (IC) to  $\text{CO}_2$  by acidification and sparring with an inert gas to remove the generated  $\text{CO}_2$ . Samples that have now been freed from IC interference are then injected into TOC analyzers. When the organic carbon oxidized into  $\text{CO}_2$ , it is released from the sample, detected, and reported as mg/L or ppm TOC or dissolved organic carbon (DOC).

### 2.2. Hydraulic Fracture Fluid Preparation

A series of standard laboratory tests were performed to address and evaluate the performance of the fluid; all the measurements were performed according to standard procedures defined by the API RP 39 (1998). First, water based Hydraulic Fracture Fluid was prepared. by 0.4% Guar Gum solution with Sodium Borate as a cross-linker with concentration of 100, 200, 300, 400, 500, 600, microgram. The viscosity was measured using Kinexus pro+ Research grade rheometer for complex fluids characterization under different conditions. First, the effect of the shear rates on fluid viscosity were studied under reservoir temperature for shear rate values of 10 to 200  $\text{S}^{-1}$  for the different samples according to the API RP 39. The effect temperature was also addressed under shear rate of 170  $\text{S}^{-1}$  for temperature range of 25 to 65°C with heating rate of 4°C/minuets as required by API RP 39.

### 2.3. Solar Distillation Device



**Figure 1.** Solar Distillation Device.

The device is design in Square shape with (140×120 cm) with declining angel 15 degree to increase device efficiency consist of Row Water inlet, Distillation surface (glass), Collecting chamber, Treated water outlet, Drain line (Figure 1). Historically, Glass has the property of selectively allowing only the higher energy radiation to pass through and blocking the longer wavelengths. The distiller benefits from this feature as most of the incoming radiation is captured but is not allowed to radiate back. When Radiation from the sun strike the glass cover and reflect onto the still surface, the

black material speeds the rate of evaporation. Upon releasing the latent heat of vaporization the saturated vapor condenses in the lower surface of the glass cover to serve as a condensing surface which have temperature lower than the water inside. It is made slanting so that any water droplets that are formed finally move along the gradient where they finally deposit the condensate into collector. The device was Posited to be exposing to sun ray, the drain valve was opened to flush the bottom from any dust or other materials, then drain valve was closed and the device was filled about 75% of its volume; the inlet valve was closed and the treated water was collected from the outlet after a while.

### 3. Results and Discussion

Following the procedures described previously, the water

was analyzed before and after treatment and the results were presented in Table 2. It was observed that the values of the Conductivity, Total dissolve solid, Salinity, and TOC were highly affected and decreased with distillation while Oxygen Demand (COD) were increased from 50.49 and 121.9.

The properties of the water before distillation were founded with good matching for the irrigation requirements in term of Total Suspended Solid and Turbidity.

Two Hydraulic fracturing fluid were prepared using the two types of water (raw and distilled water) with 0.4% Guar and additives as presented previously; Figure 2 and Figure 3 presented the effect of water properties in the fracturing fluids; from the figure it is observed that the viscosity was increased about 2 time when the water distilled by this techniques. While Figure 5. presented the Hydraulic fracture fluid performed with the Distilled Water.

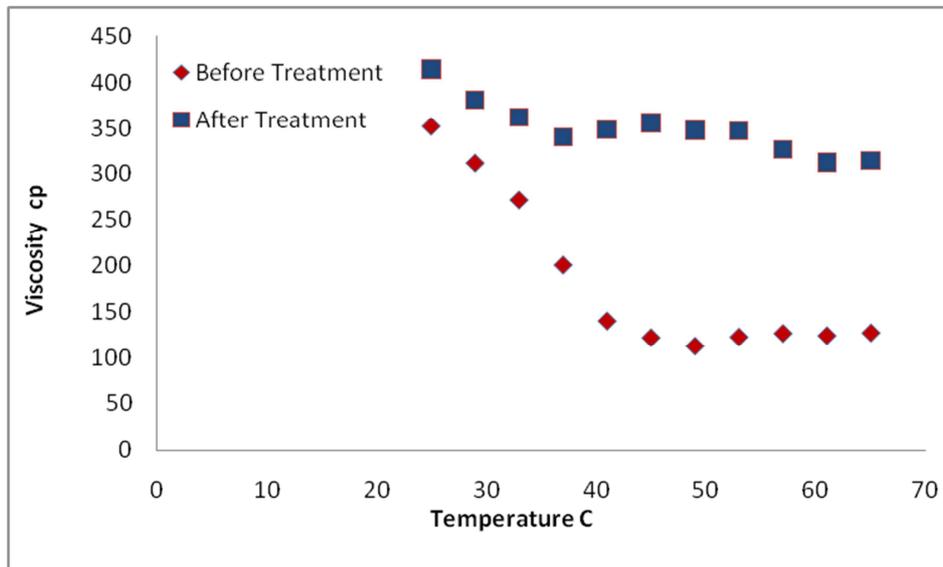


Figure 2. Fracturing Fluids at Different Temperature.

