Powder Technology 318 (2017) 46–61

Contents lists available at ScienceDirect

Powder Technology

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

Convective heat transfer in slurry flow in a horizontal Y-shaped branch pipe

Bibhuti Bhusan Nayak [a], Dipankar Chatterjee [b,*]

[a] Department of Mechanical Engineering, National Institute of Technology, Durgapur 713209, India
[b] Advanced Design and Analysis Group, CSIR-Central Mechanical Engineering Research Institute, Durgapur 713209, India

ARTICLE INFO

Article history:
Received 20 December 2016
Received in revised form 1 March 2017
Accepted 17 May 2017
Available online 23 May 2017

Keywords:
Fly ash-water slurry
Y-shaped branch pipe
Heat transfer
Numerical simulation
Eulerian model

ABSTRACT

This work is involved with the three-dimensional numerical prediction of the thermo-fluidic transport characteristics of fly ash-water slurry in a Y-shaped branch pipe. Spherical coal fly ash particles are considered as the dispersed phase. The fly ash particles are having mass median diameters of 13 and 34 μm, mean flow velocity ranging from 1 to 5 m/s and concentration ranges from 10 to 50% by volume. The granular Eulerian multiphase model following a finite volume approach is used to perform the numerical simulation. The turbulent transport is addressed by the RNG $k-\varepsilon$ turbulence model. The novelty of the work is the analysis of the convective heat transfer for the fly ash-water slurry flowing through the branch pipeline. The results reveal that increasing the size of the fly ash particles, the convective heat transfer coefficient increases for all the velocities in the range. For smaller particle size, the inlet pipe has more pressure drop than the outlet pipes at smaller velocity and vice versa at higher velocity. For larger particle, the outlet pipes have more pressure drop than the inlet pipe for all the velocities. Moreover, the pressure drop and heat transfer increase because of the formation of two pairs of counter-rotating stream wise vortices at the downstream of the bifurcation.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

The branching junctions appear frequently in pipeline networks as well as in the biological systems such as the blood circulation and air respiration networks. Some commonly used branches for regular branching are the T-junction, Y-junction, cross and star junctions etc. The Y-junction is a very common component in a pipeline network. This is mainly used for distributing (diverging) the flow from the main pipe to several branching pipes and for accumulating (converging) flows from several other pipes to the single leading pipe. The behavior of the flow at the junction changes depending on the inflow and outflow directions. As such, the three-dimensional flow through a junction subjected to thermal non-homogeneity is a very complex thermo-fluidic phenomenon because of the occurrence of the recirculation in the outlet pipes. Usually, the recirculation region (flow reversal region) develops in the branched portions just after the bifurcation due to which the flow is distorted. Because of the low flow velocity in this recirculation region, it has a very weak convective effect on the temperature field and acts as a thermally insulating region. When multiple phases present in the split at the junction, the transport process becomes further complicated. The ratio of the phases in the outlet pipes may vary significantly from that prevailing at the inlet. The process is controlled by the momentum fluxes of various phases present in the system. This kind of flow is significantly influenced by the phenomena of flow separation and reattachments as well as the reverse and the secondary flows. The size of the separation region is observed to increase with the inflow velocity.

An effort is made here to capture the thermo-fluidic transport characteristics of the two-phase flow of fly ash-water slurry in a Y-shaped branch pipe using computational technique. The fly ash is a fine powder formed from the non-combustible matter in the coal [18], typically produced in the thermal power plants. The overall hydrodynamical characteristics for the multiphase slurry flow under the present consideration are considerably affected by the inlet flow velocity, fly ash particle concentration and size. The thermal transport is in turn dictated by the flow behavior. The appropriate prediction of the thermo-hydrodynamic behavior needs careful experimentation by varying all the controlling parameters, which is very difficult to achieve if not impossible. The Computational Fluid Dynamics (CFD) technique can be successfully used as a strong tool to aid and complement the costly experimental activity.

