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Theoretical and Experimental Evaluation of Solar Desalination Still Performance in Different Times

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Abstract

The object of this work is the evaluation of performance of solar still. This work represents the performance of a solar desalination still as a second stage of proposed zero discharge desalination processes to reach fresh water and also concentrated brine from the effluent wastewater of the desalination unit of the Mobin petrochemical complex. Therefore a solar desalination still is constructed after a pretreatment unit to concentrate the softened wastewater to about 20 weight percent. The concentrated wastewater is as a suited feed for a forced circulation crystallizer. During one year, the effects of major parameters such as ambient temperature and solar insolation rate are investigated, experimentally.

Keywords

Performance, Efficiency, Proposed Process, Energy, Solar

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1. Introduction

The sun is a great natural resource of energy. On a sunny day, the sun provides approximately 1000 watts of power per square meter (W/m^2). This energy from the sun can be used in many ways—from passive solar heating to day-lighting; from heating water for steam turbines to directly generating electricity through photovoltaic devices. This paper focuses on solar energy by means of photovoltaic devices. The solar extends from the ultraviolet into the infrared (~300nm – 2500nm). Photons (packets of light energy) whose energy is greater than that of the band gap of the photovoltaic device can be converted, by the device, into electrons, thus generating a current. The following diagram shows a plot of the solar spectrum, indicating the UV, visible, and IR portions of the spectrum, as well as showing where the band gap of silicon is located. The more light that hits the device, the more current will be generated. The power provided by the solar cell depends both on this current that is generated and the voltage that is produced on the device from the light hitting it. The Solar desalination processes can be categorized in two main types: direct and indirect collection system. The direct method utilizes solar energy to produce distillate directly in the solar collector, whereas in indirect collection systems, two sub-systems are applied, one for solar energy collection and the other one for desalination. Single effect solar still is one of the direct collection systems which can be passive or active. The solar still integrated with a heater or solar concentrator panel is generally referred to as an active solar still while others are referred to as passive stills. Water reservoir commonly called solar still is one passive type which can be used to convert saline, brackish water into drinking water. The operating performance of this type can be augmented by several techniques such as applying single slope in cold climate versus double slope in hot climate, cover cooling, using additional condenser and injecting black dye in the wastewater. Salinity-gradient solar still is the other type with a vertical saltwater gradient, so that the denser saltier water stays at the bottom of the still and does not mix

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with the upper layer of fresher water (Leblanc et al., 2011; Lu et al., 2001). Consequently, the lower salty layer gets very hot and this heat can be used to make electricity.

Totally, solar stills have many advantages: combined collection and storage of solar energy, ease of construction and on-demand extraction of heat. Salinity-gradient solar stills can directly collect and convert solar energy to thermal power. Also, solar stills can be utilized as one solar desalination unit in zero discharge desalination process.

In this experimental work a solar desalination still as desalination unit is introduced. The mentioned solar desalination still is proposed after a pretreatment unit and these processes are two main serial stages of proposed zero discharge desalination, ZDD, processes. A solar still which is coupled with other desalination process has been studied in previous works but the superiority of this work is that the solar desalination still and pretreatment unit are applied to treat the effluent concentrated brine from desalination unit of Mobin petrochemical complex. Salinity-gradient solar still is the other type with a vertical saltwater gradient, so that the denser saltier water stays at the bottom of the still and does not mix with the upper layer of fresher water (Leblanc et al., 2011; Lu et al., 2001). Consequently, the lower salty layer gets very hot and this heat can be used to make electricity. Totally, solar stills have many advantages: combined collection and storage of solar energy, ease of construction and on-demand extraction of heat. Salinity-gradient solar stills can directly collect and convert solar energy to thermal power. Also, solar stills can be utilized as one solar desalination unit in zero discharge desalination process. In this experimental work a solar desalination still as desalination unit is introduced. The mentioned solar desalination still is proposed after a pretreatment unit and these processes are two main serial stages of proposed zero discharge desalination, ZDD, processes. In previous works solar still which is coupled with other desalination process has been studied but the superiority of this work is that the solar desalination still and pretreatment unit are applied to treat the effluent concentrated brine from desalination unit of Mobin petrochemical complex. Total hardness of raw wastewater is reduced in pretreatment unit and the solar still is located after pretreatment unit to concentrate brine wastewater. In this stage, drinking water and concentrated brine is produced. The effluent stream from solar still is conveyed to one forced circulation evaporator in order to production of salt crystals and distillate. Wet crystals are discharged from the crystallizer and lose 70 percentage of water content in the centrifuge, approximately. Finally, surface water content of crystals is removed in the rotary dryer.

