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Heat transfer enhancement and pumping power in confined radial flows using nanoparticle suspensions (nanofluids)

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ABSTRACT

This paper presents a numerical investigation of heat transfer enhancement capabilities of coolants with suspended nanoparticles (Al_2O_3 dispersed in water) inside a confined impinging jet cooling device. Steady, laminar radial flow of a nanofluid in a axis-symmetric configuration with axial coolant injection has been considered. A single phase fluid approach was adopted to numerically investigate the behavior of nanofluids in the present application. Good agreement was found between numerical results and available experimental data. Results indicate that heat transfer enhancement is possible in this application using nanofluids. In general, it was noticed that the mean Nusselt number increases with particle volume fraction and Reynolds number and decreases with an increase in disk spacing. On the other hand, the important increase in associated pumping power may impose some limitations on the efficient use of this type of nanofluid in a radial flow configuration.

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1. Introduction

Impinging jets, whether confined or unconfined, have been used for efficient cooling in a multitude of industrial applications for ages. Indeed, these types of flows typically produce high localized heat transfer coefficients. Depending on the application, flow conditions can range from laminar to highly turbulent. Impinging jets with or without confinement have been widely considered in engineering literature over the past several decades. Downs and James [1] as well as Jambunathan et al. [2] and Tesar [3] have provided literature reviews on the subject. More recently, Lytle and Webb [4] and Behnia et al. [5] have considered the effects of confinement on impinging jet heat transfer. When reducing the distance separating a large flat frontal area nozzle from the impinged surface (i.e. confining the impinging jet), the resulting flow is essentially akin to radial flow between two surfaces (or disks). This configuration has also been well considered in literature (see for example [6,7] etc.). The subject is still of importance today, as evidenced by the recent work of Baydar [8,9], Gao and Ewing [10] and Sagot et al. [11].

Although the characteristics and performances of confined impinging jets have been evaluated in the past, the limitations imposed by the lackluster heat transfer capabilities of traditional coolants seriously limit further heat transfer enhancement possibilities. The use of specialized fluids, such as FC-77 liquid, has also been considered and used in a variety of applications, notably in the specific case of liquid jet impingement for applications in electronics cooling [12]. More recently, nanoparticles placed in suspension in typical coolants (such as ethylene glycol, water and various types of oils) have generated an incredible amount of interest. Indeed, since the first published paper on the subject by Masuda et al. [13], the amount of published research results has increased exponentially. A review of current literature reveals that a good proportion of research activities so far on nanofluids has been on the evaluation and modeling of effective thermophysical properties (i.e. thermal conductivity, viscosity and, more recently, specific heat). Nanofluids are to this day controversial in many areas such as inconsistencies in published data, disagreements on the heat transfer mechanisms, etc… As a result, more research is certainly required before a consensus can be made on their qualities as heat transfer fluids. These various interesting aspects of nanofluids have now been quite well covered in comprehensive literature reviews on the subject (see in particular [14–17], etc…).

Although considerable attention has been placed on the heat transfer enhancement capabilities of nanofluids, surprisingly, few authors seem to have an interest in quantifying potentially limiting factors (such as considerable increases in viscosity) that can decrease the overall benefits of the use of nanofluids in practical applications. Indeed, whilst some have indicated that the presence of

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