Fresh Water Generation from Saline &Contaminated Textile Wastewater using an Active Solar Still Coupled with a Solar Pond System

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Adnan Tariq

I would like to dedicate this work to parents for their efforts, my supervisor for being a constant inspiration and motivation, and my friends for their encouragement.

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SGSP	Salinity Gradient Solar Pond
NCZ	Non Convective Zone
UCZ	Upper Convective Zone
LCZ	Lower Convective Zone
PLDE	Low Density Polyethylene
CCL	Compacted Clay Liner
GCL	Geo-membrane Clay Liner
PVC	Poly Vinyl Chloride
NTU	Nephelometric Turbidity Unit
RO	Reverse Osmosis
MBR	Membrane Bio-Reactor
NF	Nano Filtration
ED	Electro Dialysis
VCD	Vapor Compression Distillation
MED	Multi-Effect Distillation
MSF	Multi-Stage Flash Distillation

ABSTRACT

More than 70 % of the available water in Pakistan is unsafe for drinking purposes as per WHO guidelines. The situation is alarming in Sindh and southern Punjab, as the TDS level of more than 57% of raw water is greater than 3000 mg/L and 14.7 % have the TDS within the range of 1500-3000 mg/L. The unavailability of energy efficient water treatment technologies makes the water purification more difficult. Pakistan has an average of more than 10 hours of sunshine throughout the day of 5-7 kWh/m^2 insulation.

This study was conducted to harness the solar energy potential of Pakistan, using the solar stills coupled with a solar pond system, to device a reliable, clean and cheapest alternative technique to provide safe drinking water to the arid regions.

For the designed system, the feed water having the TDS within the range of 1500-5000 mg/L showed an overall TDS removal efficiency of 99%. The coupling of the solar still with solar pond increased the yield by 45%, which was almost doubled when the temperature difference between the coolant and solar still was greater than 20˚C. A maximum yield of 16 liters per day of treated water was obtained which is equivalent to the requirements of a normal size household.

In the solar pond, the feed water was pre-heated to a maximum of 37˚C using solar radiations. The solar pond was continuously run for a period of six weeks, using different composition of salts. Three thermal gradient layers were established using NaCl salt and a combination of NaCl & $MgCl_2$. A combination of NaCl & $MgCl_2$ pond was able to retain more thermal energy. The treatment performance of the proposed system was also monitored on the textile wastewater having the COD, BOD_5, TSS and TDS of (1212, 658, 2218 and 268) mg/L respectively. A positive trend in the removal of all the parameters was

observed, the COD dropped from 1212 to (42, 36 & 74) mg/L in three completed runs. An overall removal of 85% was observed in chlorides, 76% in fluorides, 95% in ammonia and no heavy metals were detected in both, the feed and product water.

Chapter 1

INTRODUCTION

1.1 Background

In Pakistan, the per capita water availability has already been reduced to less than 1000 m^3 per capita per day, making it a water scarce country (UNDP Report, 2016). Excessive population and industrial growth, enhancement in agricultural production and excessive water consumption due to modern lifestyles have led to an imbalance between the demand and supply of fresh water globally. The situation in a country like Pakistan is worsen by the fact that the sources of fresh water available to around 80% of the total population are contaminated with sewerage, being the primary cause, and toxic chemicals from industrial and domestic effluents, agricultural run-off carrying pesticides and the illegal dumping of hazardous solid waste . According to UNICEF report, 40 % of the total patients in Pakistan suffer from water borne diseases. 16 million people in Pakistan suffer from water borne diseases and around 3 million are consuming water from unsafe water sources (UNDP Report on water and sanitation, 2018).

Study of Pakistan Council of Research in Water Resources (PCRWR) reveals that the major cities of Pakistan would suffer drought conditions very soon due to rapid depletion of ground water resources and rising salinity level. With the annual population increase of 3.2 % and inadequate reservoirs to store water, Pakistan is expected to face a water shortage of 33 MAF by the year 2025 according to a UN report. (UNICEF report, 2011).

The Total Dissolved Solids (TDS) level in 57.5 % of the available water sources in Sindh, Pakistan is more than 3000 mg/L and 14.7 % have the TDS within the range of 1500-3000 mg/L which collectively make more than 70 % of the available water unsafe for drinking purposes as per WHO guidelines (Mahessar et al., 2019).

Conventional techniques for desalination of water can be classified as thermal and membrane desalination. Thermal distillation uses multi-stage flash (MSF), multi-effect distillation (MED) and vapor compression distillation (VCD). The membrane distillation consists of reverse osmosis (RO), nano filtration (NF) and electro dialysis (ED). (Fritzmann et al., 2007).

The salts are removed from the water via evaporation-condensation method in thermal distillation. The membrane techniques utilize a membrane through which the water is forced to pass through and all the salts are retained by the membrane.

However, both these techniques have a set back as these require a large amount of energy (Mowla and Karimi, 1995) and are not cost effective for areas like Pakistan because of the unavailability of energy. According to Bouchekima et al. (1998), improvements made in the solar distillation technology has made it an ideal technique for the desalination of water in the remote areas where the demand of water is less than 50 m^3 per day.

Pakistan has an average of more than 10 hours of sunshine throughout the day of 5-7 kWh/m^2 insulation (Ibrahim et al., 2003) as shown in figure 1. In the figure, different regions in Pakistan are divided depending upon the amount of solar radiation they achieve in a period of 24 hours. This solar energy can be harnessed, using the solar stills coupled with a solar pond system, to device a reliable, clean and cheapest alternative technique to provide safe drinking water to the arid region. Solar ponds are an effective way for storing salt water and utilizing solar energy for capturing heat by salts which can be further used using a heat exchanger.

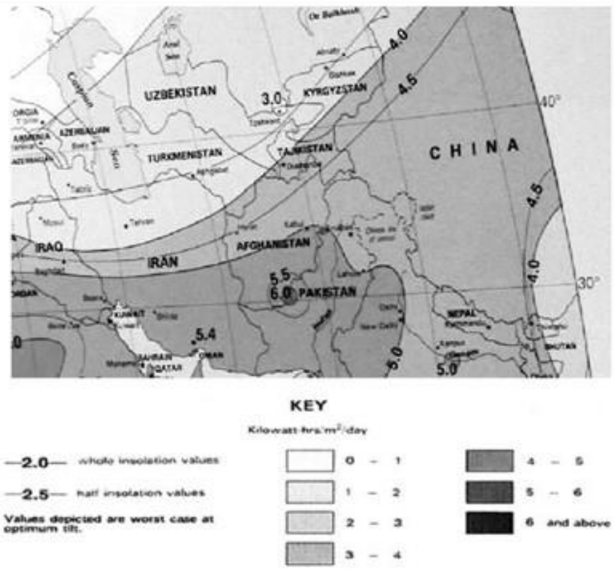

Figure 1. Solar insolation map of Pakistan (Courtesy) of Advanced Energy Group, (http://www.solar4power.com).

1.2 Aims and Objectives of the study

The purpose of the study is to propose a low energy treatment technology for the rural areas of Pakistan and to increase the amount of the distillate from solar still by pre-heating the feed water using a salinity gradient solar pond (SGSP) and to check its treatment performance on textile wastewater. In accordance with this, following objectives of the study were identified:

- Design, installation and operation of an active solar still
- To study the system's efficiency by coupling it with a solar pond system

- To study the effect of different composition of salt on the temperature profile of solar pond
- To study the treatment performance of the system on colored textile wastewater

1.3 Significance and Novelty

The study is based on pilot scale Salinity Gradient Solar Pond coupled with solar still in Pakistan. Following considerations make the project significant and novel:

1. Zero-discharge system: The system will be a zero-discharge system. It encourages the waste brines from industrial applications to be utilized for heat extraction in a solar pond. The heat extracted by the raw feed saline or contaminated water will increase water vapor evaporation capacity and ultimate extraction of pure water. The concentrate/reject from solar stills can be used as feed again for solar pond in case of saline feed water. The reject of contaminated wastewater can be utilized for dye and heavy metals recovery.

2. Easy Up-scaling Potential: The system can be easily upgraded to enhance the distillate production by installing multistage stills.

3. Experimentation with Textile wastewater: A new aspect of the study is the contaminated wastewater treatment using solar stills. No previous research has ever been conducted on this aspect.

The research project has been fully funded by US Pakistan Center for Advanced Studies in Energy, (USPCAS-E), NUST.

1.4 Scope

The study is conducted to develop a pilot scale unit for the production of fresh water from saline and contaminated textile wastewater. The research will propose a solution for the drinking water availability for the people in South Punjab, Sindh and Baluchistan region of Pakistan.

1.5 Advantages and Applications

Desalination is the separation of salts from water to make it fit for drinking purposes. About 90 percent by volume of global desalination, thermal and membrane desalination technologies are used worldwide. One such promising technology is Solar Distillation, which is a simple process to evaporate the vapors, which are condensed to get the pure water. Solar Stills can be installed at household level as well on commercial level. Solar Stills are a suitable option for the saline regions in Southern Punjab and Sindh to get pure water. The treatment of contaminated water will enable the industries to treat their wastewaters with this simple and cost effective technique.

SGSPs have the capability to capture and store solar energy, which can be extracted and used for different purposes. Thermal energy stored in the solar ponds has been utilized for better quality salt production, aquaculture (using saline or fresh water to grow fish or brine shrimp), dairy industry to preheat feed water to boilers, fruit and vegetable canning industry, fruit and vegetable drying, grain industry for grain drying and production of drinking water through desalination process. One such successful application is the establishment of a 6000 m^2 solar pond at Bhuj in India near a milk processing dairy plant. Hot water was supplied from the pond to the dairy (Gawade, 2013).

Another advantage of solar ponds is that these technologies utilize a waste product from different industrial processes, which is the reject brine, as a basis to build the salinity gradient. The heat storage of solar ponds is massive, so it can be extracted day and night and during periods of cloudy weather.

Chapter 2

LITERATURE REVIEW

2.1 Site Selection

The initial step towards the installation of a solar still coupled with a solar pond is the selection of a proper site. The major factors considered before the site finalization are:

1) Climate
2) Topography
3) Soil conditions

2.1.1 Climate

The system is to be placed in the area of maximum solar radiations exposure. Also, the disturbance caused by the winds has the potential to damage the gradient of the layers established in the solar pond. So, the solar pond is to be protected from such harsh climates. Moreover, the debris and other particles may deteriorate the clarity of the water in the solar pond as a result of surface run-off generated after rains. To cater for all these problems, the solar pond is built above the land surface and the covers, which also served as external reflectors during the time of radiations exposure, are used to protect the established layers from harsh weather conditions.

2.1.2 Topography

The land where the solar still coupled with the solar pond system is to be placed must be flat in order to ensure that the layers established in the solar pond as a result of different concentration of the salts deposited in each layer must not be disturbed. Moreover, the flat surface will also ensure the same level of water depth across the solar still. This depth of water in the solar still is directly related to the amount of water vaporized in the solar still.

2.2 Liner

Different types of liners have been used in order to ensure that the thermal energy of the solar pond is retained. A black liner is accepted widely and used by multiple solar ponds in order to harness the solar energy. (Hawlader, 1984).

A liner having the texture of Nylex solid vinyl having a thickness of 0.75mm was applied on the solar pond built in Indian Institute of Technology, New Delhi. Blue color liner was used with the purpose to minimize the effect of reflection. Moreover, with time, dust and debris begin to pile up over the liner which can prevent the liner from getting damaged by the intensity of heat of the solar radiations. (Kaushika, 1984).

The plastic liner can increase the cost up to 25 %. For this purpose, Clay, which is also locally available, can be used. The overall cost of the product water is directly related to the cost of liner and the salt used and an expensive liner and salt has the tendency to take the cost up by 15-30%. The cost of thermal energy can be increased by 10-13 %. The life of the solar pond is dependent on the kind of liner used which can increase the life and durability of the SGSP to 30 years. (Agha, 2009).

Other options for the liners are clay. Clay also reduces the construction cost. Cheap plastics, sandwiched between the clay, have also been used a liner in a solar pond constructed in Israel having a total area of 40,000 m^2. Low density polyethylene (PLDE) is another cheap option but it has to be compacted with layers of clay on either side prior to its use. The major advantage of using PLDE is its high rigidity. The compacted clay liners are also an option but it is difficult to build them up. There is also a possibility of cracks in these compacted clay liners during their build up.

The compacted clay liner (CCL) are preferred over geometric clay liner (GCL) due to their less cost, durability and resistivity to puncture and cracks. (Silva & Almanza, 2009)

In last twenty years, El-Paso has used the following three liners:

- XR- 58130,
- GCL
- Polypropylene Liner.

