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International Communications in Heat and Mass Transfer 32 (2005) 902–912
International Communications in HEAT and MASS TRANSFER
www.elsevier.com/locate/ichmt

# Analysis of the heat transfer in the entrance region of optimised corrugated wall channel☆

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Available online 1 April 2005

**Abstract**

In this work the analysis of the heat transfer in the entrance region of a channel composed by a corrugated profile and a flat wall is presented. The laminar and incompressible flow of a Newtonian fluid is assumed inside the channel, and an uniform heat flux is imposed on the external surface of the corrugated wall. The governing equations are solved with the help of a finite-element method, and the results are compared with the heat transfer coefficient in the entrance region of a flat channel. In order to investigate the sensitivity of the convective heat transfer coefficient to the Reynolds number under laminar conditions, the analysis have been performed for different values of the flow rate. The effect on the flowfield of the of the corrugated profile amplitude is also discussed.


*Keywords:* Optimum profile; Laminar flow; Entrance region; Forced convection

## 1. Introduction

The optimization of the heat exchange surface is a possible strategy to enhance the convective heat transfer process when it is not possible to act directly on the flow behavior. The presence of non-smooth walls may induce flow instabilities and recirculation near the heat exchange surface even at low Reynolds numbers. In this cases, if the eddy velocity is not too low, the convective transport determined by the eddies can enhance the transfer of energy from the fluid adjacent to the wall to that in the core.

☆ Communicated by J.W. Rose and Briggs.

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doi:10.1016/j.icheatmasstransfer.2004.08.027

Moreover, if the flow becomes chaotic or turbulent, a strong convective transport occurs, due to the turbulent mixing in the flow. Obviously, the corrugated profile introduces an additional cost in terms of an augmented pressure loss. The flow behavior within wavy channels for simple and complex corrugations was investigated from many researchers by means of experiments and numerical simulations [1–7]. Rush et al. [8] have experimentally found that in a sinusoidal wavy channel with amplitude of the corrugation of size comparable to the channel height, recirculation occurs even at very low Reynolds number. Therefore, the corrugated profiles make the flow unsteady and macroscopic mixing occur. The onset of the unsteady behavior, and mixing, moves upstream towards the channel entry as the Reynolds number increases. The experiments have also shown that heat transfer enhancements occur for a wavy channel even at low Reynolds numbers, and that the Nusselt number is larger than in a flat channel of comparable external size at the same flow rate. Numerical simulations of the heat transfer in the entrance region of a sinusoidal wavy channel, based on the assumption of stationary flow, have been performed by Wang and Chen [9]. They found that an effective enhancement of heat transfer occurs for significantly larger amplitudewavelength ratio of the corrugations period, especially for high values of the Reynolds number. Complex, but streamwise periodic, corrugations profiles have been investigated in the periodic flow regime by Fabbri [10], with same assumptions as in the work by Wang and Chen [9]. By using a genetic algorithm, an optimal fifth order polynomial profile has been found. For this profile, the enhancement of the heat transfer, with respect to that for a flat channel of the same external size, is found to increase with the Reynolds and Prandtl numbers.

In the present work, the velocity and temperature fields in the channel entrance region upstream of the optimum wall shape determined by Fabbri [10] is investigated. The influence of flow development on the heat transfer performance of this optimum corrugated profile is studied with the help of a finite element formulation. The computational domain consists of a two-dimensional channel with a periodical corrugated profile as interface between solid and fluid regions. At the lower boundary of the channel a uniform heat flux is imposed, while at the inlet boundary, a laminar velocity profile and a uniform temperature distribution are assigned. The performance of the corrugated wall channel is then compared with that of a reference channel composed of two zero-thickness flat walls and having the same amplitude of the corrugated wall channel.

## 2. Numerical model

In this study, the heat transfer in the entrance region of the corrugated channel shown in Fig. 1 has been analyzed. The channel is composed of a flat and a corrugated wall with variable thickness described by a fifth order polynomial function $f(x)$. In order to analyse the effects on the flowfield of the corrugation amplitude, the minimum value of the profile $f_{\min}(x)$ is set to be constant, while the maximum amplitude $f_{\max}(x)$ is changed. The corrugation is periodic with wavelength $l$, and the channel is composed at the inlet by a flat period and downstream by nine periods of the corrugated profile. At the flat inlet section, a laminar developed profile for the streamwise component of the velocity and an uniform temperature distribution are assigned. At the outlet section of the channel, the velocity and temperature distribution obtained from the solution of the periodic flow inside a single period of the corrugation are imposed. At the lower boundary of the channel a uniform heat flux is assigned, while each other boundary of the solid region is assumed as an insulated wall. The flow is considered to be steady, laminar and incompressible. If it is also assumed that the fluid has Newtonian behavior, the