# The Application of a Single Slope Solar Still in a Refinery Wastewater Treatment: An Experimental Study

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**Abstract.** An alternative resource for energy and water has become essential to ensure long-term sustainability. Industrial wastewater is one of the main environmental challenges which could affect one's life, due to its related pollution. Using solar distillation systems could be the key solution to treating industrial wastewater. In this work, an experimental apparatus was fabricated and tested according to Al-Samawa city climate conditions, to treat the oily-waste water from a refinery. Two different sources of raw wastewater samples with different physical and chemical characteristics were used. Five different runs were performed on different days in November at a sunshine time between (10 AM – 2 PM). The results of the condensate water showed that TDS was reduced by 94 %, conductivity reduced by 95 % and PH increased from an average value of 6.4 to 7.4.

**Keywords.** Solar radiation; solar still; oily wastewater.

## INTRODUCTION

Sun is the source of all the solar energy received on earth. Sun radiation is a clean and sustainable source of energy that never ends. In general, Middle-East countries rely mainly on oil resources rather than solar energy to run different applications in different sectors. Crude oil is transformed into petroleum and other useful by-products through refining processes. Crude oils refining generates large volumes of wastewater produced which consists of cooling water, process water, stormwater, and sewage [1]. Approximately 0.4–1.6 times the volume of the processed crude oil is discharged as petroleum refinery wastewater [2]. Refinery wastewater pollution primarily demonstrates itself in the following areas: affecting potable groundwater resources; hazarding aquatic resources; threatening human health; air pollution; altering the production of the crop; degrading the natural environment, and even, most likely, because of the convergence of the oil burner safety concerns that emerge [3].

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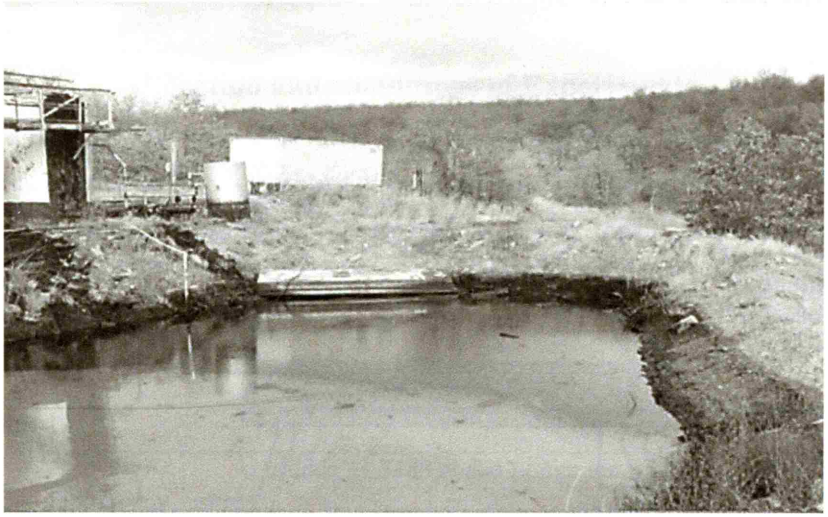

**FIGURE 1.** Photograph of an Industrial wastewater near refinery in Al-Samawa city.

This issue has arisen the necessity to treat the refinery wastewater by eco-friendly technique prior to discharge into the surrounding environment. Treatment of wastewater demands a significant amount of energy, wastewater treatment plants consume energy profusely, whether they are used to treat industrial or municipal wastewater. Typically, 1084.23 kWh $MG^{-1}$ is the average amount of energy consumed per million gallons of treated wastewater [4].

Among various methods of wastewater treatment solar still seems to be a promising one [5]. Solar stills offer various advantages, including flexibility of use, competitive prices, and negligible environmental effect [6]. The simplicity of solar still making it perfect for usage in rural and remote areas. Environmentally, a solar still is considered as a green energy method that purifies wastewater using the sustainable solar radiation to generate clean water instead of conventional sources of energy. Another important benefit is utilizing solar stills as decentralized wastewater treatment systems, such systems treat wastewater at the source, eliminating the need for costly pipeline networks and massive central wastewater treatment plants [4].

