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Single phase cooling of large surfaces with square arrays of impinging water sprays☆

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The single phase heat transfer from an upward facing, 100 cm^2 (0.01 m^2) copper surface, to square arrays of impinging water sprays was experimentally investigated. Three models of commercially-available full-cone pressure nozzles, of varying flow and pulverization characteristics, were used in runs where average impinging coolant mass flux covered the 0.28–7.2 kg/m^2 s range. Array geometry was varied by adjusting nozzle-to-nozzle and nozzle-to-impingement surface distances. Experimental apparatus construction allowed for good drainage of spent coolant and unrestricted air entrainment to spray cones. The area-averaged heat transfer coefficient was found to be a strong function of coolant mass flux. Droplet Sauter mean diameter and nozzles discharge velocity appear to have secondary effects on the single phase heat transfer. Only one single geometric aspect ratio was found necessary for correlating measured data. The proposed correlation agreed with the experimental data within 18.9% error bounds (mean absolute error of 6.29%).

1. Introduction

Continuous heating, cooling and drying in the industrial processing of various products rely on the high transport capabilities of impinging jets. The technique finds extensive use in drying of textiles and paper, tempering of glass and plastic materials, quenching of metallic parts and cooling of electronic components, gas turbine blades and pistons of heavily loaded internal combustion engines. During the past fifty years much has been done to characterize jet impingement hydrodynamics and heat transfer. A significant volume of information, on both chemically reacting (flame) and non-reacting jets, may be found in available reviews [1–3]. Literature on free surface liquid jet impingement hydrodynamics and heat transfer (single phase and boiling) is comparatively recent [4,5]. Arrays are used to extend the high transport characteristics of single jets to the processing of large surface products.

Spray cooling literature and data, contrasting with the jet impingement background, is sparse. A few studies on the single phase heat transfer of impinging sprays, however, are available [6–10]. Early studies focus on the boiling regimes, as the technique finds use on the controlled water quenching of metals and thermal processing of both steel and non-ferrous alloys [11–14]. The scarce information available on non-boiling spray impingement signs that fairly uniform distributions of local heat transfer, over the cooled surface, may be obtained [15,16]. Such uniformity would hardly be verified with single or multiple impinging jets (submerged or free surface). To further extend the advantages of spray impingement to the thermal processing of large surface products one must, as in the case of jet arrays, deal with a number of neighboring spray nozzles. Relatively few experimental data on overlapping sprays and spray arrays heat transfer are available [17–21]. Recent data focus on electronic components cooling, i.e., involve dielectric fluids (FC-72, FC-87 and PF-5060), heat dissipating surfaces of small dimensions (around 2 cm^2, or 2×10^{-4} m^2) and moderate pulverization pressures (0.5–4 bar).

The present work reports on experimental data on the area-averaged single phase heat transfer to square arrays of impinging water sprays. Samples of three commercially-available full-cone pressure nozzles were employed in the investigation. The experimental setup allowed for good spent coolant drainage from the (upward facing) impingement surface. Air vents on nozzles support plate allowed for unrestricted spray cones air entrainment. Pulverization pressures of 1.4, 4.8 and 8.3 bar were used. Average heat flux spanned the 20–800 kW/m^2 range.

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