International Journal of Heat and Mass Transfer 61 (2013) 505–524

Contents lists available at SciVerse ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

An overview of heat transfer enhancement methods and new perspectives: Focus on active methods using electroactive materials

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ARTICLE INFO

Article history:
Received 26 March 2012
Received in revised form 30 January 2013
Accepted 31 January 2013
Available online 8 March 2013

Keywords:
Heat transfer enhancement
Passive techniques
Active techniques
Nanofluid
Jet
Spray
Electrohydrodynamic
Acoustic
Ultrasound
Vibration
Piezoelectric
Phase change
Boiling
Condensation

ABSTRACT

The main techniques for the enhancement of heat transfer between a solid wall and a fluid are reviewed for both single phase (liquid and gas) and two-phase (boiling and condensation) systems. First, a brief description of the commonly used passive techniques is given. For each of them, we report the values of the enhancement factor given in the literature. The principal active methods, i.e. methods involving the supply of external energy, are then detailed. The physical mechanisms leading to heat transfer enhancement are identified from the analyses published to date. The paper then focuses on the techniques that use periodic deformation of a wall over time. Such a wall deformation enhances heat transfer by disrupting the boundary layer and simultaneously setting the fluid in motion. The piezoelectric materials that can be implemented to generate the channel wall dynamic deformation are reviewed. As deformation of a wall is generally of low amplitude, the technique is well suited to micro channel systems: (i) in single-phase configuration, imposing a deformation traveling wave to a micro channel wall is found to simultaneously enhance heat transfer and set in motion the fluid; (ii) boiling in a narrow space is found to involve both boiling and cavitation phenomena in the nucleation process.

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0017-9310/$ - see front matter
http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.01.083

Nomenclature

D	diameter (m)
E	electric field (V m^{-1})
$\vec{E}$	electric field strength (V m^{-1})
$\vec{F_e}$	electrohydrodynamic force (N m^{-3})
G	mass flux (kg m^{-2} s^{-1})
h	heat transfer coefficient (W m^{-2} K^{-1})
P	remanent polarization (C m^{-2})
q_c	free electric charge density (C m^{-3})
T	temperature (K)
x	radial distance from stagnation point (m)
z	axial distance nozzle to plate (m)

Greek symbols

ϵ	fluid permittivity (F m^{-1})
λ	wavelength (m)
ρ	fluid density (kg m^{-3})
σ_e	electrical conductivity (S m^{-1})

Subscripts

EHD	electrohydrodynamic
ref	reference
sat	saturation

1. The challenges, the different techniques of intensification and the target applications

The intensification of heat transfer is an important societal challenge in terms of energy saving and materials, sustainable development, thermal control, compactness, etc. The fields of application are numerous. Examples include micro and power electronics, nuclear energy, air conditioning, habitat, transportation, space and aeronautics industries, renewable energy, chemical engineering and industrial processes, etc.

Heat and mass transfers between a fluid and a wall are influenced by the thermal, mass and hydrodynamics boundary layers. During the last century, numerous studies were conducted to better control and/or to increase parietal heat transfer. Therefore, abundant literature has accumulated.

To reduce the boundary layers, intensification techniques have been used but often in a very empirical manner. Thus, the number of studies (publications and patents) undertaken on the subject has been constantly growing since the early 1960s. Bergles et al. in 1999 in their literature review [1] mention nearly 4345 publications on the topic. Intensification techniques are numerous (Webb [2], for example, identified 13 of them) and can be classified into two categories: passive and active. Passive techniques mostly consist of increasing the exchange surface area. Initially they were particularly developed to intensify the transfer between a wall and a gas. Indeed, the low conductivity of the fluid in the gaseous state implies a low heat transfer coefficient. This leads to a requirement for complex surface geometry (surface treatment, fins, etc.) to increase the exchange surface area, and also to disrupt the boundary layers and thus increase the convective heat transfer coefficient. Nevertheless, compactness is challenge which is not consistent with the increase of the heat exchange area. Another way to enhance heat transfer, which is the subject of lot of works, is to use the liquid–vapor phase change. In this case, the complexity of the geometry used to reduce the boundary layer thicknesses is not only connected to the wall but also to the distribution of the phases within the fluid. Although it is now generally accepted that the use of phase change is one of the most effective ways to intensify heat transfer, the understanding of the phenomena involved remains incomplete and the approaches are mainly empirical. For this reason, the control of heat transfers remains rough. Nevertheless, when a fluid changes phase on a wall, the heat transfers are found to be significantly increased. The reason leading to such an increase in the intensity of heat transfer can be analyzed regarding