Standardly, the work principle of solar still relies on the evaporation and condensation processes. Solar energy is used to evaporate the brine inside the solar still, and the condensate is recovered as distilled water. This process is repeated in a double- or multiple-effect solar still, where the heat of condensation is utilized to fuel a further evaporation process. The use of several effects tends to improve performance, but it comes at a cost. Active components, such as fans and pumps, are another option to improve performance, but they come at a price in terms of cost and complexity [6]. In other words, evaporation is employed to remove minerals from water, and when the water vapour rises, it cools, condenses, and drips into a collector. The method has the ability to produce a significant amount of distilled water. [7].

A solar still is an uncomplicated device (Figure 1), basically it consists from a basin which has a thin layer of water, a clear glass cover that covers the basin, and a canal for collecting the distillate water. The glass allows the sun's rays to pass through, heating the wastewater in the basin of solar still. The solar radiation is transmitted through the glass cover and absorbed by the bottom of the solar still. The difference in temperature between the water and the glass cover drives the pure water yield in a solar still. It affects the rate of evaporation from the surface of the water going towards the condensing cover within the basin. From the heated water, vapour rises and condenses. Through a channel, the condensate water is collected [8].

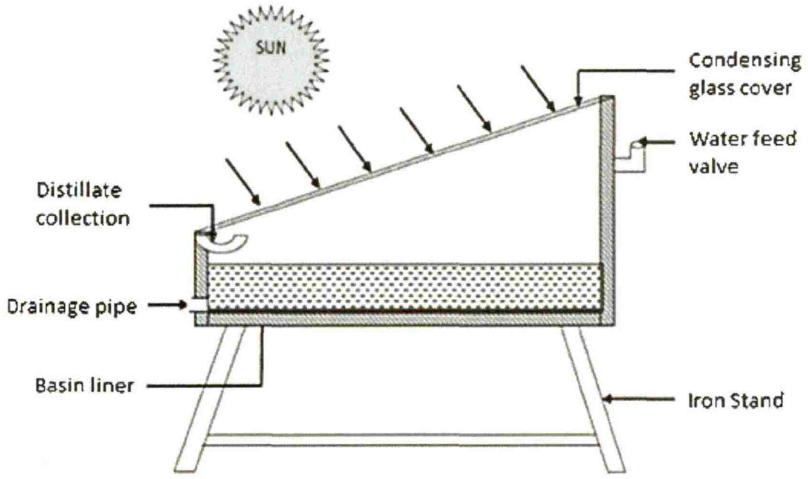


**FIGURE 2.** Schematic of a single slope passive solar still [9].

Several reviews have been written regarding solar stills, notably in the areas of design and construction, enhancement of efficiency, wick variety and modelling.

In [4] the experiment was performed by feeding three types of wastewater into a solar still. In the first trial with low-strength sanitary wastewater the TDS removal efficiency was about 98.3 %. While it was more than 99.9% in the second trial with a higher-strength sanitary wastewater. The third experiment with diluted palm oil mill effluent recorded a TDS removal efficiency of 99.44 ± 0.58%. [8] presented experimental study to evaluate using Phase Change Materials (PCMs) as an energy storage material in still solar. Their results proved that using magnesium Sulfate Heptahydrate (MgSO4 7H2O) would enhance the efficiency of solar water distillation.

[7] tested an experimental model of solar sills in the UK to optimize agriculture in greenhouses, their study provided more sustainable solutions for different weather conditions. In 2021, [10] developed a small-scale solar still to evaluated its reliability at a low temperature to remove impurities and provide drinking water during the period of the COVID-19 pandemic. This low-temperature functioning of the solar still eliminated pathogen transmission via contaminants and vapour.

[11] investigated the efficiency of a stepped solar still for producing clean water from deep underground water in the desert areas. The testing results demonstrate that stepped solar cells collected 47.18–104.73 percent more distilled water than regular solar cells. The productivity of collecting water was higher for stepped solar still than that for conventional still by about 47.18–104.73%. [12] examined the performance of solar distillation by using single basin solar still. The outcomes stated that productivity rises as relative humidity declines. The findings of combining a finned aluminum plate with a tilt single slope solar still are presented in [13], which indicated that the aluminum plate condenses the most water vapour (approximately 46%), while the rest condenses on the glass cover.

By taking Iraq as a case study, [14] presented experimental and theoretical calculations of solar still system integrated with mini solar pond. They system was designed to distillate water from R.O. rejections which used as a feed to the system. The productivity of the system was investigated and compared in diverse vital climatic conditions. The results showed that on the 20th of May productivity was 0.63 kg, while it was 1.0521 kg at the mid of June, however the highest record was on the 9th of July as it reached to 1.1427 kg.

