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The Dynamics of a Droplet Spreading on a Steel Surface

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Abstract : Spreading of a droplet over a solid substrate is a key phenomenon observed in the following engineering applications: thin film coating, oil extraction, inkjet printing, and spray cooling of heated surfaces. Droplet cooling systems are known to be more effective than film or rivulet cooling systems. It is caused by the greater evaporation surface area of droplets compared with the film of the same mass and wetting surface. And the greater surface area of droplets is connected with the curvature of the interface. Location of the droplets on the cooling surface influences on the heat transfer conditions. The close distance between the droplets provides intensive heat removal, but there is a possibility of their coalescence in the liquid film. The long distance leads to overheating of the local areas of the cooling surface and the occurrence of thermal stresses. To control the location of droplets is possible by changing the roughness, structure and chemical composition of the surface. Thus, control of spreading can be implemented. The most important characteristic of spreading of droplets on solid surfaces is a dynamic contact angle, which is a function of the contact line speed or capillary number. However, there is currently no universal equation, which would describe the relationship between these parameters. This paper presents the results of the experimental studies of water droplet spreading on metal substrates with different surface roughness. The effect of the droplet growth rate and the surface roughness on spreading characteristics was studied at low capillary numbers. The shadow method using high speed video cameras recording up to 10,000 frames per seconds was implemented. A droplet profile was analyzed by Axisymmetric Drop Shape Analyses techniques. According to change of the dynamic contact angle and the contact line speed three sequential spreading stages were observed: rapid increase in the dynamic contact angle; monotonous decrease in the contact angle and the contact line speed; and form of the equilibrium contact angle at constant contact line. At low droplet growth rate, the dynamic contact angle of the droplet spreading on the surfaces with the maximum roughness is found to increase throughout the spreading time. It is due to the fact that the friction force on such surfaces is significantly greater than the inertia force; and the contact line is pinned on microasperities of a relief. At high droplet growth rate the contact angle decreases during the second stage even on the surfaces with the maximum roughness, as in this case, the liquid does not fill the microcavities, and the droplet moves over the “air cushion”, i.e. the interface is a liquid/gas/solid system. Also at such growth rates pulsation of liquid flow was detected; and the droplet oscillates during the spreading. Thus, obtained results allow to conclude that it is possible to control spreading by using the surface roughness and the growth rate of droplets on surfaces as varied factors. Also, the research findings may be used for analyzing heat transfer in rivulet and drop cooling systems of high energy equipment.

Keywords : contact line speed, droplet growth rate, dynamic contact angle, shadow system, spreading
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