El Paso was the first one to use the clay liners made up of geo synthetic clay. In these liners, PVC is used to cover the layer of plastic which is already wrapped in the polyester membrane. This GCL liner had a life of only two years but it could be recuperated by a thickness of 0.1 cm. 0.15 cm thick polypropylene liner was used along to recuperate the bond.

Since 1970's, a polyester fabric coated in PVC has been used a liner in ponds. This is called XR-5 liner. This was used in El-Paso after coupling it with a hypalon liner. The liner had a life of seven years against the projected life of 20 years. The major reason of its failure was its inability to with stand high temperatures. It turned brittle after getting heated up and the hence the material lost its strength by approximately 10%. (Malik, Date, Leblanc, Akbarzadeh, & Meehan, 2011)

2.3 Gradient Establishment

2.3.1 Salts used in Solar Pond

Sodium chloride salt and magnesium chloride salt are commonly used in the solar ponds to entrap the heat energy in the layers of increasing salinity. Magnesium chloride is the waste product of fire extinguishers, paper, cement and fire proofing industry. On the other hand, sodium chloride is the commercial product, and has to be procured. Both the salts establish a gradient of high stability. The 1200 kg/m^3 can be obtained by using an aqueous solution of NaCl and a density of 1300 kg/m^3 can be obtained using the solution of $MgCl_2$. (Chinn, Akbarzadeh, & Dixon, 2008).

The salt, which is recovered from the sediments deposited in both the solar pond and the solar still, can also be reused and re-injected in to the bottom layer of solar pond to maintain the required salinity level. This reduces the cost and at the same time, the environmental impacts.

2.3.2 Gradient Establishment Methods

In a solar pond, the layers of different gradients can be established by different methods. These include (El-Sebai, Ramadan, Aboul-Enein, & Khallaf, 2011):

- Redistribution
- Falling
- Natural method
- Stacking

2.3.2.1 Redistribution

The redistribution method is mostly used for larger ponds. The salt solution having the homogeneous concentration salt is prepared and fresh water is added up to a certain level to dilute the salt.

The solution of the salt having the density greater than that of water is used to fill hald of the pond. The water is then added with the help of the diffuser. The diffuser, starting from the bottom of the pond, is continuously being raised up in steps. To ensure the establishment of uniform gradient, the diffuser and the water surface must reach the end level at the same time and for that, the time and height intervals are adjusted.

In Tunisia, an experimental pond was filled by using this method. The diffuser was placed at a height of 40 cm from the bottom initially. With the intervals of moving the diffuser up by 2 cm, the freshwater was injected as the increment in the water level in the pond reached 1 cm. The process was stopped at the height of 88 cm and by using this method, 88cm thickness of NCZ was observed. (El-Sebai, Ramadan, Aboul-Enein, & Khallaf, 2011).

Zangrando’s method was also used for the RMIT solar pond. The flow patterns were observed by conducting an experiment with a solution of $MgCl_2$ before the gradient establishment. The observed flow pattern was semi circular horizontal. Froude number can be a helpful tool to further classify the kind of flow that originates from the diffuser. (Chinn, Akbarzadeh, & Dixon).

In accordance with Zangrando’s, the injection was best suited at 0.05m. This means that the height of the diffuser is increased when the level in the pond increased by 0.05m.

Zangrando increased the height of diffuser by 0.1m. In this way, the surface level of the pond is increased and the solution of the salt which is above the diffuser is also diluted.

By using the Froude number, one of the most important parameter to ensure the proper mixing of the solution above the diffuser is determined. Froude number is the ratio of inertia with the buoyancy forces. As per the findings of Zangrando, the best results are obtained when the Froude number is maintained at 15. (ZANGRANDO, 1980).

2.3.2.2 Falling Method

In falling method, a hot solution of the salt is taken from the bottom of the layer without causing any disturbance to the layers above. This withdrawn hot solution is passed through an evaporator which evaporates the water from the solution leaving behind the solution having a greater concentration of salt. This concentrated salt in the less volume of water is injected again into the bottom of the pond. The volume of the water lost is added in the top surface layer by the addition of fresh water to it.

Falling method includes withdrawal of hot salt solution from the bottom layer without disturbing the layers above. The hot solution is then passed from an evaporator to evaporate some of the water. The solution left contains a higher salt concentration in a lesser volume of water. It is re-injected to the pond bottom is removed water is compensated in the surface layer. Loses from evaporation are also compensated by adding fresh water to the top layer.

2.3.2.3 Natural Method

Naturally, a gradient is established by using a diffusion process. The salt is added at the bottom to maintain the concentration in the bottom layer and top layer is washed regularly to maintain the concentration at the top. This method is well suited for larger solar ponds and it needs a lot of time for gradient establishment.

2.3.2.4 Stacking

Successive layers of decreasing concentration are made on top of each other with decreasing concentration of the slat. The bottom of the pond has the highest concentration of salt. The top layer is filled with the water of least density or the fresh water. The turbulent mixing and the molecular diffusion generated as a result of the turbulent mixing changes the profile into almost linear. With time, the layers adjust themselves to form three consecutive layers of different salt concentrations.

In turkey, a solar pond was made using sodium carbonate salt. In this pond, the gradient was established by using the above mentioned method. Brine, with high concentration of salts, was used to fill the LCZ. A floating can of plastic was used to fill the NCZ in five successive layers. A solution of lesser density was used for the NCZ and in the same way, fresh water was poured using the floating can to fill the UCZ. (Kurt, Ozkaymak, & Binark,2006).

2.4 System Maintenance and Controlling

The system is to be monitored regularly for successful operations. The parameters which must be monitored on daily basis are temperature, height and specific gravity of each layer in case of solar pond. For solar still, the temperature inside the solar still, glass angle of the top glass surface and cleaning of the glass surface to ensure the maximum transmittance of incoming solar radiations are the main factors.

El paso solar pond used the scanner technology and a data logger, which was controlled by a computer, to observe the temperature, turbidity, pH, and density of the solar pond.

The pond at pyramid hill having an area of 3000 m^2 obtained the data from a weather station for solar radiation, direction and speed of wind, ambient temperature, relative humidity and precipitation. A computer connected to the weather station collected the data. Thermocouples, installed at different heights, determined the pond temperature. Nephelometric Turbidity Unit (NTU) method was used at the two RMIT solar ponds to determine the turbidity.

For proper working of the solar pond, the water present in the solar pond must be cleared. Due to stagnation in the solar pond, algae and other bacterial growth is found in the solar pond with time. The color of water in the pond can clearly tell us about the colony of microorganisms present in the pond.

The algae can also be formed in the solar pond due to excess of nitrogen and phosphorus. This bacteria and algal growth will prevent the sunlight from reaching the bottom of the pond and will have a negative effect on the overall treatment performance of the solar pond.

These methods which can be used to control the microbial and algal growth are:

- Acidification
- Filtration
- Chlorination
- Algaecide addition

The method used by El paso was the addition of acid followed by polymerization and then saturation. The bacterial growth was controlled by using HCl. Acid was used after the dilution and the pH was maintained.

The following method was adopted for the addition of acid:

2.18ml of HCl → to make 4.5ml of diluted HCl

A flow rate of 0.15 m/s was maintained while adding the acid.

Experimental studies show that the pH must be less than 4.5 to ensure that there is low turbidity and HCl has been the most effective of all the available techniques and methods.

According to N.Kaushika, 10 ppm copper sulphate can be added while filing the solar pond to prevent the growth of algal and biological growth.

Covering of the pond from the top is also to be ensured to protect it from the external winds. The SGSP constructed in Ohio state university was the first solar pond to be covered using floating grid PVC pipes. In Australia and Israel, baffles have been used too to increase the resistance to the air movement.

Floating rings which were made up of polyethylene were used by El Paso in his solar pond. This reduced the mixing of the surface which was caused by the winds. Pyramid hill pond utilized the strips made floating rings. Cable ties were used to attach the rings with each other and couple them with the PVC tubes. Ropes kept these rings in position.

2.5 Reflector

The amount of the solar energy trapped in the solar pond is directly related to the amount of solar radiations that the solar pond is exposed to. Studies show that the area exposed to the solar radiations can be increased by using the reflectors which as a result increases the overall efficiency of the solar pond. In simple words, the potential of the heat energy which can be extracted is increased as more energy will be trapped now. The covers at the outer end of the pond can also be utilized for the extraction of more energy and to achieve the maximum efficiency of the solar pond, the use of covers and the reflectors in combination is recommended.

The reflectors can be of various types. A study conducted at Egypt (Assuit University) concluded the direct relationship between the yield and reflectors of the solar pond. The reflectors used in the Assuit pond were made up of a wooden material covered in the aluminum foil hinged with the side walls of solar pond and have a planar form. The same assembly is being used to cover the pond at the night time. Aluminum sheet reflects the maximum sunlight in the solar pond. The wooden material wrapped in the aluminum sheet was cut into 2m x 1m long sheets and attached along the total length of solar pond.

Depending upon the position of the sun, the outer reflectors are also adjusted to make use of the maximum heat energy. Proper models have been established to determine the proper numeric value of the tilt angle that is to be provided to the external reflectors. After a certain value of the tilt, no further loss or gain of the heat energy takes place with increasing the tilt angle of the reflector.

During winter seasons, the tilt angle is usually greater than the summer months due to the position of sun. After identifying the optimized tilt angle, a reflector was fixed at that angle. The tilt angle for the winters was 94 degrees while it was 67 degrees for the summers. The optimum angle which gave the best results all across the year came out to be 83 degrees. According to the pond constructed in Infant Jesus College of Engineering, the use of mirror as external reflectors can be highly beneficial. (Velmurgan & Srithar, 2008). By utilizing the tilt angle of the reflective mirror in the planar form, there is no need to improve the orientation of the solar pond.

In Turkey, a study conducted by Nalan C. Bezir and his team further investigated that the collapsible form of external covers can serve as the reflectors as well as lower the thermal heat energy losses during the rainy days and night times. During the rainy days and the night hours, the reflectors were serving as the covers and these were used to contain the heat energy while during the day times the same reflectors were used to divert maximum amount of the heat energy in to the solar pond.

The reflectors can be coupled with an electric motor to rotate them between 0 to 180 degrees. An overall increase of 25% was achieved by using these reflectors coupled with the solar pond system (Bezir, Donmez, Kayali, & Ozek, 2008). Different simulation were conducted where one of the reflector was fixed and the other was moving, in another simulation both the reflectors were fixed momentarily and in another one both the reflectors were moving to get the optimized results. An increase of 10 degrees was achieved by using these different simulations (Bezir, Donmez, Kayali, & Ozek, 2008).

Chapter 3

METHODOLOGY

3.1 STUDY AREA

3.1.1 Location

The pilot unit is installed near NUST MBR Plant located at National University of Sciences and Technology (NUST), in the city of Islamabad, Pakistan. It is located at 33.25^{o}N and 72.99^{o}E at an elevation of 547 m as shown in Figure 2. The google maps location of the site has been attached under for the reference. It was ensured that no shading occurred on the system due to the presence of NUST MBR plant in the near vicinity.

