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Computational Study of Two Phase Flow and Heat Transfer in Helical Pipes

V. Uma Maheshwar
Department of Mechanical Engineering
University College of Engineering (A),
Osmania University
Hyderabad (T.S.) [INDIA]
Email: mahesh.v@uceou.edu

R.V.S.S.R. Pavana Kumar
Department of Mechanical Engineering
University College of Engineering (A),
Osmania University
Hyderabad (T.S.) [INDIA]
Email: Pavanakumar.Rachapudi@voith.com

ABSTRACT

The paper presents Computational study of Two-phase flow and heat transfer in helical coils using computational fluid dynamics using two methods- Population balance modeling (PBM) and Non Population balance modeling (NPBM). Comparison of the flow parameters for the two phase flow between PBM and non PBM models is the focus of the study taken up. Heat transfer to flow of air– water mixture through a helical pipe, at constant pipe wall temperature, was considered in the study presented in the Paper. The bubble size distribution and coalescence and breakage of bubble groups taken care in the population balance model (PBM) and bubble distribution is ignored in the non PBM model. Important flow quantities, for air-water system, such as local void fraction, liquid velocity, and pressure drop and temperature distribution were compared through PBM and non PBM modeling systems. The obtained results for pressure drop are compared against some available correlations, and show the weakness of such correlations in the case of flow accompanied with heat transfer. The role of the centrifugal forces was identified and effect of this force on the remaining parameters velocity, pressure, and temperature is presented in helical pipes. It is concluded that CFD-PBM model has more ability to capture the main flow features compared to CFD model without PBM.

Keywords:—*Helical Pipes, Air–water Two Phase Flow; Population Balance Modeling*

I. INTRODUCTION

It has been widely reported in literature that heat transfer rates in helical coils are higher as compared to a straight tube. Due to the compact structure and high heat transfer coefficient, helical coil heat exchangers are widely used in industrial applications such as power generation, nuclear industry, process plants, heat recovery systems, refrigeration, food industry, etc.

Generally the fluid flowing through the helical coils is in the form of two phase flow. For engineering practice to understand real phenomena of the flow characteristics and frictional pressure drop, two phase flow is considered. In poly dispersed air-water mixture, the bubble size distribution plays an important role in the phase structure and internal centrifugal forces, which in turn determine the multi-phase hydrodynamic behaviors, including the spatial profiles of the volume fraction, air and water velocities, and mixing and heat and mass-transfer behaviors.

The influence of phase change is taken care to get the better results when using computational fluid dynamics(CFD). The population balance model (PBM) is an effective technique to simulate the bubble size distribution.

However, a few works were reported on the CFD modeling of the flow and heat transfer in helical pipes. Numerical simulations of in -compressible turbulent flow in helical and curved pipes are presented by Friedrich et al. [4, 5]. They considered only a small portion of pipe, 7.5 diameters long, their works would be inadequate to resolve traveling waves, since was modeled with periodic boundary conditions and in fact traveling waves are not mentioned in these works. Jayakumar et al. [6] have studied the characteristics of single phase flow in helical. CFD analysis for heat transfer to air –water two-phase mixture flowing through a helically coiled heat exchanger was reported by

Jayakumar et al. [7]. In the later work hydrodynamics of air–water two-phase flow through helical pipes are validated against the experimental results on isothermal flow conducted by previous researchers.

The main objective in this study is to compare the two-phase flow characteristics in helical pipes using a computational fluid dynamics population balance modeling with polydispersed phase to the non population balance model with dispersed phase.

1.1. Mathematical method to solve the multi phase flow

a) Mono dispersed (Two-fluid) model

b) Population balance with MUSIG model

a) Mono dispersed (Two-fluid) model

Continuity equation

$$\frac{\partial}{\partial t}(\rho_l \varepsilon_l) + \nabla.(\rho_l \varepsilon_l \mathbf{u}_l) = 0 \qquad \textit{for liquid phase}$$

