SIMULATION OF CHARGE AND DISCHARGE CYCLE OF A CONCENTRATE-BASED THERMAL ENERGY STORAGE SYSTEM.

Christopher Nicholas Salerno, Jr., Justin Andrew Lee, Rozina N. Nalbandian, and Reza Baghaei Lakeh
Department of Mechanical Engineering, California State Polytechnic University, Pomona, CA 91768, United States

ABSTRACT

Inorganic salts (e.g., chloride salts) have gained attention in the energy field as a new thermal energy storage (TES) medium. There is a potential to use the dry byproduct of water desalination, i.e., Reverse Osmosis Concentrate (ROC) as a TES medium. Using ROC as a TES medium prevents a harmful waste to be released into the environment. In this study, the heat transfer behavior of a ROC-based thermal energy storage system is studied using CFD. A computational model is developed, verified, and validated to simulate the phase change process and buoyancy-driven flow in a square ROC-based thermal energy storage element.

INTRODUCTION

Due to recent climate change concerns from burning fossil fuels, there has been a push for alternative energy resources, such as solar, wind, and hydro, to become more sustainable and cost competitive. In 2010, the United Nations Framework Convention on Climate Change [1] aimed to reduce global warming to only 2 degrees above the world's average temperature during the pre-industrial era. In the United States, roughly 32% of global warming emissions come from the electricity sector, primarily fossil fuels [2]. Solar energy can help mitigate climate change by being clean, relatively cost-competitive, and widely distributable compared with the other renewable energy resources. However, the intermittent availability caused by seasonal changes limits the widespread application. As of 2018, the International Energy Agency (IEA) [3] reported that solar energy only accounted for 15% of the total electricity energy sector but is forecasted to dominate electricity generation growth in the forthcoming decades. Latent Heat Thermal Energy Storage (LHTES) can increase both capacities by storing excess solar thermal energy, closing the gap between energy supply and demand, and providing a clean, sustainable power grid. It has been shown that thermal energy storage can significantly increase a concentrated solar power (CSP) capacity from 25% to almost 70% [4].

In our effort two major issues facing water and energy industries (i.e., concentrate disposal and low-cost thermal energy storage) are tackled simultaneously. Our team introduced a novel patent-pending approach for eliminating the concentrate of the desalination processes by recovering the water content using a heat-driven absorption process followed by repurposing the salt content of the concentrate as a medium for low-cost LHTES. A detailed and extensive techno-economic analysis showed that using unseparated and minimally processed concentrate salt reduces the cost of thermal energy storage below the U.S. Department of Energy's cost target of $15/kWh. Figure 1 illustrates the steps required for development of a concentrate based thermal energy storage module.

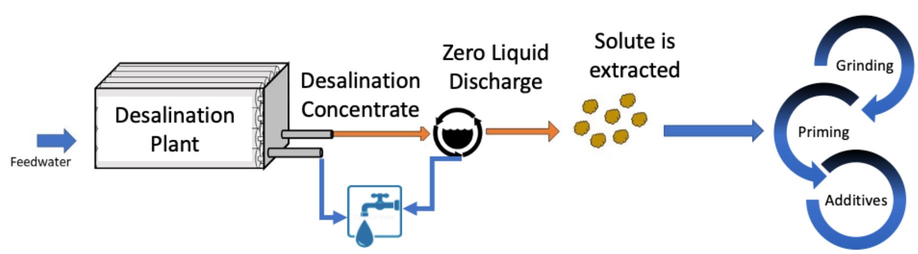

Figure 1 – Development of a concentrate-based thermal energy storage module

SIMULATION and RESULTS

A computational model was developed in ANSYS Fluent version 2020 R1 to analyze the heat transfer behavior of the concentrate salt as it undergoes a phase change during the charging and discharging cycles. The computational domain was reduced to a 2D cross-section of the square salt tube to simplify the calculations. The length of the salt tube is more than one order of magnitude larger than the hydrodynamic diameter of the tube; therefore, this model neglects the end effects, and a 2D computational domain is adopted. This assumption greatly simplified the computational model representing the 2D cross-sectional area of the leading end of the salt element held at a constant temperature which informs how natural convection affects the total heat transfer capabilities at the highest temperature.