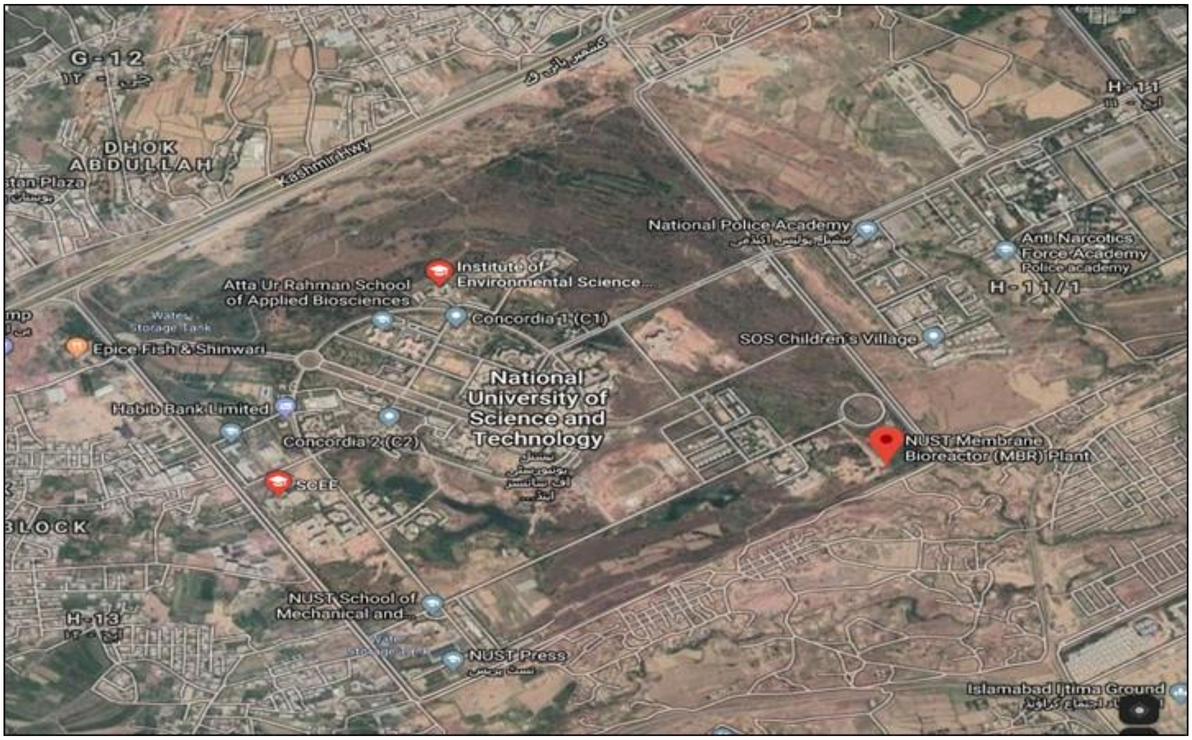

Figure 2. Google Maps Location of proposed site

3.2 Pond and Still Instrumentation

3.2.1 Temperature Measurement

The most important parameter to be monitored in the solar pond and solar still is Temperature. The temperature achieved across different layers of solar pond will give us an idea about the maximum temperature to which the water flowing the heat exchanger can be pre-heated. In this study, to measure temperature at different heights of the pond, Ten K-type thermocouples were used having the range of 0-1200^{o}C. These thermocouples were placed vertically in the observation glass at the distance of 6 inches in between so that the temperature in all three successive layers could be monitored.The measuring tip was placed towards inside of the pond while the wire was placed in the observation and measurement compartment. For reading the temperature values, digital meters were used.

For the solar still, a single thermocouple was installed at a height of 12 inches from the base of solar still and was connected to the digital meter to display the temperature inside the still. This temperature was indirect parameter to measure the amount of fresh water vapors travelling into the condenser.

3.2.2 Gravity Measurement

To measure the height of the three successive layers of the solar pond, specific gravity was measured by using three hydrometers having range of:

- 1.000-1.100.
- 1.100-1.200
- 1.200-1.300

The accuracy of hydrometers reached up to 0.001.

3.2.3 Sampling points

A total of 10 sampling points were fitted in the solar pond using the VPC valves to avoid corrosion. The sampling points were used to take the samples to measure the specific gravity of the different layers of solar pond at each step.

3.2.4 Diffuser

Solar pond must be filled without any disturbances in the top surface to develop three successive layers of increasing salinity. A Diffuser was designed, considering the Froude number equation, for this purpose. The diffuser had two Semicircular disc separated by a constant slit width. The discs were made of metal plates separated by nuts of width 2mm as shown in the Figure 3. The hole was punched in the upper disc which was welded to a pipe. Dimensions of the diffuser were calculated. Flow rate required for the density gradient to be established from fixed injection technique was calculated through a Froude

Equation. Based on the Flow rate available of up to 40l/min, the slit width was kept at 0.003 mm as calculated by the Froude equation. The diameter was calculated to be 0.35m as shown in Figure 3.

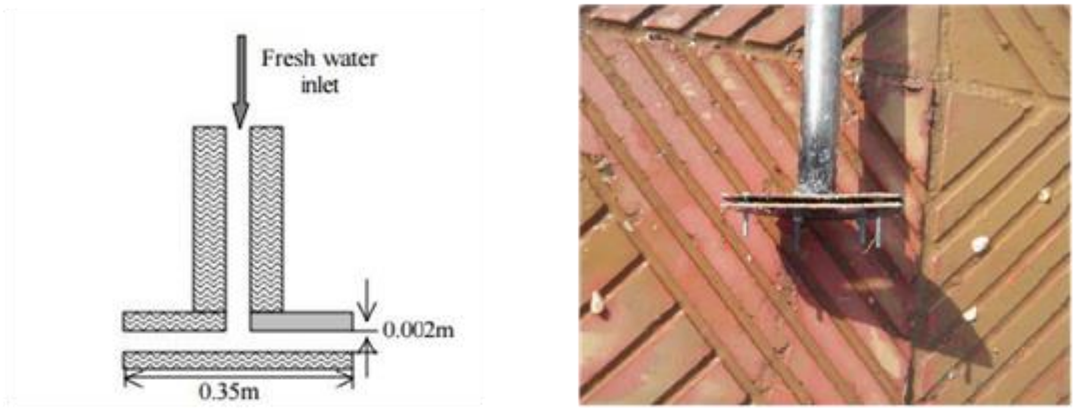

Figure 3. Injection Diffuser

3.2.5 Phase 1

In phase 1, brackish water was prepared by the addition of salt in the water and using the diffuser for injection, solar pond gradient was established and optimized at different salt concentrations. For this purpose, the salt solution was displaced in the Solar Pond with different concentrations at different depth through diffusion method. The solution was allowed to settle down and gradient was formed after 3 days with three successive layers. Daily monitoring of temperature and densities of constituent layers at 10 depths was taken. After the successful gradient formation, clear water was passed through the heat exchanger coil at three flow rates i.e. 3.5 l/min, 5.5 l/min, and 7.9 l/min to find the optimized flow rates for the heat exchange without a significant drop in storage zone of solar pond.

3.2.6 Phase 2

In the second phase, solar distiller was installed and operated under the daily sun intensity. The distillate yield was calculated without pre-heating effect after directly directing the saline feed water into solar still tank and noting the still's efficiency. After that, the feed saline water was preheated by coupling the solar still with solar pond as shown in figure 4. The feed water was passed through the heat exchanger of the solar pond and then directed into the solar still. This pre-heated water from the solar pond, upon direct heating via sun light in the solar still, was converted in to the vapors. A fraction of these vapors were collected on the glass surface of the solar still as distillate, as illustrated in figure 4, and the remaining entered into the condenser where they were condensed using fresh water as the coolant.The resultant increase in distillate yield was observed and compared.

The last step was the introduction of raw colored textile wastewater into the solar still after pre-heating through the solar pond and checking the distillate quality and quantity. After testing the distillate quality, necessary post-treatment, if required, will be recommended for further studies.

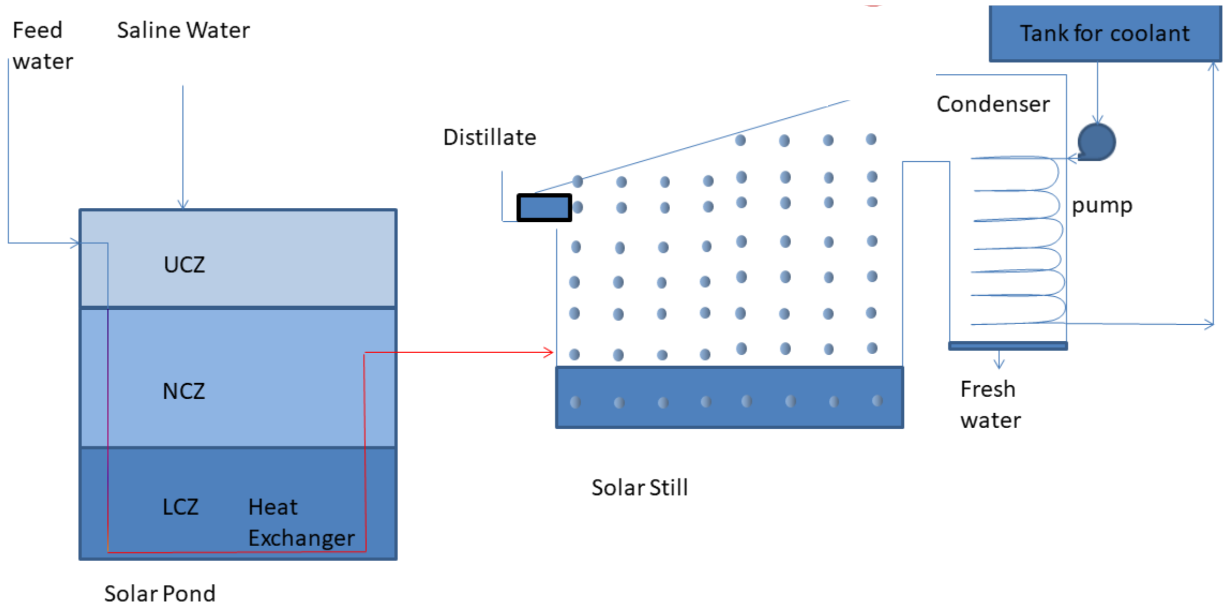

Figure 4. Process Flow Diagram

3.2.7 Design of Solar Still coupled with a Solar Pond System

The system is comprised of two units viz. solar pond and solar still which have been explained separately as below:

3.2.7.1 Solar Pond

A solar pond is shown in figure 5, of dimensions 4 x 3 ft. with 4 ft. depth, was installed with a capacity of 360 US Gallons water. Pond was made of Galvanized Iron Sheet and colored black from the inside and a Styrofoam of 5mm was used for the external insulation to prevent the heat losses from the sides and base of tank. A Polyurethane paint was installed to increase the absorption capacity of the pond. A 5mm tempered glass wall was installed at one side for visual purposes.

Figure 5. Solar Pond

Ten K type thermocouples were installed at different depths of the pond to take temperature readings as shown in figure 5. Ten water valves were also installed at certain depth to take sample water at each depth and calculate the specific gravity and densities. A U-type heat exchanger was installed near the bottom of the pond.

3.2.7.2 Solar Still

The heated water from the solar pond was entered into Solar Evaporator unit. As shown in figure 6, the size of solar still is 4 x 3 ft. with 4 ft. depth. The base of solar evaporator was covered with black Polyurethane paint to trap more heat. Both sides and base of the unit were insulated with Styrofoam sheet of 5mm to reduce heat losses. Adjustable External reflectors (ER) were installed to enhance the performance by directing the sunlight on to the evaporator unit. The angle of ER was adjusted. The top of the unit was covered with a transparent glass of 3mm thickness at an angle of 34^0 to improve distillate yield.

Figure 6.Solar Still

Some of the vapors upon striking the glass cover were directly collected at the downward side of the slope as water droplets. The rest of the vapors were passed through coiled copper tubes in an external condenser that resulted in fresh water generation due to dissipation of heat to the water used as coolant.

3.2.7.3 External Condenser

The copper coil was installed in an air tight plastic drum to serve as the condenser having the total capacity of 100 liters as shown in figure 7. A submersible pump was used to circulate the water in the coil. The incoming water vapors from the solar still were condensed by exchanging the heat with the coolant circulating in the copper tube and the condensate was received from the drum.

Figure 7. External Condensor

3.2.8 Permanent Equipment

3.2.8.1 Pump

A single-phase pump was used for the circulation of the coolant in the copper coil in the condenser. Other than this, there was no other pump and the water flow was under gravity starting from the feed water tank till the collection of fresh water from the condenser.

3.2.8.2 Feed Tanks

Two feed tanks, one having a capacity of 100 gallons and the other one having a capacity of 75 gallons, were used. The first feed tank was used to prepare the synthetic brackish water to be fed in to the solar still after heating through the solar pond and the other tank was used to store the water which was used as a coolant to condense the water vapors coming from the solar still in to the condenser.

3.2.8.3 Galvanized Iron Structure

Both Solar Still and Solar Pond were made up of GI sheet of 18 gauge. The solar pond having the dimensions of 4x3x4 feet and solar still having a tilted glass at 34^{o} of had the dimensions of 4x4.34x4 feet.

3.2.8.4 Heat Exchangers

Copper coil was molded into U-type coil for internal heat exchanger of the solar pond. The external condenser of the Solar Still was made with plastic material to minimize the heat losses having a copper tube modeled into a spiral coil.

3.2.8.5 Glass Cover

A 5 mm glass of length 4.34 ft. and 4 ft. width was used as a glass cover for the solar still.

3.2.8.6 Metal Frame Cover

A metal frame cover made with aluminum sheets serves the purpose of both solar reflector and cover during night times and rainy season. The cover was hinged so that the angle of reflectors can be adjusted accordingly.

