FEASIBILITY STUDY AND OPTIMIZATION ANALYSIS OF USING A PVT COLLECTOR FOR A REVERSE OSMOSIS BASED WATER DESALINATION PLANT

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Abstract

With the increase in greenhouse gases and concerns regarding a changing climate, there is a need to increase the development of energies that do not require the combustion of fossil fuels. Photovoltaic Thermal (PVT) systems are one example. PVT systems combine two technologies to optimize the energy efficiency of each individual system. The thermal portion of the PVT system harnesses the heat given off from a photovoltaic system thereby reducing the energy waste that would have otherwise resulted. When incorporated with a reverse osmosis water desalination plant, the recovered thermal energy from the PVT system can be used to reduce the energy required for the reverse osmosis (RO) process. The purpose of this study was to evaluate the feasibility of using a PVT water collector for a reverse osmosis based water desalination plant. The Kay Bailey Hutchison (KBH) plant in El Paso, Texas served as the physical model for this research. The driving research questions were:

1. What is the maximum RO feed temperature that can be used?
2. What is the optimum design for the PVT system that will achieve desired cooling of the PVT system and keep the RO feed temperature at/below what (1) finds?
3. How does the electrical performance of the PVT compare with PV for the same size array?

This study shows that a cooled PVT system has about a 12% higher electrical efficiency when compared to a simple photovoltaic system, and reduces the specific energy of a desalination plant up to 2%. Preliminary studies indicate 95-104ºF is the maximum temperature that can be used as the RO feed water temperature. Any temperature over 104ºF results in poor water quality. A PVT system with a heat exchanger and a flow rate of 1263 gpm reaches desired cooling and keeps RO feed temperature below the maximum. The total land area needed for the modeled PVT system would be 35,790 ft^2.

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Chapter 1: Introduction and Background

Massive urbanization, expanding industrial development, population growth, climate change, pollution of water resources and the increasing costs of freshwater extraction are factors driving the water crisis of the 21st century (March, 2015). Water stress is expected to affect anywhere from half to two-thirds of the world population by the year 2030 (March, 2015). Arid and semi-arid regions have seen a rapid decline in water availability (March, 2015). Desalination has been portrayed as a solution to all the factors contributing to this water crisis (March, 2015). One of the drawbacks to desalination is the intensification of the water-energy nexus (Gold & Webber, 2015). The energy requirements for desalination range anywhere from 16 kWh/m^3 (for multi-stage flash (MSF) desalination) to 0.5 kWh/m^3 (for reverse osmosis (RO) desalination) depending on the method and source water used for desalination (March, 2015). A possible solution to the large consumption of energy is incorporating a renewable energy source to the desalination process (Goosen et al., 2014). One option for renewable energy is using photovoltaic thermal (PVT) systems (Gold & Webber, 2015).

Southwestern North America has an insolation potential of 5.5-6.5 kWh/m^2/day (National Renewable Energy Laboratory, 2016). Photovoltaic (PV) cells can be used to absorb this solar energy and convert it into electrical energy. Some PV cells are made of crystalline silicon, either monocrystalline or polycrystalline. Monocrystalline silicon PV cells are more efficient in both energy and exergy (defined as the energy available to be utilized completely for a useful purpose) and are best suited for projects with high efficiency demands when compared to polycrystalline PV cells (Fudholi et al., 2014). The energy efficiency of a PV system can be defined as the ratio of the total electrical energy to the total solar energy hitting the PV surface (Joshi et al., 2009). Monocrystalline silicon PV modules show uniform and predictable behavior

and are the most expensive type because they are labor and energy intensive to manufacture (Tiwari et al., 2011). In contrast, polycrystalline silicon PV modules are simpler and less expensive to make although the material quality is lower than that of monocrystalline silicon cells due to the presence of grain boundaries in polycrystalline silicon cells (Tiwari et al., 2011). Other options for PV systems to be considered are flat-plate or concentrator type PV panels, glazed or unglazed panels, natural or forced fluid flow (for PVT systems), and stand alone or building-integrated systems (Tyagi et al., 2012).

There are also PV cells made from non-crystalline silicon, called amorphous (a) silicon. These cells have a lower efficiency (about 6-7% efficiency) (Tiwari et al., 2011) than their crystalline counterparts. Amorphous silicon is primarily used in thin film solar cells. Thin film solar cells are advantageous in that they are flexible and can be easily placed on a variety of surfaces such as glass, plastic, steel, etc. (Tiwari et al., 2011). The largest fall back to thin film solar cell technology is that there is significant performance degradation when used outdoors (Tiwari et al., 2011). Amorphous silicon is not the only material suited for thin film solar technologies: other suitable materials include Copper-Indium-Diselenide, Copper-Gallium-Diselenide, Copper-Indium-Gallium-Diselenide, and Cadmium Telluride (Tiwari et al., 2011). Cadmium Telluride would not be the best choice to consider due to its toxic nature (Tiwari et al., 2011).

Solar thermal collectors supply heat by absorbing solar energy. Photovoltaic thermal (PVT) solar collectors combine these two technologies into one product to produce heat and electrical energy from solar radiation (Hasan & Sumathy, 2010). By combining these two technologies, electrical and thermal efficiency can be maximized. The total energy output (electrical plus thermal) of a hybrid PVT system depends on the solar energy input, the ambient