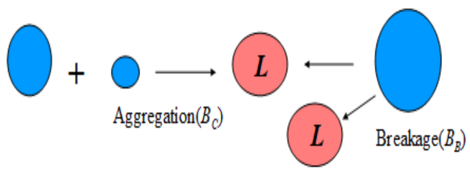
$$\frac{\partial}{\partial t}(\rho_g \varepsilon_g) + \nabla.(\rho_g \varepsilon_g \mathbf{u}_g) = 0 \qquad \textit{for gas phase}$$

b) Population balance with MUSIG (Multiple Size Group) model

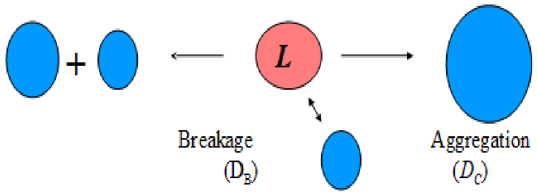
MUSIG – Multiple size group to handle polydispersed multiphase flows in which dispersed phase has a large variation in size. And provides a frame-work in which population balance method together with the break-up and aggregation models can be incorporated into 3D CFD applications.

1.2 Population Balance Modeling: Aggregation and Breakage

A bubble of size L can appear when two small sized bubbles aggregate or when a larger bubble breaks up.



Similarly, this bubble can vanish if it breaks up to form smaller bubbles or combines with other bubble to form a larger one.



1.3 Population balance method with CFD via MUSIG model

Dispersed phase is divided into several size groups and each size group is treated as separate phase in a multiphase flows MUSIG assumes that all the particle velocities are the same so that it is only necessary to solve one set of momentum equations for all the particles. It is possible to consider a large no of particles size groups (say 10 to 20 particle phase) to give a better representation of the size distribution.

Table 1: Grouping the bubble sizes

Class no	1	2	3	4	5
Diameter (mm)	0.06	0.08	0.10	0.12	0.14

II. Model Setup

Heat transfer to flow of air–water mixture through a helical pipe, at constant pipe wall temperature, is analyzed with CFD in combination with population balance model and non PBM model. The numerical simulations presented here are based on the two-fluid, Eulerian–Eulerian model, regarding the liquid phase as the continuous and the gas phase (bubbles) as the dispersed phase. Continuity equation of the liquid phase and gas phase with a source term that takes into account the death and birth of bubbles caused by coalescence and break-up processes, the momentum conservation, and the energy equation were solved. The break-up of bubbles in turbulent dispersions employs the model developed by Luo and sevendsen [8] and the coalescence rate considering turbulent collision by Prince and Blanch [9]. The drag coefficient has been modeled using drag model of Ishii-Zuber [10]. The realizable K-ε turbulence model was used for turbulence modeling in continuous phase and induced turbulence of bubbles is taken into account by using the Sato Enhanced Eddy Viscosity model [11].

III. Experimental Setup

Numerical experiments were done for a helical pipe shown schematically in Figure 1. The pipe has an inner

Diameter d, the coil diameter is dc, and the distance between two adjacent turns, called pitch is H. The results presented here are for a helically coiled pipe with 20 mm of inner pipe diameter, 300 mm coil diameter and 60 mm pitch.

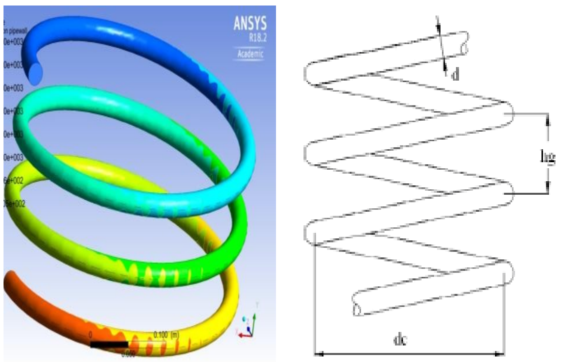


Figure 1: Pipe model in CFD

IV. Numerical Simulation

The simulations were carried out as 3-D two-phase air-water flow in a helical pipe based on the Eulerian–Eulerian description combined with Population Balance Modeling. Water was considered as the continuous phase, and air was considered as the dispersed phase. Conservation equations are discretised using finite volume technique, hybrid scheme was used for all equations. The PBM model has been used to account for the non-uniform bubble size distribution in air-water mixture. At the pipe inlet, uniform gas and liquid velocities, temperature, turbulence intensity and average volume fractions have been specified; a relative average static pressure of zero was specified at the pipe outlet. No slip boundary conditions were used at wall.