3.2.8.7 Consumables

- Salts: NaCl and $MgCl_2$ was procured to be used for gradient establishment in Solar Pond
- NaCl solution was also used for synthetic feed water preparation for Solar Still
- Chemicals ordered for water quality analysis (e.g. TDS, COD, BOD5, Specific Gravity)

3.2.8.8 Accessories

- K-type thermocouples installed at every 6 inches of the solar pond take temperature readings.
- All system components are joined together with the help of water pipe fittings e.g. tee, elbow, nipples etc.

Water valves installed with each 6 inches, along with thermocouple, at various depths of Solar Pond to take sample readings at each layer.

Table 1 sums up all the material, along with its justifications, which was used for solar pond and solar still.

Table 1. Material Selection

Sr. No.	Material	Justification
1.	Cover Plate: Glass of 5 mm	Due to high solar transmittance, availability, low cost & life
2.	Basin Material: GI sheet of 1 mm	Aluminum & Stainless steel sheets are best suited but costly
3.	Insulation: Styrofoam in 50 mm	Due to low thermal conductivity, price and availability
4.	Fittings: Stainless steel	To avoid corrosion
5.	Anti corrosive agent: PU Paint	It doesn't outgas at higher temperatures and is anticorrosive
6.	Pump: Submersible	For coolant recirculation, consumes less power
7.	Condensation Assembly: Plastic	Insulator
8.	Heat Exchanger: Copper coil	High thermal conductivity, resistance to atmospheric and water corrosion, and mechanical strength
9.	Cover angle: 34 degree	Equal to the locational latitude so that the sun rays are normal to the surface throughout the year

3.3 Gradient Establishment

A total of two solar ponds were established using the following two compositions.

- $NaCl$
- $NaCl + MgCl_2$

For NaCl pond, the study of Kamran et. Al and Rizvi et. Al conducted at IESE in 2016 and 2015 respectively was taken as the reference study. In correspondence with that, 34 kgs of Commercial Grade salt was added in 180 gallons of the water. This water was pumped into the solar pond via an injection diffuser to make sure there was no vertical disturbance caused. The layers of decreasing salinity were stacked on the top of each storage layer and fresh water was added in the final layer from the top.For NaCl + $MgCl_2$ pond, 17 kgs of each salt was taken to make the total composition of 34 kgs and it was added in 180 gallons of the water. Again, the injection diffuser was used to pump the water into the pond to eradicate all the possibilities of vertical disturbances. The layers of the decreasing salinity were formed over each other and the remaining half of the pond was filled by adding the fresh water from top.

3.4 Preparation of Synthetic Feed Water

The salt was added in the tap water to take its TDS level to 5000 mg/L and a range, keeping in account the amount of TDS present in the areas of Sindh, Balochistan and South Punjab, was prepared as shown in figure 8.

Figure 8. Synthetic Feed Preparation

The range was 1500-5000 mg/L.Small amount of a disinfectant and a de-chlorinator, sodium metabisulphite, was also added, at concentration of 2 ppm, to the feed water to inhibit bacterial growth and to neutralize chlorine in the tap water. A mixing time of 20 minutes was given at each concentration to ensure dissolution of salts. Treatment unit is as under, figure 9.

Figure 9. Treatment Unit near NUST MBR Plant

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Solar Still Alone

While the solar pond's layer was taking the time to establish, the treatment performance of a solar still unit alone was evaluated.

4.1.1 Solar Still for Feed Water of 5000 ppm

A synthetic brackish water of 5000 ppm was prepared by dissolving NaCl in the water and this feed water was entered into the solar still. A total of five runs were completed with this feed water and a maximum of 7 liters of yield was extracted against the temperature of 41^{o}C inside the solar still having the TDS level of 25. Figure 10 shows the overall performance of the solar still unit alone for the feed water having TDS level of 5000 ppm. The temperature variation during this study period in the solar still was noted to be in the range of 39 ±2 to 41±1 ^{0}C.

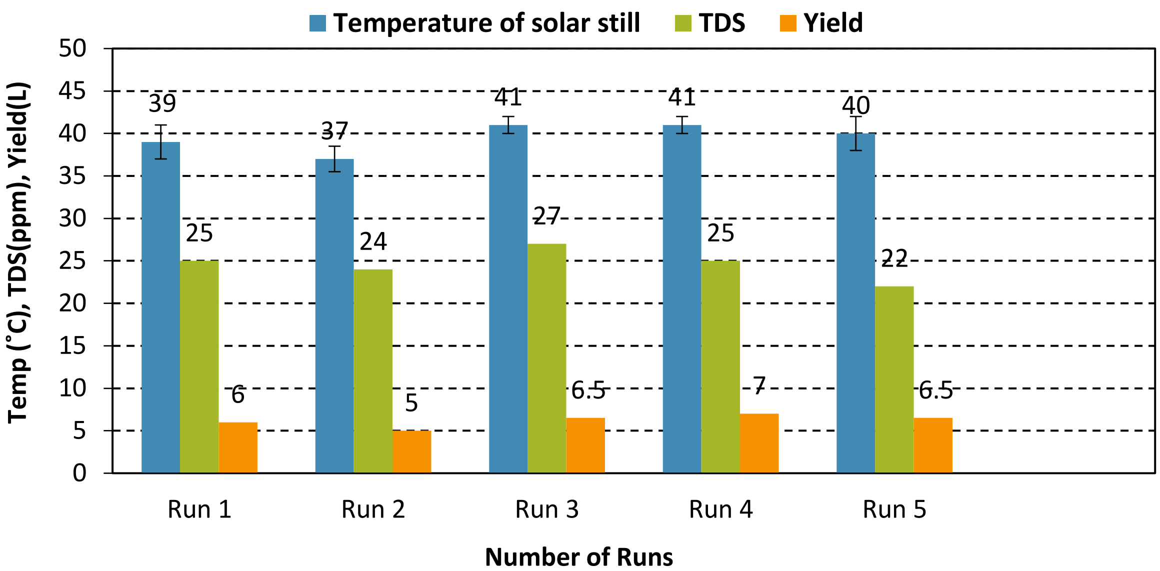

Figure 10. Treatment Performance of Solar Still for the Feed Water of 5000 ppm

4.1.2 Solar Still for Feed Water of 4500 ppm

For the second batch, a synthetic saline water of 4500 ppm was prepared and the treatment performance of a solar still unit alone was monitored. The maximum temperature inside the still went up to 41 degrees during these five runs and a maximum yield of 6.5 liters having a TDS level of 21 ppm was obtained as shown in figure 11. This figure also visualizes the temperature variation during this study period in the solar still was noted to be in the range of 37 ±1 to 41±0.5 ^{0}C.

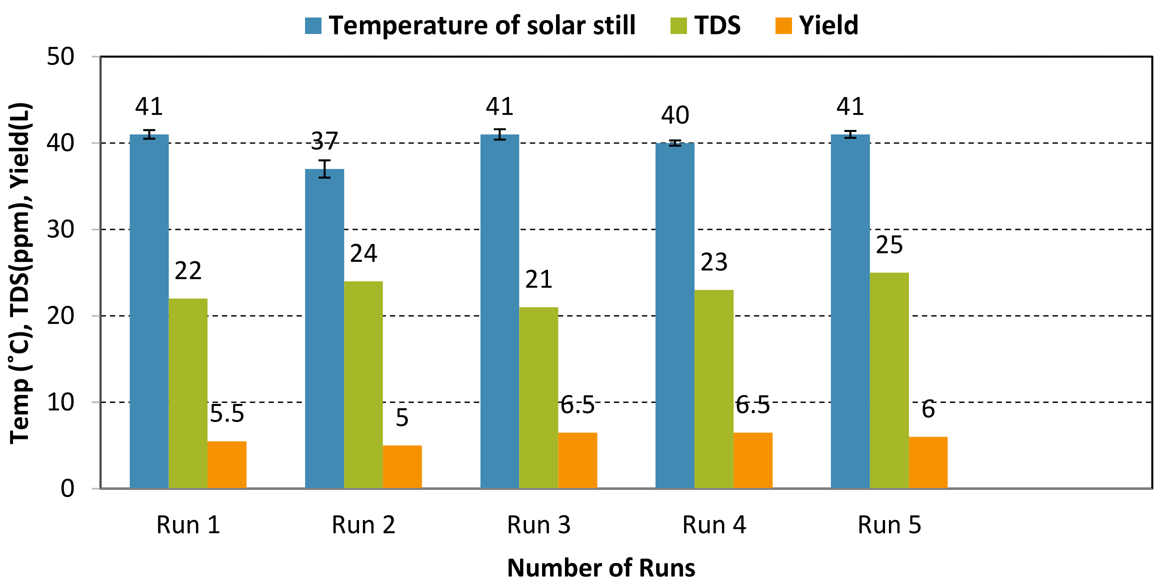

Figure 11. Treatment Performance of Solar Still for the Feed Water of 4500 ppm

4.1.3 Solar Still for Feed Water of 4000 ppm

For the third batch, a synthetic saline water of 4000 ppm was prepared and the treatment performance of a solar still unit alone was monitored. As illustrated in figure 12, the maximum temperature inside the still went up to 37 degrees during these five runs and a maximum yield of 6.5 liters having a TDS level of 22 ppm was obtained. The temperature variation, as illustrated by the figure, during this study period in the solar still was noted to be in the range of 36 ±1 to 37±0.8 ^{0}C.

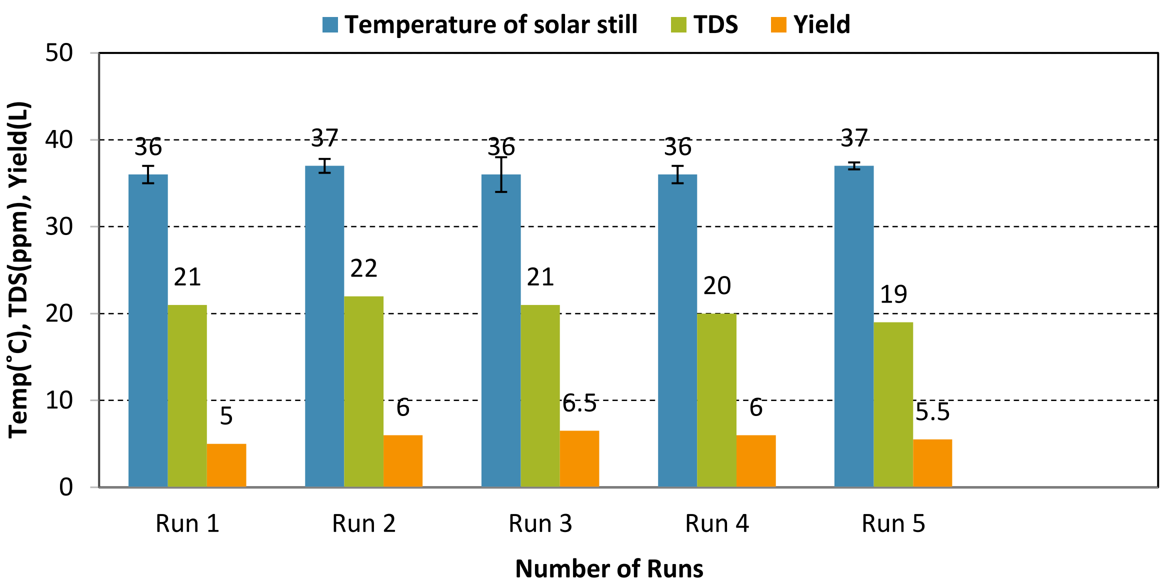

Figure 12. Treatment Performance of Solar Still for the Feed Water of 4000 ppm

4.1.4 Solar Still for Feed Water of 3500 ppm

For the next batch, a synthetic saline water of 3500 ppm was prepared and the treatment performance of a solar still unit alone was monitored. The maximum temperature inside the still went up to 37 degrees during these five runs and a maximum yield of 5.5 liters having a TDS level of 24 ppm was obtained as shown in figure 13. Figure 13 also shows the variations in the solar still of 32 ±2 to 37±0.8 ^{0}C during the study period.

