Steam generation via solar energy and localizing the light on the pinewood surface

Fateme Tavakoli-Dastjerd, Mohammad Mustafa Ghafurian, Mahdi Moghaddas-Khorasani, Mehran Sepah-Mansoor, Hamid Niazmand*

Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT

In present paper, an experimental study using pinewood in solar steam generation is carried out. The unique properties of wood such as high porosity, hydrophilicity, lightness and low thermal conductivity have led to consider for localizing light on water surface and generating steam in this paper. At the first step, steam generated by water and the pinewood which can float on the water surface was compared. The results showed that the wood as a surface membrane can improve the evaporated mass, so that its evaporation rate increased to 26.3% of water. To enhance the light absorption via wood and evaporation rate, wood's surface was carbonized with a metal plate in temperature 400°C. In addition, the optimum thickness and the effect of the duration of the carbonization process were tested. According to the results, the optimum thickness of carbonized wood and carbonized time were 10 mm and 150 s respectively. However, the using carbonated wood enhanced the evaporation rate about 1.86 times larger than water and allocated evaporation efficiency of 64.2 % to itself.

KEYWORDS

Surface evaporation, solar steam, carbonization process, evaporation efficiency, Wood

* Corresponding Author: Email: Niazmand@um.ac.ir

1. Introduction

Energy and water supply is one of the most important issues that human beings are always faced, and researchers try to provide appropriate solutions to the problems related to these issues [1]. It is difficult to use this energy, especially in providing fresh water for the world's 7.7 billion people. On the other hand, the use of fossil fuels and related energy in these systems will lead to environmental pollution as well as limited resources [2, 3]. Therefore, researchers are proposed various strategies to increase the efficiency of the vapor production unit in solar systems [4, 5]. A recently considered method is the use of nanoparticles to produce solar vapor. In this technology, nanoparticles increase the absorption of sunlight and localize heat in the fluid mass, increase the temperature, and eventually produce vapor [6-8].

Therefore, in this study, the effects of carbonized wood, as a new method, on the solar steam generation and its commercialization have been examined. The studied wood is pinewood, which can grow in all regions of Iran. So, first, the optimal thickness of the wood samples was determined and then their surface was carbonized using a hot metal plate with a temperature of 400 ˚C for different periods of 50, 100, 150 and 200 seconds to investigate the carbonization process duration in the solar steam generation under radiation intensity of 3.2 kW/m^2. Also, the evaporation results of carbonized wood will be compared with the results of plain wood and water.

Consequently, in the present study,

2. Methodology

In this study, wood was used as a membrane to produce solar steam due to its unique properties such as insulation, waterproofing, floating on the water surface, and high porosity. Unfortunately, this material is not a good absorber of sunlight [3], so to increase the absorption of sunlight by wood, a carbonization process at a temperature of 400 ˚C is employed. For this purpose, a metal plate was first continuously exposed to intense flame heat until its temperature reaches 400 ˚C. Then, the sample was placed on the hot metal for a certain period until its surface was carbonized by the high heat of the metal. The reasons that convince us to choose pinewood were a porosity of 57.8%, a water transfer rate of 1.82 mg/s, and a density of 59.86 g/cm^3. It is noted that after poplar and grape wood, pinewood is the abundant wood in Iran.

- **Experimental system**

An insulated beaker contains deionized water and wood samples were floated on the water surface to check the evaporation rate. Furthermore, the thermal conductivity coefficient for it was measured approximately 0.4 W/mK. In each experiment, the initial mass of water inside the beaker was 60 grams and was measured by three sensors which were located at a distance of 10, 30, and 50 mm from the beaker bottom. Another sensor was also used to report the ambient temperature. The solar receiver was exposed to light for 40 minutes and during this period, the temperature rising in the different mentioned heights from the beaker bottom was measured. Reduced water mass (evaporated mass) was recorded over time and the light intensity was reported by putting the sensor in the sample place.

A solar simulator was used to accurately control the evaporation performance of the samples and compare them. To provide an equal condition for all experiments and evaluate the evaporation performance, attempts were made to ensure that the fluid initial temperature and the environment temperature around the test chamber were nearly the same in all experiments. Moreover, during the experimental period, the ambient relative humidity was 19% and the air pressure was recorded 0.9 bar, but during the evaporation process, no significant modification for these two parameters (below 10%) was recorded in the chamber. It should be noted that all experiments were performed at the Mechanics and Renewable Energy Laboratory of the Ferdowsi University of Mashhad, and the equipment of the Central Laboratory of the Ferdowsi University of Mashhad was employed to calibrate equipment such as temperature sensors and digital scales.

3. Results and discussion

The performance of ordinary wood in the generation of solar steam wasevaluated and the results were compared with the generation of solar water vapor. In order to increase the evaporation rate by wood, the carbonization process was used. Results for the cases with a thickness of 10 mm with a carbonization time of 50, 100, 150 and 200 seconds were reported by a hot surface at 400 ˚C. Fig. 1 shows the evaporation mass for different carbonized surfaces compared to water. The carbonization process significantly increases the evaporation rate compared to ordinary water, so that the evaporation rate for carbonized wood in 50, 100, 150, and 200 seconds, is 1.56, 1.66, 1.87, and 1.82 times the water evaporation rate, respectively. As observed, the evaporation rate does not change much as the carbonization process takes more than 150 seconds. Therefore, it can be concluded that the optimal duration of the carbonization process for this type of wood is 150 seconds.

