Solar Distillation Still

WERC Competition

Northern Arizona University Design Team

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Ms. Rosanne Thompson

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MSC WERC

PO BOX: 30001

Las Cruces, NM 88003-8001

SUBJECT: Proposal for Development of an Improved Solar Distillation Still

Dear Ms. Thompson,

On behalf of the Northern Arizona University Design Team, we are pleased to submit our Proposal for designing the solar distillation still. We would like to thank you for this opportunity to compete in the WERC Competition. We look forward to designing a solar distillation still with the highest possible water production per unit cost. Our goal is to create a project based on the local materials in Flagstaff, AZ. We will design a still that is easy to replicate at low cost. The detailed work of services, timeline and budget is shown in this proposal.

We are looking forward to you reviewing our proposal and cannot wait to work with you in the future. If you have any questions or comments please feel free to contact us at cme69@nau.edu.

Very Respectfully,

Northern Arizona University Capstone Solar Distillation Unit Design Team.

Proposal for

Development of an Improved Solar Distillation Still

Prepared for:

New Mexico State University

Institute for Energy & the Environment

MSC WERC

PO BOX: 30001

Las Cruces, NM 88003-8001

Attn: Rosanne Thompson

Submitted by:

Northern Arizona University

Solar Distillation Still Design Team

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Flagstaff, AZ 86001

December 5, 2011

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Table and Figure List

1.0 Introduction

In many areas around the world, there is a shortage of clean drinking water. In poorer communities, the drinking water has a high chemical and bacterial content. Many of these small communities have a lack of technology with poor access to electricity. Therefore, solar distillation stills are a great solution to purifying water sources in order to provide clean drinking water to these communities.

1.1 Problem Statement

The purpose of this project is to develop new versions of solar distillation stills and document their performances based on the efficiency of purifying brackish groundwater without the addition of electricity. Through the use of solar distillation, we can use heat from the sun to evaporate potable water from the brackish water. The goal of this project is to design a still with the highest possible water production per unit cost of the process equipment.

1.2 Background

Solar water stills have been used for thousands of years. The original use was to get salt from salt water, over time, it was used to purify contaminated water and make it potable. The first documented solar stills were in the sixteenth century. The first large-scale solar still was built by a mining community in Chile in 1872. Solar stills became popular in the US Navy in World War II by making inflatable plastic stills for drinking water. Developing countries are interested in solar distillation treatment process because of their need for clean water. The water being analyzed in this competition is brackish water with a variety of dissolved chemicals and minerals. The objective for the final design is to reduce the amount of contaminants in the water with the most efficient and cost effective design. The brackish water contains a multitude of contaminants, which are outlined in the following table:

Table 1–Brackish Water Condition

Component	Value
Conductivity	6100 µS/cm
Sulfate	3300 mg/L
Chloride	550 mg/L
Hardness (as CaCO3)	3000 mg/L
Sodium	700 mg/L
Calcium	600 mg/L
Magnesium	375 mg/L
Silica	25 mg/L
Strontium	10 mg/L

The still is going to be designed to scale, and will be implemented in Flagstaff, AZ. Flagstaff's soil conditions will be a factor in the overall design. The materials being used will depend upon what is available in the City of Flagstaff. Overall, the unit producing the largest amount of distilled water for the lowest price possible will be the final design.

1.3 Stakeholders

The key stakeholder is WERC: A Consortium for Environmental Education and Technology Development. Partners included are New Mexico State University, University of New Mexico, New Mexico Institute of Mining and Technology, Dine College, Sandia National Laboratories, Los Alamos National Laboratory. This project reflects the mission to use education, public outreach, technology development and deployment to achieve environmental excellence.

2.0 Technical

2.1 Technical Process

Solar distillation stills use heat from the sun to clean water. Commonly, a solar still consists of a shallow basin with a transparent glass cover. The sun heats water in the basin and causes the water to evaporate. The evaporated water rises until it hits the glass cover where it turns back to liquid and runs down the glass until it falls into the collection trough leaving the salts, minerals and bacteria in the basin. One example is a box solar still which can be seen in Figure 1.

