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Surface wave amplification of a falling liquid film by a perforation

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Falling liquid films are utilized in many technological systems to intensify mass and heat transfers. This strategy is used mainly in absorption or distillation processes, in cooling towers, or in cooling systems for electric mobility. Such systems usually involve thin liquid films flowing over complex surfaces consisting of geometrical features or topographies, such as corrugations, slits, or perforations. The present study focuses on a falling liquid film flowing over a perforation and the possibility of liquid surface wave amplification by the perforation for enhanced heat and mass transfer across the liquid-vapour interface.

We considered a simplified configuration where a vertical flat sheet with a single circular perforation is solely supplied with liquid on its front [1]. The film free surface could be forced periodically by a loudspeaker placed at the inlet to properly examine the long-wave behavior. The liquid flow patterns developing on the front and on the back of the plate (rivulet leaking from the perforation) were observed and recorded using a CMOS high-speed camera. The instantaneous local thickness of the liquid film was measured using confocal chromatic imaging (CCI). The test plates were cut from aluminum sheets of 1 mm thickness. The perforation diameter ranged between 8 mm and 16 mm. The present experiments were carried out with propan-2-ol (Kapitza number, $\mathrm{Ka} = 348$, and highly favorable wetting). The film Reynolds number (Re) was varied between 30 and 80. All measurements were performed in the curtain mode [1]. The surface wave amplification was quantified using fast Fourier transformation of thickness variations with time.

The behavior of the waves traveling on the surface of the falling film is examined when the film free surface is periodically forced at the inlet. Vertical liquid films are unconditionally unstable with respect to long waves. However, we observed that for specific frequencies, the waves are more amplified when crossing the perforation. This amplification is related to the excitation and the resonance of sinuous waves traveling on the liquid curtain that closes the perforation. The resonance satisfies the integer-minus-one-third criterion recently found by Della Pia et al. [2] for the eigenmodes of a liquid sheet flowing in an unconfined environment. Further, the frequency of the resonating peaks shifts to higher values when the perforation diameter is increased. Last, the frequency spacing between resonance peak scales as the inverse of the perforation diameter.

Keywords: falling liquid film, liquid sheet, Kapitza waves, resonance, wave amplification.

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