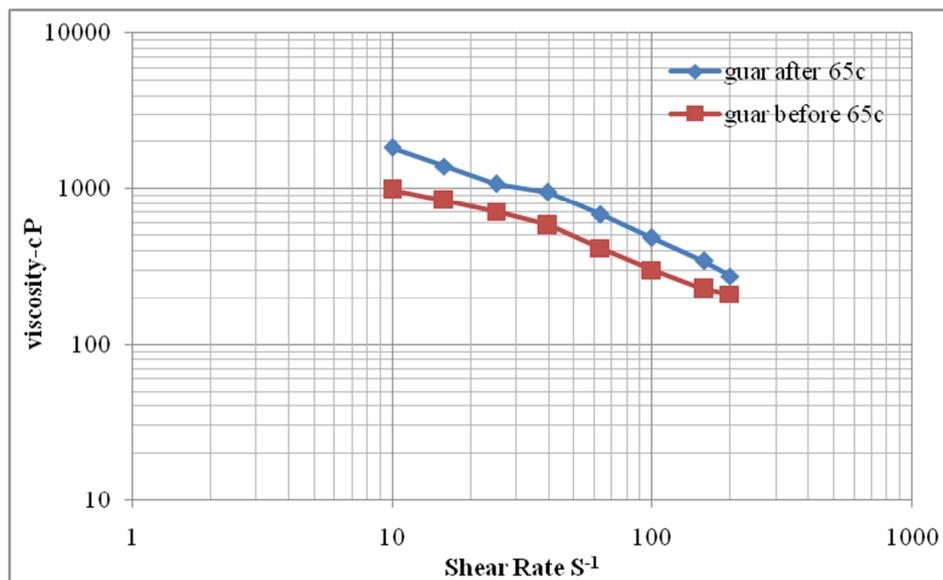


Figure 3. Fracturing Fluid at Different Shear Rates.

**Table 2.** Water Properties before and after Treatment.

| Test                  | Unit  | Result |       | Irrigation Requirements |
|-----------------------|-------|--------|-------|-------------------------|
|                       |       | Before | After |                         |
| ph value at 25°C      |       | 8.46   | 5.77  |                         |
| Conductivity          | µs/cm | 657    | 23.3  |                         |
| Total Dissolve Solid  | mg/L  | 393    | 14.19 |                         |
| Total Suspended Solid | mg/L  | 14     | 8.5   | 5-35                    |
| Salinity              | g/L   | 0.5    | 0.3   |                         |
| Turbidity             | NTU   | 0.896  | 0.575 | <0.2-35 NTU             |
| Sulfate               | mg/L  | 7.1    | 0.7   |                         |
| TOC                   | mg/L  | 135.8  | 50.49 |                         |
| COD                   | mg/L  | 96     | 121.9 |                         |

The distilled water was used as irrigation water for corn seeds to present the ability for germinations; Figure 4 presented the growing performance of the seeds; good germination was observed. However due to the present oils drop, oil and grease measurements are required.

Noted that some oils drop was observed in the distilled water which indicates that the contaminants is still available in the water and this is a serious indicator may indicate the presence of toxic fumes airborne.

#### 4. Conclusions and Recommendations

From this work it the following conclusions can be addressed:

Produced water was distilled using solar energy; the

properties of the water before and after treatment were measured; while oil and grease was not measured due to lack in instruments. Many properties were decreased with distillation while Oxygen Demand (COD) were increased 2 times.

Two fracturing fluids were performed using the raw and the distilled water with 0.4% guar gum and Sodium Borate; the viscosity of the fluid prepared with the water was found to be 2 times of that fluid prepared with the raw water.

The distilled water was used for growing corn seeds and good germination was observed.

Some oils drop was observed in the distilled water which indicates the presence of toxic fumes airborne in the field.

For irrigation issue the distilled water can be applied only for nonfood plants.



**Figure 4.** Growing Performance of Corn seeds with the Distilled Water.



**Figure 5.** Hydraulic fracture fluid performed with the Distilled Water.

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