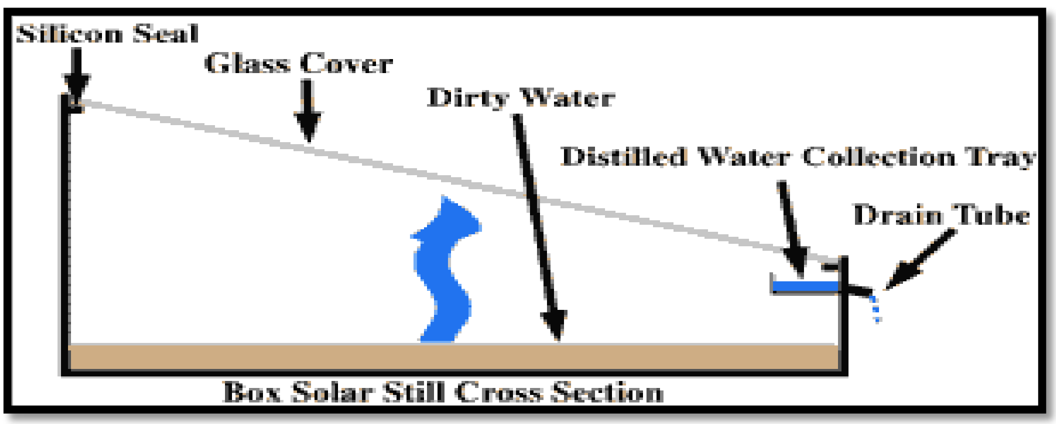

Figure 1– Box Solar Still Cross Section (Solar Solutions, 1996)

There are three technical components to a solar distillation still. These three components include the cover structure, cover material, and the base.

2.2 Cover Structure

The cover of the solar distillation still needs to provide the largest area possible so that the system can absorb the most heat in a fixed amount of time. The general cover structures are pre-shaped, triangular and ramped with a smooth inner surface so that it is easier for the evaporated water to condense and run into the collection trough. The cover should also be thicker to increase the utilization efficiency of the heat. Unfortunately, the cover cannot be too thick otherwise the construction cost will increase. The cover thickness will be based on the cost and efficiency constraints. Tests will be conducted and results will be plotted to analyze the most appropriate cover thickness. Based on the analysis, an acceptable cover thickness will be selected for the final design.

2.3 Cover Material

Since incoming radiation is used to heat the water, a cover with low absorbing and reflecting properties will be used. A smooth transparent material is ideal for cover purposes. The smoothness decreases the amount of light that will be reflected, and can be utilized to collect condensation from inside the system. Unidirectional heat transfer material reduces heat loss making it an ideal choice for cover material.

2.4 Base

The base of the solar distillation still needs to provide the largest evaporation area possible. A large area will improve the efficiency of water treatment by increasing the evaporation rate. The ideal building material for the base of a solar distillation still is either copper or iron metal surrounded by insulating material. The copper or iron metal absorbs the heat and transfers it so the water can evaporate. The insulation helps to minimize the amount of heat loss. The efficiency of the system increases by lowering the heat loss and focusing the heat on a centralized location.

3.0 Challenges

There are several potential challenges for the creation of a solar distillation still. These challenges are listed below:

- Cost - Providing a low cost product at a high efficiency will allow the final design to be easily replicated and maintained.
- Electricity - Without an outside source of electricity, other means will be utilized to heat and pump the water throughout the system.
- Location's water - The water presented at the competition may be different than the water presented at the test site.
- Efficiency - Theoretical water production efficiency may differ from actual efficiency of the still, resulting in lower production of water.
- Weather - Due to inconsistent weather conditions, it will be difficult to have ideal heating conditions for distilling the water.

4.0 Key Factors

The key factors for success concerning the improvement of the solar distillation still are listed below:

- Materials - Considerations for system performance, as well as material availability and durability at the selected location are essential for project success.
- Unit Construction and Maintenance - Ease of both unit set up and maintenance play an important role in project success.
- Production Rate - The highest production rate of potable water that can be obtained from the unit will impact the size of population that can feasibly be supported from this project.

- Cost – Water production as well as construction and maintenance is included in the overall cost. Keeping the overall cost as low as possible is a key factor for the success of the project.

Scope of Services

Introduction

The Scope of Services is provided in this section. This section is broken down into the necessary works which need to be done to design a new solar distillation unit. The order of our primary tasks is listed below:

Task 1- Project Management

Task 2- Research Overall Project

Task 3- Location

Task 4- Research and Test Material

Task 5- Research and Test Structure

Task 6- Research and Test Cover

Task 7- Research and Test Collection System/Insulated Basin

Task 8- Build and Test Models

Task 9- Project Study Report

Task 1-Project Management

1.1 Group Meeting

The solar distillation unit design team meetings will serve as the primary forum for researching the project early in this semester. For the rest of the semester, team meetings will be focused on testing and building models. Meeting hours are set for every Sunday afternoon. All team members are required to attend.

