Carbon rich materials for solar evaporation : a critical perspective on performance measurement

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Résumé

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1 Introduction

Due to global warming, population growth and pollution, water supply is becoming an important, urgent and global issue. By 2050, it is likely that 3.9 billion people, or more than 40% of the world's population, will be living in river basins subject to high water stress (1). In France, the water situation is also deteriorating, with increasingly noticeable effects such as early droughts and fires. The beginning of 2023 was marked by a winter drought with 32 days without precipitation. Another example is the predicted reduction of 10% to 40% in average annual river flows in mainland France by 2050 (2,3). One of the key measures in the "water" plan proposed by the government in March 2023 concerns the recovery of unconventional water, such as wastewater and grey water.

One method of water purification is solar evaporation, which harnesses the energy of solar radiation to vaporise water, subsequently condensing and recovering it for human consumption. The process involves placing a material on the water's surface to accelerate evaporation. This material needs to efficiently capture solar radiation while allowing water to diffuse towards the evaporation surface (4). In addition, it should minimize heat transfer to the liquid water to maintain energy at the surface. To meet these requirements, an insulating foam is combined to facilitate water diffusion to the material on the surface (5). Characterisation of the six carbon rich materials is carried out, and a critical assessment is provided for the performance measurement using 2D and 3D evaporators.

2 Evaporation material exploration

Six carbon rich materials are chosen for their specific properties. Two activated carbon (PAC and KAC), a tannin foam (TF), a PTFE-activated carbon paste (PTFE-PAC), ordered mesoporous carbons (OMC) and graphite deposited on a cellulose film (GL). The activated carbons (ACs) are commercially available, as well as the graphite spray and the

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*Intervenant

cellulose film. The PTFE is mixed with PAC using ethanol and ground to form the paste. TF is formed by foaming a tannin thermosetting resin during its polymerisation, as described elsewhere (6). The OMC are prepared through a 60 min mecanochemical synthesis using 2g of mimosa tannin (*Acacia Mearnsii*), 0.75g of Pluronic® F127 and 1.75g of water. Further information regarding the synthesis process can be found elsewhere (7).

The temperature of both dry and humid materials under solar illumination is measured, as well as hydrophilicity with a sessile drop test. Also, water adsorption and nitrogen adsorption isotherms were measured. The performance of evaporation is then measured for each material under an illumination of 1 kW.m-2. Results showed that little variation was observed as long as water was supplied to the evaporator surface (Figure 1a).

3 Critical assessment of the evaporation performance measurement

In the existing literature, the evaporation performance results are currently presented as the mass rate of evaporated water per projected surface area. The maximum theoretical amount of water that can evaporate from a surface exposed to 1 kW.m-2 illumination is 1.47 kg.m-2.h-1. It is expected that the results obtained would align with this value, except in the case of 3D materials where the structure can receive additional energy from the surrounding air, as only the illuminated area becomes hotter than the air.

Initially, the focus is on the case of 2D materials, where measurements are taken by gradually reducing the surface area using the same measurement system consisting of a beaker and an insulation layer. It is important to take precautions, such as using a film to prevent unintended evaporation or limiting the solar input to the material surface, as without these measures, the results can be artificially increased by 326%. Next, the focus shifts to the examination of 3D materials is investigated. In the literature, shafts have been utilized resulting in remarkably high values of evaporation performance. A shaft comprises a small surface area that receives direct sunlight, while its larger side surface area leads to a significant additional evaporation. When compared to a material with a wider projected area (referred to here as a pillar), the actual amount of water evaporated is lower. However, since the evaporation rate is calculated based on the projected surface area, the numerical value is increased. Moreover, when shafts are used in arrays as part of a complete system that includes water condensation, the projected surface area is increased. To investigate the effect of such geometries, a shaft and a pillar of equal height are 3D-printed to allow for a direct comparison with cotton and PAC. Results show that when the evaporation rate numbers are considered, the shaft outperforms the pillar by 1256%, However, in reality, the shaft evaporates 64% less water, as illustrated in Figure 1b, and even less than a 2D material.

Figure 1: a) Pictures of the different 2D carbon rich evaporators and b) mass of water over time for the carbon rich materials under 1 kW.m-2 illumination.

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