Analysis of the Performance in the Process of Solar Still using Textile Wastewater

S Chávez, H Terres, A Lizardi, R López, R Monzalve.
Universidad Autónoma Metropolitana, Unidad Azcapotzalco, Departamento de Energía, Área de Termofluidos, San Pablo 180, Col. Reynosa Tamaulipas, C.P. 02200 Ciudad de México, México

E-mail: scs@correo.azc.uam.mx

Abstract. In this work an analysis is realized on the performance of a solar distiller using textile wastewater from fiber dyeing processes. A solar still with shed was used, where 6 experimental tests were performed using Black B5, Blue 198 and Red 81, with and without auxiliary, for each test. Temperatures were measured on the cover of glass, container absorbent, fluid and environment. The incident solar radiation was obtained by means of modules ADAM and a pyranometer. The processing of the acquired information was done by means of the software LabVieW. An energy balance was established and the Dunkle's thermal model was used to evaluate the thermal behavior of the solar distillation. The following values were maximum values of 37.4 %, 25 % and 21.4 % for Black B5, Blue 198 and Red 81 without auxiliary respectively and 45.4 %, 34 % and 26.7 % for Black B5, Blue 198 and Red 81 with auxiliary respectively, in such a way that the efficiency increases when the textile wastewater contained auxiliary.

1. Introduction
Solar energy is defined as the radiant energy produced by the Sun as result of nuclear reactions of merger that come to the Earth across the space. Nevertheless, the solar radiation can be used in a great variety of industrial processes that demand heat energy such as the generation of steam, wash, dried, distillation and pasteurization, Samperio and Highway [1]. Therefore, solar energy is a good alternative for wastewater treatment, below are some examples.

Garcés and Peñuela, [2], used a solar cylindrical parabolic collector, built for the research of the degradation of the reactive dye orange 84. They selected the best degradation condition and mineralization of the above mentioned research to be applied in real waste water of an industry of dyeing fabric of point that they were containing this dye. They thought that the ideal concentrations for the degradation of the dye reactive orange 84 in a concentration of 340 mg/L were: 40 mg/L of dioxide of titanium and 2 ml/L of peroxide of hydrogen without air injection. Across the process of Fenton and Foto-Fenton the dye oxidizes with a combination of peroxide of hydrogen and ferrous sulphate (reactive Fenton), in acid conditions. The agent responsible for the oxidation is the hydroxyl radical, who is very reactive; it is formed for the catalytic decomposition of the peroxide of hydrogen in an acid way. The hydroxyl radical oxidize the dye, and the formed compound, it precipitates with the ferric ion and organic compounds.
Blanco [3], studied the effluent textile for Fenton's processes (Fe(II)/H₂O), Foto-Fenton (UV/Fe(II)/H₂O₂) and the combination of biological process with Fenton, the latter turned out to be the most suitable, COD (Chemical Oxygen Demand) maximum reduction was obtained by 85.60 % and 92.20 % in TOC (Total Organic Carbon) elimination. The analysis of the influence of the variables allowed to obtain the most favourable conditions of operation for all the cases, so much from the technical economic as environmental point of view, on the basis of the final efficiency of the treatment and the quality of the effluent agreement. Peláez [4], studied and analyzed the treatment of adsorption, the utilization of vegetable waste, already be directly like adsorbents or like predecessors for the preparation of activated carbon, diminishing the generation of solid residues and he found that the removal of the colour of the effluent textile.

Salazar et al., [5], compared the system of activated sludge with the membrane bioreactors, for the treatment of textile waste water. Your results indicated that, the above-mentioned process there reduce 82 - 92 % of the organic matter (CDO), 95 % of the total suspended solids (TSS), whereas the process of activated sludge reduces 54-70 % of the organic matter (CDO) and 32-43 % of TSS.

Edison et al., [6], studied the treatment of textile waste water by means of chemistry coagulation docked to processes fenton intensified with ultrasound of low frequency, and thought that about 82 % of the CDO was removed and that the wave use of ultrasound increases the efficiency of the process about 10 %.

Cortina and Márquez, [7], across a pilot plant they realized to scale the treatment of residual textile water of the processes Blue, Blinch and Dyeing Coffee, obtaining that the quality of the treated water was fulfilling with the normativity of the Mexico City for discharge in sewage, since the water was covering the parameters of smell, color, suspended solids, CDO and BOD.

2. Experimental procedure

In this work, was used the simplest solar still, which consists of a closed container with a transparent cover of glass with 3 mm thickness and an angle of inclination of 40 °, which allows the step of the solar radiation. Inside the zone of the distiller there is an absorbent container (aluminium platter) identical with dull black, where the textile wastewater was deposited after of the distillation, with an area of 0.36 m².

The absorbent container was placed in a glass with a base of 6 mm. Between the absorbent container walls and the glass support of 6 mm, 4 glass gutters with 3 mm and an angle of inclination of 5° had been placed, in such a way that the condensed one who sticks fast to each of the walls of the glass cover is gathered in the canaletas, in the base of the glass support of 6 mm, two drilled holes are had in against corner by a diameter of 9 mm, where a hose of plastic is placed for the compilation of distilled water, Figure 1.

Basically, the solar distiller used for this investigation has only one slope, it has an absorber container painted in matte black with an area of 0.36 m², the transparent cover that works as a condenser is made out of glass with a tilt angle of 40°, also the solar distiller has 4 glass gutters with a tilt angle of 5° approximately, in which condensate from the walls of the cover is collected. In figure 1 the solar still is shown.
The textile wastewater was placed in the aluminum container which absorbs the solar incidental radiation on the device. This is translated in a warming light immediately transmitted to water. This way, as the sun rises on the horizon in the morning, the temperature of the fluid is increasing; causing an increase in its steam pressure, the saturated steam inside the device begins to condense, since the internal surface of the glass cover has a minor temperature that the one of the water steam. The inclination of the glass cover, allows by means of gravity the drops of condensed water to slip downwards where the distilled water is gathered by the use of ducts.