Average volume fraction and uniform liquid velocity profile are specified for initiating the numerical solution. Convergence criterion used was 1.0E−5 for all of the equations. In this analysis, a superficial velocity of 2.0 ms−1 for each of the phases and 20% volume fraction of air at the inlet are specified. For the heat transfer cases, hot fluid (air–water mixture) at 360K enters at the top of the coil. The pipe wall temperature is maintained constant at 300K.

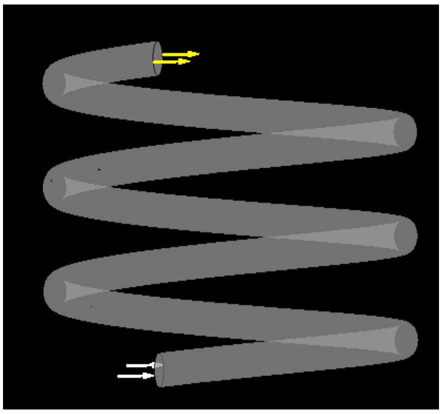


Figure 2: Pipe Inlet and out let

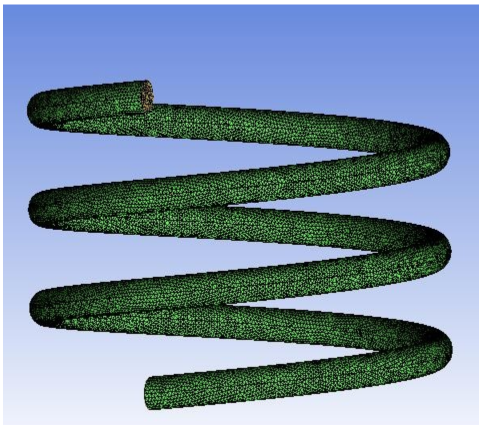


Figure 3: Pipe mesh

Domain	Nodes	Elements
Default Domain	199277	596758

4.1 Boundary Conditions

1. At the pipe inlet, uniform gas and liquid velocities, temperature, turbulence intensity and average volume fractions have been specified.
2. Superficial velocity of 2.0 ms−1 for each of the phases and 20% volume fraction of air at the inlet are specified.
3. Wall temperature is maintained constant at 300K
4. Bubbles are equally divided into 5 classes. Minimum and maximum of the bubbles diameter are 0.06 and 0.14 mm respectively for PBM model with poly dispersed fluid.
5. For non PBM model with dispersed fluid with average bubble diameter is 0.1 mm
6. Inlet Boundary condition hot fluid (air –water mixture) at 360K.
7. A relative average static pressure of zero was specified at the pipe outlet.

V. Results and Discussion

The main objective in this work is to examine of the extent to which the proposed CFD-PBM modeling is able to capture the main features of the flow with heat transfer in helical pipes. Most of these features can be obtained qualitatively and quantitatively form contour plots of phase volume fractions, velocities, pressure, and temperature distributions. The contours were presented for various sections along the length of the coil, where they are represented by the angle (θ) measured from the inlet plane of the coil (θ=0).

5.1. Air Volume Fraction with PBM Vs without PBM

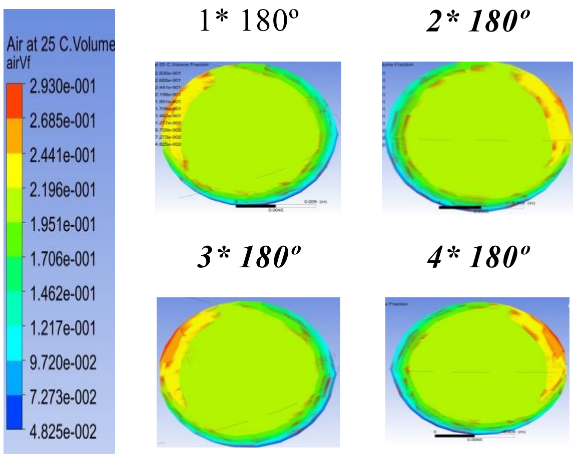


Figure 4 Contour plots of air volume fraction at different positions, CFD – PBM model