Based on the literature survey, there is a noticeable lack of research and experimental studies on the applicability of solar still system in the treatment of refinery wastewater. This study presents an experimental evaluation of usage locally designed solar still to treatment the oily wastewater that discharged by a native Iraqi refinery, located at Samawa city in Iraq.

## Location and Conditions of Experiments

In this study, the data collection was taken place in Al-Samawa Technical Institute (ATI) campus, Al-Samawa city, Iraq which is located 280 Kilometers southeast of Baghdad as shown in Figure 3. The latitude of the city on the map is 31.3188 N and the longitude is 45.2806. The site weather climate conditions and solar radiation is shown in Figure 4 and listed in TABLE 1.

**TABLE 1.** Site information and climate conditions (4)

| Meteorological aspect | Value |
|---|---|
| Site location | Latitude 31.3188 N and Longitude is 45.2806 |
| Average climate conditions | • Relative Humidity (highest in January (41 %), lowest in July (10 %))<br>• Temperature (highest in July (46.1 C), lowest in January (18.1 C) |
| Solar average irradiation | • Direct normal irradiation (4.87 kWhm-2 per day)<br>• Global horizontal irradiation (5.471 kWhm-2 per day) |

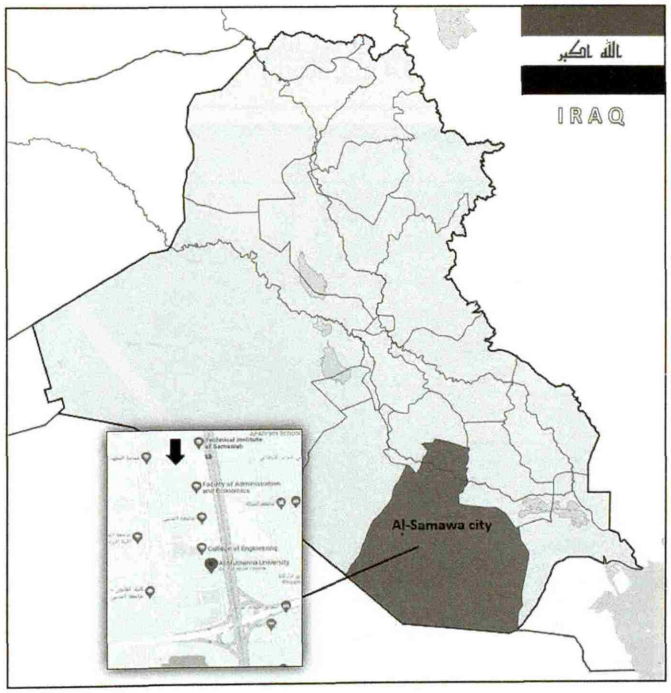


**FIGURE 3.** Experiment's location in Al-Samawa – IRAQ [12]

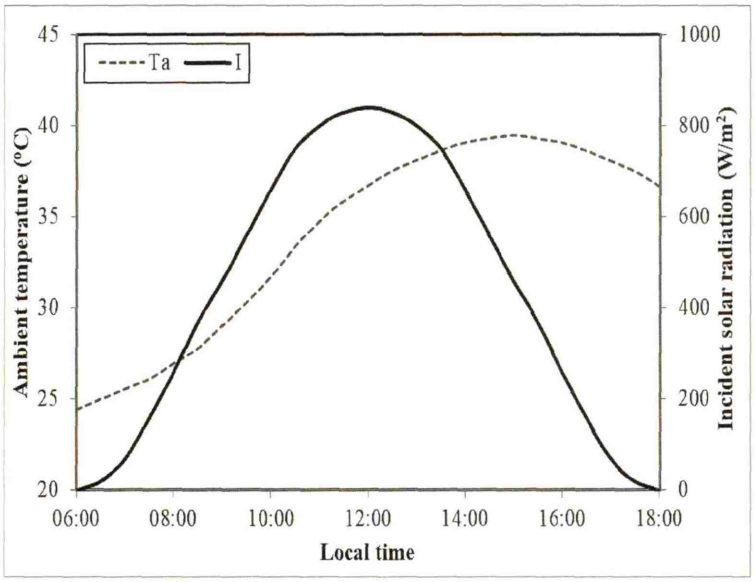


**FIGURE 4.** Hourly verarion of solar radaition vs local time in Samawa city [11]

## Experimental Configuration and Setup

Single slop solar still apparatus was design using PTC Creo 4 software and fabricated to achieve the study objectives. Figure 5, shows a photograph of the of the apparatus. All the parts dimensions are listed in Table 1. The system is a typical solar still consists of a glass window of 0.7 $m^2$ inclined in 35 degrees facing the south; the frame made of aluminum with (1 m length x 0.5 m width x 0.4 m x depth)