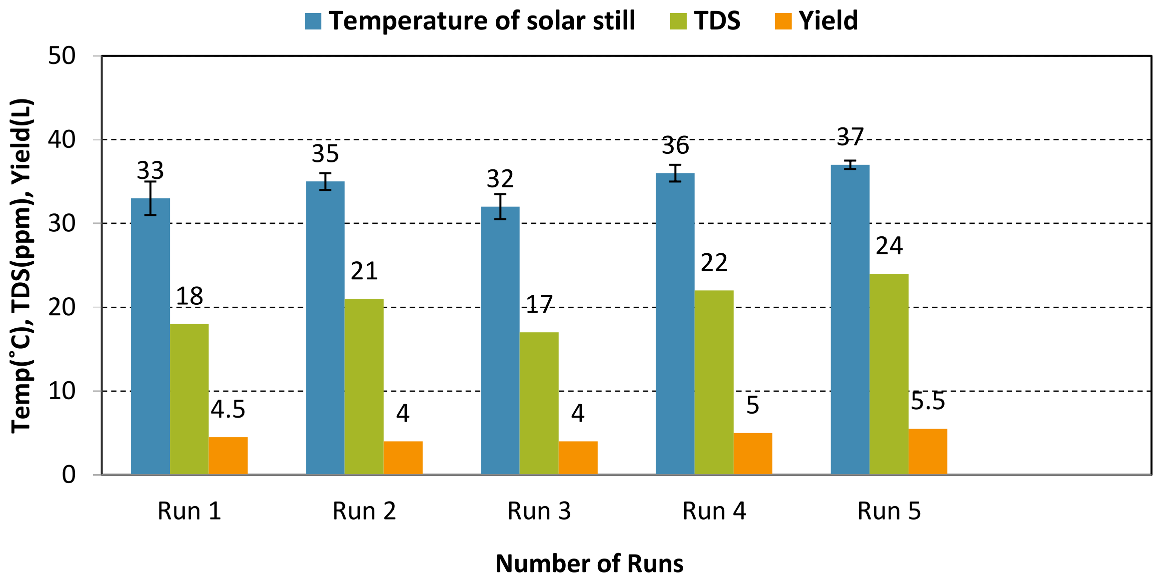

Figure 13. Treatment Performance of Solar Still for the Feed Water of 3500 ppm

4.1.5 Solar Still for Feed Water of 3000 ppm

For the next batch, a synthetic saline water of 3000 ppm was prepared and the treatment performance of a solar still unit alone was monitored. The maximum temperature inside the still, as illustrated in figure 14, went up to 37 degrees during these five runs and a maximum yield of 5.5 liters having a TDS level of 18 ppm was obtained. The temperature variation, as illustrated by the figure, during this study period in the solar still was noted to be in the range of 37 ±2 to 32±0.7 ^{0}C.

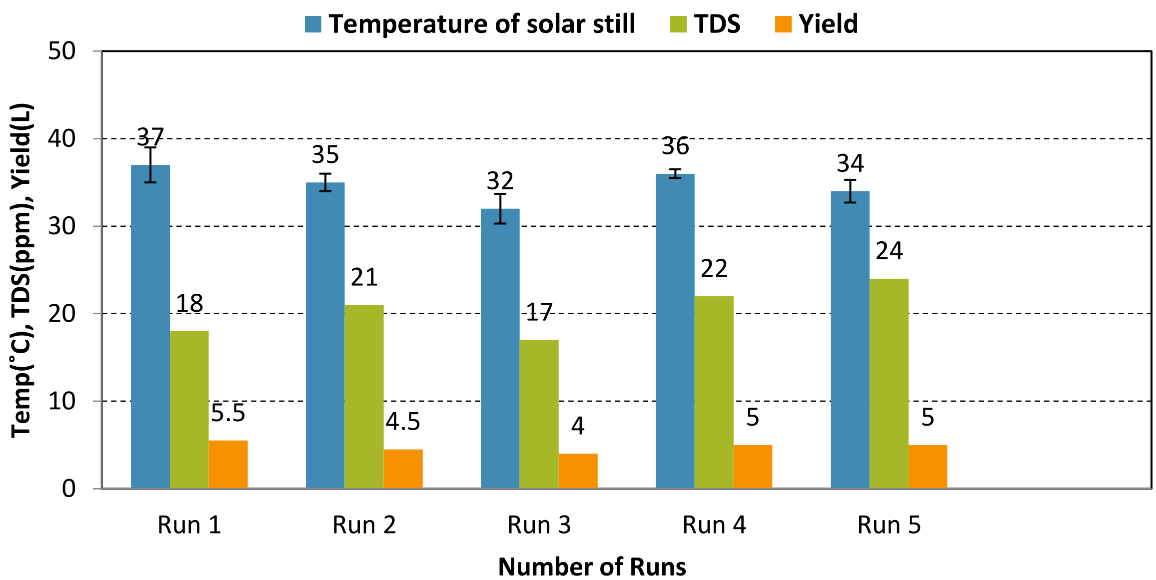

Figure 14. Treatment Performance of Solar Still for the Feed Water of 3000 ppm

4.1.6 Solar Still for Feed Water of 2500 ppm

For the next batch, a synthetic saline water of 2500 ppm was prepared and the treatment performance of a solar still unit alone was monitored. The maximum temperature inside the still went up to 39 degrees during these five runs and a maximum yield of 6.5 liters having a TDS level of 19 ppm was obtained as shown in figure 15. The temperature variation, as illustrated by the figure, during this study period in the solar still was noted to be in the range of 34 ±1 to 39±0.2 ^{0}C.

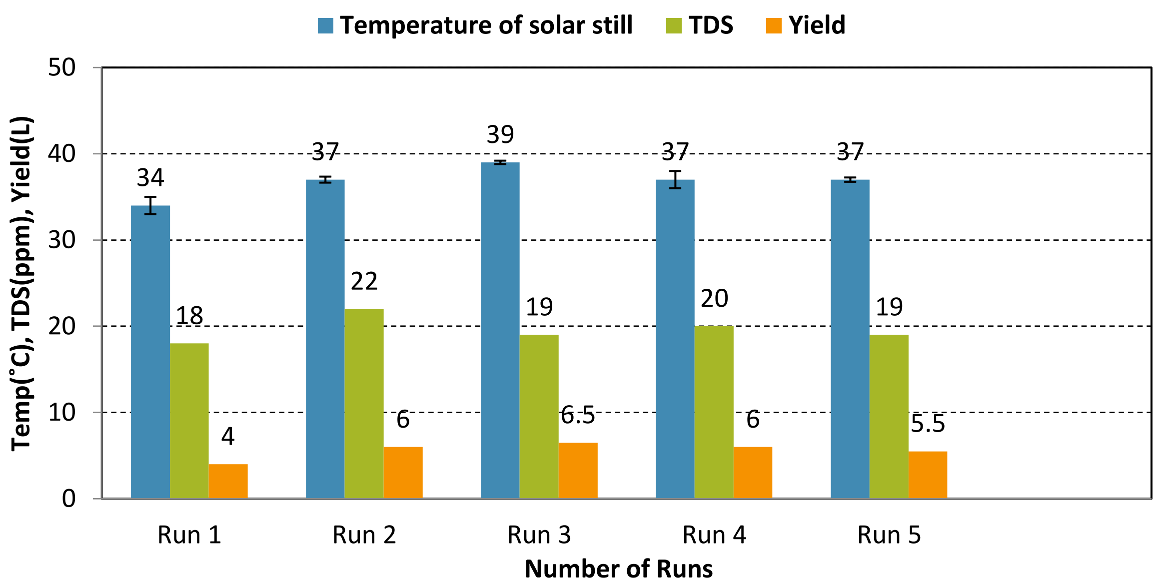

Figure 15. Treatment Performance of Solar Still for the Feed Water of 2500 ppm

4.1.7 Solar Still for Feed Water of 2000 ppm

For the next batch, a synthetic saline water of 2000 ppm was prepared and the treatment performance of a solar still unit alone was monitored. As illustrated by figure 16, the maximum temperature inside the still went up to 37 degrees during these five runs and a maximum yield of 5.5 liters having a TDS level of 18 ppm was obtained. The temperature variation, as illustrated by the figure, during this study period in the solar still was noted to be in the range of 34 ±2 to 36±0.5 ^{0}C.

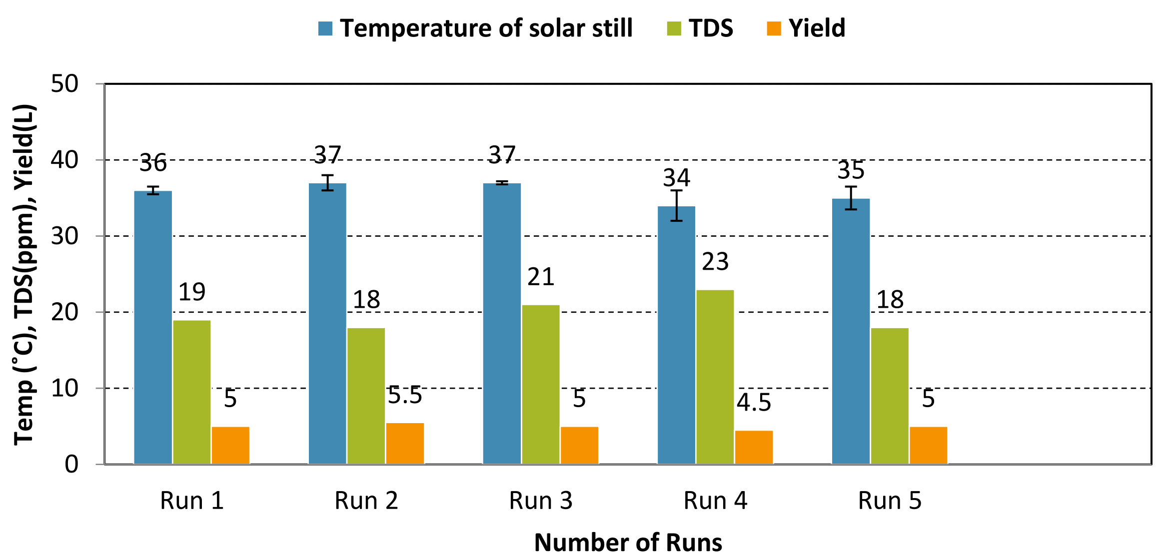

Figure 16. Treatment Performance of Solar Still for the Feed Water of 2000 ppm

4.1.8 Solar Still for Feed Water of 1500 ppm

For the next batch, a synthetic saline water of 1500 ppm was prepared and the treatment performance of a solar still unit alone was monitored. The maximum temperature inside the still went up to 38 degrees during these five runs and a maximum yield of 5 liters having a TDS level of 18 ppm was obtained as shown in figure 17. The temperature variation, as illustrated by the figure, during this study period in the solar still was noted to be in the range of 35 ±1.5 to 38±0.4 ^{0}C.

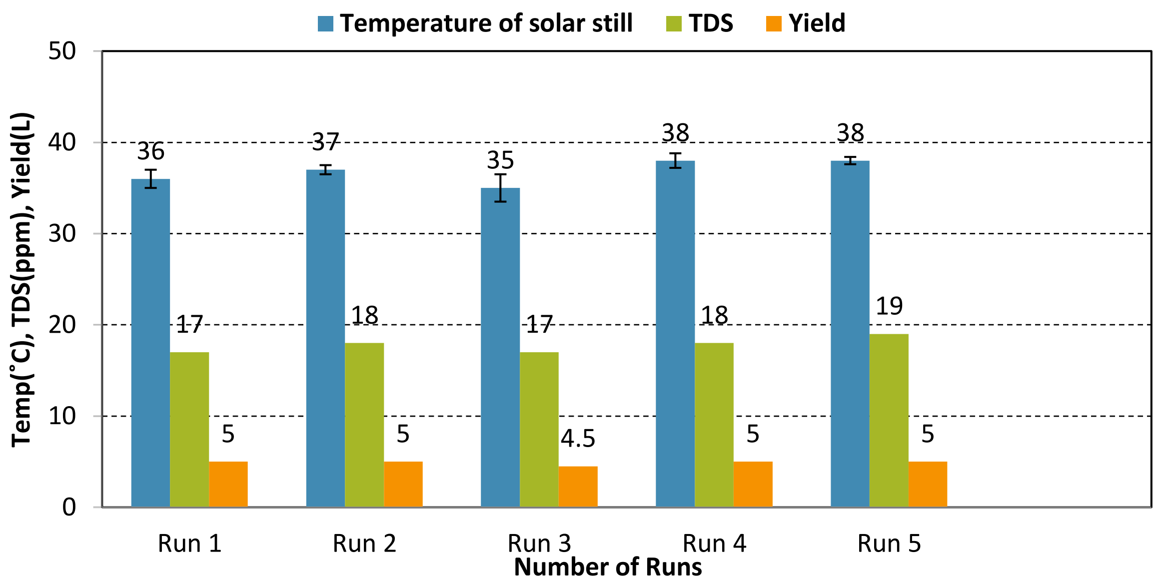

Figure 17. Treatment Performance of Solar Still for the Feed Water of 1500 ppm

4.2 Solar Pond

4.2.1 Solar Pond using NaCl

The solar pond was developed using the Commercial Grade NaCl and another one using NaCl and $MgCl_2$. For NaCl solar pond, the maximum specific gravity was 1.15. The height of UCZ, NCZ and LCZ were 0.2925m, 0.605m and 0.3125m as illustrated by figure 18.

