A biomass hydrogel solar evaporator based on low-grade tobacco leaves for water evaporation and thermoelectric conversion application

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Solar-driven water-electricity co-generation experiments:

The evaporator with thermoelectric module is put in a plastic petrie dish filled with water. The sunlight, generated by a solar simulator with an optical filter for the standard AM 1.5 G spectrum (CEL-S500/350), irradiated at the sample under specific optical concentrations. The weight loss of water was measurement by an electronic mass balance and the temperature over the process was recorded by an IR thermal camera.Voltage in the process of temperature difference power generation was measured using Deli digital multimeter, DL8490.

Calculation of the photothermal conversion efficiency：

The 0.10 g low-grade tobacco leaves (LTL) power was dispersed in 1mL water in a container with an insulating layer and the solution was illuminated with simulated solar light. The temperature of the solution was recorded using a infrared thermal imager upon simulated solar light irradiation for 20 minutes and energy conversion efficiency (η) was calculated as the following formula :

$$\eta = \frac{Q}{E} = \frac{Q_1 - Q_2}{E}$$

Where Q refers to the thermal energy generated (i.e., Q = Q1 - Q2), Q1 is the thermal energy generated of LTL powder and Q2 is the thermal energy generated of pure water. E refers to the total energy of the incident light. Q is determined by the heat capacity (C), density (ρ), volume (V) and ΔT over the period of irradiation of the solution; E is determined by the power (P) of the incident light, the irradiation area (S) and irradiation time (t). Therefore, the specific formula is as follows:

$$Q_1 = Cm\Delta T_1 = C\rho V\Delta T_1$$

$$Q_2 = Cm\Delta T_2 = C\rho V\Delta T_2$$

$$E = PSt$$

In this paper, since LTL powder are present in very low amounts in the solution, values of C (4.2 J g^{-1} oC^{-1}) and ρ (1 g cm^{-3}) for water were used in the calculations.

For example, the temperature of the water with LTL powder was 43.8 °C after the irradiation process, and the initial temperature is 15.8 °C, therefore ΔT_1 is 28.0 °C.

The temperature of the pure water was 36.6 °C after the irradiation process, and the initial temperature is 14.9 °C, therefore ΔT_2 is 21.7 °C. As the above fomulas.

$$Q_1 = C\rho V\Delta T_1 = 4.2 \times 1 \times 1 \times 28.0 = 117.6 \ J$$

$$Q_2 = C\rho V\Delta T_2 = 4.2 \times 1 \times 1 \times 21.7 = 91.14 \ J$$

$$E = PSt = 0.1 \times 1.5386 \times 1200 = 184.632 \ J$$

$$\eta = \frac{Q_1 - Q_2}{E} = \frac{117.6 - 91.14}{184.632} = 14.33 \ \%$$

As a result, LTL powder energy conversion efficiency (Q1-Q2)/E = 14.33% when the temperature difference is 28.0 °C is calculated.

Calculation of the efficiency for solar to vapor generation:

The conversion efficiency η of solar energy in photothermal assisted water evaporation was calculated as the following formula.

$$\eta = \frac{\dot{m} h_{LV}}{C_{opt} P_0}$$

Where $\dot{m}$ refers to the mass flux (evaporation rate) of water, h_{LV} refers to the total liquid vapor phase-change enthalpy (i.e., the sensible heat and the enthalpy of vaporization (i.e., $h_{LV} = Q + \Delta h_{vap}$)), Q is the energy provided to heat the system from the initial temperature to a final temperature, Δh_{vap} is the latent heat of vaporization of water P_0 is the nominal solar irradiation value of 1 kW m^{-2}, and C_{opt} represents the optical concentration. The schematic for the vaporization enthalpy of the vapor was as follows.

$$Q = C_{liquid} \times (T - T_0)$$

$$\Delta h_{vap} = Q_1 + \Delta h_{100} + Q_2$$

$$Q_1 = C_{liquid} \times (100 - T)$$

$$Q_2 = C_{vapor} \times (T - 100)$$

In this paper, C_{liquid}, the specific heat capacity of liquid water is a constant of 4.18 (g °C)$^{-1}$. C_{vapor}, the specific heat capacity of water vaper is a constant of 1.865 J (g °C)$^{-1}$.

Δh_{100} is the latent heat of vaporization of water at 100 °C, taken to be 2260 kJ kg⁻¹.

$P_0 = 1 \, kW \, m^{-2}$. $C_{opt} = 1$.

For example, the surface temperature of low-grade tobacco leaves hydrogel (LTL/H) was 37.5 °C during the evaporation process, therefore T is 37.5 °C. As the above fomulas,

$Q = C_{liquid} \times (T - T_0) = 4.18 \times (37.5 - 15.0) = 94.05 \, kJ \, kg^{-1}$

$\Delta h_{vap} = Q_1 + \Delta h_{100} + Q_2 = 4.18 \times (100 - 37.5) + 2260 + 1.865 \times (37.5 - 100)$

$\qquad = 2404.688 \, kJ \, kg^{-1}$

$h_{LV} = Q + \Delta h_{vap} = 94.05 + 2404.688 = 2498.738 \, kJ \, kg^{-1}$

$\dot{m} = 1.07028 \, kg \, m^{-2} \, h^{-1}$

As a result, evaporation efficiency $\eta = \dot{m}h_{LV}/C_{opt}P_0 = 74.3\%$.