Deliverable: Meeting agenda, minutes

1.2 Technical meetings

The solar distillation unit design team will prepare several meetings with technical advisors in order to discuss and solve specific project needs and issues. The meeting information and time need to be documented in order to review later.

Deliverable: Meeting agenda, professional help on tasks

Task 2-Research Overall Project

The solar distillation unit design team will research on the existing professional solar distillation units. We will learn the basic design concepts for solar distillation units and the pros and cons for the existing designs. During the research, we will also learn about different design materials, structures, covers and tests, in order to determine which will be used in the final design.

Deliverable: Design matrix

Task 3-Loaction

Flagstaff, Arizona is the location for which the thermal distillation unit will be tested. To ensure direct sunlight the test will be conducted at noon. The testing period will take place over the month of March. The expected climatic testing conditions can be seen in Table 1. LA Climate Data: (National Weather Service Forecast Office, 2012) Month of March 2012:

Table 2 – Flagstaff, AZ Average Climate Data for March 2012

Average Maximum Temperature(°F)	52.9
Average Wind Speed (MPH)	8.4
Average Sky Cover	0.1
Average Relative Humidity (%)	51

As seen in Table 2, the average maximum temperature was approximately 52.9 (°F). The average sky cover recorded by the National Weather Service Forecast Office was 0.1. The average wind speed was 8.4 mph, and the average relative humidity was 51%. These values reflect the average data for the month of March. The still will be located Flagstaff permanently. Therefore the overall performance of the thermal unit can be calculated by the yearly average of climate conditions. The average yearly climate conditions are shown in Table 3.

Table 3 – Flagstaff, AZ – Average Climate Data for one year

Average Maximum Temperature(°F)	62.5
Average Wind Speed (MPH)	6.6
Average Sky Cover	0.2
Average Relative Humidity (%)	51.7

As seen in Table 3, the average maximum temperature was approximately 62.5(°F). The average sky cover recorded by the NOAA was 0.2. The average wind speed was 6.6 mph, and the average relative humidity was 51.7%. These values reflect the average data for one year. Utilizing this data, the average amount of water distilled per unit of time can be calculated.

Deliverable: Location and weather conditions

Task 4- Research and Test Material

4.1 Research Materials

Materials in the structure of the solar distillation unit have a large effect on the overall efficiency. When choosing the materials to be used, a number of characteristics should be evaluated and compared.

Materials should have the following characteristics:

- High Durability
- Low cost
- High local availability
- Low skills needed
- Low cleaning necessity
- High portability
- Low toxicity

List of Common Materials include:

- Steel
- EPDM Rubber
- Butyl Rubber
- Asphalt Mat
- Cement
- Black Polyethylene
- Roofing Asphalt on Concrete
- Wood
- Fiber Glass
- Aluminum

Deliverable: Alternatives of materials, characteristics of materials, design matrix of materials.

4.2 Test material

Our group will choose the materials from the common materials listed above. Based on the specific characteristics of design materials, our group will conduct a series of relative tests to decide the top three materials for our design.

Deliverable: Design matrix, and final materials

Task 5-Research and Test Structure

5.1 Types of Structure

There are four types of structures used in a solar still. They include a concentrating collector still; multiple trays tilted still, tilted wick solar still and basin still (Joel Gordes $ Horace McCracken, 1985).

Concentrating Collector Stills use mirrors to focus sunlight onto an enclosed evaporation container. The concentration of light causes high temperatures that evaporate the water. The vapor is then transported to a separate container.

A Multiple Tray Tilted Stills has a series of shallow horizontal trays in an insulated container with a glass cover. Vapor condenses on the cover and travel to the collection unit for storage. The Unit can be tilted to be perpendicular to the sun's rays.

The Tilted Wick Solar Still uses fibers to distribute water over the exposed surface so that the expose to sunlight causes it to be evaporated. Vapor then condenses on the cover and travels to the collection unit for storage.

Basin stills have a basin, support structure, transparent glazing cover and distillate trough. Even though this still is the most commonly used, however, large units usually do not have an overall high efficiency.

