Powder Technology 286 (2015) 202–211

Contents lists available at ScienceDirect

Powder Technology

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

Prediction of Black Powder distribution in junctions using the Discrete Phase Model

Nabil Kharoua *, Mohamed AlShehhi, Lyes Khezzar

Mechanical Engineering Department, The Petroleum Institute, Abu Dhabi, United Arab Emirates

ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form 22 June 2015
Accepted 30 July 2015
Available online 8 August 2015

Keywords:
Black Powder
Turbulence
Discrete Phase Model
Junction

ABSTRACT

The present study consists in simulating turbulent gas–particle flows through pipe junctions under different geometrical and flow conditions. The purpose is to study the effects of the particles' size and orientation of the pipes with different degrees of asymmetry at junctions on phase split. Solid particles can be present in gas transmission networks as contaminants in the form of Black Powder to be eliminated. The simulation based on the standard k-ε turbulence model and the Discrete Phase Model (DPM) showed that the solid phase split can be considered to follow the air flow split closely for Stokes numbers small enough than unity (St = 0.2). While for intermediate Stokes numbers (St = 1) and slightly higher than unity (St = 5), the particles gain some independence from the gaseous phase and for the later, the pipe orientation plays a significant role. Effects of the shape of the particles and their initial positions at the inlet are also considered.

1. Introduction

Particles, such as food, cement, coal and pharmaceutical products in industrial applications, are usually transported by gas streams within networks of pipes belonging to the pneumatic conveying technology [1]. To convey particles to different locations, phase split, using junctions, is used. It is, usually, desirable to avoid mal-distribution and symmetrical junctions are, generally, recommended [2,3]. However, the particles are not always a product to transport, but rather a contaminant to be eliminated. A typical case is that of gas piping networks. Indeed, gas piping networks are designed for the transport of clean gas and junctions of different types can be used for the split between branches to transport gas to different destinations from the same source. Under the effects of corrosion, particles of iron oxides and iron sulfides, called Black Powder, form and propagate randomly inside the gas piping network [4,5]. The ideal, but very difficult, safety procedure consists in eliminating the sources of Black Powder completely. In fact, experience shows that attempts to eliminate Black Powder are still not satisfactory due to the complexity of the task and the ever present industrial constraints [6]. Consequently, Black Powder must be controlled and monitored to minimize its effects on gas producers and consumers. It is necessary, then, to understand the behavior of Black Powder particles under different working conditions to develop reliable filtering strategies.

A wealth of information on solid gas transport in pipes can be extracted from previous studies on pneumatic conveying. However, studies on gas–solid flows in pipe junctions are scarce and are devoted to numerical simulation of nasal cavity and pulmonary airways [7] and experiments on pneumatic conveying [8,9] with case-dependent semi-empirical models for pressure drop and phase split. Morimoto et al. [10] studied the pressure drop and particle behavior in T-junctions experimentally and theoretically using spherical pellets of polyethylene with an average diameter equal to 1.43 mm and a density equal to 1020 kg/m^3. They obtained a linear relation between the pressure drop (difference of static pressures between the main pipe and its branches) and particle loading in the main pipe made of acrylate with an internal diameter equal to 50 mm. They, also, investigated cases with two successive T-junctions, with different orientations, to deal with a more complex case which can be encountered in real installations. Morikawa et al. [8] did similar work for Y-junctions using polyethylene pellets with mean diameter equal to 1.1 mm (St = 1854). They found that the pressure drop coefficient, from the main pipe to the branch, depends on the angle of the junction and the discharge ratio to be proportional to particle loading in the branch. They noticed that the phase split was an approximate function of the angles of the Y-junction and independent of the initial particle loading and discharge ratio of air. Their correlation was a simple function of the angles of the Y-junction to express the ratio of projected areas. Guangbin et al. [9] studied the pressure drop and phase split in Y-junctions for pneumatic conveying applications. They used 2 mm (St = 14,611) diameter millet and glass beads particles to investigate the effects of the geometry, air flow rate, and particles loading on the pressure drop and phase split. They developed semi-empirical formula for the prediction of

* Corresponding author.
E-mail addresses: nkharoua@pi.ac.ae (N. Kharoua), malshehhi@pi.ac.ae (M. AlShehhi), lkhezzar@pi.ac.ae (L. Khezzar).

http://dx.doi.org/10.1016/j.powtec.2015.07.045
0032-5910/

pressure drop and phase split which are suitable for homogeneous suspensions of large particles only.

Simulations involving junctions are rare in the literature [2,3,11,12] due to the complexity of the configuration and the important computational effort required in addition to the limited use of unsymmetrical junctions in industry due to mal-distribution constrains. Several multiphase models, implemented in CFD solvers, are available in the literature for such applications. Each multiphase model is devoted to certain gas–solid flow regimes only [13]. The advantages of the Lagrangian approach are the flexibility in terms of the particle diameter and size distribution [13]. In contrast to previous experimental and theoretical studies, Li and Shen [11] found, by numerical simulation, that for small particles of diameters equal to 1, 5, 10 μm and a density equal to 920 kg/m^3, the air discharge ratio affects the solid phase split as well. Schneider et al. [2] performed Eulerian–Lagrangian simulations through a complex geometry of a curved bend and a Y-junction equipped with a rope splitter and riffle box as a splitting device in coal-fired power plants. The simulations showed, roughly, the effectiveness of the splitting device in eliminating the eventual effects of the ropes emerging from the bends on the flow split. Giddings et al. [14] stated that the rope effect on the phase split was important especially close to the walls and controlling its position is crucial. For lignite-fired power plants, Kuan et al. [15] performed experiments using LDA and Lagrangian particle tracking using the commercial CFD software ANSYS CFX-10.0. Their main contribution was the assessment of the effects of an additional flap fitted to the tip of the splitting device which was a good remedy to the problem of mal-distribution.

