A PASSIVE SOLAR WATER PURIFICATION SYSTEM FOR REMOTE AREAS OF AFGHANISTAN

William S. Duff
Andrew Clopper
Kelly Fagerston
Aaron Koski
Amberle Leak
Razzack Palenfo
Laura Ruff
Zach Simson
Brian Smith
Katherine Ulrich
Department of Mechanical Engineering
Colorado State University
bill@engr.colostate.edu

ABSTRACT

Water-borne pathogens in developing countries cause several billion cases of disease and up to 10 million deaths each year, at least half of which are children. Solar water pasteurization is a potentially cost-effective, robust and reliable solution to these problems.

As shown in Fig. 1, a completely passively controlled solar water pasteurization system with a total collector area of 0.45 m^2 has been developed and constructed. The system provides purified water from biologically contaminated water sources without the use of valves or electrical or mechanical power. The completely passive density-driven solar water pasteurization system was developed over a five year span so that it now achieves reliable control for all possible variations in solar conditions. The system most recently tested produced 337 litres per m^2 of collector area of treated water on a sunny day.

Recently we have begun the redesign and fabrication of the passive solar water purification system so that its principles of operation and utilization of materials and labor skills reflect those readily compatible with the remote areas Afghanistan. Design prototypes are currently being tested..

In this paper and the presentation we will provide the results from the operation of the current system and the new prototypes. We will describe our efforts to define the parameters of water purification needs in Afghanistan, to determine what labor skills and materials are compatible in

Fig.1. The Experimental Density Driven System in 2003

the remote areas of Afghanistan and how the factors were incorporated into the design of the prototypes.

1. BACKGROUND

Waterborne pathogens in developing countries cause several billion cases of disease and up to 10 million deaths each year, at least half of which are children. In the rural areas of developing countries, boiling is the means most often used for purifying water for food preparation and drinking. However, boiling is relatively expensive, consumes substantial amounts of fossil energy and the associated wood gathering contributes to depletion of forests. Among available alternatives, solar water pasteurization is one of the most promising approaches for an energy-efficient, cost-effective, robust and reliable solution to these problems (Burch and Thomas, 1998) [1].

In experiments conducted in Fort Collins, Colorado the system that was tested is essentially the same density difference driven system described in Duff and Hodgson [2,3] and pictured in Fig. 1, with some refinements to the recirculation loop and system insulation. See Duff and Hodgson [8].

Density difference driven systems take advantage of the thermal expansion of water to regulate temperature. In a density difference system, water is supplied at a fixed height. Once heated, the water flows out of the system via an elevated spillover tube. The water will not rise to the spillover point until it has reached an adequately high temperature (sufficiently low density). The spillover temperature can be tuned by adjusting the height of the supply reservoir relative to the height of the spillover tube.

Density driven temperature control was first used in solar collectors by Boettcher, et al. [4]. Experiments using density driven temperature control for water pasteurization have been conducted by Bansal, et al. [5], Cobb [6], and Saitoh and El-Ghetany [7].

1.1.Experimental Setup

1.1.1 System Description

The system is shown in Fig. 2. Five evacuated tube heat pipes with a total absorber area of 0.45m^2 are mechanically clamped to the collector tube. The collector tubes are oriented with a slope of 15˚ and a surface azimuth angle of 0˚. As the water in the collector tube is heated, the convection tube allows for water to circulate through the riser tube. The U-tube ensures that the circulation is in the proper direction (clockwise for Fig. 2). The circulation allows for the water in the riser tube to be nearly isothermal. When the water in the convection loop has reached the proper temperature, water flows over the spillover and into the holding tube. Treated water from the holding tube flows through the heat exchanger and into the treated water reservoir. Preheated water from the heat exchanger is fed into the convection loop just above the U-tube. The riser tube and convection tube intersect at the height of the supply reservoir to ensure that there is always free circulation in the convection loop.

1.1.2 Supply Reservoir

Tap water was supplied to a plastic container that served as the elevated supply reservoir. A solenoid valve controlled water flow to the container. Two signal wires were affixed to the inside of the container. One was secured to the bottom of the container and one was secured on the wall of the container. The electrical resistance between the two signal wires was used to control the solenoid valve. When the resistance was above a threshold the valve would open and allow water to flow into the container. By this method the water level in the supply reservoir was maintained to within 0.5 cm of the location of the upper control wire.

