International Communications in Heat and Mass Transfer 38 (2011) 1253–1261

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

An experimental set-up for investigating swirling decaying flow in an annular pipe☆

Kelvin Ho *, Yousif Abdalla Abakr, Andy Chan

The University of Nottingham, Faculty of Engineering, Jalan Broga, 43500, Semenyih, Selangor Darul Ehsan, Malaysia

ARTICLE INFO

Available online 16 July 2011

Keywords:
Water tunnel
Flow visualisation
Heat transfer
Swirling decaying flow
Annular pipe

ABSTRACT

This work presents the design of an experimental set-up for swirling decaying flow investigations, alongside validation experiments and preliminary experimental work. The combinations of possible investigations using such an apparatus are limitless. As a means of validation, a series of flow visualisation images for pipe flow are presented. In addition to that, the design of the axial swirl vanes used in the study was also disclosed, alongside flow visualisation images and steady and unsteady heat transfer results. Experimental validation was conducted using the dye seeding method. Results show that the fully laminar and turbulent regime is similar to published results. Streak-lines produced for swirling decaying flow are clear and easily captured using normal digital cameras.

1. Introduction

Experimental set-ups are commonly used for fluid mechanics and heat transfer investigations. Such apparatus are usually custom designed and the design varies for different working fluids because the problems that are likely to occur for water tunnels tend to differ distinctively when compared to other fluids. For instance, fluid containment and storage, fluid compressibility, viscosity, corrosiveness etc. are amongst the crucial criteria that one should bear in mind whilst designing and fabricating a fluid tunnel. Early contributions towards the development of water tunnels can be attributed to Reynolds [1], Rayleigh, Prandtl [2] and many others. Although many theories and empirical laws have been deduced throughout the classical and modern science to explain various flow phenomena, a great deal of knowledge still remains unknown up till today.

Methods and techniques for flow visualisation in water tunnels have been in existence since classical science and much have been developed since the early 20th century. Extensive reviews on the subject matter can be found in [3–8].

Vortices have fascinated mankind for thousands of years. Not until recently that the swirling phenomenon behind whirling leaves, whirlpools, dust devils, typhoons, hurricanes etc. were unravelled, owing much to philosophers like Plato, Socrates, Aristotle etc. Leonardo's theory on vertical motion in the aortic valve and its importance towards controlling the effective movements of the valve was proven to be correct [9]. The 18th and 19th centuries were the golden age for mechanics and vortices, with great names such as, Leibniz, d'Alembert, Bernoulli, Euler, Lagrange, Laplace, Cauchy, Stokes, Newton [10], Helmholz, Maxwell, Navier, Lord Kelvin, Rayleigh etc. The work of those aforementioned has provided solid stepping stones for peers in the 20th century. Although attempts to formulate a unified vortex theory has failed but its contribution towards science and engineering has been great. Studies on different vortex configurations by Prandtl, Von Kármán, GI Taylor etc. help in understanding the instability of vortices which leads to a turbulence built-up. More details on the history of the development of fluid mechanics and vortices can be found in [11,12].

Swirling flow in pipes can be produced through active and passive methods [13], namely through, rotating pipes, tangential inlets, guided swirlers, radial swirlers and axial swirlers. The development of heat transfer enhancement techniques can be traced back to the time of Newton [10], and subsequently to the work of Joule [14], Whitham [15], Jakob [13] etc. Extensive reviews can be found in numerous published literatures [13,16–18]. Swirling decaying flow produced by axial swirl vanes can be found in the work of Zhang et al. [19]. The authors used the algebraic Reynolds stress model (ASM) developed in [20,21] to investigate the heat transfer characteristics in an annular duct under swirling turbulent flows. The following general conclusions were obtained: (1) an increase in swirl number or the axial inlet velocity will increase the heat transfer coefficient of both the local Nusselt number at the inner and outer wall and thus the overall heat transfer coefficient of the annular system. Ahmadvand et al. [22] conducted an experimental and CFD study on the steady-state heat transfer and fluid flow characteristics of swirling decaying flow generated using axial swirl vanes in a pipe. The study was conducted for an inlet Reynolds number from 10,000 to 30,000 for three different blade angels (30, 45 and 60). The thermal performance was found to increase between 50 and 110% depending on the vane angle. Recent

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail address: choon-seng.ho@nottingham.edu.my (K. Ho).

0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.07.003