Twin Background Subtraction Technique for liquid film thickness and temperature measurements

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1. Introduction

The development of techniques to measure the thickness or temperature of a liquid film has been a hot topic for many two-phase flow studies. Various methods based on different physical principles have been proposed in the literature depending on the range of thickness investigated, fluid properties, wall material, and interface properties. The variety of techniques found in the literature that can be adopted for liquid film thickness measurement can be classified in acoustic methods, electrical methods, optical methods, nucleonic methods.

2. Method

The novel technique is based on non-invasive optical, infrared measurement, named Twin Background Subtraction (TBS). The technique allows the simultaneous measurement of the temperature and the thickness of a thin film within infrared transparent ducts or walls. The maximum thickness measurable depends on the attenuation coefficient of the fluid for the particular IR wavelengths investigated. A mid-wave IR camera obtains two signals coming from two different backgrounds and attenuated by the liquid film positioned in-between. The following simplified equations give the signals S1 and S2 recorded by the MWIR camera (3.6-5.1µm) as a function of the film temperature T_F and each background temperature T_1 and T_2. The solution of the system of equations gives us the film temperature T_F and the film transmissivity τ_F that, together with the Beer-Lambert law correlating the liquid transmissivity with its equivalent linear attenuation coefficient, is used to estimate the film thickness:

$$S_1 = \underbrace{\epsilon_1 T_{B1}^4 \cdot \tau_F \tau_W^2}_{\text{Background 1}} + \underbrace{\epsilon_W T_F^4 \cdot \tau_F \tau_W}_{\text{Rear window}} + \underbrace{\epsilon_F T_F^4 \cdot \tau_W}_{\text{Fluid}} + \underbrace{\epsilon_W T_F^4}_{\text{Front window}}$$

$$S_2 = \underbrace{\epsilon_2 T_{B2}^4 \cdot \tau_F \tau_W^2}_{\text{Background 2}} + \underbrace{\epsilon_W T_F^4 \cdot \tau_F \tau_W}_{\text{Rear window}} + \underbrace{\epsilon_F T_F^4 \cdot \tau_W}_{\text{Fluid}} + \underbrace{\epsilon_W T_F^4}_{\text{Front window}}$$

$$\tau_F = exp(-\xi_F \cdot L)$$

3. Results

A water film formed between two square, slightly convex sapphire windows, kept parallel or slightly inclined, was investigated. The film thickness ranged between 0-700 µm, the temperature between 15-50°C, with backgrounds at constant temperatures of 15°C and 45°C, respectively. The technique shows high accuracy in the range of 0-300µm.

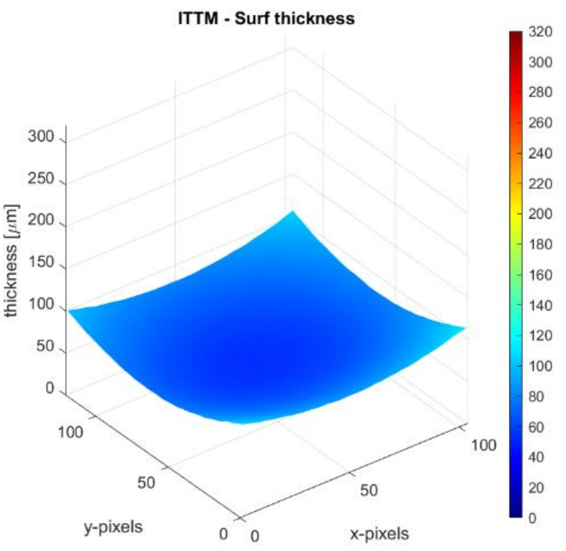

Fig. 1 Surface of the film thickness measured.

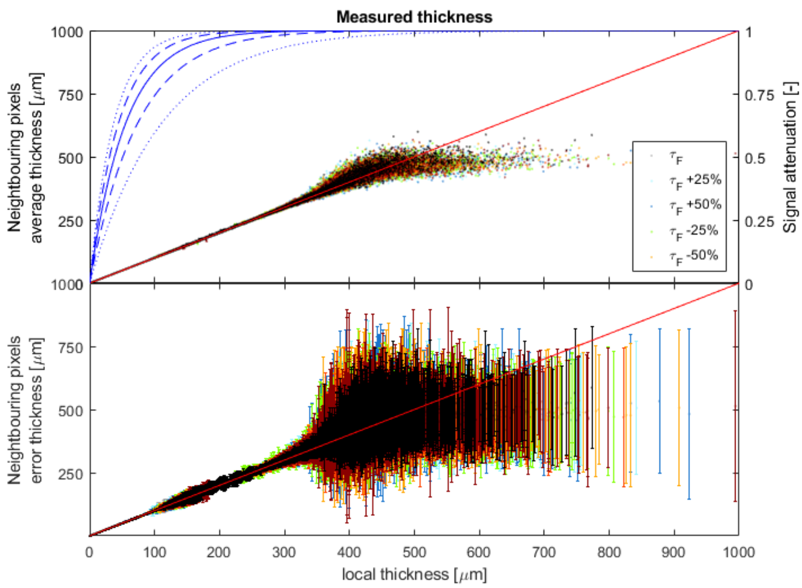

Fig. 2 Moving average of 9 pixels and its error (CI 95%) vs local thickness; theoretical attenuation (blu lines).

4. Conclusion

For attenuation under 90% of the signal, the technique results to be very promising for the study of multiphase flows. The TBS application with a thicker ethanol film is under study to be deployed on pulsating heat pipes.