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Field evaluation of a community scale solar powered water purification technology: A case study of a remote Mexican community application

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HIGHLIGHTS

- PVRO water purification system is designed and tested in rural Mexican community.
- The technical and economic feasibility of approach under field conditions is shown.
- Community members are successfully trained to operate and maintain the system.
- The work suggests that PVRO clean water is a viable approach for rural communities.

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ABSTRACT

Lack of clean water in small remote communities in the developing world is a major health problem. Water purification and desalination systems powered by solar energy, such as photovoltaic powered reverse osmosis systems (PVRO), are potential solutions to the clean water problems in these small communities. PVRO systems have been proposed for various locations. However, small PVRO systems with production on the order of 1 m^3/day for remote communities present some unique technical, cost and operational problems. This paper reports on a project in which a PVRO system is designed, fabricated and deployed in remote village in the Yucatan Peninsula of Mexico. The community residents are indigenous people who are subsistence farmers and beekeepers. Technical and economic models used to configure the system for the community are presented. A plan is developed in cooperation with the community aimed at making the system self-sustaining in the long term. Methods and materials are developed to permit the community members to operate and maintain the system themselves. The results provide insights for the design and deployment of small community-scale PVRO systems in remote communities.

1. Introduction

1.1. Motivation

By some reports as many as 800 million to 1 billion people today lack access to clean water [1]. Many of these people live in small, remote, poor communities. The residents of these communities are often forced to drink brackish groundwater, rainwater from cisterns, or water found in open ponds, streams or rivers, as they cannot afford commercially purified water. These sources generally contain dissolved salts, chemicals, minerals, biological contamination, toxic metals or other anthropogenic pollutions that make them unsuitable and unsafe as drinking water. The village of La Mancalona, Mexico, shown in Fig. 1 [2], in the Campeche State on the Yucatan Peninsula, is one such community. It has two primary sources of water. The first is very hard, brackish well water and the second is rainwater that is collected and stored in cisterns and surface ponds. Rainwater harvesting alone would not meet the village's demand for purified water. Testing has shown that even collected rainwater can contain unsafe amounts of contaminants. Both sources have unacceptable levels of biological contamination that make them unsafe and unpleasant to drink. The remoteness of this village and the limited income of its people make the purchase of commercially produced purified bottle water an infeasible option. This situation is not unique [3]. La Mancalona is representative of many communities in the developing world that need affordable, local, clean water. This paper describes a practical system deployed in La Mancalona designed to meet the needs of this community, along with its successes and challenges.

1.2. Background

Clean water systems have been proposed for off-grid, remote communities [4–9]. These studies suggest that the appropriateness of the

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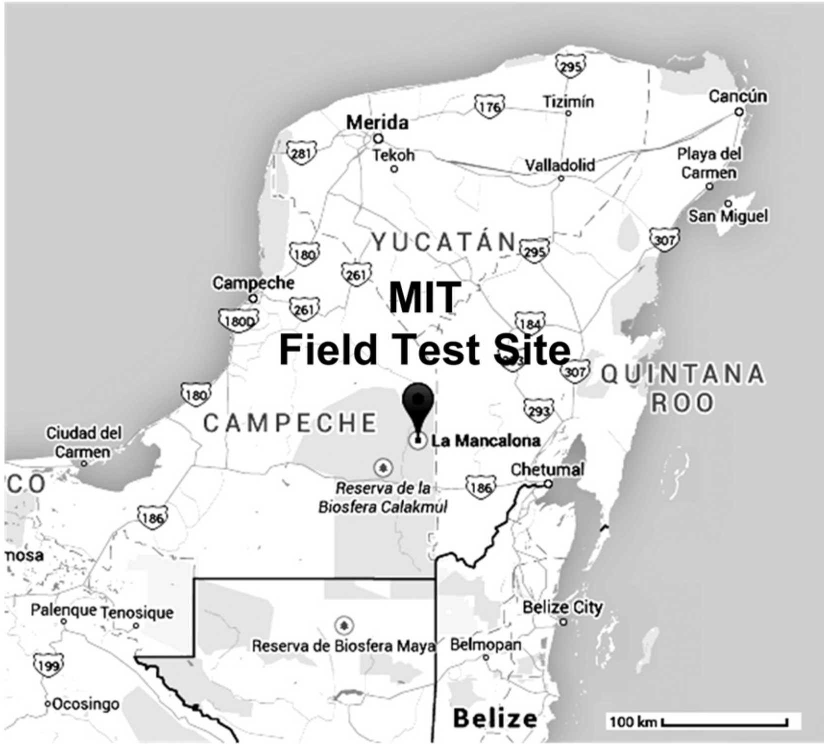