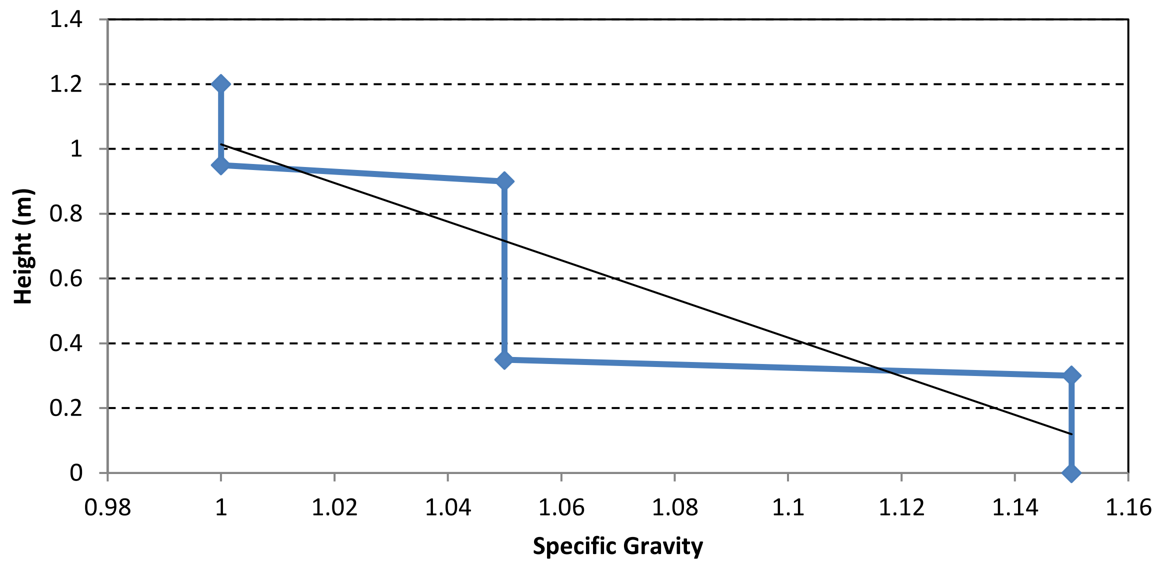

Figure 18. Density variations across different layers of solar pond

Figure 18 shows the temperature profile of the solar pond during the period of 22 days. UCZ, being the top most layer, showed a little changes with time depending on the weather conditions that it has been exposed to. An increasing trend of temperature was observed in LCZ. A more obvious increment in the temperature was shown by the layer containing the maximum amount of salt i.e. LCZ and it attained a temperature of 41oC on the 21st day.

The ambient temperature during this period has also been shown in figure 19. Keeping the heat losses in to the account and with the expectancy of increase in the ambient temperature during the months of June and July in the areas of Southern Punjab and interior

Sind, the maximum temperature in the LCZ of the solar pond is expected to be increased at least by 10^{o}C.

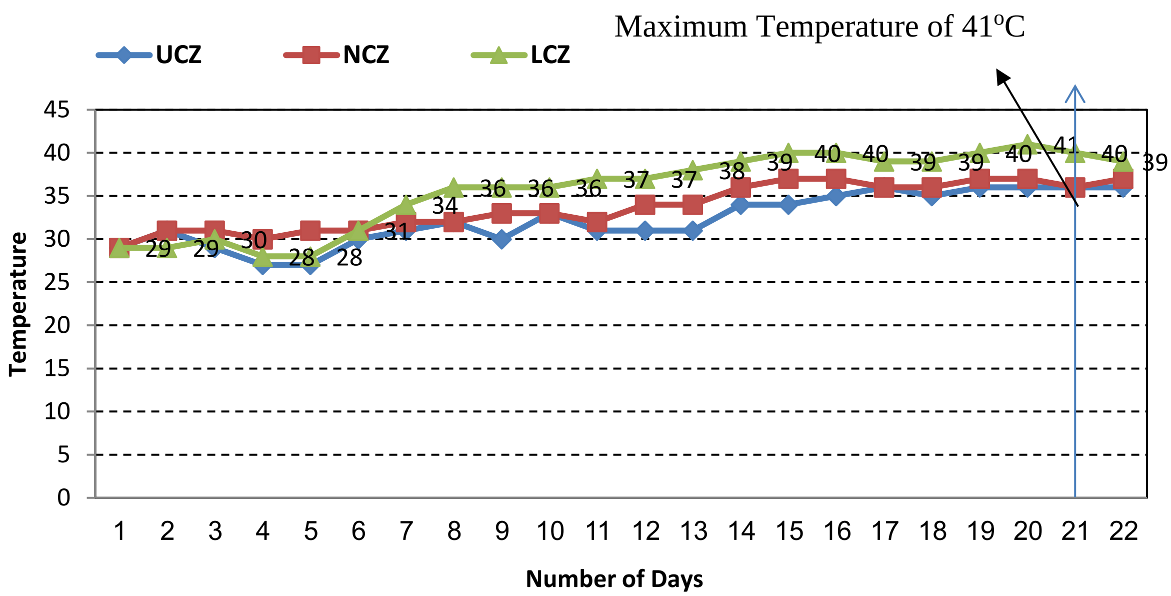

Figure 19. Temperature Profile of Solar Pond

Ambient Temperature (˚C)

36	**35**	**33**	**36**	**37**	**38**	**39**	**42**	**40**	**40**	**41**	**41**	**41**	**42**	**40**	**40**	**41**	**42**	**43**	**41**	**43**	**42**

For NaCl + $MgCl_2$ solar pond, the maximum specific gravity was 1.18. The height of UCZ, NCZ and LCZ were 0.308, 0.532 and 0.36.

4.2.2 Solar Pond using NaCl + $MgCl_2$

For NaCl + $MgCl_2$ solar pond, the maximum specific gravity was 1.18. The height of UCZ, NCZ and LCZ were 0.308m, 0.532m and 0.36m as shown in figure 20.

To measure the height of the layers of UCZ, NCZ and LCZ in both the solar ponds, the samples were drawn from the sampling points which were left in the solar pond after a distance of 6 inches across the height. After drawing the samples from every six inches, the specific gravity of the water was monitored using hydrometers. The difference in the specific gravity gave the idea of the new layer formation across the solar pond.

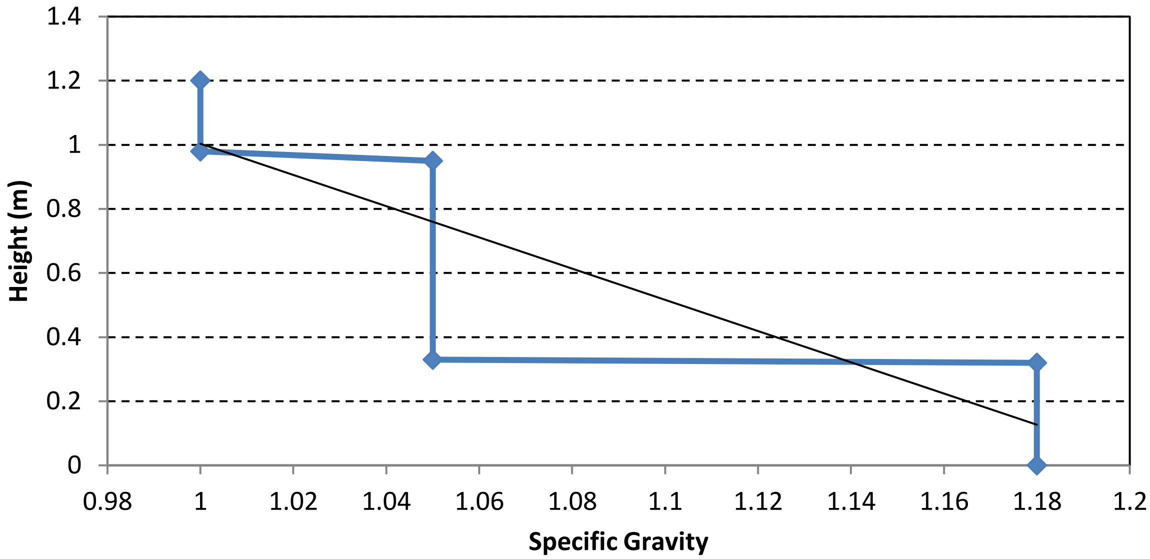

Figure 20. Density variations across the layers of solar pond

Figure 20 shows the temperature profile of the solar pond during the period of 22 days. UCZ, being the top most layer, showed a little changes with time depending on the weather conditions that it has been exposed to. An increasing trend of temperature was observed in LCZ. A more obvious increment in the temperature was shown by the layer containing the maximum amount of salt i.e. LCZ and it attained a temperature of 39°C.

The ambient temperature during this period has also been shown below. Keeping the heat losses in to the account and with the expectancy of increase in the ambient temperature during the months of June and July in the areas of Southern Punjab and interior Sind, the maximum temperature in the LCZ of the solar pond using NaCl + $MgCl_2$ is expected to be higher than the solar pond using NaCl because the second pond has shown better heat retention properties against the same ambient temperature which is confirmed by the stable temperature in the LCZ of the pond as illustrated by figure 21.

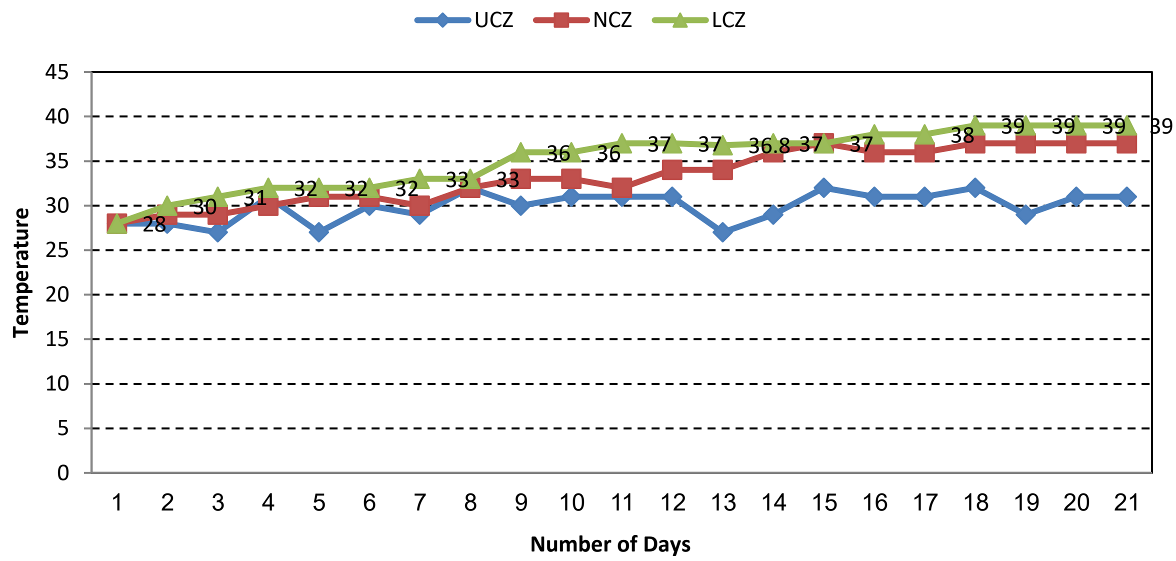

Figure 21. Temperature Profile of Solar Pond

Ambient Temperature (°C)

31	32	33	36	36	36	33	35	36	35	36	34	35	36	32	34	34	33	35	34	34	33

4.2.3 Comparison of NaCl with NaCl + $MgCl_2$

The comparison of NaCl pond with the NaCl + $MgCl_2$ is shown in table 2. It shows the difference of specific gravity, height of UCZ, LCZ and NCZ. It can be inferred from the table that $MgCl_2$ + NaCl has a greater height of LCZ as compared to NaCl alone, which can ultimately result in storing more amount of heat energy in the LCZ . This is due to the +2 charge on the ions of Magnesium Chloride. A specific gravity of 1.18 was also achieved in case of mixed salt combination as compared to NaCl alone.