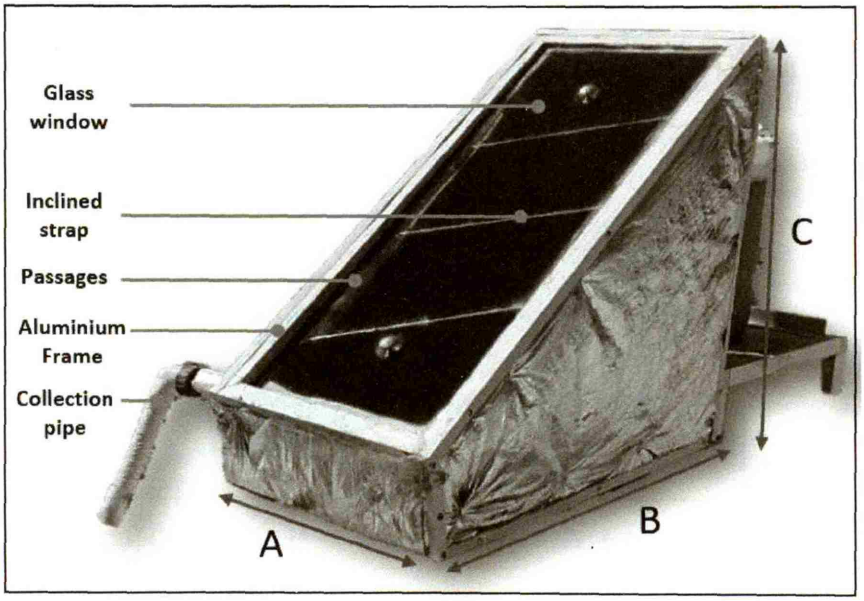


**FIGURE 5.** Photograph of experimental setup of solar distillation apparatus.

The basin dimensions were (0.9 m length x 0.5 m width x 0.15 m depth) and it was painted in black to increase its absorption capability. Two PVC tubes were cut in half and placed in side and bottom of the system to collect the distilled water. The oily waste water storage tank of 20 liters was connected to the system using a valve and pipe. The outlet distilled water is collected in collection tank. All walls of the apparatus were insulated from the environment using fiber wool to prevent heat dissipation and losses from the system. The temperature inside the basin was monitored using k-type thermometer of ± 2 °C. To increase the amount of the system productivity three straps of glass were attached into the glass window as shown in Figure 2. The general layout of the apparatus configuration and parts are illustrated in Figure 5.

**TABLE 2.** Solar still parts dimensions in m.

| Part index | Geometric Parameters | Dimensions (m) |
|---|---|---|
| A | Basin width | 0.5 |
| B | Basin depth | 0.9 |
| C | Distill system height | 0.75 |

## Collecting Data Method

Prior to each test, a regular check-up was made to ensure that the insulation layer around the absorber glass still stands from previous tests. Five different runs at different days. All raw samples were initially tested to obtained its PH, TDS, and other chemical and physical properties. The test starts by feeding the apparatus with raw water by using an inlet valve located at the rear. The basin tanks of the distilled apparatus were filled with 5 L of raw sample. Temperature inside and outside the tank were monitored using K-type thermocouple. Five different readings were taking every 10 minutes and an average reading was considered to achieve better accuracy. The test time was between (10 am – 2 pm) for all runs. The water as shown in Figure 6 was initially condensed on the glass cover than it was guided by three glass straps into the side passages. Finally, the pure water was collected inside the collection tank.