The desalination salt compositions were obtained with analytical chemistry data combined with thermodynamic software to predict the precipitation of salt species out of a simulated aqueous solution. Three concentrate samples were analyzed to find the ionic composition. The dominant anions were chlorides, carbonates, bicarbonates, sulfates, and hydroxides for all samples and the dominant cations were sodium, calcium, magnesium, and potassium. The ionic composition was then used in the OLI Studio: Stream Analyzer software to calculate the expected salt species using water chemistry techniques. The weighted average of the thermophysical of the dominant species were used as the property of the salt for simulation. Figure 2 shows how the adopted heat capacity value compares with other salt species that exist in the desalination salt. The natural convection and phase change of the desalination salt in charge and discharge cycles is simulated in Figure 3. Presence of solid state near the heat transfer boundary suggests the need of heat transfer enhancement through additives to enable more efficient heat transfer during discharge process.

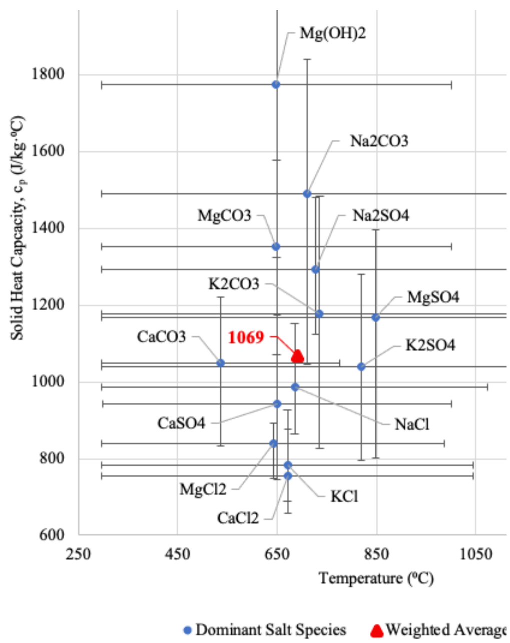

Figure 2 – Heat capacity of dominant salt species in desalination salt

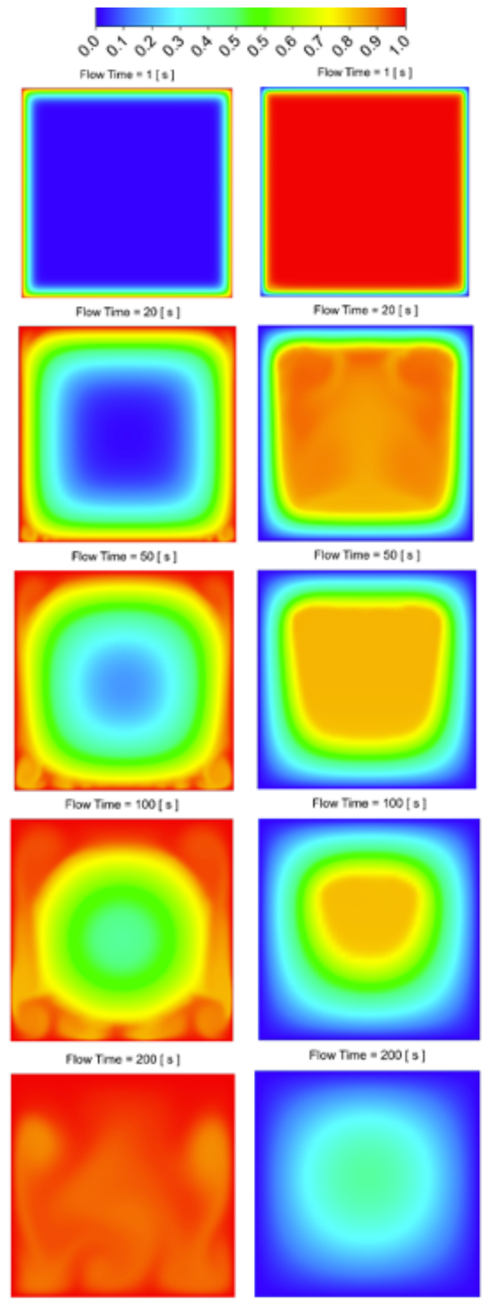

Figure 3 – Time-lapse of charge (left) and discharge (right) showing contour plots of dimensionless temperature