1.1.3 Data Collection

T-type thermocouples were used to measure temperatures.

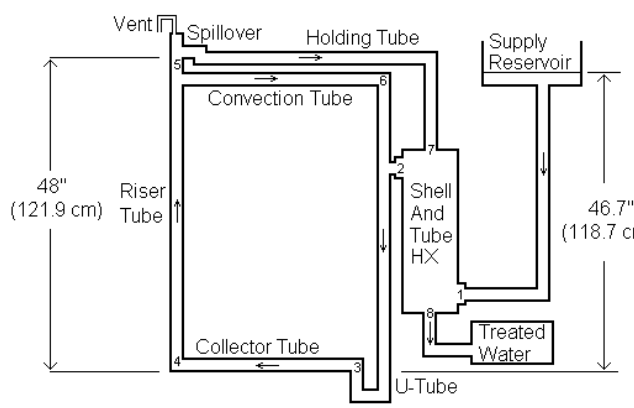

Fig. 2. Schematic of Density Driven System with an Internal Convection Loop. Numbers indicate the location of thermocouples. Arrows indicate the direction of flow. Water flows from the supply reservoir though the shell side of the heat exchanger.

The thermocouples were placed as close to the center of the flow stream as possible. Solar radiation values were measured with an Eppley PSP Pyranometer. The pyranometer was located adjacent to and oriented the same as the solar collectors (slope=15°, surface azimuth angle=0°). The treated water reservoir was weighed at the start and end of each test day to determine the daily production. In addition, strain gages were used to monitor production and make a rough calculation of the flow rate throughout the test day. The temperatures, solar radiation and strain gage values were collected every minute.

1.1.4. Performance

Fig. 3 and 4 show spill-over temperature, solar flux, and flow rate profiles for September 25, 2004 and October 18, 2004, respectively. The spill-over temperature corresponds to location (5) on figure 1. September 25th in Fig. 3 was a mostly sunny day though a brief period of clouds interrupted the flow through the system. October 18th in Fig 4 was a cloudier day. The system experienced three separate periods of production.

Fig. 5 and Table 1 display daily production data for twelve test days. The figure shows that daily water production varies nearly linearly with insolation. The data suggests that a minimum total insulation of about 9 MJ/m^2 is required for the system to produce treated water.

1.1.5. Time-Temperature Pasteurization Analysis

Fig. 3 and 4 show irradiance and the daily temperature profiles for inlet (thermocouple location 5 on Fig. 2) of the holding tube for September 25th, 2004 and October 18th, 2004. When water is flowing there is little temperature drop within the holding tube. Both temperatures in the holding tube experienced sharp drops on September 25th, indicating that the temperature fluctuations in the circulation loop affect the water entering the holding tube.

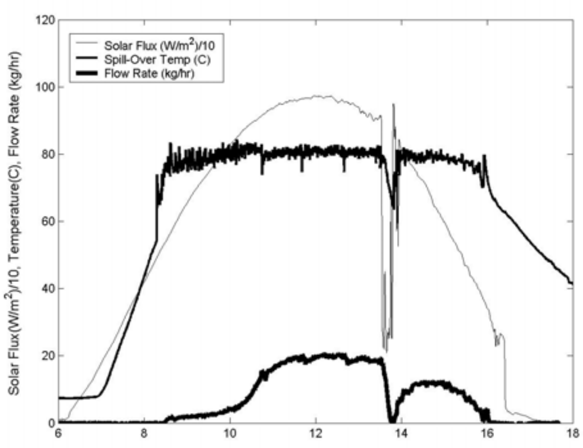

Fig 3: Solar flux, spill-over temperature, and flow rate profiles for September 25th 2004. Temperature corresponds to location (5) on Fig. 1.

