11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

3D CFD SIMULATION OF CIRCULATING FLUIDIZED BED BOILER

Wojciech P. Adamczyk[1], Gabriel Węcel[1], Marcin. Klajny[2], Paweł Kozolub[1], Adam Klimanek[1], Ryszard A. Bialecki[1*], Tomasz Czakiert[3]

[1] Institute of Thermal Technology, Silesian University of Technology, Konarskiego 22, 44-100 Gliwice, Poland, wojciech.adamczyk@polsl.pl, www.itc.polsl.pl
[2] Marcin Klajny, Foster Wheeler Energia Polska Sp. z o.o., Staszica 31, 41-200 Sosnowiec, Poland, marcin.klajny@fwpl.fwc.com, www.foster.wheeler.pl
[3] Faculty of Environmental Protection and Engineering, Częstochowa University of Technology, J.H. Dąbrowskiego 73, 42-200, Częstochowa, Poland, tczakiert@is.pcz.czest.pl, www.is.pcz.czest.pl

Key Words: *CFD, circulating fluidized bed, oxycombustion, dense DPM*

1. Motivation

Fluidization is a unit operation where solid particles are floating in fluid as a result of a dynamic equilibrium of drag and gravitational forces. At such conditions, the two phase solid fluid mixture behaves similar to a fluid. The transport of mass, momentum and heat in fluidized bed are more intensive than in static granular material, thus fluidization is encountered in process industry and energy sector. Drying, catalytic cracking and polymerization, coal gasification, incineration of organic, biological and toxic wastes are but a few examples of processes where fluidized bed technology is used. In the context of coal combustion, Circulating Fluidized Bed (CFB) technology offers substantial advantages over the standard pulverized coal (PC) boilers. The main benefit when using CFB is its flexibility in fuels used to fire such units. High concentration of inert solid material in the CFB boilers stabilizes the combustion process. Hence, large CFB units may be fuelled by low rank brown coals (lignite and sub-bituminous), biomass, sludge and wastes, fuels that are very difficult to combust in PC boilers.

The paper concerns oxycombustion, where coal is combusted in a mixture of recirculated CO_2 and pure oxygen. Such technology is used to reduce the costs of the Carbon Capture process.

2. Hydrodynamics of fluidized bed

The difficulties in modelling fluidized bed come from the high load of particles whose mutual interactions should be accounted for. Standard Euler Lagrange technique of solving the transport equations of the continuous phase in Euler coordinates frame while tracking the particles using Lagrangian frame neglects the particle interactions and hence cannot be used to simulate fluidized bed. Large number of particles and complex solid-fluid interaction does not allow for direct application of the powerful Particle Finite Element Method [1]. A standard way of modelling fluidized bed remains thus the Euler-Euler approach where the particles within a certain diameter span, are treated as a continuous phase. Still, this approach leads to prohibitive execution times, even when additional measures, like population balance techniques [2], are implemented. The present paper uses an alternative approach where the continuous phase is modelled using Eulerian frame, particles are tracked in Lagrangian frame. The interactions between particles and wall and particles are modelled using the Kinetic

Theory of Granular Flow (KTGF) [3], being an extension of the kinetic molecular theory. KDGF equations are solved in Eulerian frame and introduce notions like granular temperature, granular viscosity and the like. The details can be found in [4].

3. Combustion and desulphurization

Combustion of coal particles in a fluidized bed involves coupled processes of hydrodynamics of the particle flow, interactions and energy transfer between particles, flue gas and walls, devolatization and chemical reactions. This is accompanied by removing of the sulphur oxide by its reaction with lime. Simulation of the mass transfer and chemical reactions can be accomplished straightforward while tracking the particles. The difficulty here is the knowledge of the kinetics of the processes, which specifically when oxycombustion is concerned, is difficult to obtain.

4. Mathematical model

The mathematical description of transport phenomena in CFB boilers is cumbersome and requires not only an in-depth knowledge of the physics, but also several empirically determined parameters. Last not least, the numerical behaviour of the discretised set of governing equations requires special measures to obtain convergent schemes. So far, no fully 3D model of a CFB boiler is reported in the literature. Because of these difficulties, the design and operation of the fluidized bed is a result of years of experiences in designing, building and testing rather than simulations.

5. Results

The paper presents first a 3D CFD model of a pilot installation whose aim is to validate the simulations, and a similar model of a large, full scale CFB boiler. Although the workhorse of the simulation is ANSYS-FLUENT, a commercial CFD solver, alone obtaining convergent results required a development of special strategy. Moreover, the CFB boiler consists of several units (separators, heat exchangers etc) whose coupling with the combustion chamber has been implemented by a set of user defined functions.

REFERENCES

[1] S. R. Idelsohn1, E. Oñate2 and F. Del Pin, The particle finite element method: a powerful tool to solve incompressible flows with free-surfaces and breaking waves, *Int. J. Numer. Meth. Engng,* **61** pp. 964–989, (2004).

[2] R. Fan, D.L. Marchisio, R.O. Fox Application of the direct quadrature method of moments to polydisperse gas–solid fluidized beds. *Powder Technology,* **139** pp.7–20, (2004).

[3] L. Huilin, H. Yurong and D. Gidaspow, Hydrodynamic modelling of binary mixture in a gas bubbling fluidized bed using the kinetic theory of granular flow, *Chem. Eng. Sci*. Vol. **58,** pp. 1197-1205, (2003).

[4] W.P. Adamczyk, A. Klimanek, P. Kozołub, R.A. Białecki, G. Węcel, T. Czakiert: *Comparison of the standard Euler-Euler and hybrid Euler-Lagrange approaches for modelling particle transport in a pilot-scale circulating fluidized bed experimental test-rig*. Particuology, accepted, online, DOI: 10.1016/j.partic.2013.06.008