Experimental Thermal and Fluid Science 44 (2013) 680–696

Contents lists available at SciVerse ScienceDirect

Experimental Thermal and Fluid Science

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

Effect of inlet geometries and heating on the entrance and fully-developed friction factors in the laminar and transition regions of a horizontal tube

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ARTICLE INFO

Article history:
Received 31 August 2011
Received in revised form 2 May 2012
Accepted 7 September 2012
Available online 16 September 2012

Keywords:
Isothermal and non-isothermal
Entrance and fully developed flow
Friction factor
Laminar and transition regions
Correlation

ABSTRACT

In this article a detailed study on the effects of different inlet geometries and heating on the friction factor in the entrance and fully developed regions of a horizontal tube under different flow regimes is presented. For this purpose, accurate pressure drop measurements were made in the entrance and fully-developed regions of a 1.48 cm inside diameter horizontal circular straight tube with square-edged and re-entrant inlets under isothermal and non-isothermal (uniform wall heat flux) boundary conditions. The working fluid used in the experiments was different mixtures of ethylene glycol and water and the Reynolds number for the experiments ranged from about 800 to 22,000 to cover laminar, transition, and turbulent regimes. Due to the presence of secondary flow, the effect of heating on the friction factor was significant in the laminar and transition regions. The heating condition caused an increase in the lower and upper limits of the isothermal transition boundaries and a decrease in the entrance and fully developed flow apparent friction factors in the laminar and transition regions. Available correlations for the prediction of non-isothermal fully developed friction factors were compared with our experimental data. Owing to lack of the non-isothermal entrance flow correlations in the laminar and transition regions, correlations for prediction of the non-isothermal entrance and fully-developed friction factors in these flow regimes for the square-edged and re-entrant inlets were developed.

1. Introduction

For proper design of thermal systems, for example compact heat exchangers involving horizontal tubes being heated by uniform wall heat flux boundary condition, proper knowledge of the friction factors and heat transfer coefficients in the tube for the entrance and fully developed regions with different inlet geometries under different flow regimes (laminar, transitional, turbulent) is essential. In the past studies, researchers indicated that factors such as the entrance flow, buoyancy, and inlet geometry have influence on the heat transfer coefficient and friction factor. For the accurate prediction of heat transfer coefficient and friction factor, those effects should also be properly introduced into the correlations. However, it is not clear whether all correlations have been developed with consideration of the above-mentioned effects for the entire flow regime. Therefore, a brief summary of the available heat transfer and friction factor correlations is provided first.

The general heat transfer correlations available in the open literature for uniform wall heat flux boundary condition and different flow regimes in the entrance and fully-developed regions developed by various researchers are summarized in Table 1A [1–7]. Table 1B provides the application range of these correlations. As shown in Table 1B, the heat transfer correlation provided by Ghajar and Tam [3] is the most complete correlation and is applicable to both the entrance and fully developed regions, the entire flow regime, and accounts for the effects of forced and mixed convection and different inlet geometries. For the listed correlations for the laminar and turbulent regions, they have been well verified in the literature. For the transition region, Tam and Ghajar [8] made an in-depth comparison of all the available horizontal tube correlations for the forced and mixed convection transition regions and stated that the correlation developed by Gnielinski [6] worked well in the forced convection transition region and the correlation developed by Ghajar and Tam [3] worked well in the forced and mixed convection transition regions. Therefore, it can be concluded that the correlations listed in Table 1A provide accurate heat transfer coefficients in the tube for the entrance and/or fully developed regions with different inlet geometries and flow regimes.

For friction factor, some of the most pertinent works were reviewed by Kakac [9], Shah and London [10], Bhatti and Shah [11]. Table 2A summarizes the typical friction factor correlations [4,11–19] for the isothermal and non-isothermal boundary

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http://dx.doi.org/10.1016/j.expthermflusci.2012.09.008