Fig. 1. MIT PVRO field test site in La Mancalona, Campeche, Mexico [1].

technology for a given community relies heavily on the available water sources, local climate, water demands and the socioeconomic characteristics of the community. Rainwater collection is a common strategy that works well in regions with sufficient rain, but requires water management to ensure water availability over the year. It is essential that rainwater cisterns are sized appropriately, and the collected water still requires disinfection and filtration to ensure it is healthy for human consumption.

For large communities, towns and cities, technologies such as solar thermal multi-stage flash and multi-effect distillation have been suggested [10]. However, these concepts do not scale well for small communities with limited or expensive grid power, such as those under 1000 people, which is the focus of this work. They also require skilled operators and technicians, which is not feasible for small, remote communities. Finally, the distribution of the purified water from large scale facilities to these communities, such as bottled water, is expensive and unreliable [11]. Locating small-scale renewably powered systems within the communities could solve these communities' clean water problems.

Simple community or household systems include solar stills [8, 12–14], gravity-fed filtration systems include solar stills [15]. These systems are intended to be very low cost and simple to operate. While they are effective in some applications, they are not appropriate for all communities with different climates and water chemistries. These systems have some important limitations. Gravity fed-filters are slow and may not remove all the contaminants/salts, and tablets are suitable for disinfection but not for removing the salts. Solar thermal desalination technologies are more cost-effective at larger scales [16], and chlorine and iodine tablets for disinfection [4]. Collected rainwater, pond, river, and groundwater have biological contaminants that cannot be removed by simple filtration.

Reverse osmosis can be sized appropriately for small communities and can be powered using renewable technologies. Small water purification technology concepts for off-grid communities include photovoltaic reverse osmosis (PVRO) and wind-powered RO systems [5,8,12–14, 17,18]. A detailed review of renewably powered RO systems has been presented, which contains a number of references [17]. Many of its references discuss design and laboratory experimental results for these systems, including [18]. While providing interesting and useful results, they provide very limited information on the performance of this technology when operated by non-expert community members in remote locations. It is clear that realistic testing of PVRO systems under representative field conditions is required to demonstrate its feasibility, as reported in this paper.

Research has suggested that community-scale PVRO systems are technically and economically feasible in locations with a substantial number of sunny days, such as in parts of Mexico [4]. These systems can be designed to remove biological contamination as well as dissolved salts and minerals. The focus of this work is to demonstrate the effectiveness of a small-scale PVRO system in a representative community. The village of La Mancalona, in the Yucatan peninsula, was chosen for this demonstration project. Large-scale RO commercial facilities in the region provide the purified water sold in 20-liter bottles in the nearest large town. This water would have to be delivered from distances more than 40 km from the village. The cost of the water and the delivery distance and road quality makes this option unaffordable and unreliable for residents of La Mancalona.

For the past 6 years, the MIT Field and Space Laboratory has been developing the technology for small-scale solar powered systems to produce safe drinking water for such communities [4–7]. These systems use reverse osmosis powered by photovoltaic panels. With their real-time embedded computer control, they are efficient and semi-autonomous. They can be run for long periods of time under variable power conditions without the need for the constant attention of a skilled operator. See Fig. 2.

The technology's effectiveness has been demonstrated in the laboratory and at field stations, including remote communities [19–23]. However, detailed results aimed at understanding how such systems can be