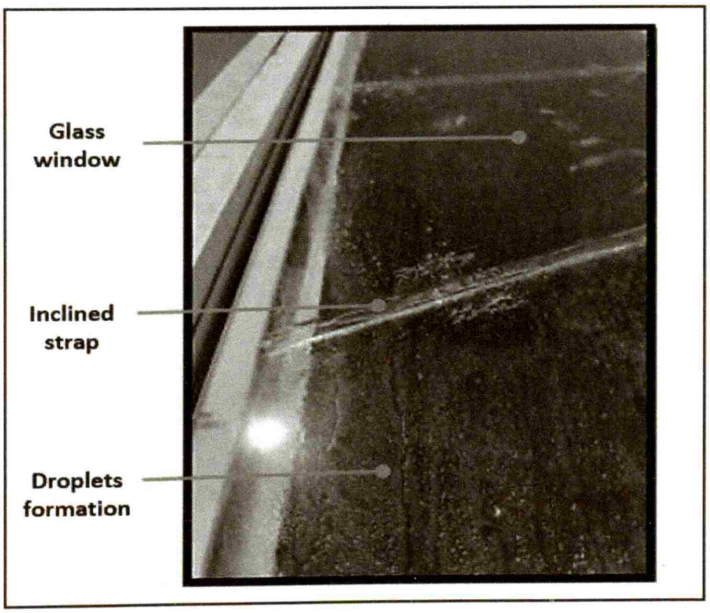


**FIGURE 6.** Photogrph of droplet formation and condensation process on the absorber glass

## RESULTS AND DISCUSSION

### Solar Still Apparatus Temperature Measurements

Figure 7, shows the temperature measurements inside the still basin in period of time between (10 AM -14 PM). As illustrated below the temperature is increasing gradually inside the tank to reach the maximum at around 13:05 PM to an average value of 58.6 C, then it decreased slightly due to the inclination of solar radiation beam. The apparatus was able to keep the basin's temperature above 55 C for the period of time between 11:45 AM to 13:45 PM, resulted in more productivity of the distilled pure water.

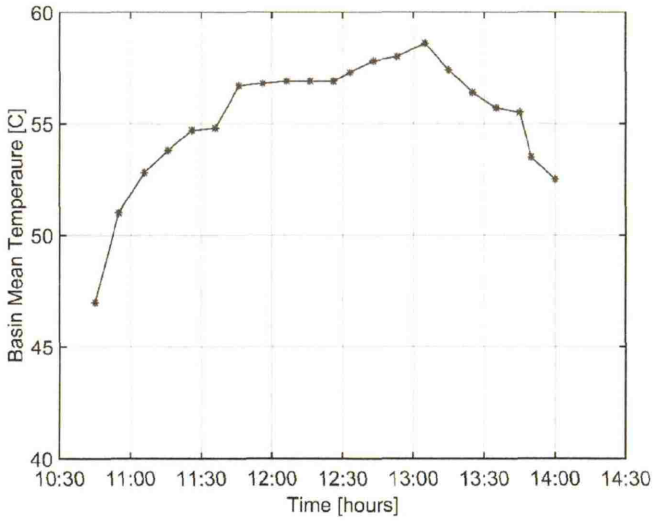


**FIGURE 7.** Temperaure measuremnts of basin mean vs time in hours.

### Oily Waste Water Sample Experiments

In this study, the importance was paid to apparatus units to treat environmental pollutants and recyclable materials with the simplest possibilities and the lowest costs to apply on wastewater refinery. The characteristics of the wastewater in the refinery such as total dissolved solids (TDS), pH, and other chemical and physical properties are shown in table 3.

**TABLE 3.** Properties of refinery wastewater

| Parameter | value |
|---|---|
| TDS | 2440 ppm |
| Turbidity | 59.4 NTU |
| pH | 8.34 |
| Dissolved oxygen content | - |
| density | 999 kg/ $m^2$ |
| conductivity | 2843 µs/cm |

## The Effect of pH

Through the intention of scientific and practical, the importance of pH on the performance of the treatment of wastewater procedure, investigations remained presented by pH of 2 to 9. The organic removal increased with the decreasing pH, through the method of exposure to solar radiation and high weather temperature, the percentage of removal of dissolved solids and organic materials is high, as the pH value gradually decreases in the direction of acidity. As well as the content of oxides and basic compounds associated with organic and inorganic salts. It is worth noting the change in color towards the high purity of the water from yellowy heavy oily color to colorless and clear water as shown in Figure 8 and Figure 9.

