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Technical Note

On the effect of thermocapillarity for falling liquid film flow with consideration of humidity condition

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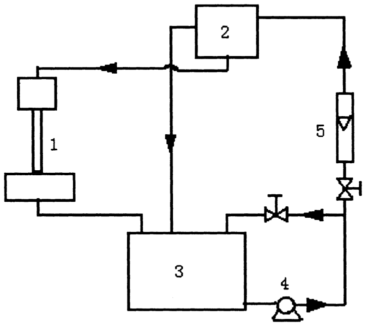
Falling thin liquid film is of importance in the heat and mass transfer of chemical and thermal engineering. The falling thin film flow was found to be intrinsic, unstable and easy to breakdown, while the temperature distribution on the free interface is non-uniform [1], resulting in thermocapillarity on the interface. Simon and Hsu [2] noted early in 1970 that, lateral film redistribution, caused by thermocapillarity at the free interface, became pronounced with increasing heat flux, which distorts the films flow until the thinnest region reached the condition to sustain a dry patch. Bohn and Davis [3] developed their critical heat flux prediction model according to this argument. Recently, Joo, et al. [4] showed analytically the existence of the spanwise thermocapillarity, and we reported the experiments on the dryout heat flux of falling liquid film [5]. Despite these studies of the critical heat flux prediction, the specialized knowledge on thermocapillarity is still lacking. As a result, the current study has specialized in the experimental measurement of thermocapillarity for pure water and moist air case, intending to further examine experimentally the influence of humidity on the spanwise thermocapillarity and critical heat flux of falling liquid films.

The experiment was conducted with the test setup described previously [5]. As shown in Fig. 1, the entrance sector was a 90 mm long and 18 mm OD plexiglass cylinder. The test section was a 300 mm long, 0.5 mm thick and 18 mm OD stainless cylinder. The surface finish and measurement uncertainty in the outer diameter of these cylinders was 1.6 μm and 0.05 mm, respectively. Falling liquid films were formed from a 0.5 mm width annular orifice. A 100 mm inner diameter, 150 mm depth water container was provided at the up end of the entrance section. The upper water tank was used to keep water level stable. There were several pairs of T-type thermal couples used to measure the inlet temperature, the temperature difference between inlet and outlet and the temperature of two spots on the vertical wall. Two outlet temperatures were measured by setting two thermal couples at the different spots around the perimeter of the test column.



1—entrance and test section, 2—upper tank,
3—lower tanker, 4—pump, 5—flowmeter

Fig. 1. Schematic diagram of experimental system.

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Table 1
The outlet temperature difference around the periphery with different dry-bulb temperatures, T_d[a]

T_d (°C)	q_w (J/m^2 s)			
(*a*) $Re = 3150$ and $T_s = 15°C$				
	6210	14,810	19,090	23,930
18.5	0.6	1.5	2.1	2.7
19	0.4	1.2	1.6	1.8
(*b*) $Re = 1680$ and $T_s = 15°C$				
	2360	6440	14,140	
18	0.2	0.6	1.6	
19	~0.0	0.3	0.5	

[a] Re is the Reynolds number; T_s is the wet-bulb temperature (°C); $\Delta T = (T_1 - T_2)$, T_1 and T_2 being the temperature of different measuring spots (°C); q_w is the wall heat flux, W/m^2.

Table 2
The breakdown heat flux of different wet-bulb temperature T_s for $Re = 1140$ and $T_d = 20°C$

T_s (°C)	15	16	17.5
q_w (J/m^2 s)	24300	20600	13400

These two measurements were noted as case *a* and case *b*. The inlet temperature was a bulk one in the upper container of the test section. The test section was heated by electricity directly with the two electric poles being located at the two ends of the test section.

A HP 34970A data acquisition/switch unit and HP 34902A 16-channel multiplexer were coupled and utilized as the data acquisition system. It has $6_{1/2}$-digit multimeter accuracy, stability and noise rejection. The reading rate is up to 600 readings per second on a single channel. In this experiment, the integrating interval was set to 1PLC (equivalent to 20 ms), the corresponding resolution was $6_{1/2}$, and the attached noise error is (range of measurement) × 0.1%. The experimental data were collected by a 586/300 MHz PC, with time interval 0.030 s. In every test run, the temperature was obtained by averaging the 100 data of every channel.

The thermocapillarity can be represented by the Marangoni number, defined as

$$\mathrm{Mar} = \frac{\gamma \Delta T l_0}{2\mu\kappa}$$

where γ is the surface tension temperature gradient; κ is the thermal diffusivity; μ is the dynamic viscosity; l_0 is the spanwise characteristic length; ΔT is the corresponding temperature difference of the spots on the wall surface. Larger Marangoni number indicated a stronger thermocapillarity.

The typical experimental measurements were summarized in Table 1, for illustration. The two outlet temperatures were different for case (*a*) and case (*b*), resulting from the action of the spanwise thermocapillarity. The experimental measurements, under different relative humidity, indicated that, the falling liquid film contacting with low relative humidity moist air had smaller thermocapillarity, and the degree of thermocapillarity was strengthened with increasing wall heat flux. The dryout heat flux of the different relative humidity conditions shown in Table 2, increased with decrease in relative humidity. This was consistent with our previous deduction [5], implying that the falling liquid film will have a higher dryout heat flux under the easily evaporating condition.

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