Performance optimisation of laminar fully developed flow through square ducts with rounded corners

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A study on combined first and second law based optimisation of thermal-hydraulic performance of laminar fully developed flow through square ducts with rounded corners has been presented in this paper. The objective functions have been considered according to suggestions of Webb and Bergles. Four specific geometric constraints have been imposed on the shape of the ducts and these ducts have also been subjected to three different thermal and (or) hydraulic constraints. Two different thermal boundary conditions have been considered and the correlations for friction factor and Nusselt numbers have been adopted from the study of Ray and Misra. The results obtained from the present study clearly show that the optimal duct geometry strongly depends on geometric and thermal-hydraulic constraints, as well as, the objective functions and hence, no general comment can be made with respect to the superiority of a particular geometry of the ducts. Nevertheless, the present study also shows that although entropy generation minimisation may be considered to be an important tool, one requires being careful in using it for thermal-hydraulic optimisation since it may lead to contradictory results for some of the performance evaluation criteria.

1. Introduction

Much effort in the past has been aimed at providing economical methods for improving the thermal performance of heat exchangers. Improvement is generally identified in terms of augmented heat transfer, which would require less surface area and consequently a smaller heat exchanger. At the same time, reduction in pumping power for a specified heat duty or approach temperature difference is also desirable. Various augmentation techniques, both active and passive, have been developed to achieve these objectives, and they are also well documented (see for example, Ray [1], for details). In general, heat transfer augmentation is brought about by disrupting the development of thermal boundary layers and therefore is associated with enhanced pumping power. Usually, the pressure drop and heat transfer characteristics of flow in enhanced ducts are highly nonlinear. As a result, it is almost impossible to make a general statement regarding superiority of any specific augmentation technique with respect to the overall thermal-hydraulic performance. Webb and Eckert [2], Bergles et al. [3,4], Bergles [5], Webb [6] and Webb and Bergles [7] have therefore introduced several performance evaluation criteria (PEC) for the assessment of overall improvement in thermal-hydraulic behaviour. However, since all of the criteria prescribed in these works are mainly based on first law of thermodynamics, none of these analyses takes into account the amount of entropy generated due to the overall process, although enhanced entropy generation is a natural consequence of increased temperature difference and pressure drop.

In order to overcome this drawback, Bejan [8,9] has proposed an optimisation procedure, based on second law of thermodynamics, in which minimisation of irreversibility or entropy generation (Entropy Generation Minimisation method or EGM method), associated with an augmentation technique, is used as the objective function. Subsequently, Nelson and Bergles [10] have further extended the optimisation analysis by treating the entropy generation as a variable, as suggested by Bejan [8]. However, in many of their cases, Nelson and Bergles [10] have evaluated only one objective function while treating the entropy generation as a constraint. PEC equations, based on both first and second law analyses have been developed by Zimparov and Vulchanov [11]. These equations have been further extended by Zimparov [12] in order to include the effect of fluid temperature variation along the