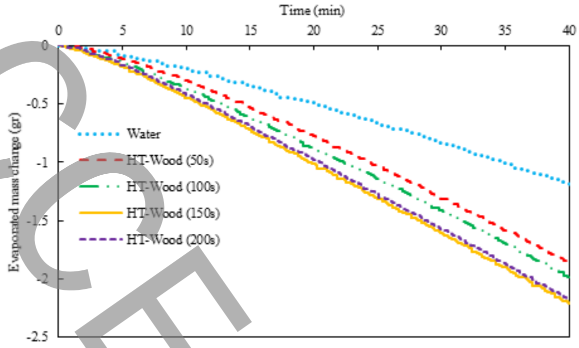

Fig. 1. Time variations of fluid evaporated mass for different carbonized surfaces and water at a light concentration of 3.2 kW/m^2

According to Fig. 2, carbonized wood has the highest evaporation efficiency in 150 seconds, so that in radiation intensity of 3.2 kW/m^2, the evaporation efficiency is 64.2±3.1, which is 2 and 1.5 times the evaporation efficiency of water and ordinary wood, respectively. After that, the highest evaporation efficiency is respectively related to carbonized wood with the periods of 200 seconds (63%), 100 seconds (57.9%), and 50 seconds (54.9%). The reason for this issue can be attributed to the light absorption. Because, based on the DRS[2] report for the ordinary wood and carbonized wood, the carbonization process increases the absorption of light, especially in the visible spectrum region.

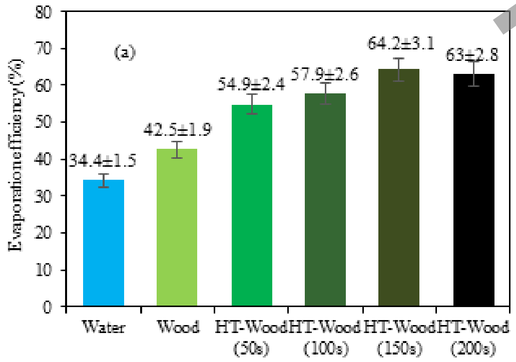

Fig. 2. (a) Evaporation efficiency of water, simple wood, and carbonized samples during 50, 100, 150 and 200 seconds

4. Conclusions

In the present paper, the performance of wood as a surface membrane in the generation of solar steam was examined. Next, circular blocks of pinewood with a diameter of 32 mm and different thicknesses were prepared using a laser system. Ordinary wood was first floated on the water surface with different thicknesses, and its evaporation rate was measured at a radiation intensity of 3.2 kW/m^2 and the optimal thickness was determined. Then, to increase the light absorption by wood, the carbonization process with a temperature of 400 ˚C was employed and the effect of the carbonization process duration (50, 100, 150, and 200 seconds) on the evaporation performance was studied. The results indicated that using ordinary wood with a thickness of 10 mm increases the evaporation rate maximally by 1.26 times the water evaporation rate. The results also illustrated that the carbonization process improved the evaporation rate as well as evaporation efficiency compared to ordinary wood. So that the evaporation efficiency of carbonized wood in the periods of 50, 100, 150, and 200 seconds is 1.63, 1.68, 1.87, and 1.83 times the water evaporation efficiency, respectively.

[2] Diffuse Reflection Spectroscopy

References

[1] M.M. Ghafurian, H. Niazmand, New approach for estimating the cooling capacity of the absorption and compression chillers in a trigeneration system, International Journal of Refrigeration, 86 (2018) 89-106.

[2] M. Vafaei, M. BarzgarNezhad, S.E. Shakib, M. Ghafurian, Experimental study and economic evaluation of a cascade solar water desalination unit in various conditions, Amirkabir (Journal of Science and Technology), (2018). (In Persian)

[3] M.M. Ghafurian, H. Niazmand, E. Ebrahimnia-Bajestan, R.A. Taylor, Wood surface treatment techniques for enhanced solar steam generation, Renewable Energy, 146 (2020) 2308-2315.

[4] Z. Saadi, A. Rahmani, S. Lachtar, H. Soualmi, Performance evaluation of a new stepped solar still under the desert climatic conditions, Energy Conversion and Management, 171 (2018) 1749-1760.

[5] K. Rabhi, R. Nciri, F. Nasri, C. Ali, H.B. Bacha, Experimental performance analysis of a modified single-basin single-slope solar still with pin fins absorber and condenser, Desalination, 416 (2017) 86-93.

[6] M. Ghafurian, H. Niazmand, Ebrahimnia bejestan E, Performance evaluation of multi-wall carbon nanotube in solar fresh water production. Articles in Press, Amirkabir Journal of Mechanical Engineering, Accepted Manuscript, Available Online from, 12 (2018). (In Persian)

[7] G. Ni, N. Miljkovic, H. Ghasemi, X. Huang, S.V. Boriskina, C.-T. Lin, J. Wang, Y. Xu, M.M. Rahman, T. Zhang, Volumetric solar heating of nanofluids for direct vapor generation, Nano Energy, 17 (2015) 290-301.

[8] H. Jin, G. Lin, L. Bai, A. Zeiny, D. Wen, Steam generation in a nanoparticle-based solar receiver, Nano Energy, 28 (2016) 397-406.