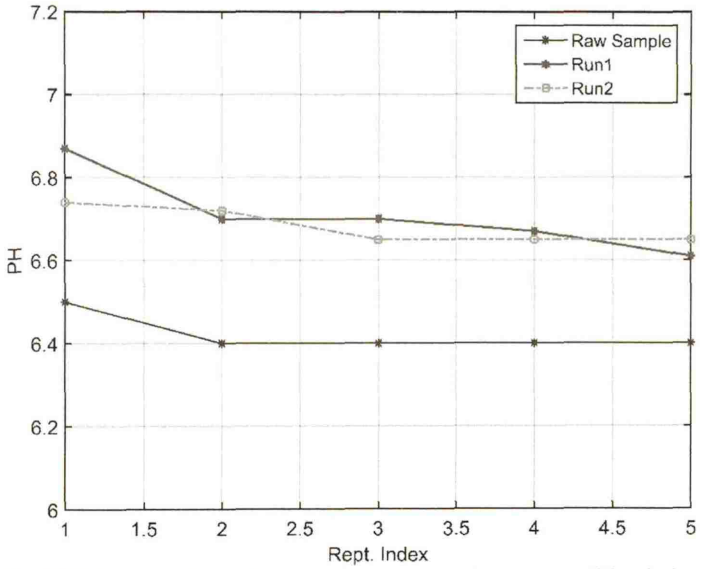


**FIGURE 8.** The relationship between the pH index and repetition index.

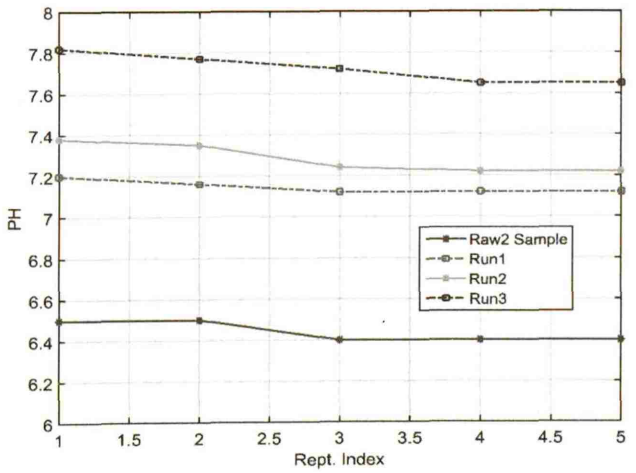


**FIGURE 9.** The relationship between the pH index and repetition index.

in the above figure shows the direct relationship between time and the gradual pH change, where the greater the distillation time, the greater the efficiency of separation and extraction of impurities and organic and inorganic emulsions because of the process is carried out at a rate of temperatures lower than

the degree of total evaporation of water, which makes it difficult to evaporate the impurities and emulsions associated with the water molecule.

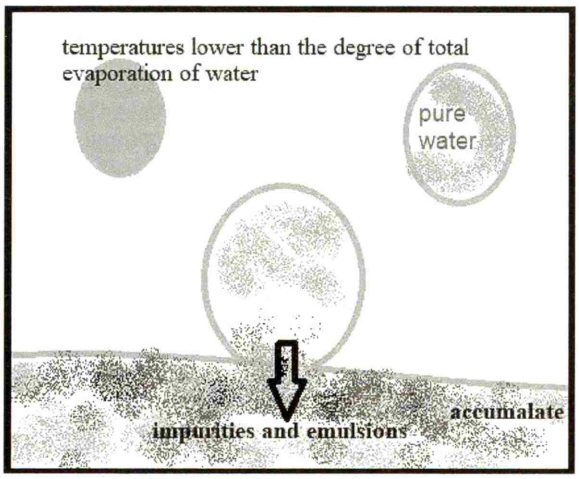


**FIGURE 10.** The condensation Phenomenon inside the solar still

## The Effect of Total Dissolved Solids (TDS)

It represents the amount of organic and inorganic substances and salts dissolved in water. Therefore, it is considered an important criterion in measuring and determining the quality of water after treatment. A high effect on the value of TDS was observed when using this method, a solar energy treatment Apparatus and getting rid of all emulsions and solid particles in wastewater, where the removal percentage reached 99.1%, and this reflects the effectiveness of the Apparatus and the method used. Where it Show in from the samples that were produced from the distillation process of two types of raw materials inside the apparatus, and it was shown that the separation efficiency increased by increasing the residence time and the extent of the water's exposure to solar radiation and the internal heat reduced in the apparatus. The blue curve corresponds to the results of the first crude samples, and the red curve is the results of the second crude samples, and a very high removal rate was observed, even though the process conditions occurred in November as shown in Figure 11 and Figure 12.