In this study, Y and T junctions, with different orientations were investigated to quantify solid phase (in the form of Black Powder particles) split at pipe intersections. In particular, the present work investigates the effects of the size (Stokes number), initial position, and shape of particles in addition to the geometrical configuration of the pipe junction. The amount of Black Powder generated in gas pipelines yields generally a dilute solid laden gas flow regime; as a consequence, the Discrete Phase Model combined with the k-ε turbulence model are used to simulate the flow. The simulation results were validated with the experiments of [9,16] before being extended to other relevant configurations. The results will be useful in addressing the problem of Black Powder movement, routing and behavior inside gas transmission and distribution networks through one-dimensional approaches.

The next section presents the configurations of the pipe junctions considered in addition to the numerical simulation methodology adopted. The results are discussed in the subsequent section followed by the main conclusions.

2. Numerical approach

This section describes the methodology of the present numerical simulation work. Different configurations of pipe junctions were considered in conjunction with their corresponding computational grid. The gas–solid flow is governed by a combination of Navier–Stokes equations, for the gaseous phase, and the force balance equations for the solid phase presented in Section 2.2. Then, the boundary conditions, necessary for solving the abovementioned equations, are detailed followed by a brief description of the numerical tools and the simulation steps. A series of simulations were conducted using the commercial software FLUENT 14.0 [17].

2.1. Geometrical configuration and computational mesh

The gas–solid flow in y junctions, shown in Fig. 1a, was validated with the work of [9]. It should be noted that a block of tetrahedral cells was generated nearby the junction due to the complexity of the geometry (Fig. 1c). Elsewhere, the mesh was made up of structured hexahedral cells. Another study was considered for the validation of the phase split in T-junctions with finer poly-dispersed sand particles

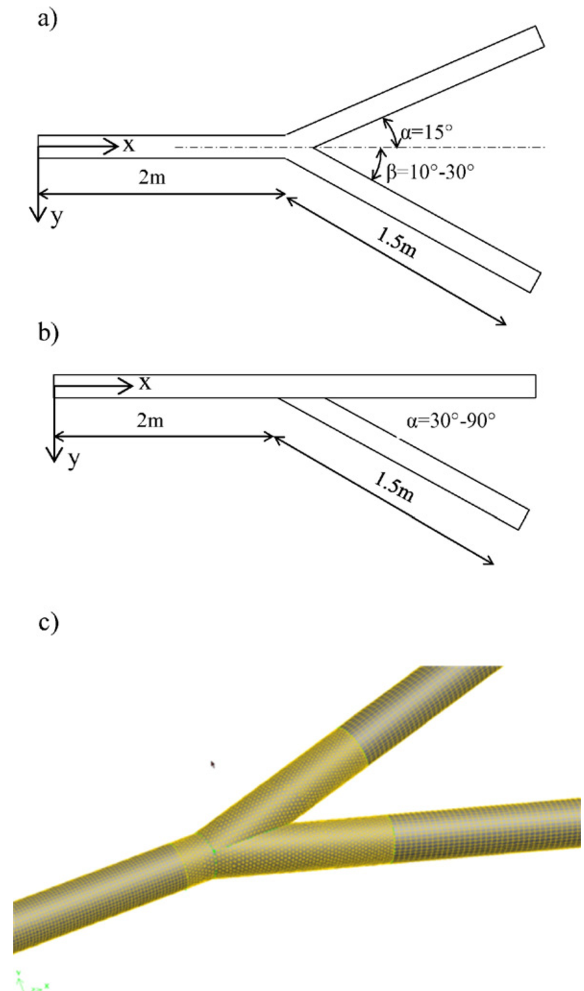

Fig. 1. Geometrical configurations studied and computational grid.

[16]. A grid independency test was performed with three different meshes for all the cases considered.

After validation, the geometry, described in Fig. 1b, was used to replicate the gas–solid flow in realistic pipe network with fine Black Powder particles. Three grids, meant to represent coarse, medium and fine resolutions were generated for each junction with different angles. These were used to ensure grid independency for the simulations with Black Powder. The numbers of cells, for the different cases considered, are presented in Table 1. Fig. 2 shows clearly that differences, less than 5%, are generated for the simulation of Black Powder split within the 30° junction. The medium grid (Table 1) was retained for the remaining series of simulations involving Black Powder particles.

Table 1
Details of the computational grid for the cases considered.

		Coarse grid		Medium grid		Fine grid	
		Number of cells	Size ratio[a]	Number of cells	Size ratio[a]	Number of cells	Size ratio[a]
[9]		76,400	2.5	232,000	1.7	388,000	1.5
[16]		118,000	41	240,000	33	360,000	28
Black Powder	30°	151,353	170	282,440	–	500,000	111
	60°	141,000	–	262,022	–	459,000	–
	90°	132,000	–	245,063	–	430,000	–

[a] Cell size to particle diameter ratio.