Surface Roughness and Its Effects on the Heat Transfer Mechanism of Spray Cooling[4]

R. Mesler.[5] These investigators have presented interesting results, which certainly reveal that surface roughness has an effect on the heat transfer in spray cooling. The exceptionally high heat fluxes that are achieved with spray cooling are remarkable. This discussion centers on two interpretations they make of their results. First, they only recognize heterogeneous nucleation as the source of nuclei for the nucleate boiling, which appears to account for the exceptionally high heat fluxes. Research has shown that another mechanism can operate to cause nucleation in liquid films, that is, secondary nucleation. Second, they postulate the existence of an ultrathin liquid film but provide no direct experimental support. An examination of the postulated ultrathin liquid film relative to their other observations reveals a contradiction that questions the suitability of the postulate.

First, the paper discusses only heterogeneous nucleation as the mechanism responsible for the onset of nucleation in their experiments, but research over the last 15 years has provided evidence for another mechanism that operates to produce nucleation in liquid films (Bergman and Mesler, 1981; Carroll and Mesler, 1981; Kim et al., 1983; Mesler and Mailen, 1977; Mesler, 1982; Udomboresuwan and Mesler, 1986). When liquid drops strike a liquid surface, they entrain gas or vapor bubbles. When the liquid is superheated these entrained bubbles serve as nuclei for more bubbles to grow. When nucleate boiling occurs in a liquid film, bubbles bursting from the film produce drops close to the liquid film. Some of the drops return to the film where they can entrain bubbles and thus produce a chain reaction. The bubbles bursting from the film thus sustain further nucleation. The process has been called secondary nucleation after the analogous process that produces nuclei in crystallization. By supplying a liquid film on a heated surface with a spray, as in the present study, abundant sources of nuclei are created that are independent of the surface temperature.

Their study includes results of a pool boiling experiment where it was observed that a surface temperature of about 105°C was necessary for the onset of nucleation. They observed that for spray-applied liquid films nucleation occurred at temperatures below this. This observation can be interpreted as an indication of nucleation initiated by drop-entrained bubbles.

Second, the authors do not examine a postulated ultrathin liquid film in light of all their other observations. These authors state in their conclusions that "For roughness greater than 1 μm, nucleation plays a major role in the heat transfer. However, for films of the order of 0.1 μm, heat is conducted through the (ultrathin liquid) film and evaporated on the surface." This implies that for a surface roughness less than 1 μm the spray-applied liquid film will be on the order of 0.1 μm thick. Apparently the basis for this statement is that it is conceivable that a postulated film 0.1 μm thick might exist on a polished surface with roughness less than 1 μm. The authors offer no direct evidence that a film of such a thickness exists. It appears significant that the portion of the heat flux versus surface temperature plots for surfaces polished with any of the abrasives studied look quite similar at surface temperatures above 100°C. The plots all level off at a high value for the heat flux but the value is higher the smoother the surface. The authors state, "Spray cooling of an ultrathin liquid film on a flat surface enhances heat removal by evaporation, nucleate boiling being enhanced by early bubble departure." This implies that nucleation occurred in the liquid film applied to the smoothest surface as well as in the films applied to the rougher surfaces. How can the authors be so sure that the mechanism for heat removal is so different for the smoothest surface at the high surface temperatures and high heat fluxes when the plot of heat flux versus surface temperature is so similar? How is it that nucleation is being enhanced by early bubble departure? Is this a new mechanism for nucleation?

It is useful to examine the suitability of the postulated ultrathin film by considering it with respect to the observation that an increase in liquid flow rate is accompanied by an increase in the heat flux. An increase in liquid flow rate must cause an increase in liquid film thickness. Yet an increase in film thickness should cause a decrease in the heat flux according to the logic applied elsewhere in the paper. There is therefore a contradiction that questions the suitability of the postulated ultrathin liquid film in explaining the situation. The logic applied here is the same logic as the authors use in arguing that the thinner film accounts for the increase in heat flux with an increase in air flow rate.

A couple of other comments would seem to be in order. The authors explain that heat removal can be enhanced by maximizing microlayer evaporation. However, they do not mention the crucial role of the liquid film in making this possible (Mesler, 1982). In a liquid film a bubble can escape very rapidly because the bubble needs only to break out of the film. Furthermore, the film very quickly re-establishes itself. Escape is so quick that the microlayer does not have time to dry out as when a bubble grows by itself in an abundance of liquid. In that case the microlayer drys out well before the bubble escapes, leaving the surface dry and delaying further microlayer evaporation until the bubble has departed and another bubble grows.

The investigators found that increasing either or both air flow rates and liquid flow rates increased the maximum values of heat flux. Increasing either the air flow rate or the liquid flow rate should act to supply more liquid to the film. It has been noted in previous research that taking additional steps to keep a surface wet with a liquid film increases the maximum heat flux (Mesler, 1982).

Spray applying a liquid film on a surface with a temperature above the saturation temperature of the liquid benefits heat transfer in two ways. First, droplets in the spray entrain bubbles to provide an abundant supply of bubble nuclei to sustain nucleate boiling in the film. Second, the film acts in concert with the nucleate boiling to promote microlayer evaporation where heat can be conducted from the surface to the vapor region through an extremely thin liquid film, the microlayer.

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Authors' Closure

The authors appreciate Professor Mesler's interest in our paper. We would like to respond by stating our current understanding on the heat transfer mechanisms in spray cooling.

The current knowledge of the thermophysics of spray cooling on surfaces is based on observations in experiments performed

[4]By M. R. Pais, L. C. Chow, and E. T. Mahefkey, published in the February 1992 issue of the ASME JOURNAL OF HEAT TRANSFER, Vol. 114, No. 1, pp. 211–219.

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