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Enhanced steam generation based on a bilayer water and light absorber

Modelling and optimization of capillary imbibition and water evaporation

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Introduction

Enhanced steam generation is a robust and promising process for water purification. This is a method of increasing the evaporation efficiency by localizing the heat at the water-air interface using an black absorber. It is worth mentioning at this stage that the two functions of localized heating and water imbibition are different functions that can be separated in their implementation. However, one can note that a vast majority of state-of-the-art implementations show that both functions are integrated together, which is typically a black and porous medium, hence providing simultaneous light absorption and water absorption capabilities. In addition, there is a concern about thermal conductivity so as to minimize loss of the surface-localized generated heat into the surrounding water bulk. As of late, bilayer structure black absorbers have been developed in different combinations of photothermal materials and porous media aiming to achieve efficient steam generation.

Bilayer modelling

First layer modelling : heat transfer

Second layer modelling : perforated open pore

Capillary imbibition in transit state

In a perforated pore, the capillary phenomenon can be obtained from the following differential equation:

$$2a \cos \theta \cdot \frac{H}{r_{pore}} = \sigma \left( \frac{r_{pore}}{r_{pore}^2} - \rho g H \cdot \frac{H}{r_{pore}} \right) = \frac{\mu}{r_{pore}} \cdot \frac{dH}{dt} = \frac{d}{dr} \left( \frac{r_{pore}^2}{H} \frac{dH}{dt} \right)$$

- $\sigma$ is the surface tension of water.
- $\theta$ is the contact angle.
- $r_{pore}$ is the radius of the perforated pore.
- $\mu$ is the water viscosity.
- $H$ is the capillary height.

Capillary imbibition in steady state

We assumed that the water only gets vaporized at the surface, which means there is no evaporation happened during the capillary imbibition. While in the steady state, we can get:

$$p_e = \Delta p + \rho g L$$

where $p_e$ is the capillary pressure (or Laplace pressure) while $\Delta p$ is the pressure due to the water motion in the porous media. By combining the hydraulic conductivity with Darcy’s law, the flow rate through the perforated pores is:

$$Q(r_{pore}, N, L) = \frac{2a \cos \theta \cdot \pi r_{pore}^3 N^2 - nN^2 \times \rho g L \times r_{pore}^4}{8\mu L}$$

- $N$ is the number of perforated pores.
- $L$ is the thickness of porous media.

Theoretical results & Simulation results

For the reason that the flow rate increases monotonically with the number of pores $N$, so in the modelling of open pores, the radius of the hole and the thickness of the hole are more noticeable.

Conclusion

- The theoretical results have a good agreement with simulation results in water imbibition phenomenon.
- When giving a certain water imbibition flow rate, with the help of this modelling, we can determine the geometry from the perforate pore size, the number of pores and the thickness of absorber.
- The modelling of thermal conductivity and density in close pores need to be added to the current model in the following study.