As water flows through the holding tube its temperature drops. The temperature of the water as it leaves the holding tube is the minimum temperature it has had in the holding tube. Thus the holding tube outlet temperature represents the minimum holding temperature of the process. Since the volume of the holding tube is known, the holding time at a particular time of day can be calculated by integrating the mass flow rate backwards through time. In this way it is possible to determine when the water that is currently leaving the holding tube entered the holding tube. To take into account the possibility of a high centerline velocity the holding time determined with this method was multiplied by a factor of 0.5.

When the temperature and holding time data for the system are examined during periods of reduced flow, such as occurred on October 18th 2004, the temperature drops experienced in the circulation loop do not appear to affect the overall process of the system. The data are actually a collection of many constant temperature processes. It is not enough for part of this data to have an acceptable holding time and temperature. In order for the process to be effective every data point needs to have a temperature above and to the right of the required inactivation level.

Fig. 6 shows the thermal inactivation data for the pathogens examined in Duff and Hodgson [2. 3] along with the system's process data for all test days. From this figure it is clear that the system should provide significant protection for those pathogens where sufficient thermal inactivation data is available. Unfortunately, there is not adequate thermal inactivation data for some important pathogens.

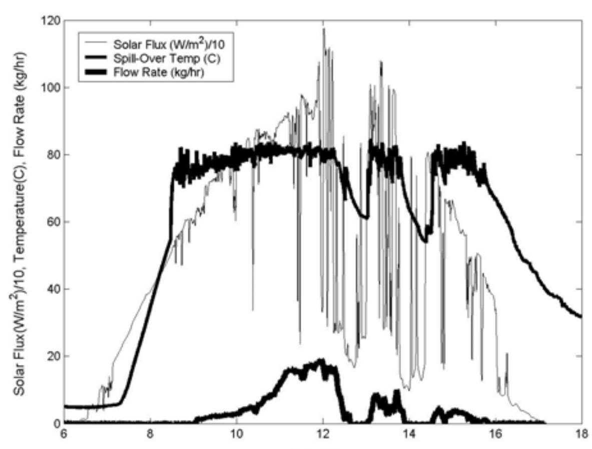

Fig 4: Solar flux, spill-over temperature, and flow rate profiles for October 18th 2004. Temperature corresponds to location (5) on Fig. 2.

Not only does the system produce significant amounts of treated water, the treatment process operates at higher temperatures and for longer times than the inactivation studies reported in Duff and Hodgson [2. 3]. Though adequate thermal inactivation information does not exist for some important pathogens, there is no data to suggest that the process will not be viable.

