Implementing Sustainability with a Solar Distillation Project

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Abstract

Students in the mechanical and civil engineering programs at West Texas A&M University are exposed to sustainability in a wide variety of required courses in the freshman through senior level coursework. The projects in these courses are carefully selected to provide an in-depth understanding of sustainability through analytical and experimental studies. In thermal-fluid design, students were asked to build an environmentally friendly and energy efficient systemfor the distillation of wastewater produced in agricultural processing facilities in west Texas. The solar still was to be augmented with evacuated solar tubes collector to enhance the solar performance of the still and increase the daily production yield rate. West Texas is a dry land area with an annual rain fall of less than 20 inches per year. This project addresses the need set into effect by watermanagement practices for this region regarding water conservation, reuse and reclamation of wastewater to extend the life time of the Ogallala Aquifer, a major source for water irrigation.Due to having low investment and operation cost, students learned that solar distillation is a feasible system for use in semi-arid and arid regions where solar energy is abundantly available. Field tests show the augmentation of the still with evacuated solar tubes increased its production rate by 263%. The maximum daily production was 1.4 kg/m² day for the passive distillation system, and 3.6 kg/m² day for the active distillation system.

Keywords

Solar Distillation, Solar Tube, Active System, Passive System, Yield Rate

Introduction

In the mechanical and civil engineering programs at West Texas A&M University, students are exposed to sustainability in a variety of courses such as Fundamentals of Engineering at the freshman level, Thermal-Fluid Design, Machine Design, Structural Design, and Capstone Design at the senior level. In Thermal-Fluid Design, students are expected to apply heat transfer and fluid mechanics concepts to the design of thermal-fluid systems. Emphasis is on design calculations, component and system modeling, and optimization including economic considerations. Students learning outcomes related to this course include all of ABET accreditation criteria: 3(a) through 3(k). Two of those criteria specifically address the need for sustainability. Criterion 3(c) recognizes the need to incorporate sustainability within engineering design. It states that engineering programs must demonstrate that students have [1]:

"an ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability"

In addition, Criterion 3(h) states that students should demonstrate [1]:

"the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context"

Even though Criterion 3(h) does not mention sustainability by word, it has the three main pillars needed for sustainable development: Economic growth, environmental protection, and social equality [2].The project discussed in this paper, design of a solar distillation system, addresses the need to design a system for a sustainable use by relying on renewable and natural energy resources instead of conventional power resources, mainly electrical power. Since the electricalpower production in the United States relies approximately 70% on fossil fuels [3], the implementation of solar power instead of electrical power for the operation of the water distillation system will eliminate the environmental impact and fossil fuel dependency that is associated with the operation of such system. The project identifies with ABET student learning outcome criteria and particularly those dealing with sustainability.

Project Objectives

West Texas has a semi-arid environment with an average annual rainfall of about 478 mm based on the latest meteorological data since 2003[4]. The monthly average temperature west Texas ranges from 2.8 °C in January to 25.7 °C in July with mean monthly sunshine hours of 3,300. The Ogallala Aquifer, one of the largest underground fresh water aquifers in the world, is the primary source of agriculture irrigation in this area. Due to heavier use and a lack of adequate recharge to replenish the aquifer's supply, it became apparent several decades ago that the aquifer was declining significantly. Some studies [5] have shown that the Ogallala aquifer is expected to become non-productive by the year 2030. As a result, several water management practices that include water conservation, reuse and reclamation of wastewater were put into effect to extend the life time of the aquifer [6].The objectives of the design project are:

- 1) To design an environmentally friendly system that relies on renewable power for treating contaminated water in agricultural processing facilities, and therefore reduce the amount of fresh water consumed.
- 2) To perform an economic assessment that examines the feasibility of implementingsuch a system.

Design of the Solar Distillation System

A solar still was built at the Alternative Energy Institute on West Texas A&M University campus for the distillation of waste water produced in agricultural processing facilities. The passive system consisted of a steel basin and a collecting jar to hold the distillate (Fig. 1). The steel basin had a base of dimensions $0.85m \times 0.85m$ and a Plexiglas cover that was inclined at 30° with respect to the horizontal surface. It was estimated that a surface inclined at this angle would receive about 70% of the optimum solar radiation intensity throughout the year [7]. Since Canyon has positive latitude, the inclined surface was set to face south. The inclination of the solar still cover causes the condensing distillate to slide down the glass surface and collect into a tray that drains into a holding jar where distilled water is collected. To maximize the amount of heat absorption by the water, the interior walls of the steel basin were painted black. In this passive system, solar radiation received by the water through the Plexiglas cover was the only source of energy for heating the water.

