Case Studies in Thermal Engineering 5 (2015) 134–142

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

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

A numerical study on helical vortices induced by a short twisted tape in a circular pipe

Wen Liu, Bofeng Bai *

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China

ARTICLE INFO

Article history:
Received 24 December 2014
Received in revised form
4 March 2015
Accepted 12 March 2015
Available online 14 March 2015

Keywords:
Helical vortices
Swirling flow
Twisted tape
Vorticity

ABSTRACT

Helical vortices, as one kind of secondary flows, are recently observed downstream of the short twisted tape. The behaviors of vortices, which have significant effects on the efficiency of twisted tape, are not well understood. As such, the formation and development of helical vortices induced by the short twisted tape are studied numerically. The results show that two symmetrical stable helical vortices are present downstream of the twisted tape. The values of radial velocities cannot be neglected due to the presence of the vortices. The vortices form in the twisted tape and remain the structure downstream of the twisted tape. Torsion promotes the formation of helical vortices. The intensities of helical vortices decay along the streamwise direction. With the increasing Reynolds numbers, the intensities of helical vortices increase, and the trend is in agreement with the swirl intensities. The intensities of helical vortices decay slowly compared with the intensities of swirling flow.

1. Introduction

Full length twisted tape insert has been widely applied in industry, as a simple and cheap continuous swirl flow device for heat transfer augmentation in heat exchangers. The penalty of the present technique is the increase of friction pressure drop. Several modifications of twisted tape have been reported in literatures, such as short inlet tapes, serrated tapes and intermittently spaced tapes. The primary motive in these variations is to reduce the pressure drop while maintaining the thermal performance of a full length insert.

Full length twisted tape has been investigated for a long time, researches [1–3] mainly focused on heat transfer and friction coefficient, only a few studies regarding the vortex structure. Double helical longitudinal vortices are observed in the turbulent flow field through measurement [4]. The vortex structure in the laminar flow is the same, confirmed through smoke flow visualizations [5] and computational simulations [6]. However, the visualizations and simulations about vortex motion are restricted to the secondary flow in fully developed flow. The formation and development of vortices, which have significant effects on the vortex motion in the fully developed flow induced by full length twisted tape, are not well understood. This limits the enhancement of heat transfer.

Short twisted tape is a more promising embodiment [7]. The tape is long enough to initiate swirl, and decays in the subsequent empty pipe section. The decay region without the twisted tape seriously reduces the pressure drop, while the improvement of enhancing heat transfer is maintained [8,9]. One significant existing problem of the technique is the limited

* Corresponding author.
E-mail address: bfbai@mail.xjtu.edu.cn (B. Bai).

http://dx.doi.org/10.1016/j.csite.2015.03.003
2214-157X/

Nomenclature

A	pipe cross section area, m^2
D	pipe diameter, m
D_H	hydraulic diameter, m
H	180° twist pitch, m
I	turbulence intensity
J^n_{ABS}	absolute vorticity flux, s^{-1}
k	turbulent kinetic energy, $m^2\ s^{-2}$
R	pipe radius, m
r	distance in radial direction, m
Re	Reynolds number
S	swirl number, $=\left(\int \rho u_a u_t r dA\right)/\left(R\int \rho u_a^2 dA\right)$[18]
U_b	inlet velocity, $m\ s^{-1}$
u	fluid velocity, $m\ s^{-1}$
u_a	axial fluid velocity, $m\ s^{-1}$
u_i	mean fluid velocity, $m\ s^{-1}$
u_r	radial fluid velocity, $m\ s^{-1}$
u_t	tangential fluid velocity, $m\ s^{-1}$
u'	fluctuating fluid velocity, $m\ s^{-1}$
$\overline{u'}_i$	mean fluctuating fluid velocity, $m\ s^{-1}$
z	distance in Z direction, m

Greek letters

α	inverse effective Prandtl numbers
δ	tape thickness, m
δ_{ij}	Kroneker delta
ε	turbulent kinetic energy dissipation rate, $m^2\ s^{-3}$
θ	angle, °
μ_t, μ_{eff}	turbulent viscosity, Pa s
ρ	density, $kg\ m^{-3}$
ω_a	axial vorticity component, s^{-1}
ω_{da}	dimensionless of axial vorticity component

Subscripts

a	in axial direction
r	in radial direction
t	in tangential direction

awareness concerning vortex behavior in the swirl flow which suppresses its application and structure optimization. Recently, the secondary motion in the swirling flow downstream of a 180° twisted tape was studied, two corotating helical vortices were observed in the experiment [10,11]. However the helical vortices motion, such as vortex formation and development, are not well understood. The most dominant heat transfer enhancement mechanism of circular tube fitted with twisted tape is the vortices motion generated by the tape. Grasping the underlying mechanism of vortices motions is essential to enhance heat transfer, and meanwhile reduce energy consumption.

The turbulent swirling flow is studied numerically in this study, to clarify the helical vortices hydro-dynamics in the swirling flow induced by the short twisted tape. Helical vortices formation and development are reported. The present study improves the understanding of the vortices formation and development in the swirling flow, thus enabling the development of more efficient heat exchanger devices.

2. Numerical simulation

2.1. Geometry model and mesh generation

The 180 degree twisted tape considered is a typical short twisted tape. Fig. 1 shows the circular pipe, twisted tape geometry and notations. In order to correlate the calculation with the experimental data [11], the structure parameters of the simulation are the same with the parameters in the experiment. The pipe diameter (D) is 25.40 mm, the pipe length (L)

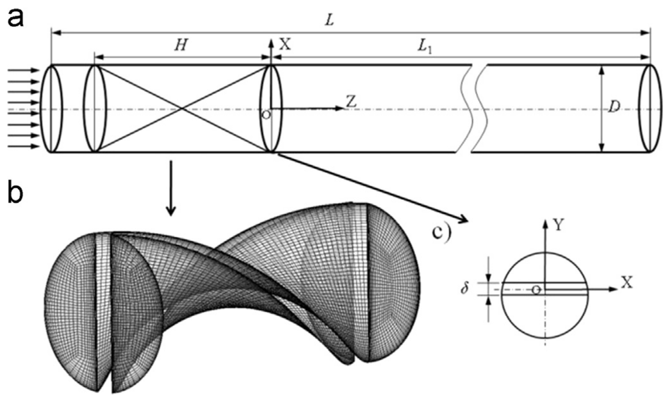

Fig. 1. Geometry model of a circular pipe with a twisted tape: (a) computational domain, (b) twisted tape showing the structure grids and (c) cross section at $z=0$, the direction of arrows represents the flow direction.