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A Numerical and Experimental Study of the Gas–Particle Flow in Pipework and Flow Splitting Devices of Coal–Fired Power Plant

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Abstract

In power plants using large utility coal–fired boilers for generation of electricity the coal is pulverized in coal mills and then it has to be pneumatically transported and distributed to a larger number of burners (e.g. 30–40) circumferentially arranged in several rows around the burning chamber of the boiler. Besides the large pipework flow splitting devices are necessary for distribution of an equal amount of pulverized fuel (PF) to each of the burners. So called trifurcators (without inner fittings or guiding vanes) and "riffle" type bifurcators are commonly used to split the gas–coal particle flow into two or three pipes/channels with an equal amount of PF mass flow rate in each outflow cross section of the flow splitting device.

These PF flow splitting devices are subject of a number of problems. First of all an uneven distribution of PF over the burners of a large utility boiler leads to operational and maintanance problems, increased level of unburned carbon and higher rates of NO_x emissions. Maldistribution of fuel between burners caused by non uniform concentration of the PF (particle roping) in pipe and channel bends prior to flow splitting devices leeds to uncontrolled differences in the fuel to air ratio between burners. This results in localized regions in the furnace which are fuel rich, where insufficient air is present to allow complete combustion of the fuel. Other regions in the furnace become fuel lean, forming high local concentrations of NO_x due to the high local concentrations of O_2. Otherwise PF maldistribution can impact on power plant maintanance in terms of uneven wear on PF pipework, flow splitters as well as the effects on boiler panels (PF deposition, corrosion, slagging).

In order to adress these problems in establishing uniform PF distribution over the outlet cross sections of flow splitting devices in the pipework of coal–fired power plants the present paper deals with numerical prediction and analysis of the complex gas and coal particle (PF) flow through trifurcators and "riffle" type bifurcators. The numerical investigation is based on a 3–dimensional Eulerian–Lagrangian approach (MISTRAL/PartFlow–3D) developed by Frank et al. The numerical method is capable to predict isothermal, incompressible, steady gas–particle flows in 3–dimensional, geometrically complex flow geometries using boundary fitted, block–structured, numerical grids. Due to the very high numerical effort of the investigated gas–particle flows the numerical approach has been developed with special emphasis on efficient parallel computing on clusters of workstations or other high performance computing architectures.

Besides the aerodynamical interaction between the carrier fluid phase and the PF particles the gas–particle flow is mainly influenced by particle–wall interactions with the outer wall boundaries and the inner fittings and guiding vanes of the investigated flow splitting devices. In order to allow accurate quantitative prediction of the motion of the disperse phase the numerical model requires detailed information about the particle–wall collision process. In commonly used physical models of the particle–wall interaction this is the knowledge or experimental prediction of the restitution coefficients (dynamic friction coefficient, coefficient of restitution) for the used combination of particle and wall material, e.g. PF particles on steel.

In the present investigation these parameters of the particle–wall interaction model have been obtained from special experiments in two test facilities. Basic experiments to clarify the details of the particle–wall interaction process were made in a test facility with a spherical disk accelerator. This test facility furthermore provides the opportunity to investigate the bouncing process under normal pressure as well as under vacuum conditions, thus excluding aerodynamical influences on the motion of small particles in the near vicinity of solid wall surfaces (especially under small angles of attack). In this experiments spherical glass beads were used as particle material. In a second test facility we have investigated the real impact of non–spherical pulverized fuel particles on a steel/ceramic target. In this experiments PF particles were accelerated by an injector using inert gas like e.g. CO_2 or N_2 as the carrier phase in order to avoid dust explosion hazards. The obtained data for the particle–wall collision models were compared to those obtained for glass spheres, where bouncing models are proofed to be valid. Furthermore the second test facility was used to obtain particle erosion rates for PF particles on steel targets as a function of impact

angles and velocities.

The results of experimental investigations has been incorporated into the numerical model. Hereafter the numerical approach MISTRAL/PartFlow–3D has been applied to the PF flow through a "riffle" type bifurcator. Using ICEM/CFD–Hexa as grid generator a numerical mesh with approx. 4 million grid cells has been designed for approximation of the complex geometry of the flow splitting device with all its interior fittings and guiding vanes. Based on a predicted gas flow field a large number of PF particles are tracked throughout the flow geometry of the flow splitter. Besides mean quantities of the particle flow field like e.g. local particle concentrations, mean particle velocities, distribution of mean particle diameter, etc. it is now possible to obtain information about particle erosion on riffle plates and guiding vanes of the flow splitting device. Furthermore the influence of different roping patterns in front of the flow splitter on the uniformness of PF mass flow rate splitting after the bifurcator has been investigated numerically.

Results show the efficient operation of the investigated bifurcator in absence of particle roping, this means under conditions of an uniform PF particle concentration distribution in the inflow cross section of the bifurcator. If particle roping occurs and particle concentration differs over the pipe cross section in front of the bifurcator the equal PF particle mass flow rate splitting can be strongly deteriorated in dependence on the location and intensity of the particle rope or particle concentration irregularities. The presented results show the importance of further development of efficient rope splitting devices for applications in coal–fired power plants. Numerical analysis can be used as an efficient tool for their investigation and further optimization under various operating and flow conditions.