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SOLAR COOKING USING PCM HEAT STORAGE – EXPERIMENTAL INVESTIGATIONS OF THE SUNSTORE SOLAR COOKER

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Introduction

Problem

According to the World Health Organization (WHO), more than three billion people worldwide rely on wood, dung, and charcoal as energy sources for cooking [1]. The reliance on those energy resources comes along with negative health impacts, gender inequality, deforestation and adverse effects on the global climate.

A solution to overcome the usage of polluting energy sources is solar cooking. However, traditional solar cookers come along with a major drawback – they require a great adjustment of user behaviour. Not only is their operation limited by the time of the day and seasonality, but they also tend to require longer cooking times.

Idea

PCM solar cookers, which use latent heat storage to allow for cooking after sunset, present a more flexible solution than traditional solar cookers.

A novel prototype of a PCM solar cooker is the SunStore cooker. The device is a cylindric aluminium container that is filled with the eutectic mixture of Sodium acetate and Potassium acetate.

To charge the SunStore cooker, solar irradiation is concentrated on the top of the storage container. This is realized by means of a Heliac tracker, which is equipped with flat Fresnel lenses, that concentrate sunlight in the same way as magnifying glasses, see figure 1.

After charging, the SunStore cooker is kept in an insulation case to release the heat of solidification for cooking in accordance with the users' habits and preferences.

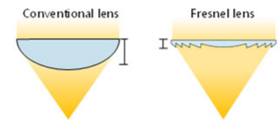

Figure 1: Comparison of conventional and Fresnel lens

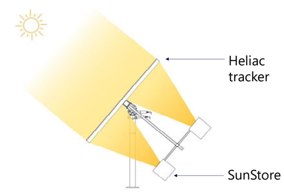

Figure 2: Experimental set-up for the charging experiment

Methods

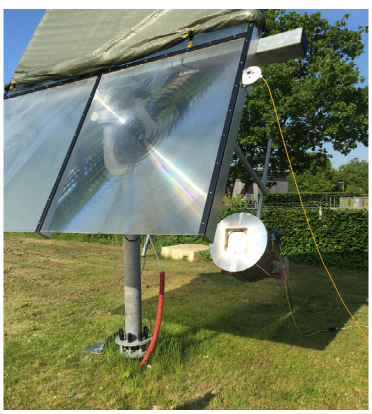

Figure 3: Experimental set-up for the charging experiment

Charging

The set-up for the charging experiment consisting of a Heliac tracker, the SunStore cooker that is bedded into an insulation case and a pyranometer, and several temperature sensors.

The pyranometer installed next to the tracker measures the total irradiance on the lens throughout the experiment additionally the DNI is measured at a climate station in the vicinity of the test facility. In total seven temperature sensors are installed, see figure 4.

To increase the absorption of the sunlight, the SunStore cooker is equipped with a 1 mm aluminium plate, which is painted with black anti-reflective coating. Good thermal contact between the cooker surface and plate is achieved by a thin layer of evenly distributed graphite powder.

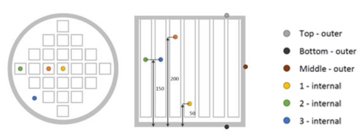

Figure 4: Location of temperature sensors

Discharging

The performance test for the discharging are based on a standardized water boiling test for clean cooking stoves [2]. A cooking process is approximated using a defined amount of 2.5 kg tap water, which allows for the comparison of several development stages or with other technologies.

The experimental set-up for test comprises an insulation casing for the Sunstore, a 5L stainless steel pot (with and without lid) and two temperature sensors measuring the water temperature and the temperature of SunStore.

To quantify the power output of the device, the test is split into two phases: the heating of the water to the boiling point (eq. 1) and a simmering stage (eq. 2). In the WBT, simmering is defined as the variation of the water temperature of up to 6 K from the boiling point [2].

$$P_{heating} = \frac{m_{e,heating} C_{p,H2O} \Delta T_{heating} + \Delta m_{heating} \Delta h_{VL,H2O}}{t_{heating}} \quad (1)$$

$$P_{simmering} = \frac{\Delta m_{simmering} \Delta h_{VL,H2O}}{t_{simmering}} \quad (2)$$

Results

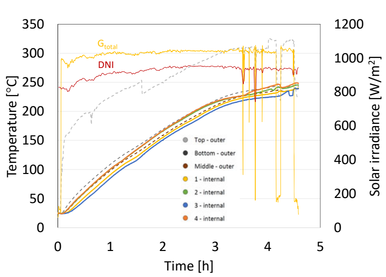

Figure 5: Temperature and solar irradiance profiles in the charging experiment

Figure 6 shows the temperature of the SunStore and the 2.5 kg water in the pot during two cooking performance tests with and without a lid on the pot. It can be observed that the temperature of the SunStore, have a high degree of similarity while the water temperature in the pot deviates in the two cooking tests. The water in the pot with the lid reaches boiling after 48 minutes and simmering for another 4 hours while the water temperature in the pot without a lid never reaches boiling point. The output power for the experiment with lid is presented in table 1.

Figure 5 shows the respective temperature levels inside SunStore, as well as the irradiance on the lens during the charging experiment. It can be seen, that the PCM's melting temperature of 235 °C is exceeded in the entire container after 4.5 h. Over this period a total amount of 4.2 kWh direct solar irradiance is transferred to the lens on the tracker.

Table 1 : Discharging power for heating of water and 45 min of simmering

$m_{t=0}$	$t_{heating}$	$\Delta T_{heating}$	$\Delta m_{heating}$	$\Delta m_{simmering}$	$P_{heating}$	$P_{simmering}$
2500g	48 min	76.4 K	7.4 g	170.9 g	410 W	143W

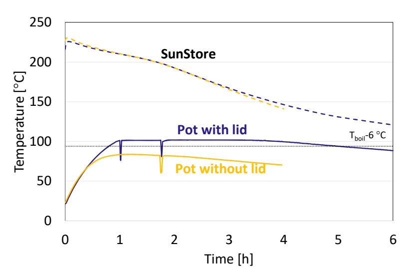

Figure 6 : Temperature curves for the discharging experiments using a pot with 2.5 kg water

Nomenclature

$\Delta h_{VL,H2O}$	Evaporation enthalpy of water	$m_{e,heating}$	Mass of water at the end of heating periode
$\Delta m_{heating}$	Evaporated mass of water during heating periode	$P_{heating}$	Discharing power during heating periode
$\Delta m_{simmering}$	Evaporated mass of water during simmering periode	$P_{simmering}$	Discharge power during simmering periode
$\Delta T_{heating}$	Difference in water temperature	$t_{simmering}$	Simmering time
$m_{t=0}$	Mass of water at the start of the experiment	$t_{heating}$	Heating time

References

[1] Burning opportunity: Clean household energy for health, sustainable development, and wellbeing of women and children," tech. rep., World Health Organization, 2016.

[2] U.S. Environmental Protection Agency, Partnership for Clean Indoor Air (PCIA), "The water boiling test version 4.2.3 - cookstove emissions and efficiency in a controlled laboratory setting."

Conclusion

The results show that the PCM heat battery can be charged in the solar tracker within 4.6 h on a sunny day. The results also show that a charged heat battery can bring 2.5 kg of water to boil in a pot with lid in 48 minutes and keep the temperature above 94 °C for another for 4 hours. It is expected that the technology successfully can replace the use of polluting fuels for cooking in regions with abundant solar radiation.