Deliverable: Providing basic information about structures, structure alternatives

5.2 Test Structure

Based on the types of structures provided above, our group will build several structural models to test and analyze, in order to decide the best one.

Deliverable: Design matrix, final design

Task 6-Research and Test Cover

6.1 Cover structures

Generally, the cover of the solar distillation unit should provide the largest area as possible. This allows more heat to be absorbed in a fixed time. The cover design should be pre-shaped triangular or ramp and have smooth inner surface. Compared to the collection system, the cover is thicker and has a higher utilization efficiency of the heat. However, utilizing heat at a higher efficiency will also increase the construction cost. Therefore, the new cover needs to meet the low cost with high utilization efficiency of the heat. To meet the requirements, testing and drawings will be provided to choose the best cover design. After creating a number of designs, a comparison of the acceptable efficiency to cost, the thickness of the cover, will be made to select the best design.

Deliverable: Alternative covers, design matrix

6.2 Testing covers

The cover of the solar distillation unit will have a high radiation absorbing level, and low light reflection surface. The following heat balance equations will be used in choosing the covers:

$M_g \frac{dT_g}{dt} = a_g H_S + q_w - q_a$((Jinyang Xu, Yefa Li, 2004))

Mg= the mass of cover material

Tg= temperature of cover surface

ag=the cover material absorb rate

Hs= the total solar radiation

qa=heat from cover to the surrounding(include radiation and convention)

qw=heat from water to cover material(include radiation, convention and latent heat of evaporation)

$$M_w \frac{dT_w}{dt} = a_w H_S + a_a H_s - q_w - q_{HT}$$ (Jinyang Xu, Yefa Li, 2004)

Mw= the mass of water

Tw= temperature of water

aw=the water absorb rate

Hs= the total solar radiation

aa= the base absorb rate

qw=heat from water to cover material(include radiation, convention and latent heat of evaporation)

qHT= the loss heat form water to base

In order to determine the heat efficiency for the unit different materials, different thickness of materials and different depths of water in unit will be used. The cover material also needs to reduce the loss of heat. Unidirectional heat transfer material will most likely be the best choice.

Deliverable: Testing, final design

Task 7-Reasearch and Test Collection System/Insulated Basin

7.1 Collection Design/Insulated Basin

The insulated basin needs to be able to store the contaminated water while it is waiting to be distilled and transport the clean distilled water into storage. The insulated basin will be flat so that the condensed water on the inclined cover may drip to a collection tube, where it will drain clean distilled water into a holding tank. The water will be released into the insulated basin using a float valve, which will open the valve to the source of the contaminated water once the water level begins to drop due to evaporation. Once the water is condensed on the cover, it drains into a tray that is positioned at the end of the angled cover. The tray is angled so it is able to drain into the end of a tube which feeds into the collection system.

Deliverable: Process of collection system

7.2 Test Collection System/Insulated Basin

This will be evaluated by researching different materials, heat retention, and ability to attract solar radiation. The area of the unit will be evaluated, as well as how the water will be stored once distilled and the source of the contaminated water. The water needs to be collected by a material that does not melt, emit chemicals, or produce rust when exposed to water, solar radiation, and heat over long periods of time.

Deliverable: Design Matrix and alternative materials for collection system

Task 8-Build and Test Models

After obtaining all the information from the research and tests, our group will determine and build our best solar distillation unit models. We will test the models and analyze the output of the units. The approximate method of estimating the output of the unit is given by:

$Q = E * G * A/(2.3)$ (Practical Action, 2002)

where:

Q = daily output of distilled water (litres/day)

E = overall efficiency

G = daily global solar irradiation (MJ/m^2)

A = aperture area of the still ie, the plan areas for a simple basin still (^{2})

After comparing the efficiencies and the daily outputs of the unit, our team will decide on our final model design and build it.

Deliverable: Build units and build final unit

Task 9-Porject Study Report

9.1 Draft Project Study Report

Our group will prepare the general draft of the project study report. The draft will follow the requirements and standards of the WERC competition. The draft will clearly document the purpose of the project, summarize our research, describe the alternatives, analyze the testing results, and describe the final building process. The draft will be revised and provided to the WERC competition.

Deliverables: Draft project study report

9.2 Final Project Study Report

Our group will update the Project Study Report and provide an administrative Final Project Study Report to the WERC competition for review.

Deliverable: Final Project Study Report

The timeline for designing a new solar distillation still is based on the scope of services. There are nine major tasks, and the timeline will follow the order of each task. The detailed timeline is shown in Figure 2.

