Solar Updraft Tower Using Compost Waste Heat and Transpired Solar Collectors

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ABSTRACT

This paper explores the use of ways to enhance energy production capability in Solar Updraft Towers (SUT) by using Compost Waste Heat (CWH) and Transpired Solar Collector (TSC) renewable energy technologies in unison. The current research presents experimental and numerical modeling results for the SUT CWH greenhouse walls constructed from TSC materials. The paper includes the results obtained for the power production from a 1/5th sized scaled model of a SUT using CWH and TSC in unison. Numerical heat transfer simulations are also presented showing the effect of greenhouse roof tilt angle and inlet tower air velocity on the overall heat transfer coefficient of the SUT system.

Keywords: solar chimney, composting, waste heat, transpired collector

1 INTRODUCTION

The SUT is also referred to in the literature as a Solar Chimney, in which turbines located at the base of a large chimney mounted on the roof of a solar greenhouse are used to produce electricity via the natural convection updraft set up by the solar chimney which causes a wind velocity on the order of 9 mph (4 m/s) to spin a series of shrouded turbine blades to produce power. Figure 1 shows the configuration being studied herein.

Figure 1: Solar updraft tower with compost waste heat removal and transpired collector walls.

Figure 1 shows the SUT chimney tower, which has a turbine located at its base, the CWH greenhouse building used to house the composting waste heat harvesting portion of the technology, and the TSC walls which are used to fabricate the walls of the CWH greenhouse. The concept of using the SUT with CWH has been published by our research team in previous studies including [1-2], whereby the civil engineering design of a compost waste heat to energy solar chimney power plant and its associated economic advantages is given. In the study of [3] a comprehensive thermal-fluids analysis of a hybrid solar/compost waste heat updraft tower is presented. In the work of [4] CFD analysis of hybrid solar tower using compost waste heat and photovoltaics is presented. The review of solar updraft tower power generation given by [5] notes the current SUT CWH research of our team as being novel and innovative. The recent study of [6] provides a case study of energy recovery from commercial-scale composting. The current paper extends the proposition of using SUT CWH with TSC first given by [7]. The concept of using TSC walls with an SUT and CWH is illustrated in Figure 2.

Figure 2: Use of TSC walls for the greenhouse walls of the SUT CWH power plant.

As shown in Figure 2, the TSC walls are used in unison with the SUT and CWH to augment the convective flow fed into the power turbine of the SUT CWH TSC power plant. The merits of using the TSC in conjunction with a SUT employing CWH were first introduced in [7]. In the case study of [8] a 2 CFM TSC system with solar radiation of 500 W/m² is seen to give a ΔT = 20 °C of temperature...
potential. This amount of temperature differential is directly proportion to an increase in heat transfer coefficient (HTC) per

\[ h = a\Delta T \]  

(1)
as discussed in [7].

2 NUMERICAL MODELING

A numerical Computational Fluid Dynamics (CFD) Heat Transfer model was constructed to predict the behavior of a particular SUT due to changes in the HTC, \( h \) slope of the roof, \( \beta \) velocity of inlet air into chimney, \( V \), etc. Figure 3 shows axisymmetric model used, while Figure 4 shows a zoomed in view of the the mesh used for the numerical CFD model.

Figure 3: Numerical heat transfer model mesh of of SUT with CWH and TSC.

Figure 4: Zoomed in view of numerical heat transfer model mesh of SUT with CWH and TSC.

The numerical simulations were performed with ANSYS FLUENT CFD Numerical Heat Transfer software. Typical results of the numerical analysis are shown in Figure 5.

Figure 5: Numerical heat transfer simulation results for effect of SUT greenhouse roof slope \( \beta \), on tower entrance temperature, \( T_0 \) and HTC.

Results from the numerical heat transfer model show that the heat transfer coefficient (HTC) varies from 15 < \( h < 25 \) W/m\(^2\)-K depending on whether the side walls of the CWH greenhouse are fabricated out of plain walls, \( h = 15 \) W/m\(^2\)-K, or TSC type walls \( h = 25 \) W/m\(^2\)-K. For the generic trends it is found that composting addition always results in more heat and therefore higher temperatures. The non-compost configuration shows a modest increase in temperature in all cases as the HTC increases. Regarding the slope of the roof, \( \beta \) as the roof was sloped, some roof angles show increase in temperature with increased HTC, while other roof angles show flat or decreasing temperature with increased HTC. This phenomena is believed to the fact that addition of compost causes reduced buoyancy driven flow in the base of the SUT at some angles. In summary, taller towers causes increased velocity and angled roof CWH greenhouse maximizes the tower velocity by reducing flow resistance into the tower. Additional parasitic heat sources mostly contribute to increasing the air temperature into the tower with minor effects on increasing velocity.

3 PROTOTYPE EXPERIMENT

Figure 6 shows the experimental prototype built at California State Polytechnic University at Pomona.

Figure 6: Prototype 1/5\(^{th}\) scale of SUT with CWH and TSC.
Figure 6 shows the 1/5th scale prototype of the SUT CWH TSC power plant with details of the SUT greenhouse sidewall construction, foam insulation, and structure comprising the prototype. The following equation from [9] relates the power output of the SUT to the temperature drop across the chimney, $\Delta T$ and the height of the tower, $h$ are used to reduce the data

$$P = c_s \rho KA \Delta T \sqrt{2gh \Delta T/T_s}$$

while the prototype power is related to the actual power via the similarity relationships of fluid mechanics and turbomachinery [10]

$$\left( \frac{P}{\rho \omega D^5} \right)_{\text{prototype}} = \left( \frac{P}{\rho \omega D^5} \right)_{\text{actual}}$$

The relationships of (2) and (3) are used to compare the performance the prototype to actual SUT CWH TSC powerplant. Preliminary findings are shown in Figure 7.

![Figure 7: Comparison of prototype to actual power plant power output predictions.](image)

REFERENCES