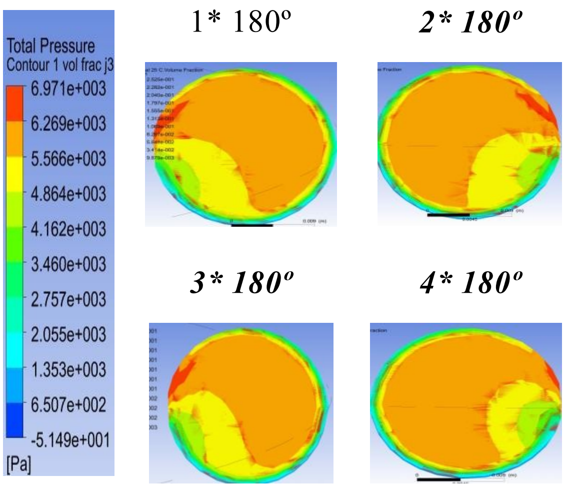


Figure 5 Contour plots of air volume fraction at different positions, CFD – without PBM model

5.2. Pressure with PBM Vs without PBM

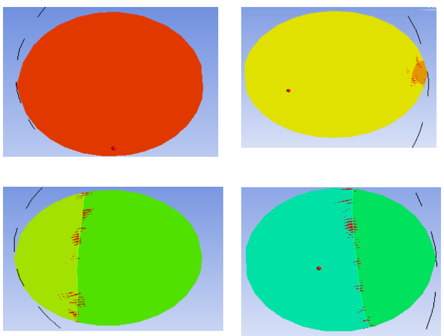


Figure 6. Contour plots of pressure at different positions, CF

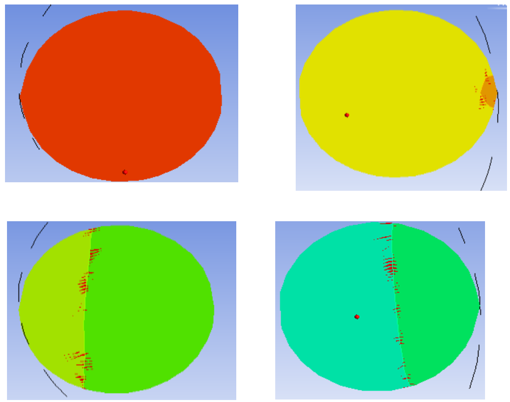


Figure 7 Contour plots of pressure at different positions, CFD – without PBM model

The obtained result for pressure drop per unit length calculated from the simulation results is shown in table 1, in comparison with various correlations for pressure drop. It may be noted that a lot of scatter is present in the pressure drops estimated by the different correlations, as also reported by Jayakumar et al. [7]. It is also found that the correlation by Kasturi et al. [12] give considerably higher value. Two CFD models (with PBM and without PBM) for pressure drop give consistent results for pressure drop. The main reason for large deviation of above mentioned correlations may be the fact that they are presented for isothermal or adiabatic conditions of gas-liquid flow in helical pipes, whereas this study is not cover each of them. Therefore, the use of these correlations under this condition may be under question.

5.3 CFD validation with other experiments

With PBM 4819 -2179 = 2640 Pa = 2.64 K. Pa

Without PBM 4724.5 -2207.66 =2516 Pa = 2.516 K. Pa

Table 2: Comparison of pressure drops (K Pa/m)

This work					
CFD with PBM model	CFD without PBM model	Jaya-kumar et al [7]	Czop et al [13]	Xin et al [14]	Kas-turi et al [12]
2.64	2.516	2.5	2.07	2.97	4.96

5.4. Water Temperature with PBM Vs without PBM

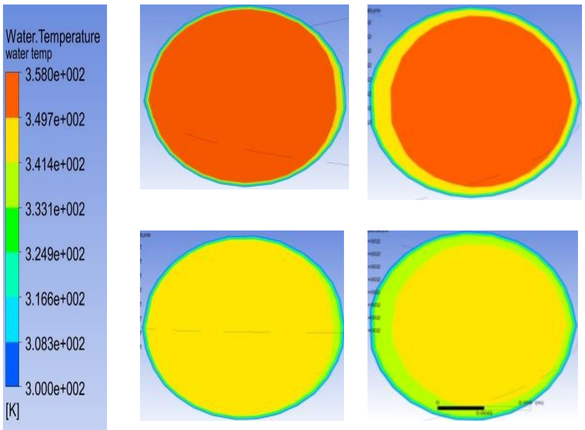


Figure 8 Contour plots of water temperature at different positions, CFD – with PBM model