Similarly, the surface temperature of pure water was 29.2 °C during the evaporation process, therefore T is 29.2 °C. As the above fomulas,

$Q = C_{liquid} \times (T - T_0) = 4.18 \times (29.2 - 15.5) = 57.266 \, kJ \, kg^{-1}$

$\Delta h_{vap} = Q_1 + \Delta h_{100} + Q_2 = 4.18 \times (100 - 29.2) + 2260 + 1.865 \times (29.2 - 100)$

$\qquad = 2423.902 \, kJ \, kg^{-1}$

$h_{LV} = Q + \Delta h_{vap} = 57.266 + 2423.902 = 2481.168 \, kJ \, kg^{-1}$

$\dot{m} = 0.41358 \, kg \, m^{-2} \, h^{-1}$

As a result, evaporation efficiency of pure water is $\eta = \dot{m}h_{LV}/C_{opt}P_0 = 28.5\%$.

The surface temperature of blank hydrogel was 35.5 °C during the evaporation process, therefore T is 35.5 °C. As the above fomulas,

$Q = C_{liquid} \times (T - T_0) = 4.18 \times (35.5 - 14.3) = 88.616 \, kJ \, kg^{-1}$

$\Delta h_{vap} = Q_1 + \Delta h_{100} + Q_2 = 4.18 \times (100 - 35.5) + 2260 + 1.865 \times (35.5 - 100)$

$\qquad = 2409.318 \, kJ \, kg^{-1}$

$h_{LV} = Q + \Delta h_{vap} = 88.616 + 2409.318 = 2497.934 \, kJ \, kg^{-1}$

$\dot{m} = 0.67939 \, kg \, m^{-2} \, h^{-1}$

As a result, evaporation efficiency of blank hydrogel is $\eta = \dot{m}h_{LV}/C_{opt}P_0 = 47.1\%$.
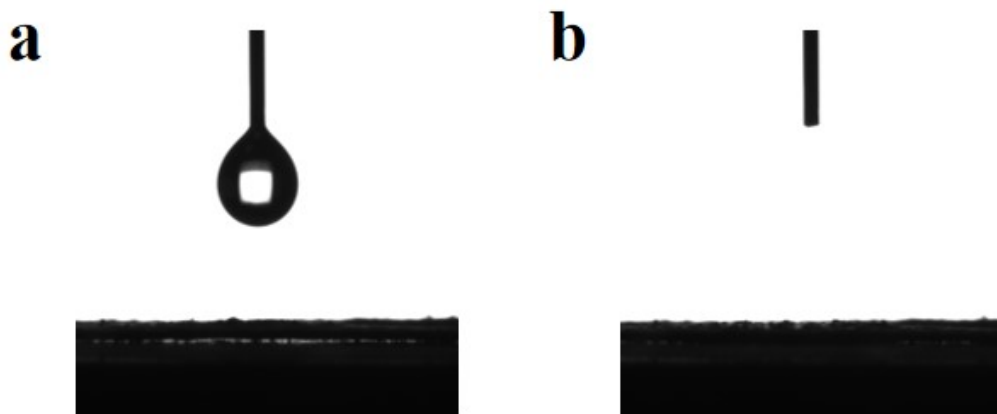
Figure S1. Photos of LTL/H model.