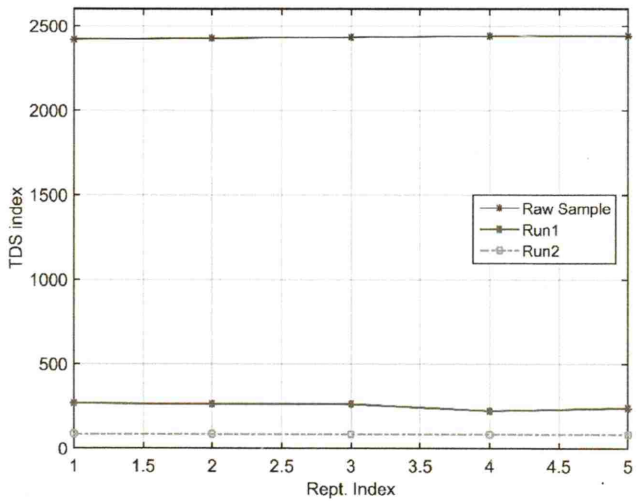


**FIGURE 11.** Variation of TDS index values with different repetition index. Results of RAW1 samples.

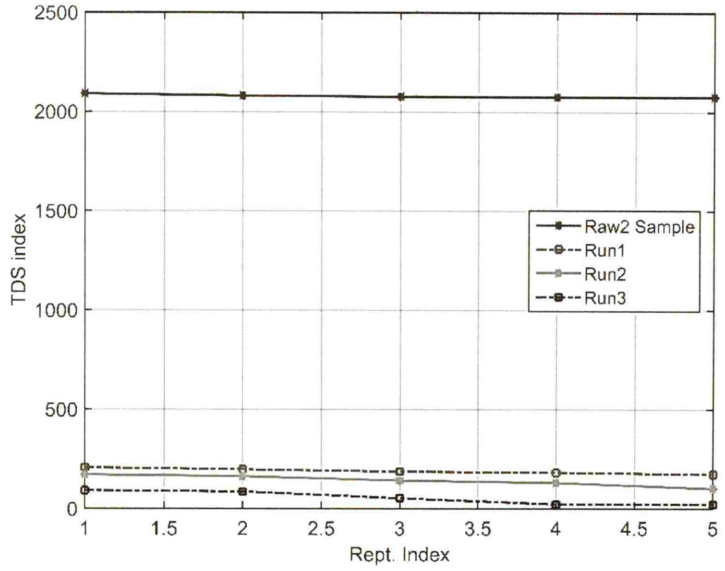


**FIGURE 12.** Variation of TDS index values with different repetition index. Results of RAW2 samples.

And when all the results were taken, the initial represented by the raw characteristics and the final (the last sample that was tested) seems the steepness of the curve by a large decline This difference is how effective the treatment process is from the first sample and gradually to reach the highest removal rate as shown in the figure 13 and Figure 14.

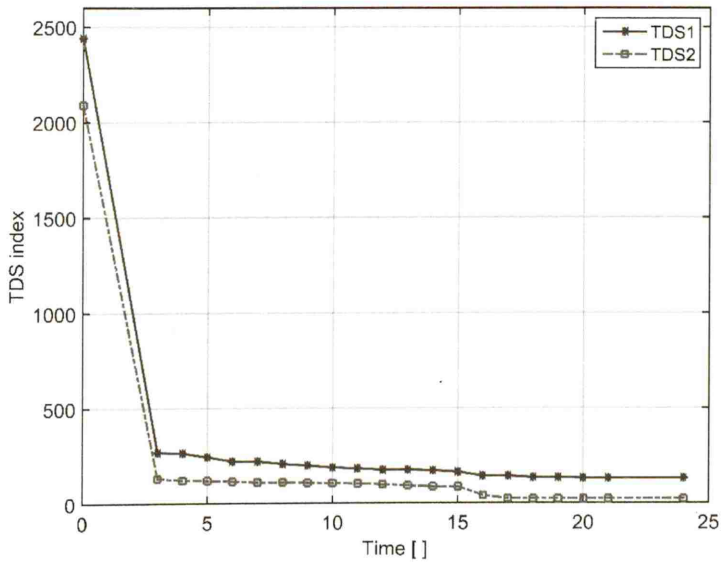


**FIGURE 13.** The Overall Relationship between the Initial to The final results TDS index and Time.

## Effect of Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Because dissolved salts and other inorganic chemicals conduct electrical current, conductivity increases as salinity increases. Organic compounds like oil do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. From the measurement of the conductivity of the raw wastewater refinery entering the apparatus and the results of samples, it is shown in the Figure 14 and Figure 15.