Duan et al. [7] conducted experiments in Y-shaped branch pipe to understand the flow distribution property of gas-solid two phases. Pneumatic conveying of millet and micro-glass bead of diameter 2 mm in the pipe was considered for different branch angles of 5°, 10°, 15°, 20°, 25°, 30°. The solid mass ratio was observed to decrease with an increase in the branch angle. The mass ratio was further observed to increase with decreasing superficial gas velocity when the latter comes lower than the deposition velocity. Liu et al. [17] performed experiment in Y-shaped branch pipe with changing branch angle to

---

* Corresponding author.
E-mail address: d_chatterjee@cmeri.res.in (D. Chatterjee).

http://dx.doi.org/10.1016/j.powtec.2017.05.036
0032-5910/© 2017 Elsevier B.V. All rights reserved.

predict its resistance properties for a two-phase flow of gas and solids. Two different solid materials such as the micro-glass bead and millet with identical particle diameter for varying solid density were considered in the experiment. The pressure drop trends were obtained on each branch to show its resistance properties. It was concluded that the pressure drop trends of the two different solid materials were similar and were strongly influenced by the branch angle as well as the gas velocity. The pressure drop on the branch with bigger angle was found to be less. The solid with the less branch angle and larger solids loading ratio began to deposit more easily. Abdulwahhab et al. [1] numerically investigated a three-dimensional turbulent flow in a 90° T-junction with sharp corners using ANSYS CFX 13 [2] for a Reynolds number of 36,000. It was found that the pressure loss coefficient and friction loss coefficient depend on the flow rate ratio and not on the Reynolds number. Singh et al. [21] computationally studied the effect of bend angle for a Y-shaped branch pipe for the flow of water and air at different Reynolds numbers. They found that the resistance coefficient increases from bend angle 45° to 90° and decreases at an angle of 180° due to the sudden impact of the water jet on the pipe wall. Aslam et al. [4] simulated the flow of water in a Y-shaped pipe of 1-inch diameter having equal lengths using ANSYS CFX. The effect of bend angle at 45°, 60°, 90° and 180° on resistance coefficient was studied. It was observed that the resistance coefficient vary with the change in the flow parameters.

The critical survey presented above suggests that there are not much studies on the multiphase transport in a Y-shaped branch pipe. More specifically, there is no reported study on the convective heat transfer for a liquid-solid slurry flowing through the branch pipeline. Accordingly, the present work aims at studying the influence of the dispersed particles on the pressure drop and heat transfer of liquid-solid slurry flow in a horizontal Y-shaped branch pipe. This is proposed to be achieved using the spherical coal fly ash particles of diameters 13 μm and 34 μm suspended in water at high concentrations of particles ranging from 10 to 50% and flowing with the velocity in the range of 1–5 m/s in the bifurcated pipe. For the disposal of the fly ash produced by the combustion of the coal in thermal power plants it is essential to estimate its heat transfer and pressure drop characteristics. The CFD software Ansys Fluent [3] is used for analyzing the slurry flow in the pipeline. The Eulerian multiphase model coupled with the kinetic theory of granular flow is applied for the flow simulation. For better prediction of the heat transfer, the fly-ash particles should be considered as granular phase since under such condition the friction and collision among the particles and the solid boundary are taken into account. In general, tracking the trajectories of each individual particle (via Lagrangian particle tracking) is the most physically accurate approach and requires minimal modeling. However, this approach becomes expensive at high volume fractions. On the other hand, the Eulerian approach provides the best compromise between the cost and the accuracy; hence, one can therefore choose the granular-Eulerian model, in most cases.

2. Mathematical formulations

2.1. Physical problem

Fig. 1 shows the physical problem under consideration schematically. A horizontal Y-shaped branch pipe with each branch and the upstream main pipe of length $L = 5$ m and an inner diameter of $D = 0.053$ m is considered as the slurry transportation device. Water is considered as the carrier fluid, which contains the fly ash particles and enters the pipe with the mean inlet velocity range of 1 m/s ≤ V ≤ 5 m/s and solid concentration range of 10% ≤ C_{vf} ≤ 50% at a temperature $T_{in} = 300K$. The pipe wall is kept at a constant temperature $T_w = 400K$. Simulations are carried out for the flow of the fly ash particles having sizes of 13 and 34 μm in water. The physical and thermal properties of the carrier and the dispersed phases are taken at a temperature $T_f = (T_{in} + T_w)/2$ and are given in Table 1.