The solar distillation system (Fig. 2) was then enhanced by augmenting the solar still with a solar collector; thus converting the system to an active distillation system [8]. Figure 3 describes the

schematics diagram of the active distillation system. Figures 4a and 4b show the detailed construction of the solar collector panel. The solar collector panel was constructed of two arrays of nine evacuated solar tubes paired with parabolic reflectors (Fig. 5a) that were overlaid with Mylar sheeting. The arrays were constructed using plywood, and were hinged together. The nine evacuated solar tubes in each array ranin series, and the two arrays ran in parallel. The evacuated solar tubes, made of borosilicate glass, had double walls with vacuum between the walls to absorb and trap the incoming energy from solar radiation. Figure 5b shows a schematic diagram of the operation of the evacuated solar tube. High reflective aluminum and copper coating was used to minimize the heat loss from the evacuated tubes. The tubes had an inner diameter of 43 mm, an outer diameter of 58 mm, and a length of 500 mm. The purpose of the solar tubes collector was to preheat the water before it entered the basin of the solar. A circulator pump was used for this application. The solar tubes collector provided an extra boost of thermal energy to the circulating water resulting in an increase in the evaporation rate and an improvement in the productivity of the system.



Fig. 1Passive solar distillation system



Fig. 2 Active solar distillation system



Fig. 3 Schematics diagram of the active solar distillation system



Fig. 4a Construction of the solar collector panel walls



Fig. 5a Evacuated solar tubes paired with parabolic reflectors



Fig. 4b Construction of the solar collector parabolic reflectors



Fig. 5b Schematic diagram of the operation of the evacuated solar tube

Thermocouples were installed inside the still on several walls, on the inner and outer surface of the glass cover, in the water basin, in the still enclosure above the water surface, at the inlet and exit from the solar collector panel, and in the surrounding air outside the still.All thermocouple wires were connected to a data acquisition device (Omega OMB-CHARTSCAN-1400), which in turn was connected to a portable computer that recorded the temperature data at a sampling rate of 1 data point per minute. Daily solar insolation (solar radiation intensity) was measured using Solar Survey 200R Irradiance Meter by Seaward Electronic Ltd.

Field Tests

Several tests were conducted to evaluate the performance of the solar still with and without the augmentation under the climatic conditions of West Texas (Table 1) for over the past two years. For all tests, temperature data were recorded for a period ranging from three to four days, the duration time of each test. The first series of tests (Tests No. 1 through 7 in Table 1) were conducted on the passive system while the second series of tests (Tests No. 8 through 11 in Table 1) were conducted on the active system. For all tests, water was poured into the still to a depth of 5 cm for a total volume of 36 liters. The conditions of the tests were as follows. The average

wind speed in these tests ranged from 3.61 to 7.29 m/s, average ambient temperature ranged from 18.4 to 31 $^{\circ}$ C, and average water temperature in the basin ranged from 25 to 40 $^{\circ}$ C. For the solar distillation system with augmentation, the mass flow rate of water circulating in the system was 0.11 kg/s.

					Average Temperatures			Distillate
Test	Dates	Description	Duration	V_{w}	T_a	T _{encl} .	T_{w}	Yield
No.		-	(hr)	(m/s)	(°C)	(°C)	(°C)	Rate(kg/m ² day)
	(Year 1)							
1	March	passive, insulated	81.1	5.6	25.5	39.0	31.8	1.35
2	April	passive, insulated	83.0	6.4	18.4	23.8	25.4	0.11
3	April	passive, insulated	108.3	6.3	24.1	30.1	29.4	0.68
4	May	passive, insulated	90.0	5.9	27.8	34.2	31.3	0.79
5	June	passive, not	95.0	6.4	31.0	38.6	37.4	1.31
		insulated						
6	July	passive, not	95.8	7.3	28.3	34.9	34.1	0.76
		insulated						
7	August	passive, not	96.1	3.6	25.5	31.1	30.2	0.24
		insulated						
	(Year 2)							
8	April	active, insulated	72	6.2	20.3	27.8	29.8	2.35
9	May	active, insulated	72	6.0	16.5	26.3	27.7	3.04
10	June	active, insulated	72	6.1	29.2	38.4	39.8	3.60
11	August	active, insulated	72	5.6	26.5	36.2	38.1	2.46

Table 1.Operatingconditions for passive and active stills

Analysis of Test Measurements

Figure 6 shows typical results of the temperature time history (Test No. 5 in Table 1) of the glass inner and outer surface, basin water, outside ambient air, and humid air inside the enclosure. In this test, temperature data were recorded for a period 95 hours. Water temperature is shown to peak between 55 and 60 °C during daylight and drop to 22 °C during the evenings. The ambient temperature peaked at 42 °C during daylight and dropped to about 21 °C during the evenings. Figure7 shows typical results of the time history of the solar insolation (solar radiation intensity) in a 24-hour period. The results are shown for the test conducted on summer season in Canyon, Texas. The perturbation that is seen in the data is due to presence of clouds moving into the area at certain times during the day.