Figure S2. (a) Digital photograph of water contact angle measurement for the surface of LTL before water droplets fall. (b) Digital photograph of water contact angle measurement for the surface of LTL after water droplets fall.
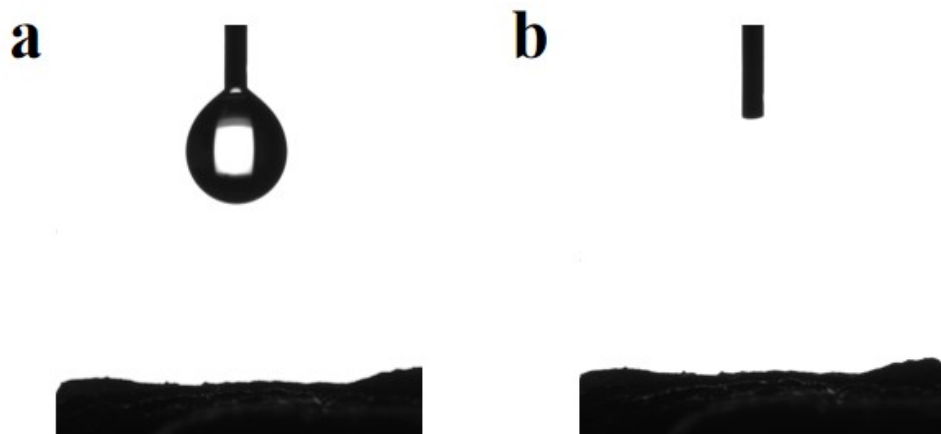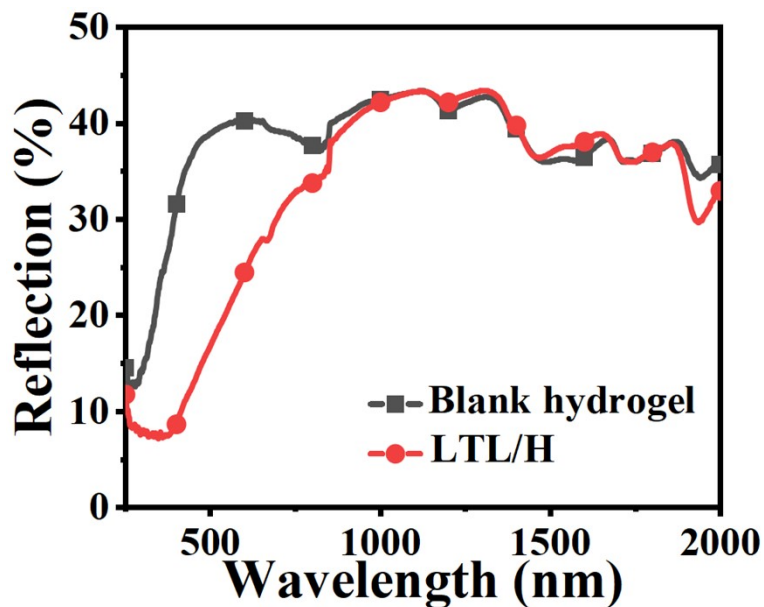
Figure S3. (a) Digital photograph of water contact angle measurement for the surface of LTL/H before water droplets fall. (b) Digital photograph of water contact angle measurement for the surface of LTL/H after water droplets fall.

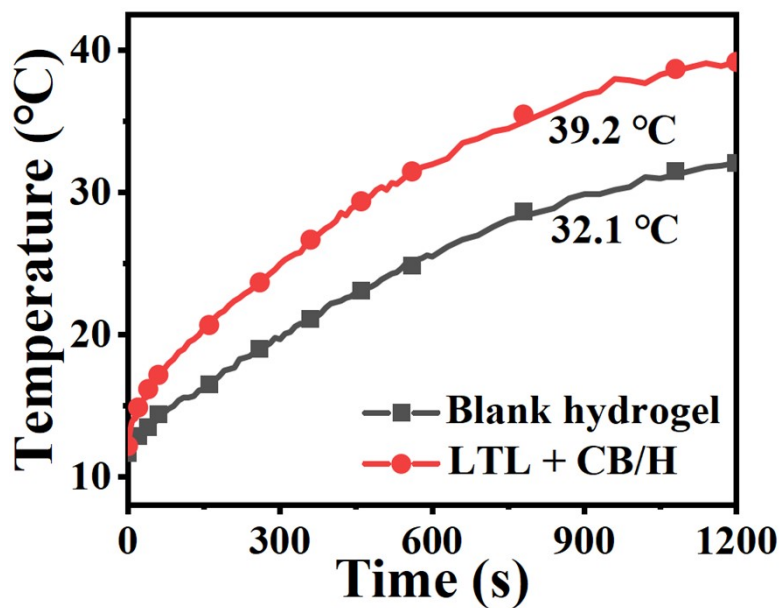**Figure S4.** The light reflection spectra of LTL/H and blank hydrogel.

Figure S5. Surface heating ability of blank hydrogel and low-grade tobacco leaves + carbon black (CB) hydrogel (LTL + CB/H) under the irradiation of a solar light.
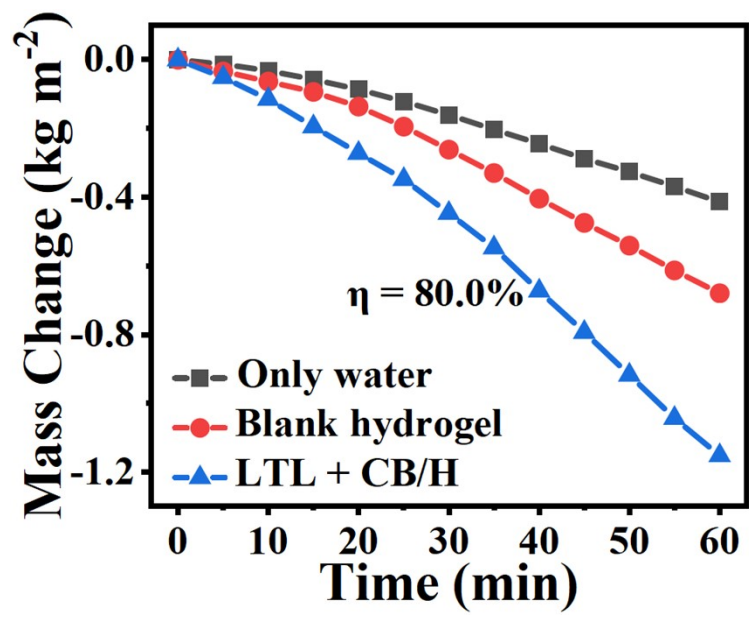
Figure S6. Water evaporation rate diagram and efficiency diagram of LTL + CB/H.