Experimental Thermal and Fluid Science 35 (2011) 112–120

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Flow past confined delta-wing type vortex generators

Azize Akcayoglu *

Mersin University, Faculty of Technical Education, Tarsus, Mersin, Turkey

A R T I C L E I N F O

Article history:
Received 20 December 2009
Received in revised form 5 July 2010
Accepted 19 August 2010

Keywords:
Non-circular duct
Triangular flow passage
Delta wing
Vortex generator
PIV

A B S T R A C T

This paper presents the results of an experimental study of flow structure in horizontal equilateral triangular ducts having double rows of half delta-wing type vortex generators mounted on the duct's slant surfaces. The test ducts have the same axial length and hydraulic diameter of 4 m and 58.3 mm, respectively. Each duct consists of double rows of half delta wing pairs arranged either in common flow up or common flow-down configurations. Flow field measurements were performed using a Particle Image Velocimetry Technique for hydraulic diameter based Reynolds numbers in the range of 1000–8000. The secondary flow field differences generated by two different vortex generator configurations were examined in detail. The secondary flow is found stronger behind the second vortex generator pair than behind the first pair but becomes weaker far from the second pair in the case of Duct1. However, the strength of the secondary flow is found nearly the same behind the first and the second vortex generator pair as well as far from the second vortex generator pair in the case of Duct2. Both ducts are able to create a counter-rotating and a second set of twin foci. Duct2 is able to create the second set of twin foci in an earlier streamwise location than Duct1, as these foci are well-known to their heat transfer augmentation. A larger vortex formation area and a greater induced vorticity field between vortex pairs are observed for Duct2 compared with Duct1. As the induced flow field between the vortex pairs increases the heat transfer, and as the flow field between the vortex cores is found larger in the case of Duct2, therefore, it is expected to obtain better heat transfer characteristics for Duct2 compared with Duct1.

1. Introduction

Recently, increased efforts have been made to obtain more efficient heat transfer surfaces for non-circular flow passages encountered in many industrial areas such as electronics, gas turbines, aerospace, nuclear, biomedical, and ships. Therefore, heat transfer applications considering mixed convection and internal flow in non-circular channels and ducts such as square, rectangular, trapezoidal, polygonal, and triangular, have been studied extensively by many researchers. In these channels, the hydrodynamics and the thermal fields are strongly related to each other. This paper presents experimental results of hydrodynamics inside an equilateral triangular duct.

Non-circular flow passage geometries are required for size and volume constraints [1]. For example, in the case of gas turbines triangular cross-sectional channels are preferred in order to effectively cool turbine blades and vanes and to achieve more compactness. In addition, in the development of membrane technologies, generally triangular cross-corrugated membranes are used as turbulence promoters to intensify heat and mass transfer by generating strong turbulence and secondary flows inside the duct. Moreover, internal cooling passages near the leading edge of the airfoils are usually triangular in cross-section. Early investigators including Cremers and Eckert [2] and Leung and Probert [3] handled the subject of heat transfer and mechanical characteristics of insulated triangular ducts. As [4,5] indicated, heat exchangers with triangular passages are characterized by high ratio of heat transfer area to core volume. They have lower fabrication costs than shell and tube heat exchangers [6]. Another benefit with this configuration is that it is easy to construct with very thin materials and the mechanical strength is rather high with even very thin foils [7]. Gupta [8] found that the triangular ducts have superior heat transfer performance than ducts of circular, semi-circular and square cross-sections. Among the triangular configurations, equilateral triangular ducts give the best convective heat transfer performance [9]. Leung and Probert [3] reported that to achieve the maximum rate of heat transfer, the apex angle of the isosceles triangle should be 60°, i.e., the duct's cross-section should be equilateral. Zhang [10] found the highest fully developed Nusselt number values for equilateral triangular cross-sectional ducts. Therefore in the present experiments an equilateral triangular duct was chosen to be manufactured to examine the flow details inside the duct.

Cooling and heating techniques of non-circular ducts may be augmented by different mechanisms such as creating electric or

* Tel.: +90 324 6274804; fax: +90 324 6274805.
E-mail address: azize.akcayoglu@gmail.com

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doi:10.1016/j.expthermflusci.2010.08.012