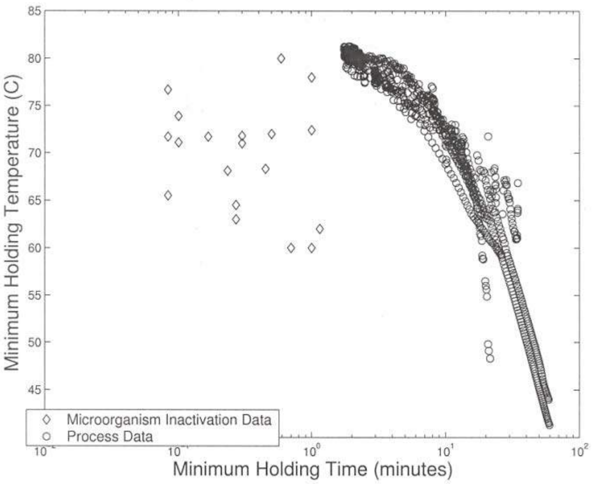

Fig.6: Process Time-Temperature versus Microorganism Deactivation

TABLE 1: DAILY PRODUCTION DATA

Date 2004	Sun (MJ)	Production (kg)	Date 2004	Sun (MJ)	Production (kg)
3-Aug	5.9	12	28-Sep	2.4	1
4-Aug	10.7	99	29-Sep	9.0	51
5-Aug	9.3	69	2-Oct	3.3	7
10-Aug	9.0	72	3-Oct	7.6	61
11-Aug	13.1	152	4-Oct	9.7	96
13-Aug	12.9	147	5-Oct	8.7	70
14-Aug	12.8	138	6-Oct	1.9	0
15-Aug	12.5	131	7-Oct	10.2	103
16-Aug	12.5	128	8-Oct	10.7	68
17-Aug	7.8	65	9-Oct	10.6	92
24-Aug	6.2	21	10-Oct	9.5	76
26-Aug	7.0	23	11-Oct	6.0	10
10-Sep	5.9	33	12-Oct	9.9	92
11-Sep	11.9	101	13-Oct	10.4	78
12-Sep	4.0	1	14-Oct	6.2	6
13-Sep	6.0	8	15-Oct	1.3	1
14-Sep	7.4	10	16-Oct	9.3	31
15-Sep	12.0	74	17-Oct	4.1	1
16-Sep	10.4	89	18-Oct	8.5	38
17-Sep	11.5	89	19-Oct	3.5	0
18-Sep	9.6	71	20-Oct	8.0	16
19-Sep	4.9	7	21-Oct	8.5	48
20-Sep	7.7	47	22-Oct	3.5	1
23-Sep	11.6	91	24-Oct	3.7	1
24-Sep	7.8	33	25-Oct	6.9	24
25-Sep	10.6	82	26-Oct	8.5	32
26-Sep	10.4	81	27-Oct	5.1	3
27-Sep	8.9	85	28-Oct	8.7	47

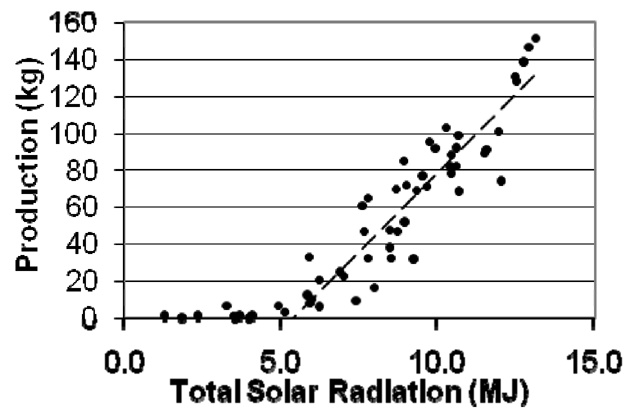

Fig. 5: Daily production as a function of solar radiation

2. CURRENT WORK

Recently we have begun the redesign and fabrication of the passive solar water purification system so that its principles of operation and utilization of materials and labor skills reflect those readily compatible with the remote areas Afghanistan. We are working with a solar collector manufacturer and individuals and agencies with first-hand experience in these remote areas. Prototypes are currently in the design phase with operational systems planned for early 2010.

The United States government has allocated substantial funds to improve conditions in remote areas of Afghanistan. One of stated purposes of these allocations is the delivery of purified water. One of our primary goals is to realize wide scale use in Afghanistan of the passive solar water pasteurization system.

In this paper and the presentation we will provide the results from the operation of the current system and the new prototypes. We will describe our efforts to define the parameters of water purification needs in Afghanistan, to determine what labor skills and materials are compatible in the remote areas of Afghanistan and how the factors were incorporated into the design of the prototypes.

2.1. Water Purification Needs in Afghanistan

Water quality issues are rampant in many developing countries. One of the main problems for the general public is the presence of pathogens in the available water. Some of these pathogens can cause extreme illness and infectious disease usually resulting in death. In recent years, there has been great effort to improve drinking conditions in these countries. Non-profit organizations as well as military groups are pushing for water purification systems to be established throughout these countries.

According to UNICEF Afghanistan has one of the least percentages of clean water available for drinking with only 17% of the rural population having sustainable access to clean drinking water. This is a result of conflict, some of the worst droughts in recent history, lack of infrastructure and minimal education about safe drinking water. As a result of the inability to obtain clean drinking water, diarrheal diseases and tuberculosis are chronic threats to the public health. As well, urban drinking water supplies are experiencing cross-contamination with coliform bacteria causing another risk to the state of the public health. Some of the population uses wood to boil water for purification; however, this leads to heavy exposure to smoke and emissions for the women and children who spend most of their time indoors. Furthermore, the use of wood leads to deforestation and environmental degradation. It is evident that the people of Afghanistan are in need of a sustainable and reliable way to access clean drinking water to improve their health and environmental condition.

