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Heat transfer rate and uniformity in multichannel swirling impinging jets

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ABSTRACT

The influence of the swirl number on the wall heat transfer distribution on a flat plate with a swirling air jet impinging on it is experimentally analyzed. This investigation is concerned with a swirling nozzle based on helical inserts, which is easily applicable in an industrial environment. Measurements are performed at a fixed value of the Reynolds number *Re* (28,000), for five values of the swirl number *S* (0, 0.2, 0.4, 0.6 and 0.8) and for five values of nozzle-to-plate distance *z* (2, 4, 6, 8 and 10 diameters), with infrared thermography and with the *heated thin foil* sensor. Results obtained with swirling impinging jets are compared with those obtained with a circular impinging jet in the same testing conditions. The obtained experimental data supply information on the behaviour of circular jets, multichannel jets, weak swirl jets and strong swirl jets. Their performance in terms of heat transfer uniformity and heat transfer rate is accounted for through evaluation of mean value and standard deviation percentage of the Nusselt number on the impinged area. The dependence of heat transfer rate and uniformity on the swirl number is also explained. In particular, this study shows two aspects: the multichannel jet induces a general enhancement in heat transfer with respect to the circular impinging jet, the swirl motion decreases the rate and increases the uniformity of heat transfer.

1. Introduction

The high heat transfer rate obtainable with impinging jets is widely recognized and explained in scientific literature [1,2] and the use of jets is very popular in many industrial applications such as paper drying, glass tempering and turbine blades cooling. A huge quantity of data is available for single, row and multiple jets with also correlations for heat and mass transfer [3,4].

The flow topology of circular impinging jets is well known [5,6]; it depends strongly on nozzle diameter and nozzle-to-plate distance and can be subdivided in few characteristic zones: the free jet region, the impinged area, the wall jet area, the flow separation zone and the entrainment region (see Fig. 1a). The impingement area and the wall jet area are characterized by very different heat transfer rates; therefore, one of the main limitations of jet impingement heat transfer is the radial non-uniformity.

For some applications such as electronic cooling or chemical vapour deposition, high values of heat and mass transfer with radial uniformity are requested. The swirling impinging jet could be a possible solution to achieve both high heat transfer and radial uniformity. As the flow visualizations by Huang and El Genk [7] show, swirling impinging jets are characterized by tangential velocity components that cause a spiral-shaped motion and the broadening of both the impinged area and the wall jet area (Fig. 1b); this aspect is also coupled, especially near the stagnation point, with an axial flux weakening. The flow field of the swirling impinging jet can be divided in 6 characteristic sections: free jet, impinged area, spiral flow mixing region, flow separation region and internal flow mixing region. The swirl causes the flow to open radially; the spiral effect and the high air velocity on the outer surface of the free jet seem to generate more entrainment than that observed in conventional jets. In the central region, toroidal recirculation zones are generated in the case of high swirl as PIV (Particle Image Velocimetry) measurements by Alekseenko et al. [8] show. The impinged area is significantly larger in the swirling jet compared to the conventional jet, while the spiral flow mixing and the flow separation regions essentially coincide with respectively the wall jet and the flow separation regions in the circular impinging jet; the entrainment region is similar to that of the circular jet, but seems to produce a more marked effect.

Generally, it is possible to obtain a swirling flow either by mixing two air flows or by using an insert inside the nozzle. The first study on a swirling impinging jet is due to Ward and Mahmood [9]. The swirling jet designed by Ward and Mahmood, which is based on the concept of mixing an axial air flow with a tangential one, is characterized by a radial distribution of the local convective heat transfer, which, respect to the circular jet, is slightly more uniform

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