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Stability and Heat Transfer Characteristics of Condensing Films

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The overall objective of this research is to investigate the fundamental physics of film condensation in reduced gravity. The condensation of vapor on a cool surface is important in many engineering problems,[1,2] including spacecraft thermal control and also the behavior of condensate films that may form on the interior surfaces of spacecraft.

To examine the effects of body force on condensing films, two different geometries have been tested in the laboratory: 1) a stabilizing gravitational body force (+1g, or condensing surface facing "upwards"), and 2) de-stabilizing gravitational body force (-1g, or "downwards"). For each geometry, different fluid configurations are employed to help isolate the fluid mechanical and thermal mechanisms operative in condensing films. The fluid configurations are a) a condensing film, and b) a non-condensing film with film growth by mass addition by through the plate surface.

Condensation experiments are conducted in a test cell containing a cooled copper or brass plate with an exposed diameter of 12.7 cm. The metal surface is polished to allow for double-pass shadowgraph imaging, and the test surface is instrumented with imbedded heat transfer gauges and thermocouples. Representative shadowgraph images of a condensing, unstable (-1g) n-pentane film are shown in Fig. 1a-b. The interfacial disturbances associated with the de-stabilizing body force leading to droplet formation and break-off can be clearly seen in Fig. 1b. The heat transfer coefficient associated with the condensing film is shown in Fig. 2. The heat transfer coefficient is seen to initially decrease, consistent with the increased thermal resistance due to layer growth. For sufficiently long time, a steady value of heat transfer is observed, accompanied by continuous droplet formation and break-off.[1,2]

The non-condensing cell consists of a stack of thin stainless steel disks 10 cm in diameter mounted in a brass enclosure. The disks are perforated with a regular pattern of 361 holes each 0.25 mm in diameter. Non-condensing experiments in -1g have employed 50 cSt and 125 cSt silicone oil pumped through the perforated disks at a specified rate by a syringe micropump. The time to droplet break-off and the disturbance wavelengths appear to decrease with increasing pumping rate.

The ability to reliably perform multi-point, ultrasonic measurements of the film thickness has been demonstrated. A linear array of eight transducers of 6 mm diameter (with a beam footprint of comparable size) are pulsed with a square-wave signal at a frequency of 5 MHz and a pulse duration of approximately 0.3 μs. For thin films (60 μm to 2-3 mm in thickness) the layer thickness is determined by frequency analysis, where the received ultrasound pulse is Fourier transformed and the spacing between the peaks in the frequency spectrum is analyzed.[3] For thicker layers (up to at least 1 cm in thickness), time-domain analysis is performed of the received ultrasound pulses to generate directly the layer thickness.

A time-trace of the film thickness at a point using a single transducer in the linear array is shown in Fig. 3 for the case of an unstable (-1g) n-pentane film. The oscillations in film thickness are evidently due to the passage and/or shedding of droplets from the cooled plate surface. The entire transducer array was used to measure the changes in film thickness resulting from the passage of gravity waves generated either by an oscillating wall or the impact of a single droplet on the free surface of a film. The enclosure in both cases was 14 cm square and the transducer spacing was 12 mm. Best results were obtained using as test fluid a mixture of 50% glycerol and 50% water with a fluid layer thickness of 3-5 mm. In both cases the measured wavelengths and wave propagation speeds using the ultrasound technique compared reasonably well with those observed by optical imaging.

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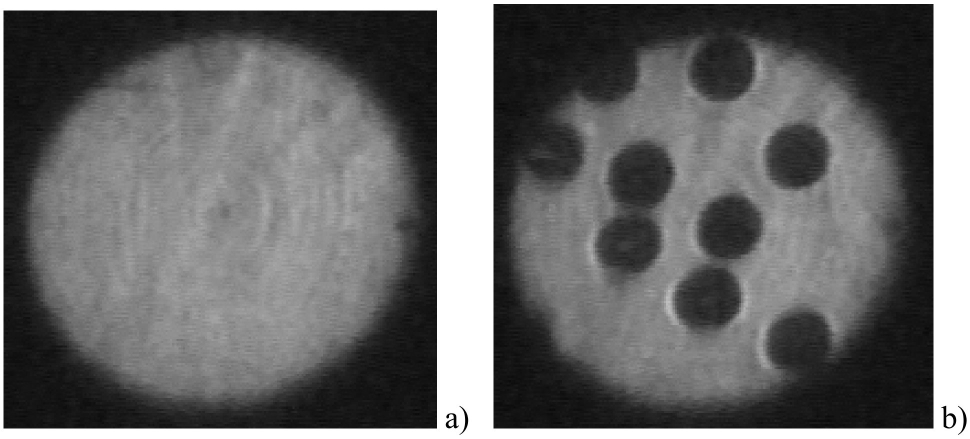

Fig. 1a-b Condensing n-pentane film in unstable (-1g) configuration. a) 30 s after start of condensation, T_{wall} = 13.9 C, T_{sat} = 18.1 C; b) 40 s after start of condensation, T_{wall} = 13.9 C, T_{sat} = 21.3 C.

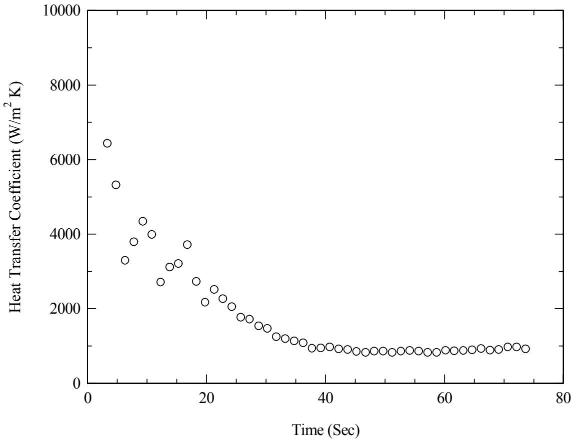

Fig. 2 Time evolution of heat transfer coefficient for unstable (-1g), condensing n-pentane film.

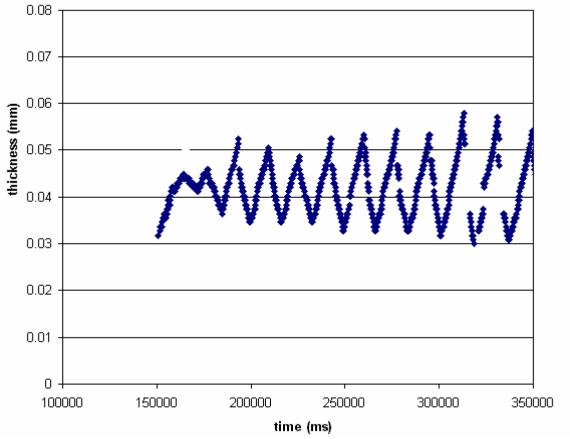

Fig. 3 Ultrasound point measurements of film thickness for unstable (-1g) condensing n-pentane film.