Table 2. Comparison of NaCl pond with NaCl+$MgCl_2$ pond

Specifications	**Pond**	
	For NaCl	**For NaCl + $MgCl_2$**
Height of Pond	1.2m	1.2m
Height of UCZ	0.2925m	0.308m
Height of NCZ	0.605m	0.532m
Height of LCZ	0.3125m	0.36m
Specific Gravity	1.15	1.18

4.2.4 Solar Still with Solar Still Coupled with a Solar Pond System and Solar Still Coupled with a Solar Pond System having Controlled Coolant Temperature

The test results of solar still unit alone are compared with the solar still coupled with the solar pond system and solar still coupled with the solar pond having controlled coolant temperature in the figure 22.

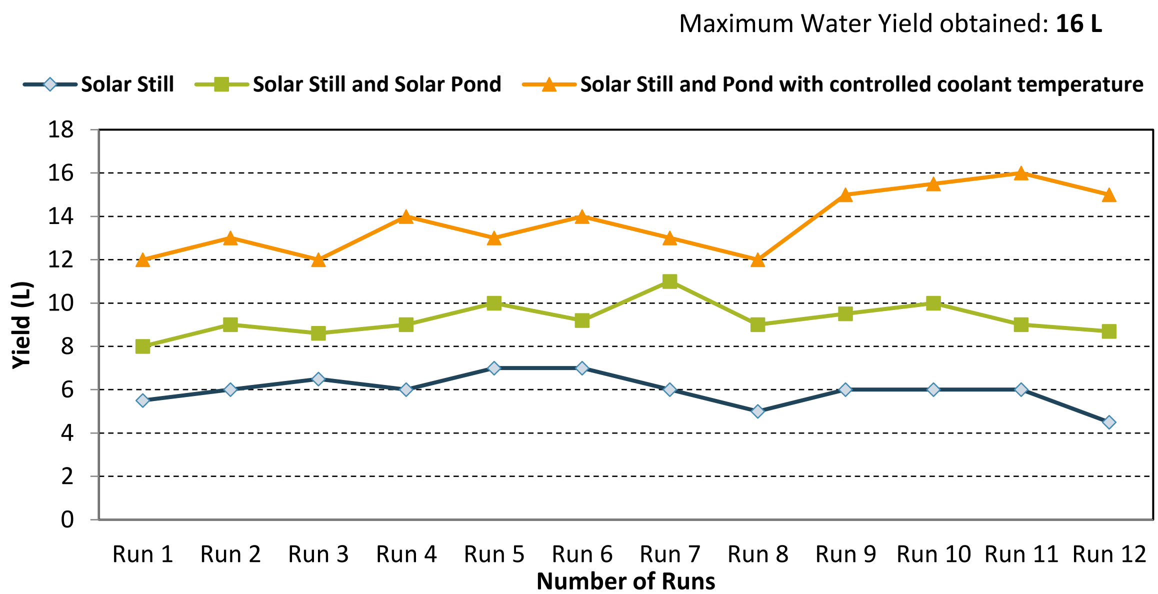

Figure 22. Temperature Performance of solar still, solar still coupled with solar pond and solar still coupled with solar pond having controlled coolant temperature

The temperature of the coolant was controlled and the difference of temperature was maintained at 20 ^{0}C between the coolant and incoming vapors in the condenser chamber of the system. This had a positive impact on the overall yield and the maximum water yield obtained was noted to be 16 Liters, when the solar still was coupled with a solar pond system and the difference of the temperature between the coolant and incoming vapors was maintained as shown by the orange line in figure 22. In figure 22, the green line shows the water yield of the solar still coupled with the solar pond system without maintaining the temperature of the condenser and the blue line shows the water yield of the solar still alone.

4.2.5 Treatment Performance of Solar Still Coupled with a Solar Pond System

The treatment performance of a solar still coupled with a solar pond system without maintaining the coolant temperature in the condenser is shown in figure 23. The impact of not controlling the temperature had a direct effect on the water yield produced by the system. The temperature variation, as illustrated by the figure, during this study period in the solar still was noted to be in the range of 51 ±0.5 to 57±0.2 ^{0}C.

The treatment performance of the unit is as follows:

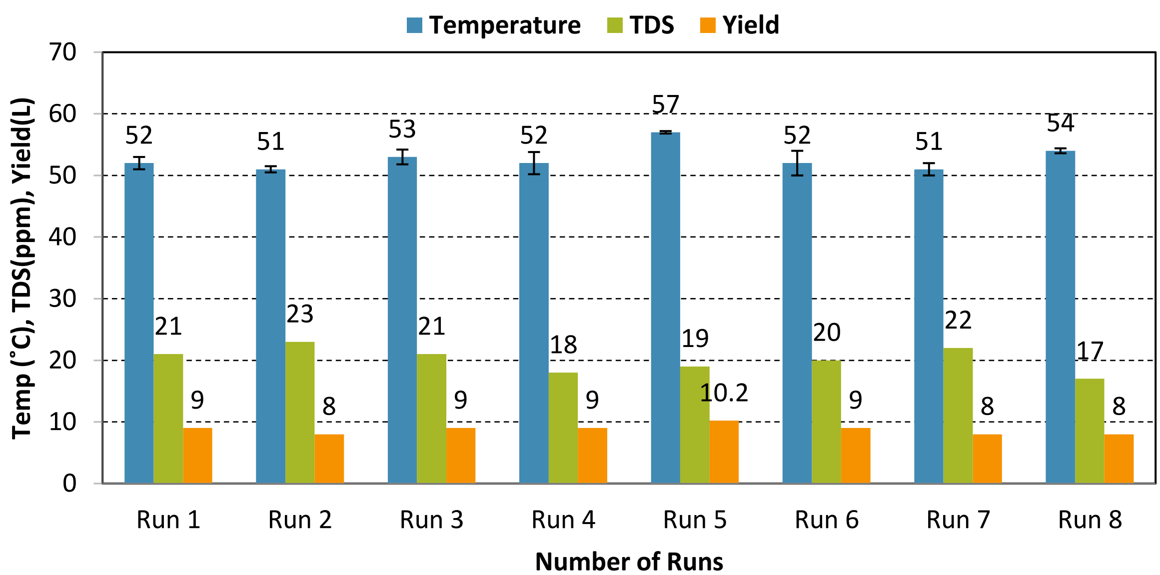

Figure 23. Temperature Profile of Solar Still coupled with Pond

A synthetic saline water of 4500 ppm was prepared and the treatment performance of a solar still coupled with a solar pond system was monitored. The maximum temperature inside the still went up to 57 degrees during these eight runs and a maximum yield of 10.2 liters having a TDS level of 19 ppm was obtained. However, when the temperature difference of 20 ^{0}C was maintained in the condenser chamber of the solar still coupled with a solar pond system for the same run as illustrated in figure 23, the water yield of 16 liters was obtained. The comparison of water yield with and without the controlled coolant temperature is shown in figure 22.

4.2.6 Treatment Performance on Textile Wastewater

The final set of experiments was conducted on the system using textile wastewater as the feed water.

4.2.6.1 Wastewater Characteristics

A real time waste water of the textile facility was collected after conducting a composite sampling of more than 2 days. The characteristics of the feed water are shown in table 3.

Table 3. Wastewater Characteristics

Sr. No	Parameter	Unit	Value
1.	pH	-	8
2.	BOD5	mg/L	658
3.	COD	mg/L	1212
4.	TSS	mg/L	268
5.	TDS	mg/L	2218
6.	Phenolic Compounds	mg/L	0.2
7.	Grease and Oil	mg/L	10
8.	Chloride	mg/L	211
9.	Flouride	mg/L	0.7

10.	Cyanide	mg/L	0.05
11.	An-ionic Detergents	mg/L	1.1
12.	Sulfate	mg/L	81
13.	Sulfide	mg/L	3.3
14.	Ammonia	mg/L	15
15.	Chlorine	mg/L	ND
16.	Cadmium	mg/L	BDL
17.	Chromium	mg/L	0.453
18.	Copper	mg/L	1.7
19.	Lead	mg/L	BDL
20.	Mercury	mg/L	BDL
21.	Selenium	mg/L	BDL
22.	Nickel	mg/L	BDL
23.	Silver	mg/L	0.003
24.	Total Toxic Metals	mg/L	2.452
25.	Zinc	mg/L	0.58
26.	Arsenic	mg/L	BDL
27.	Barium	mg/L	0.901
28.	Boron	mg/L	0.487
29.	Iron	mg/L	0.474
30.	Manganese	mg/L	0.038

4.2.6.2 Treated Water Quality

The treated water quality was tested against all the parameters of National Environmental Quality Standards. The overall treatment performance of the system on textile wastewater is summarized as:

- **COD Removal**

The COD of the textile wastewater sample was 1212 mg/L. A total of 3 runs were conducted on this feed water and the COD of the product water was noted to be 45 mg/L, 36 mg/L and 74 mg/L in three respective runs. This is illustrated in figure 24. The overall COD removal was 96%, 97% & 93% respectively.

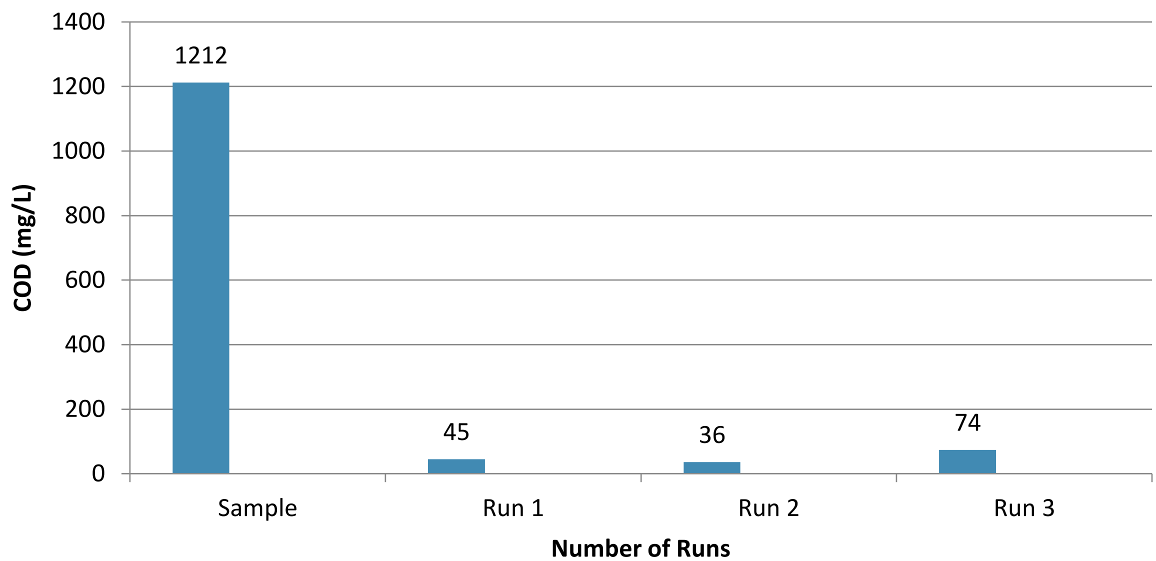

Figure 24. COD removal efficiency

- **BOD Removal**

The BOD of the textile wastewater sample was 658 mg/L. A total of 3 runs were conducted on this feed water and the BOD of the product water was 27 mg/L, 25 mg/L and 30 mg/L in three respective runs as shown by figure 25. The overall BOD removal was 95%, 96% & 94% respectively.

The feed sample had some organic solvents and dyes which can evaporate with the water vapors and can be a source of contamination in the product water. This was the reason of the amount of BOD and COD found in the product water.

