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Heat transfer from a surface into a confined gap over a saturated porous plate

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ABSTRACT

Experiments were performed to study the heat transfer from a 35 mm wide heated foil into a confined gap over a saturated porous plate, with a nominal pore size of 50 μm, using distilled water as the working fluid. The surface temperature distribution on the central portion of the heated foil was measured using a high speed thermal imaging camera. Experiments were performed for gap sizes of 0–1000 μm and heat fluxes of 11.7–58.3 kW/m^2. The gap size was found to have a significant effect on the boiling dynamics beneath the heated surface, with the highest heat flux achieved for a gap size of 600 μm, similar to previous results for a heated surface with a width of 10 mm. The results here indicate that the boiling dynamics within the confined gap were independent of the heater width. The heat transfer performance, however, was not with earlier dry-out for the wider heated surface considered here.

1. Introduction

Capillary pumped loops are passive two-phase heat transport devices that can provide relatively isothermal heat removal even at high heat fluxes. The cross section of a typical capillary evaporator is shown schematically in Fig. 1. Heat is typically transferred to the working fluid in a porous wick through a series of fins. The vapor generated below the heated fins passes to channels located between the fins, where it is carried out of the evaporator and on to the condenser. The condensed liquid is drawn back to the evaporator by the capillary pressure developed in the porous wick. Thus, the capillary evaporator provides both the heat and the driving force to the working fluid in a capillary pumped loop. There have been a number of investigations to develop models for capillary evaporators [1–7] and to experimentally characterize the heat transfer from heated fins to saturated porous structures [6–13]. The results indicate that the presence of the vapor below the fin and its penetration into the porous wick limit the heat transfer performance of the evaporator.

Figus et al. [5] proposed that introducing a gap between the heated fin and the porous wick would allow vapor to escape more easily and reduce vapor penetration into the porous structure. Later measurements showed that this was the case. Platel et al. [9] found no evidence of vapor penetration into a porous plate with 20 μm pores for a gap of 100 μm and proposed that the gap should be larger than the pore size to prevent vapor penetration. Schertzer et al. [12,13] found evidence of vapor penetration into saturated porous plates with 50 and 200 μm pores when a narrow heated fin was in contact with the porous plate, but again did not find evidence of significant vapor penetration into the porous plate when there was a gap of 100 μm between the heated surface and the plate. The vapor did appear to periodically build up beneath the heated surface before being exhausted when the gap was less than 100 and 200 μm, respectively. The vapor below the heated surface escaped more easily for larger gap sizes and Shertzer et al. [13] proposed that offset distance should be 3–5 time the pore size.

The boiling dynamics in the gap between a heated surface and porous plate will depend on the width of the heated surface in addition to the channel and pore sizes. The effect of the size of the heating surface has been considered for confined boiling in gaps between two solid walls in a vertical orientation [14] and inverted orientation (downward facing heated surface) [15]. Misale et al. [16] also considered the size of the lower unheated surface below a downward facing heated surface. The effect of the surface size does not appear to have been considered for boiling in a gap over a porous plate. The boiling between a downward heated surface and porous surface will differ from boiling between solid surfaces because liquid enters through the bottom porous wall rather than through the ends of the channel counter to the exiting vapor flow.

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Nomenclature

Bo	Bond number $\left[\frac{(\rho_l-\rho_g)gG}{\sigma/G}\right]^{1/2}$
g	acceleration due to gravity, m/s^2
$\bar{h}$	average heat transfer coefficient, W/m^2 K
h_{fg}	latent heat of evaporation, kJ/kg
I	current, A
k	conductivity, W/m^2 K
q''	heat flux, kW/m^2
G	gap distance between the heating surface and the porous plate, m
t	time, s
T	temperature, °C
T_{ave}	time and space averaged temperature of the heating surface, °C
T_b	bulk liquid temperature, °C
V	electric potential across the electrodes, Volts
Greek symbols	
ρ_g	density of the vapor, kg/m^3
ρ_l	density of the liquid, kg/m^3
Φ	porosity
σ	surface tension, N/m
ε	emissivity of the heating surface

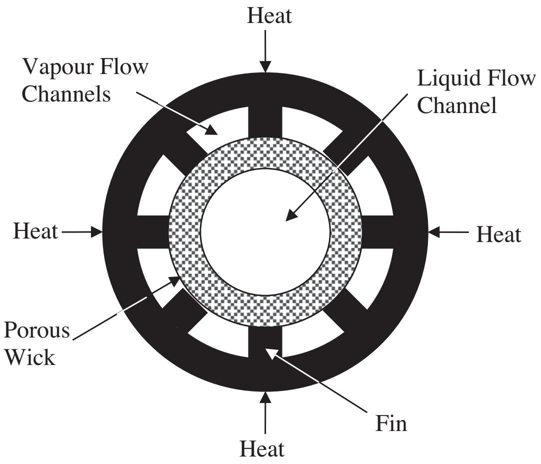

Fig. 1. Cross section of a typical capillary evaporator.

The objective of this work was to investigate the heat transfer from a 35 mm wide heated surface into a gap over a saturated porous plate with a nominal pore size of 50 μm used by Shertzer et al. [13]. Experiments were performed for gap sizes between the heated surface and the porous plate of 0–1000 μm. A high speed thermal imaging camera was used to measure the unsteady surface temperature distribution on the heated surface. The results differed from the results for the 10 mm wide heated surface used by Schertzer et al. [13], indicating that the heat transfer does depend on the width of the heater. The experimental facilities are described in the next section. The results are then presented and discussed.

2. Experimental facility

The experiments were performed using the facility shown schematically in Fig. 2 that consists of a main test section with the porous plate and heated foil assembly, a constant head tank that supplies preheated water to the test section, a pump, and a system reservoir. Details of the experimental facility and its construction can be found in Khammar [17]. Water was continuously pumped into the constant head tank and allowed to overflow back to the system reservoir to maintain the water level in the constant head tank. The water in the constant head tank was heated to 60 °C using a 1 kW plug heater controlled by a PID controller with input from a T-type thermocouple in the tank. Water from the constant

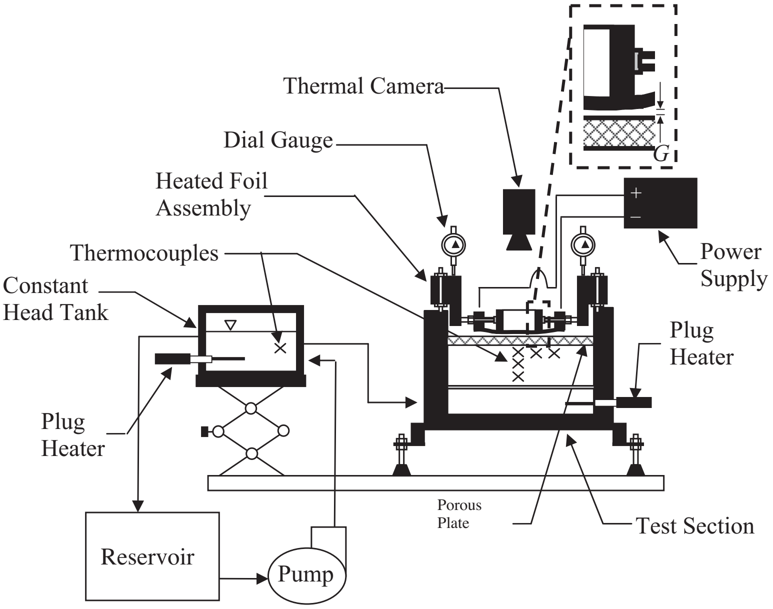

Fig. 2. Schematic of the experimental facility.