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A numerical study of nanofluid forced convection in ribbed channels

Oronzio Manca*, Sergio Nardini, Daniele Ricci

Dipartimento di Ingegneria Aerospaziale e Meccanica, Seconda Università degli Studi di Napoli, Real Casa dell'Annunziata, via Roma, 29, 81031 Aversa (CE), Italy

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In this paper a numerical investigation on forced convection with nanofluids, composed by water and Al_2O_3 nanoparticles, in a two-dimensional channel is carried out. A uniform heat flux is applied on the external walls. A single-phase approach is employed to model nanofluids and the fluid properties are considered constant with temperature. The particle size is set equal to 38 nm and nanoparticle volume fractions from 0% to 4% are considered. The flow regime is turbulent and Reynolds numbers are in the range 20,000–60,000. Furthermore, square and rectangular shapes and different arrangements of ribs are analyzed in terms of different dimensionless heights and pitches of elements. The investigation is accomplished by means of Fluent code and its aim consists into find arrangements of ribs such to give high heat transfer coefficients and low pressure drops in presence of water–Al_2O_3 nanofluids. Results are presented in terms of temperature and velocity fields, and profiles of average Nusselt number, average heat transfer coefficients and required pumping power. Heat transfer enhancement increases with the particle volume concentration but it is accompanied by increasing required pumping power. The heat transfer improves, as Reynolds number raises, but also an increase of pumping power is observed.

1. Introduction

Heat transfer enhancement represents an active and important field of engineering research since it contributes to the effectiveness increase of heat exchangers. The improvement of the heat transfer rates in the thermal devices by adopting suitable techniques can result in significant technical advantages and cost savings. These targets could be achieved by the employment of different available techniques, divided by Bergles et al. [1] in *passive* and *active* ones. Passive methods use special surface geometries, like rough surfaces, or fluid additives to achieve the aim of heat transfer enhancement whereas the active techniques require external power sources, such as mechanical aids, electric or acoustic fields and surface vibration [2,3]. Among the available passive methods, the employment of ribbed surfaces already covers several commercial applications but other techniques has recently burst on the scene of engineering research, like the use of nanoparticles as additives in the working fluids in order to improve their thermal conductivity and convective heat transfer coefficients, consequently [4].

Considerable data exist for single-phase forced convection flow over rough surface for geometries like flat plates, circular tubes, non-circular channels, longitudinal flows in rod bundles, annuli and flow orthogonal to circular tubes. Artificial roughness is used in various application like evaporators, condensers, steam condensers, gas turbine blade cooling channels, nuclear reactors heat exchangers, solar air heaters, etc. [5–9]. Several experimental studies confirmed that this technique consisted of an efficient passive method to enhance the forced convection heat transfer by investigating on conventional configurations, like flat plates, circular tubes, non-circular channels, longitudinal flows in rod bundles, annuli [2,10–15]. When a fluid flows in a ribbed channel or duct, ribs tend to break the laminar sub-layer and create local turbulence, due to flow separation and reattachment between consecutive ribs. As a result the thermal resistance reduces and heat transfer mechanisms improve. This effect overcomes the fin-effect, due to the increased heat transfer area, provided by the ribs, mounted on the walls [12]. However, the introduction of artificial roughness leads to increasing friction losses thus it results to be convenient to enhance that the turbulence only in a region close to the heat transferring surface, such as in the viscous sub-layer. This can be done by keeping the height of roughness elements to be small in comparison with the duct dimensions. Wang and Sunden [13] underlined that the local heat transfer was strongly dependent on the rib shape, for example regarding the region just downstream the rib. Promvonge and Thianpong [14] suggested the use of triangular-shaped ribs by carrying out experiments in rectangular channels with ribs, arranged in in-line and

* Corresponding author. Tel.: +39 081 5010217; fax: +39 081 5010204.
E-mail addresses: oronzio.manca@unina2.it (O. Manca), sergio.nardini@unina2.it (S. Nardini), daniele.ricci@unina2.it (D. Ricci).

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