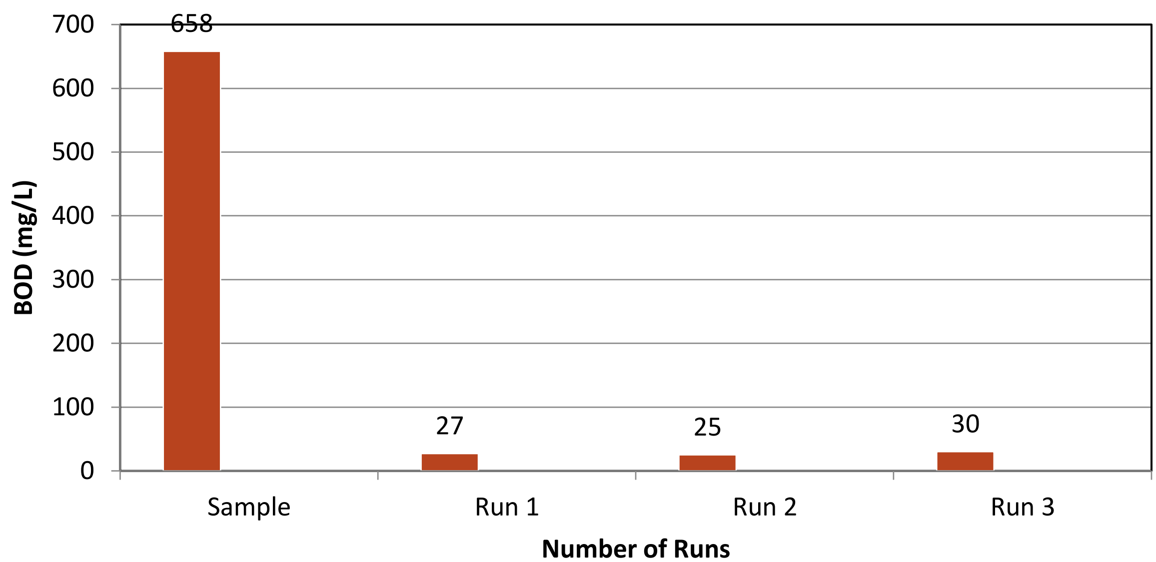

Figure 25. BOD removal efficiency

- **TSS Removal**

The TSS of the textile wastewater sample was 268 mg/L. A total of 3 runs were conducted on this feed water and the TSS of the product water was 5 mg/L, 4 mg/L and 6 mg/L in three respective runs as shown in figure 26. In this research, TSS removal efficiency was 98.1%, 98.5 and 97% respectively. The results for TSS removal are in accordance with the ones observed by Shatat et al. (2010), showing the TSS removal efficiency on low and high strength domestic wastewater and palm oil mills wastewater. The values reported by Shatat et al. were 2.4 and 7.7 ppm for the domestic wastewater and 9.7 ppm for palm oil mills wastewater.

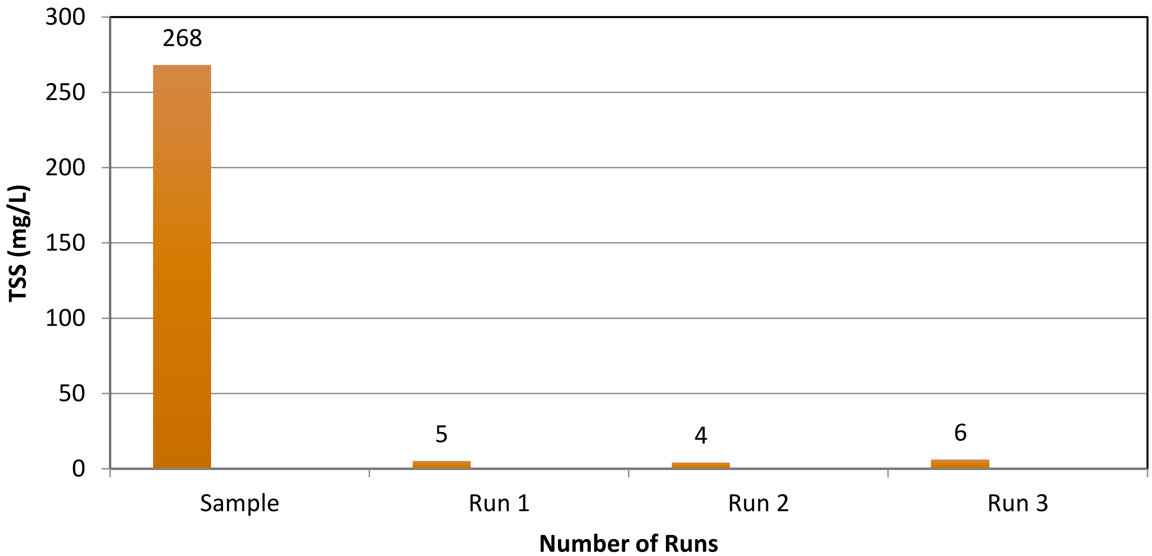

Figure 26. TSS removal efficiency

- **TDS Removal**

The TDS of the textile wastewater sample was 2218 mg/L. A total of 3 runs were conducted on this feed water and the TDS of the product water was noted to be 292 mg/L, 286 mg/L and 278 mg/L in three respective reporting the removal efficiency of 86%, 87% and 87.5% as shown in figure 27. The results have been compared with the previous observation of Ahsan et al. (2014) in which the TDS removal efficiency was 24% for sea water desalination. However, in this research, the TDS removal efficiency of above 85% was observed.

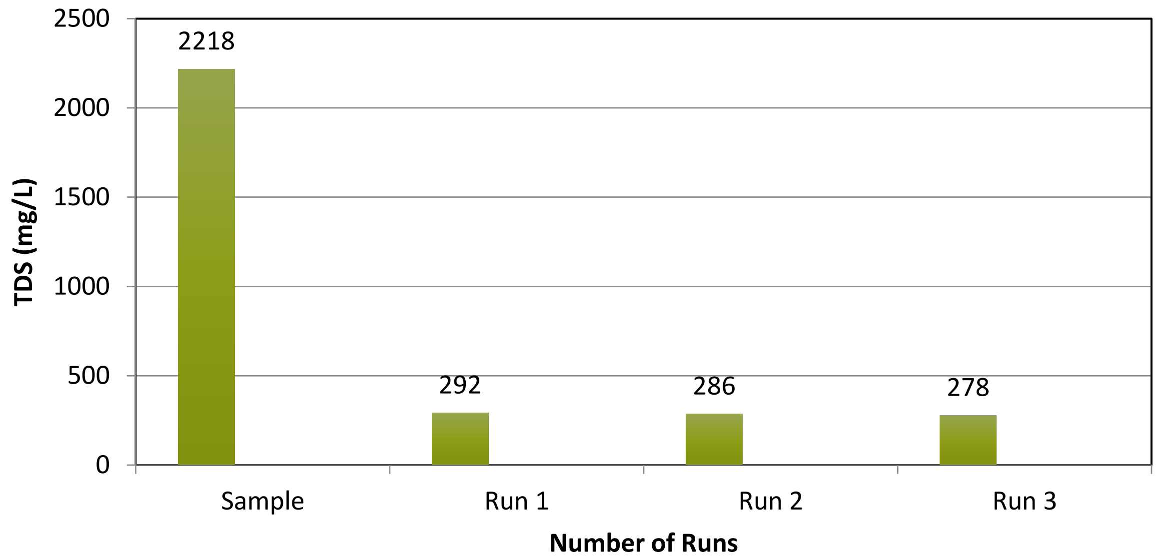

Figure 27. TDS removal efficiency

- **pH Removal**

The pH of the textile wastewater sample and the product water from all the completed runs remained within the normal range of 7-9. The figure 28 summarizes the pH of the sample and the product water.

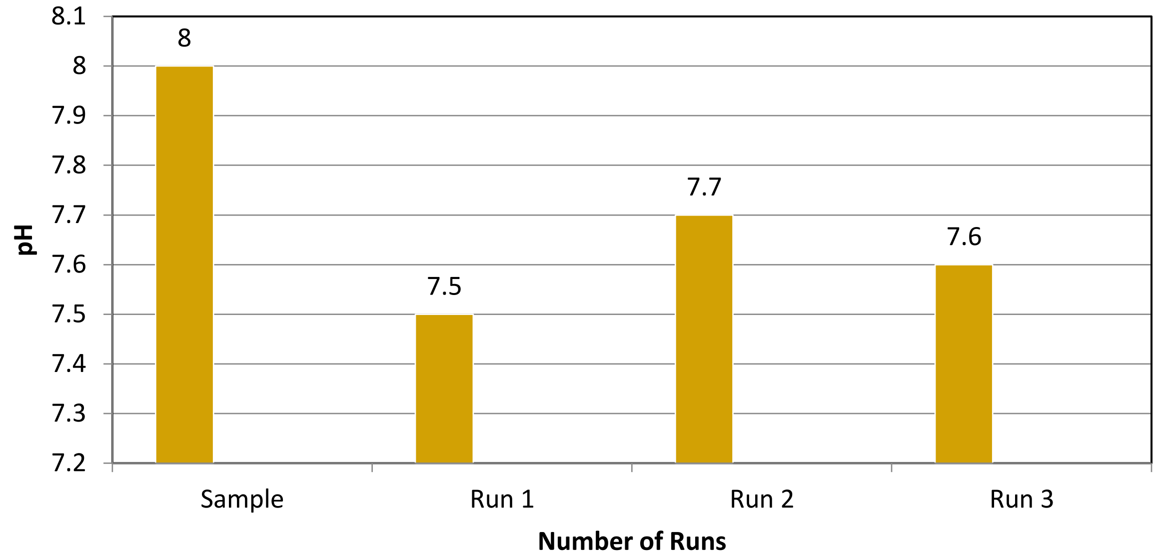

Figure 28. pH

- **Other Parameters**

The textile wastewater sample and the product water from all the three runs were tested against all parameters of National Environmental Quality Standards and their results are summarized in the table 4. The most important thing to note is the absence of the heavy metals in both the feed as well as the product water. The use of heavy metals is banned for all the textile facilities which are exporting their products. The textile facilities are being enforced by the international regulations and standards to use the environmental friendly chemicals during their production. However, for the textile facilities which are targeting the local industry, these conditions might change and the traces of heavy metals in their wastewater samples can be found.

Table 4. Product water characteristics

Lead	Wastewater (mg/L)	Run 1 (mg/L)	Run 2 (mg/L)	Run 3 (mg/L)	Average (mg/L)	Percent Removal
Lead	BDL	BDL	BDL	BDL	---	---
Mercury	BDL	BDL	BDL	BDL	---	---
Selenium	BDL	BDL	BDL	BDL	---	---
Nickel	BDL	BDL	BDL	BDL	---	---
Total Toxic Metals	2.452	0.179	0.858	1.086	0.707	71%
Zinc	0.58	0.049	0.341	0.219	0.203	65%
Arsenic	BDL	BDL	BDL	BDL	---	---
Barium	0.901	0.028	0.602	0.823	0.484	46%
Boron	0.487	0.151	0.227	0.244	0.207	57%
Iron	0.474	0.095	0.093	0.362	0.183	61%
Manganese	0.038	0.009	0.031	0.027	0.022	42%
Chloride	211	23	39	27	29.7	85%
Fluoride	0.7	0.1	0.2	0.2	0.167	76%
Cyanide	0.05	0.02	0.01	0.02	0.0167	66%
An-ionic Detergents	1.1	ND	ND	0.006	0.006	99%
Sulfate	81	0.82	26	13	13.27	83%
Sulfide	3.3	ND	ND	0.02	0.02	99%
Ammonia	15	0.66	0.87	0.32	0.616	95%
Chlorine	ND	ND	ND	ND	---	---
Cadmium	BDL	BDL	BDL	BDL	---	---
Chromium	0.453	BDL	0.011	0.008	0.0095	97%
Copper	1.7	BDL	0.018	0.011	0.0145	99%

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

- The designed system has shown an overall TDS removal of 99% for the saline water. The product water, after re-mineralisation, can be consumed for the drinking purposes in saline areas.
- Solar pond can be used as a pre-heating technology for saline water to increase the fresh water yield of the solar still.
- The coupling of solar still with solar pond increased the yield of the fresh water by 45%. The yield was doubled by controlling the coolant temperature. The temperature difference between the coolant and the temperature of incoming water vapors in the condenser has to be above 20˚C.
- The layer formation with $MgCl_2$ + NaCl took less time as compared to NaCl. Moreover, $MgCl_2$ + NaCl has shown better heat retention properties because of greater height of LCZ.
- The TDS removal efficiency of above 85% was achieved by using textile wastewater as feed water. Moreover, the solar still coupled with a solar pond system was found sustainable to remove zinc, barium, boron, iron, manganese, fluoride, chloride, cyanide, an-ionic detergents, sulfates, sulphides, ammonia, chromium and copper.

5.2 Recommendations

- EPDM liners must be used along with PU paint as the insulation material to minimize the heat loss through the side walls and base of the solar pond and still.
- For fresh water generation using solar stills, a number of smaller units in series are a preferable option to increase the overall yield and to have a better control of the system.
- A disinfectant unit is recommended to be installed with the system if the system is to be operated on any of the industrial and domestic wastewater sources.
- Fins and sponges can be used in the solar still to increase the evaporation area.
- For future studies, the industrial brine can be used in the solar pond to check its heat retaining capacity.
- A multi stage filter consisting of 5µm, 1µm and AC cartridge must be installed for the post treatment so that the effluent can be used for potable purposes in case of textile wastewater as feed water.
- The presence of heavy metals is to be continuously monitored in case of any industrial wastewater sources.

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