Six experimental proofs were realized using Black B5, Blue 198 and Red 81, with and without auxiliary. The auxiliary are chemical substances that are added to the dyeing bath to accelerate the dying process, in this case was used Na$_2$SO$_4$ as electrolyte and Na$_2$CO$_3$ as alkali. For each of the distillations were obtained information of temperature through the use of thermocouples type K and solar incidental radiation by means of a pyranometer, the experimental information was obtained by of ADAM modules and the software LabView. The process of distillation was carried out in May, 2017, inside the facilities of the Universidad Autónoma Metropolitana campus Azcapotzalco. In every test the information was registered every 10 minutes during an interval of time from 10:00 am to 16:00 pm, due to the fact that in this period of time major sunstroke takes place. The Figure 2 shows the complete instrumentation of the solar distiller.

![Solar Still](image1)

![Computer Equipment](image2)

![Thermocouples type K](image3)

![Pyranometer](image4)

![ADAM Modules](image5)

Figure 1. Solar still.

Figure 2. Solar still and instrumentation equipment.
3. Thermal efficiency

The thermal efficiency in the solar distillers, can be obtained of different forms, the simplest is by means of its productivity, which generally is in the habit of being a more practical measure and certainly being related to the thermal efficiency. The productivity of the solar device is the volume of revealed that can be produced in every square meter of the evaporating condenser (glass cover) and in addition for every day.

Another way of measuring the thermal efficiency of the solar distillers, is analyzing the participative necessary flows of heat to evaporate the initial volume of solution and the heat with a proper amount of Sun received, both taken in an interval of time that generally is per day, within this way the thermal efficiency is a measure of the heat fraction that is used really in the process of evaporation-condensation.

The behavior of the solar distiller is characterized by the different transfers of heat (convection, evaporation, radiation) and mass that happen in its interior, where an energy balance is established and the thermal model of Dunkle's [8], is used to evaluate the coefficients of heat transfer for convection and evaporation and they are given for:

Where:

\[ h_{c,g-w} = 0.884\left[\Delta T'\right]^{1/3} \]  

\[ \Delta T' = \left( T_w - T_g \right) + \frac{\left( P_w - P_g \right)(T_w + 273)}{268.9 \times 10^3 - P_w} \]  

\[ h_{E,w-g} = 0.0163h_{c,w-g} \left( \frac{P_w - P_g}{T_w - T_g} \right) \]

The thermal general efficiency is considered to be the relation of the heat transfer by evaporation and the solar radiation that affects the container absorbent, in agreement with Zoori [9] and Tiwari et al. [10], it is given as:

\[ \eta_I = \frac{h_{E,w-g}A_w\left( T_w - T_g \right)}{H_fA_p} \]

4. Result

By means of the experimentation in the solar distiller using textile wastewater, to obtain the temperatures and the solar radiation and using the experimental information a spreadsheet is realized to obtain the thermal efficiency of the device in each of the test, applying the equations. (1) to (4). Figures 3 and 4, show the results of the efficiencies for textile waste water with the dyes Black B5, Blue 198 and Red 81, with and without auxiliary.
5. Discussion

The maximum energy efficiency of the solar distiller using textile wastewater was 45.4 % for the test with Black B5 dye with auxiliary. The tests with Blue 198 and Red 81 with auxiliary, reached an efficiency of 34 % and 26.7 %, respectively.

However, for the test with the dyes Black B5, Blue 198 and Red 81 without auxiliary were the maximums of 37.4 %, 25 % and 21.4 % respectively reached. The figures 3 and 4, display that the efficiency increased within the time, reaching the highest values at the end of the test, this is caused by the energy that remains stored in the similar device as time is going. Also, is observed that the curve of the distribution of efficiency for each test is not uniform, by reason of the suffered alterations over the time. This happened because the solar radiation changes its intensity every instant due to several factors i.e. effects of atmospheric cloudiness, powder suspended particles, angle of the glass cover and the direction of the solar beams, what the temperatures meet affected in the distiller, due to these
changes, the coefficients of heat transfer by convection and evaporation are affected and therefore the thermal efficiency has variations. Therefore, the device only was used 35.3 % of the energy from the Sun for the dyes that they contain auxiliary and 27.9 % for the dyes without auxiliary.

6. Conclusion
The efficiency is a fundamental characteristic of functioning for the solar distiller. In other words, is the energy used in the vaporization on the quantity of energy that affected the device. Reaching a maximum efficiency for the Black B5 dye with and without auxiliary of 45.4 % and 37.4 % respectively. In agreement with the results it is concluded that for dark tonalities higher efficiencies are achieve in comparison with the use of clearer ones. Likewise, it also affects if the dye has an auxiliary as it in this occasion does; Na₂SO₄ and Na₂CO₃. Substances with values of specific heat different from that of the water, allow that the evaporation of this ones should be more rapid compared with the samples where only dye was contained. In addition to the previous factors the climatological conditions presented for every test. In spite of the fact that they were done in the same month, the incidental radiation was different for every day. Finally, it noticeable that there is a difference of 7.4 %, in average in the thermal efficiency.

Nomenclature

| Subscript | Description |
|-----------|-------------|
| A         | Area, m²    |
| T         | Temperature, ºC |
| P         | Pressure, Pa |
| Hₜ        | Solar Radiation, W/m² |
| hᶜₜₔₚ    | Coefficient of heat transfer for convection of the water towards the glass, W/m²K |
| hₑₜₔₚ    | Coefficient of heat transfer for evaporation of the water towards the glass, W/m²K |

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