2.2. Labor Skills and Materials in Afghanistan

One of the most important design aspects of the passive valve-less flow-through solar water pasteurization system is ease of construction. All of the necessary components and materials will be included in a ready to assemble kit and tools are not required. See Fig. 7 and references [9, 10, 11 and 12]. The system will include a step-by-step training manual illustrating exactly how each part goes together. The system is also colored coded to make assembly easier and allow for an individual who speaks another language to build it using the pictures and colors. To prove the ease of use, the design team completed a community involvement activity with a local high school. See Fig. 8. The high school students, who have little technical background knowledge, were able to assemble the water purification system in around 45 minutes without the help of the team.

Availability of materials will vary by location in Afghanistan and therefore it was deemed essential to include all materials that will be needed to run the system. The system has been designed to withstand various snow loads, large gusts of winds, and other environmental conditions that are prevalent in various regions in Afghanistan. The frame of the system is built out of wood to create a sturdy and robust structure while the pipes are made of copper to promote excellent heat transfer and withstand large amounts of UV exposure. The plastic tubing and containers that hold the water are all FDA approved and are rated to tolerate high temperatures and are resistant to melting in direct sun light. These material selections will ensure the system is safe and can undergo the diverse weather conditions in Afghanistan.

Fig. 7. Current System

2.2. Labor Skills and Materials Compatible in the Remote Areas of Afghanistan

2.3. How these Factors Were Incorporated into the Design of the Prototypes.

3. REFERENCES

1. Burch, J. D., and Thomas, K., An Overview of Water Disinfection in Developing Countries and the Potential for Solar Thermal Water Pasteurization, NREL/TP-550-23110, National Renewable Energy Laboratory, Golden, Colorado, 1998

Duff, William S. and David Hodgson, “A Completely Passive Continuous Flow Solar Water Purification System”, International Solar Energy Society 2007 Solar World Congress, Beijing. China, September 2007.

2. Duff, W.S. and Hodgson, D., Continuous Flow Density Driven Passive Solar Water Pasteurization, Proceedings of the International Solar Energy Society – Solar Engineering 2004, Portland Oregon, 2004

3. Duff, W.S. and Hodgson, D., A simple high efficiency solar water purification system, Solar Energy, vol. 79, pages 25-32, July 2005.

4. Boettcher, A., Heybutzki, H., Krug, W., Self-Regulating Solar Water Heaters with Very Short Start-Up Phase, Proceedings, 8th Congress International Solar Energy Society, Perth, W. A., 1984

5. Bansal, N.K., Sawhney, R.L., Misra, A., and Boettcher, A., 1988, Solar Sterilization of Water, Solar Energy, 40, pp. 35-39, 1988

6. Cobb, J., Simple Self-Regulating Solar Pasteurizer for Contaminated Water, Proceedings, 1998 American Solar Energy Society Conference, Albuquerque New Mexico, 1998

7. Saitoh, T.S., and El-Ghetany, H.H., Solar water-sterilization system with thermally-controlled flow, Applied Energy, 64, pp. 387-399, 1999

8. Duff, W.S. and Hodgson, D., A Completely Passive Continuous Flow Solar Water Purification System, ISES Solar World Congress September 14th 2007 in Beijing, China

9. "UNICEF - Afghanistan - The Big Picture." UNICEF - UNICEF Home. 26 June 2006. Web. 11 Mar. 2010. http://www.unicef.org/infobycountry/afghanistan_background.html

10. "Core Health Indicators." Web. 11 Mar. 2010. http://apps.who.int/whosis/database/core/core_select_process.cfm?countries=afg&indicators=PopAccessImprovedWaterUrban&indicators=PopAccessImprovedWaterRural&indicators=PopAccessImprovedSanitationUrban&indicators=PopAccessImprovedSanitationRural

11. Munsch, Holger, and Daud Saba. "Afghanistan: Findings on Education, Environment, Gender, Health, Livelihood and Water and Sanitation." (2005).

12. Evaluation of investment options for the development of oil and gas infrastructure in Afghanistan . March 28, 2005. HILL international.

Fig. 8 Members of the Team and High School Students who Conducted the Erection Test.