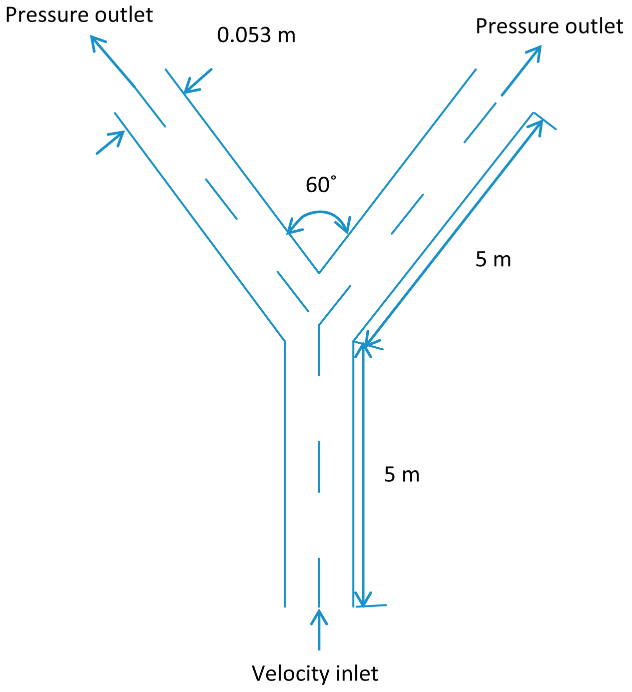

Fig. 1. Schematic diagram of the physical problem.

2.2. Governing equations

The conservation equations of mass, momentum and energy for each phase in the Eulerian multiphase approach forms the governing system of partial differential equations. Considering an incompressible flow with no phase change and the sum of the volume fractions of the phases as unity, the system of equations for the solid and the liquid phases is presented as:

2.2.1. Continuity equation

$$\frac{\partial}{\partial t}(\alpha_s \rho_s) + \nabla \cdot \left(\alpha_s \rho_s \vec{v}_s\right) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}\left(\alpha_f \rho_f\right) + \nabla \cdot \left(\alpha_f \rho_f \vec{v}_f\right) = 0 \tag{2}$$

2.2.2. Momentum equations

$$\begin{aligned}\frac{\partial}{\partial t}\left(\alpha_s \rho_s \vec{v}_s\right) + \nabla \cdot \left(\alpha_s \rho_s \vec{v}_s \vec{v}_s\right) = -\alpha_s \nabla P - \nabla P_s + \nabla \cdot \overline{\overline{\tau}}_s + \alpha_s \rho_s \vec{g} \\ + \alpha_s \rho_s \left(\vec{F}_{lift,s} + \vec{F}_{vm,s}\right) + K_{fs}\left(\vec{v}_f - \vec{v}_s\right)\end{aligned} \tag{3}$$

$$\begin{aligned}\frac{\partial}{\partial t}\left(\alpha_f \rho_f \vec{v}_f\right) + \nabla \cdot \left(\alpha_f \rho_f \vec{v}_f \vec{v}_f\right) = -\alpha_f \nabla P + \nabla \cdot \overline{\overline{\tau}}_f + \alpha_f \rho_f \vec{g} \\ + \alpha_f \rho_f \left(\vec{F}_{lift,f} + \vec{F}_{vm,f}\right) + K_{sf}\left(\vec{v}_s - \vec{v}_f\right)\end{aligned} \tag{4}$$

Table 1
Thermo-physical properties of the fly ash particles and water.

Properties	Fly ash	Water
Diameter (μm)	13, 34	–
Density(Kg/m^3)	2270	971.82
Viscosity(Ns/m^2)	–	0.3544×10^{-3}
Specific heat($J/Kg^{\circ}C$)	745	4196
Thermal conductivity($W/m^{\circ}C$)	1.38	0.67

Download English Version:

https://daneshyari.com/en/article/4914905

Download Persian Version:

https://daneshyari.com/article/4914905

Daneshyari.com