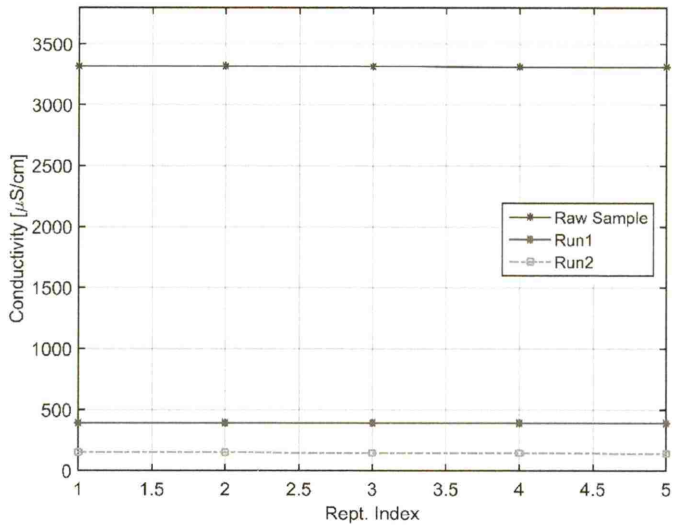


**FIGURE 14.** Raw1 samples; Variations of conductivity with different repetitions of different condensates.

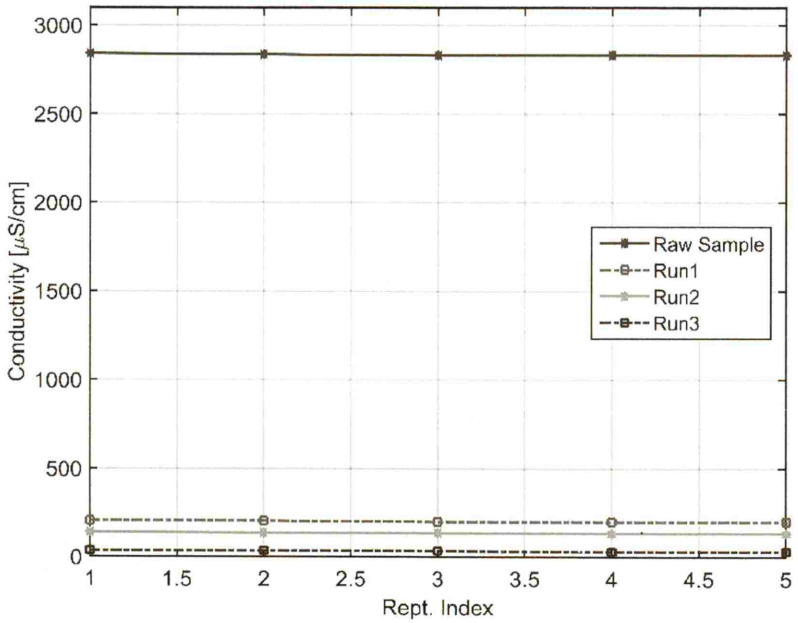


**FIGURE 15.** Raw2 samples; Variations of conductivity with different repetitions of different condensates.

## CONCLUSION

In this study has been investigated that the use of solar energy to an effective wastewater treatment remediation of oil content bearing refinery wastewater by directly connecting the Distillation and Stripping processes that occur due to thermal reduction of solar energy future the using of solar energy to treat dissolved solids and organic from oily wastewater It is considered a qualitative leap in the adoption of alternative energy in oil refineries. Lastly, the operating conditions were improved and obtainable to attain the finest removal quantity of organic reduction. The mathematical associations originate have high regression coefficients aimed at altogether the thoughtful replies, which demonstrates the satisfactory alteration of the polynomial second-order model. The premium organic elimination (98%) remained got a pH of 5.3, and 99.1% inorganic removal this technique can be future as a relaxed method to refinery wastewater conduct.

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