Fig. 6 Transient response of the temperature at various locations in the solar distillation system

Fig. 7Typical hourly solar radiation intensity (Day 2 of Test No. 5)

The ratio of the daily solar insolation to the yield rate is an indicative measure of the effectiveness of the system. The lower is this ratio, the higher is the thermal efficiency of the system. This is reflected by the test data presented in Fig. 8. The figure shows as the daily solar insolation per yield rate drops below 13 MJ/L, the thermal efficiency of the system increases sharply. The results show the passive distillation system whose basin was un-insulated performed poorly with efficiencies below 9%, while the active distillation system had efficiencies reaching close to 19%. The passive distillation system whose basin was insulated had efficiencies that lied between those two systems. Figure 9 shows the distilled water yield rate as function of the total daily solar insolation. The results show the yield rate peaked at 3.6 kg/m²day when the total daily solar insolation reached 33 MJ/m²day.



Economic Assessment

The total cost of the distillation system is about \$250 for the passive system, and \$550 for the active system. Based on the daily yield rate predicted from the performed tests and based on the

size of the still basin(surface area of 0.85m x 0.85m), the annual yield rate is about 93.6 gallons for the passive system and 247.5 gallons for the active system. At an average total cost (fixed and variable cost) of \$0.37/gallon for water distillation in West Texas Panhandle region [9], the cost of the passive solar distillation system can be recovered after 7.2 years from installation, while the cost of the active solar distillation system can be recovered after 6 years from installation (Fig. 10). The active system produces distillate at a cost reduction of 16.8% compared to the passive system. Even though the cost of producing one gallon of distilled water from active solar distillation system far exceeds the cost of distillation per gallon during the first 6 years for the Panhandle region of West Texas, the proposed active solar distillation system provides alternative means for reclaiming water in farmlands using renewable power which draws its energy from natural resources (solar energy). As discussed earlier, the construction of such systems incurs a capital cost which will take some period to recover. The construction of the systems requires energy and leaves a carbon footprint on the environment. However, the operations of such systems (passive or active solar system) have a negligible carbon footprint on the environment (the water circulation pump for the active solar distillation system operateson solar power).



Gathering Feedback from Students

At the end of the project, students were asked the following questions:

- 1) Why is it important to incorporate sustainability considerations during the design phase of a project?
- 2) Why is it important to investigate sustainability initiatives across the globe?

Below are some of the students' responses to question 1:

- "Sustainable design will decrease impact on the environment"

- "To minimize waste energy which equals money"
- "To not hurt the environment any more than can be retained"
- "To take into consideration future use and future impacts at the project"
- "Resources will always be finite"

Also, the following are some of the students' responses to question 2:

- "To reduce the further negative impact on the environment"
- "Some countries environments are worse than ours"
- "To achieve a consensus on how engineering projects should be conducted and decrease unwanted impacts"
- "So the world can progress evenly towards a sustainable future"
- "Because it is a global environment. Changes in China affect all to some extent."

Conclusions

Mechanical Engineering students in thermal-fluid system design course at West Texas A&M University designed an active solar distillation systemfor the distillation of wastewater from agricultural processing facilities using evacuated tubes solar collector to test the feasibility of the system in West Texas climatic conditions. To investigate the feasibility of the distillation system, the active solar distillation systemwas tested against a passive system. Based on the results of their field tests, the students reached the following conclusions:

- \circ Compared to a passive still, the evacuated tubular collector coupled solar system increased the maximum temperature of the water in the basin by at least 20 °C on average.
- Compared to a passive still, the evacuated tubular collector coupled solar system increased the distillate production rate by a factor of 2.6.
- Students economic analysis showed that the evacuated tubular collector coupled solar still can provide an alternative means for reclaiming water in farmlands with a payback period of approximately 6 years.

Feedback gathered from the students at the end of their project reveals that the majority of the students had a clear understanding to the importance of incorporating sustainability considerations during the design phase of any engineering project. Their responses also showed a mature understanding to the importance of investigating sustainability initiatives across the globe as well.

Acknowledgement

The authors acknowledge USDA-Ogallala Aquifer Program for financially supporting the project under Grant No. 281119. The authors would like to thank the Alternative Energy Institute at West Texas A&M University for providing their outdoor facility for the students in Thermal-Fluid Design course to run the fieldtests.

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