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Effect of Spraying Pressure on Spray Cooling Enhancement of Beryllium-Copper Alloy Plate

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Abstract

Spray cooling technology relying on phase change mechanism has a notable ability to remove high heat fluxes. Particular problems are experienced when cooling from the high temperature, stable film boiling regime through Leidenfrost to nucleate boiling. The heat transfer characteristics of water spray impingement cooling of stationary flat surface was numerically investigated. Simulations were conducted on a highly heated plate of known dimensions and made of beryllium-copper alloy. The material is subjected to non-stop intensive cooling beneath a full cone spray nozzle. The only controlling parameter taken during the numerical study was water spray pressure. The effect of the controlling parameter on the cooling rates was critically examined during spray impingement cooling. The thermal investigation was achieved through the solution of heat conduction equation. Experimental data are used to study the influence of the dispersion function $g(x, y)$, by varying spraying pressure from 1 bar to 4 bars, on heat transfer enhancement within the metal initially at the temperature of 815 °C.

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Keywords: COMSOL multiphysics; Nozzle; Pressure; Water-spray; Temperature; Heat transfer.

1. Introduction

Spray cooling can be used to transfer a considerable energy through the latent heat of evaporation. Heat transfer rates much higher than can be attained in pool boiling are possible with spray cooling since the vapor can be removed from the surface more easily. Spray cooling is capable of removing large amounts of heat between the cooled surface

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and the liquid, with reported heat fluxes capabilities of up to 1,000 W/cm^2 for water; many previous studies have emphasized the effect of spray parameters and test conditions on heat flux and convection coefficient.

Nomenclature

c_P	specific heat capacity, J/(kg·K)
F	nozzle's orifice area, m^2
$g(x, y)$	dispersion function, mm^3/(mm^2·s)
$g_{max}(0)$	maximum dispersion (surface centre)
H	nozzle height, m
h	heat transfer coefficient, W/(m^2·K)
k	thermal conductivity, W/(m·K)
p	fluid pressure, Pa
q''	heat flux, W/m^2

Greek symbols

β	coefficient of volume expansion, K^{-1}
ΔT_{sat}	boiling temperature difference (T_w–T_{sat}), K
δ	plate thickness, m
ξ	nozzle's dimensionless characteristic
ρ	density, kg/m^3
σ	variance
Ψ	fluid statistical parameter, kg/(m^2·s)

Subscripts and superscripts

a	ambience
lg	evaporation
ls	fusion
sat	saturation
s	surface
t	time
w	wall

An experimental hydrodynamic study resulted in interesting correlation quantifying and defining the dispersion of a water jet beneath liquid sprayers [1]. Besides nozzle's geometrical characteristics, the equation obtained took into consideration two essential parameters, spraying pressure and nozzle height.

A numerical simulation is performed to investigate the effect of water-spray characteristics for the removal of heat fluxes of the order of 300 W/cm^2 during cooling of steel plates at high temperature [2]. The simulation is carried out with eight different sprayers, in the range of ejected fluid pressure of 1-3 bars. It was observed that for lower temperatures, the predicted local heat transfer coefficient increased significantly.

Enhancement of forced convective heat transport through the use of evaporating mist flow is investigated analytically and by numerical simulation [3]. A two-phase mist, consisting of finely dispersed water droplets in an airstream, is introduced at the inlet of a longitudinally finned heat sink. The simulations indicate that significantly higher heat transfer coefficients are obtained with mist flows as compared to air flows, highlighting the potential for the use of mist flows for enhanced thermal management applications.

Four different spray axis incident angles are tested in order to investigate the effect of the spray inclination angle on the heat transfer performance of rhombus- pitch shell and tube spray evaporator [4]. It is shown that the optimal heat transfer performance is obtained using a spray axis incident angle of 60°.

Some numerical investigations were undertaken on the effects of spray angle on spray cooling of extruded aluminum alloy plate to look for an optimal range of spray angle value that can improve the cooling performance [5]. A commercial Fluent code was employed to calculate the temperature distribution within the cooled plate.