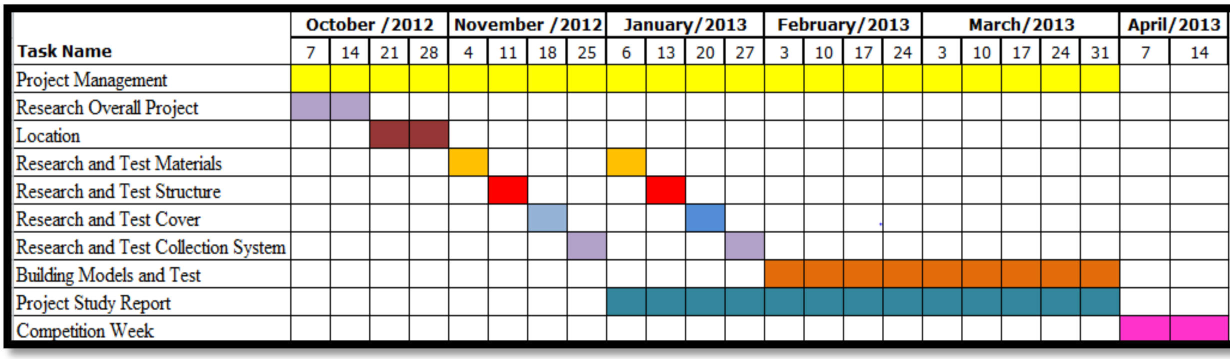

Figure 2 – Timeline for Design a Solar Distillation Still

As seen in Figure 2, project management will take place throughout the duration of this project. Project management will be accomplished primarily by the means of emails and weekly team meetings. Each task meeting is set for 12:00 pm to 3:00 pm on Sundays. Meeting hours are subject to change and all team members are required to attend. As shown in the timeline above, researching the overall project will take place the first two weeks of October. Researching the location will take place the second two weeks of October. The research of materials, structures, covers and collection systems will take place during the month of November. Upon completion of task research, the testing of these components will be done in January. After testing, construction of alternative stills will begin. Solar distillation stills will be tested, analyzed, and revised in order to construct the most efficient design. The project report will begin in the month of January and continue until competition week.

The budget for designing a new solar distillation still is provided in this section. The average payment of an environmental engineering is 39.72 dollars per hour (Cbsalary, n.d). There are five members in the Northern Arizona University Solar Distillation Design Team. The cost is based on the timeline provide in last section. Direct labor costs and direct non-labor costs are shows in Table 4.

Table 4 – Cost for Design a Solar Distillation Still

Direct Labor Costs

Research Phase		
Overall Project	$ 1,191.6	
Location	$ 1,191.6	
Materials	$ 119.16	
Structure	$ 119.16	
Cover	$ 238.32	
Collection System	$ 119.16	
Research Phase Subtotal		$ 2,979
Testing Phase		
Materials	$ 1,191.6	
Structure	$ 1,191.6	
Cover	$ 1,191.6	
Collection System	$ 1,191.6	
Testing Phase Subtotal		$ 4,766.4
Construction Phase		
Building Models	$ 3,574.8	
Testing	$ 3,574.8	
Final Model	$ 3,574.8	
Construction Phase Subtotal		$ 10,724.4
Project Study Report	$ 516.36	

Direct Labor Subtotal		$ 18,986.16 X_1
Adjusted Direct Labor Cost		
Direct Labor Multiplier (#)*X_1		$ 43,668.17 X_2
Adjustment Direct Labor + Profit		
Percent of Profit 10 %		$ 48,034.98 X_3
(1+(%/100))*X_2		
Direct Non-Labor Costs		
Construction Material Cost	$ 300	
Competition Application Fee	$ 800	
Travel (Gas)	$ 200	
Hotel	$ 1000	
Meal	$ 1575	
Direct Non-Labor Charges Subtotal		$ 3,875 X_4
TOTAL FEE REQUESTED [X3+X4]		$ 51,909.98

As seen in the table above, the total fee requested is $31,025. The direct labor charges are $18,986. Using the multiplier as 2.3, the adjusted direct labor charge is $24.682. As a result, adjustment direct labor and profit is $27,150. The non-labor cost includes construction material, competition application, travel, hotel and meal. As estimated each cost, the total direct non-labor charges is $3,875.

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