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Bionic inspired study of heat pipe from plant water migration

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Abstract

Heat pipe is well regarded as super thermal conductor and has a wide range of applications in the variety of industry sections. A great number of researches have been done on enhancing the performance of heat pipe through improving the flow pattern. The research on plant water migration based on bionic engineering approach provides a very interesting path to the fluid flow enhancement inside heat pipe, and improvement of inner structure as well. The main forces that drive the water migrates in plants are capillary effect, friction, gravity and transpiration effect, and which are also the main driven forces in heat pipe. Although most researches on heat pipe focus on capillary effect against gravity, transpiration effect is still very important as dragging force occurs when water evaporates. And all these can be investigated through plant water migration. A mathematical model describing the water migration process in plant is proposed in this paper. And the result obtained from mathematical calculation is compared with the experimental measured result using Nuclear Magnetic Resonance (NMR) technology. The perfect matching between the two results confirmed the possibility of using the mathematical model to analyze fluid flow in micro channels, including heat pipe. And it also successfully put transpiration effect and friction into consideration, which give out a clearer view of the forces inside heat pipe for further research.

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Keywords: bionic engineering; plant water migration; NMR

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Nomenclature

p	pressure
γ	viscosity
θ	contact angle
r	radius
ρ	density
g	gravity
h	height
E	evaporation flux density
A	surface area
K_h	hydraulic conductivity
f	friction factor
w	width of helical structure in xylem
d	gap between helical structures
ε	gap between simplified roughness
δ	width of simplified roughness
t	height of simplified roughness

1. Introduction

Heat pipe is well regarded as super thermal conductor and has a wide range of applications in the variety of industry sections. It has already become an important heat transfer device in industry. A series of researches have been carried out to improve the heat pipe performance, especially the capillary heat pipes.

Capillary heat pipe is a typical widely used heat pipe. Many forces are involved to drive the fluid flows through the wick structure in capillary heat pipe. These forces on fluid are very complicated, in a manufactured micro channel like capillary heat pipe, as the wick structure can be seen as porous media. Capillary effect occurs in the process of moving the agent from cold end to hot end, and gravity may apply as well. At the hot end, an additional driving force may take place when water evaporates, even though most researchers don't consider it as contributing. Friction is a significant force affecting the flow as well. For capillary heat pipe improvement, a change in wick structure can help generate effective results.[1]

Water transports in plants from root to leaf through the vascular system, xylem and phloem. Xylem and phloem are formed by a brunch of dead-cell rings, in vast number of shapes, through evolution. Xylem is believed to be the conduit in which water moves upward from root to leaf, while phloem is the one in which nutrients moves downward. The inner structure of xylem is similar to the wick structure in capillary heat pipe. Therefore, the research on the water migration process may contribute to detect the water flow behaviours in capillary heat pipe. The bionic study of the relationship between plant and water is called Hydraulic Architecture (HA) , which is firstly proposed by Zimmerman in 1978[2].

Xylem conduits can be simplified as a microscale conduit, with the surface of xylem wall affecting the contact angle of water just like the wetting of wick structure. And all the forces discussed in heat pipe would happen as well in nature, especially woody plants, as water moves upward from root to leaf with the contribution of capillary effect against gravity and friction, and then vaporized into air by transpiration effect. Therefore, studying the natural phenomenon could support the enhancement of heat pipe performance.

2. Mathematical Model

2.1 Cohesion & tension theory

The Cohesion & Tension theory (C-T theory) is the most popular and acceptable theory to explain the sap rising in plant. [3, 4] The C-T theory is first proposed by Dixon and Joly in 1895,[3] and then the model is further developed