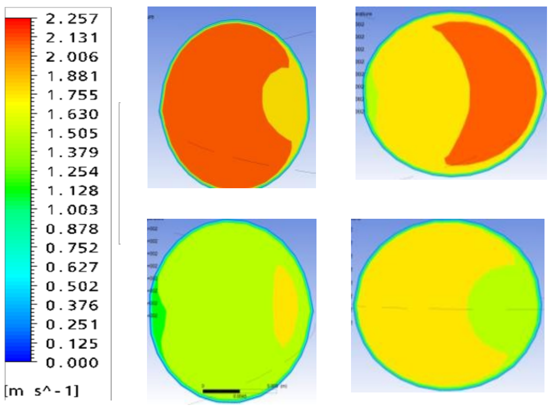


Figure 9 Contour plots of water temperature at different positions, CFD – without PBM model

5.5 Air Velocity with PBM Vs without PBM

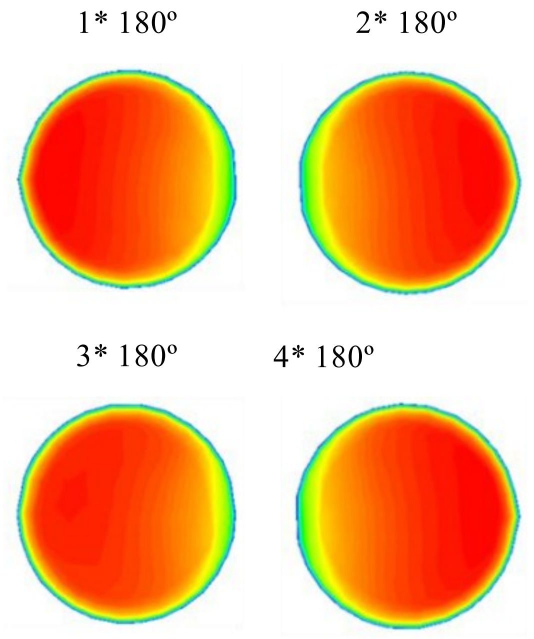


Figure 10 Contour plots of air velocity at different positions, CFD – PBM model

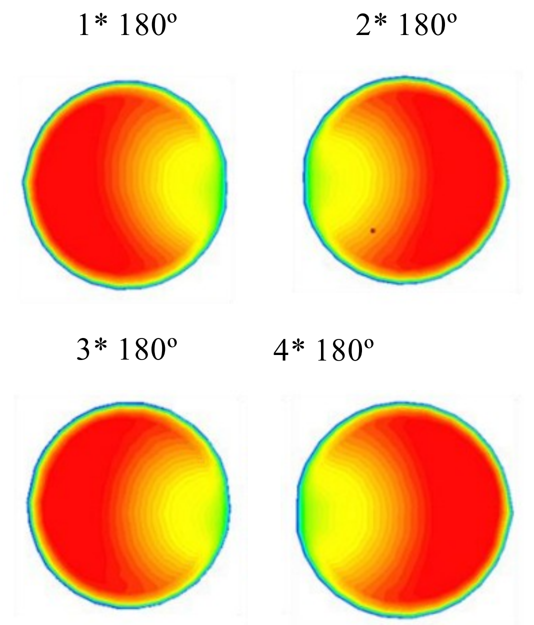


Figure 11 Contour plots of air velocity at different positions, CFD – without PBM model

VI. CONCLUSIONS

Air-water two-phase flow with heat transfer through a helical pipe is simulated using computational fluid dynamic modeling combined with a population balance model. The bubble size distribution and coalescence and breakage of bubble groups handled through the population balance model (PBM).

It was found that centrifugal forces cause creation of a high velocity region at the outer side of the helical pipe walls. Centrifugal forces leads to the higher volume fraction region of water at the outer side of the helical pipe wall. In other words, increasing the pressure on the outer side of the wall causes buoyancy forces, and therefore the air bubbles tend to migrate away from the wall.

CFD-PBM model is compared against CFD model without PBM and finally the CFD-PBM model has more abilities to capture the flow features

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