2. Materials and Methods

The sun gives off radiating waves of heat and light energy. The sun emits many other kinds of radiation called the electromagnetic spectrum, such as X - rays and ultraviolet waves. All the waves emitted from the sun move rapidly as tiny bundles of energy called photons. These photons travel vast distances from the sun through the vacuum of space. The sun delivers two forms of energy on the Earth: material radiation and electromagnetic radiation. For us only the electromagnetic one is important. There are many reasons why Concentrating Solar Power (CSP) is so interesting and why it should play a major role in the future energy mix. Apart from the fact that solar energy is the most abundant renewable source of energy on earth, the technological advances in the past decades have allowed CSP systems to reach a stage which indicates good potential to attain economic viability, given appropriate condition, in comparison with fossil sources. Today's CSP systems can convert solar energy to electricity more efficiently than ever before, they can be exported to the developing world and an additional advantage is their lack of significant environmental degradation. Since CSP systems produce both heat and electricity, they can be useful in some industrial applications; they have durability and low operation and maintenance costs. Another key competitive advantage of concentrated solar power systems is that they closely resemble the current power plants in some important ways. The solar desalination still produces drinking water when solar radiation is absorbed by the concentrated brine and causes water to evaporate. The thermal desalination solar still which is used in this research is composed by a metallic basin with a dimension of 100 cm × 170 cm × 46.5 cm and a glass roof. The thickness of roof and walls is 4 mm to enhance the transmissivity coefficient. The desalination solar still is made from stainless steel-316 to prevent corrosion which may happen due to high temperature and high concentration of concentrated brine wastewater. The net evaporation rate area of solar desalination basin is 1 m^2, facing south with an inclination of 29° (the latitude of Shiraz) to achieve the most solar radiation.

3. Results and Discussion

Figure 1 shows variation of average temperature of wastewater layers in the solar desalination still in each month. It is clear that the temperature decreases from bottom to the surface of wastewater slightly thereby decreasing density. In this Figure, average temperature difference between layer 1 and layer 5 of wastewater is 26.3°C, 30.26°C, 28.73°C and 27.86°C in winter, spring, summer and autumn, respectively. Therefore thermal resistance of wastewater has the highest value during spring and heat decreases slowly. So the best proposed time to gain highest thermal energy is on spring.

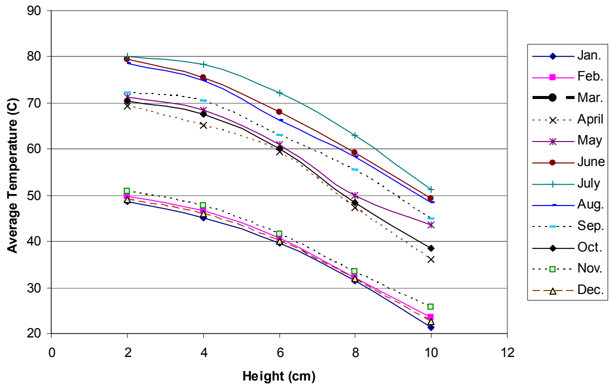

Figure 1. The variation of average temperature versus height.

Figure 2 shows variation of specific gravity of concentrated wastewater layers on 30 June 2011. The specific gravity of concentrated brine wastewater at the bottom of solar desalination basin reaches to 1.250 kg per cubic meter. So, the highest thermal energy is saved in this region of solar desalination still. The experiments show the specific gravity of wastewater reduces sharply to 4 cm depth and then has slight reduction to 10 cm. The specific gravity reaches 1.06 at the surface of concentrated wastewater.

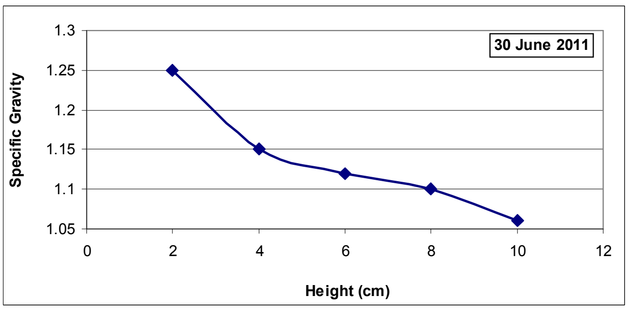

Figure 2. The variation of specific gravity versus height.

As mentioned, this solar basin is a pool of saltwater which acts like collector with integral heat storage for supplying thermal energy. therefore, the solar still efficiency is the amount of energy utilized in vaporizing water in the basin over the amount of incident solar energy on the basin. Finally, the thermal (energy) efficiency for the solar basin can be expressed as Equation 1.

$$\eta = \frac{H_{net}}{H_{in}} \quad (1)$$

Where, the net heat is expressed as the Equation 2 according to the energy balance for the solar basin.

$$H_{net} = I\alpha_w A_w + H_{c,w-s} - H_{c,w-g} - H_{r,w-g} - H_{e,w-g} \quad (2)$$

Also, the input heat is defined according to the Equation 3.

$$H_{in} = I\alpha_w A_w + H_{c,w-s} \quad (3)$$

So, the thermal efficiency values are determined during the test period.

4. Conclusion

Undoubtedly, the Sun is one of the most important sources that will be able to provide future demand of power, as fossil fuel resources are limited and more and more countries become industrialized and seek energy. The performance of one passive direct solar desalination basin is studied in this research. This solar system reuses the waste brine to produce concentrated liquor and distilled water, as a basic unit in zero discharge desalination systems.

As indicated by experimental data, when the solar basin is built well the solar desalination system can result in excellent thermal performance. The results indicate the insolation rate is the most effective factor on the evaporation rate in the solar basin. Therefore, the production rate of potable water increases to 5 liter per square meter day when the value of insolation rate is 24601.92 kJ per square meter day on the June.

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