CFD of Air/Water Two-phase Flow in Small Horizontal Pipe

Jun Yao¹ and Yufeng Yao²

¹ School of Engineering, University of Lincoln, Brayford Pool, Lincoln LN6 7TS, UK
² Faculty of Environment and Technology, University of the West of England, Bristol BS16 1QY, UK

Corresponding author: jyao@lincoln.ac.uk

Abstract: Computational Fluid Dynamics (CFD) has been applied to investigate air/water two-phase flow characteristics in an 8.8mm I.D small horizontal pipe. Simulation has successfully predicted water film thickness using newly developed user defined wave function model. Due to strong gas/liquid interference, liquid film coverage along the top wall of the pipe was thickened resulting in a fully developed annular flow. Compared to the wavy annular flow regime, droplets are found to experience earlier broken at the liquid wavy front when travels from the low wall to the top wall of the pipe. The finding is expected to use in an ongoing industry applications associated with a novel air/water pump design.

Keywords: CFD, air/water two-phase flow, wavy and full annular flow regimes.

1 Introduction

Considerable efforts have been made in recent years to understand the complex air/water two-phase flow regime e.g. its transient process and evolvement from bubbly flow, slug flow, and wavy annular flow up to full annular flow. The annular flow in particular has very important industry applications and subsequently there are theoretical models having been developed to consider conditions, such as inflow velocity, mass flow rate, fluid properties and tube or system dimensions, etc. [1]. Unlike vertical pipe flow, the film distribution in a horizontal pipe is non-uniformly distributed [2] due to gravity effect, introducing additional challenges in accurately predicting the flow. Recent advancement in computer power and numerical method make it possible to carry out detailed investigation by using modern computational fluid dynamics. By combining with system performance estimation, it can largely improve prediction accuracy and shorten turn-around time in design and optimization process from Laboratory up to industry scales.

2 Problem Setup and CFD Results

The problem considers air/water two-phase flow in an 8.8mm I.D. horizontal small pipe. CFD method is used to model flow pattern, transient behaviour, wavy annular flow structure and their transient to a full annular flow, etc. The CFD predicted film thickness will be compared with the available experimental data. Figure 1 illustrates time history of wavy flow pattern developments. It can be seen that due to buoyancy effect there are strong interfacial shear occurred at air/water interfaces. This will affect flow instability and eventually lead to the formation of annular flow along the pipe walls. The simulation also predicts the entrainment, the plug/slug flow transient to wavy annular flow patterns (as seen in Figures 1a, 1b, 1c), in good qualitatively agreement with published results [4]. The predicted water film thickness is also compared with experimental data of Shedd et al. [5, 6] quantitatively (not shown here) with reasonable good agreement being achieved.
Figure 1. VOF contours of water fraction distributions representing flow transient from initially plug flow to finally full annular flow patterns. (a) plug flow; (b) slug flow; (c-f) wavy annular flow; (g) annular flow.

3 Conclusions and Future Work

CFD simulations are performed to investigate the transient process from an initially plug flow to slug flow, wavy annular flow and finally full annular flow in a small horizontal pipe. The CFD predicted film thickness and its distribution are in good agreement with the available experimental data. The turbulence kinetic energy and eddy dissipation rate is found very high in full annular flow particularly near the top wall, compared to those in wavy annular flow. This may be attributed to higher liquid film coverage resulting from the wave-driven droplets travel and attachment. Consequently, this leads to the rapid increase of the film thickness. Furthermore, the water fraction in the central area of the pipe is found lower in a full annular flow case, compared to that of a wavy annular flow case. The discrepancies of the liquid film thickness predicted at the bottom wall and the upper wall can be useful for follow-up investigations e.g. refining the existing user defined function (UDF), exploring the descretised particle model (DPM), studying large pipe to understand model scalability.

References