A State-of-the-Art Review on Computational Fluid Dynamics (CFD) Based Modeling of Fluidized Bed Gasifier

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Abstract – *Gasification process had proved to be a benchmark in the renewable energy production processes. There are variety of gasifiers working on different input conditions and various feed stocks. The modeling of these gasifiers has been a continuous effort by the researchers in order to obtain better efficiency and output. CFD modeling is widely utilized and recommended for the better obtainability of power with optimized results and desired output conditions CFD proves to be a very significant and versatile tool in the designing and operation of fluidized bed gasifying system. This article presents the review of the modeling of a fluidized bed gasifier based on computational fluid dynamics approach. Fluidized bed gasifier founds higher application opportunity in power generation.*

Key Words: CFD, Fluidized bed gasifier, gasification, combustion.

1. INTRODUCTION

In today's world the usage of non-renewable energy sources are being used on its peak in order to satisfy the mammoth population which is resulting in its faster depletion. In order to cope up with the never ending power demand problem alternate sources of energy also known as renewable sources are to be used at a higher rate. More and more attention should be focused on the use of cleaner fuels among which fluidized bed combustion and gasification proves to be of great importance because it is easily obtainable and environment friendly. For the improved study of this process many methods to model the gasifier are being studied and continuous research is carried out for the betterment in power generation. Computational fluid dynamics modeling is also one of the modeling methods. Computational Fluid Dynamics (CFD) is an economical and effective modeling tool to study combustion and gasification in fluidized bed. Reliable CFD models are essential for the optimization of fluidized bed unit's design, as it can predict inert material concentration in bed, fuel mixing efficiency, temperature profiles of solid and gaseous phase present in dense bed, temperature profile of furnace, heat flux etc. [1] Majority of the CFD studies in literature on fluidized bed devices in past has been focused on isothermal modeling of dense bed [1] which is presented in the papers of Gao et al. [2], Behjat et al. [3], Gnanapragasam and Reddy [4],Wang et al. [5], Chen et al. [6].

Fluidized bed combustion and gasification can be treated as a multiphase reactive flow phenomenon. In a multiphase problems between gases and fuel particles which is also known as a reactive flow problem. The fuel that is used for combustion and gasification reaction can exist in the solid, liquid or gaseous form in the inert sand particles and the gasifying agent is air in combustion and steam-air in case of gasification. Currently there are three numerical techniques used for the studying combustion and gasification in fluidized beds in literature and these are Eulerian-Lagrangian with single particle or a particle parcel and a group of particles, Eulerian-Eulerian TFM and Discrete Element Method (DEM-CFD) within Eulerian-Lagrangian concept.[1]. The other CFD technique which is Eulerian-Lagrangian DPM with single particle or a particle parcel and a group of particles is mostly used in region of freeboard where the diluted particle conditions are present also termed as a region above dense region. To study freeboard in fluidized beds different authors have touched different aspects. They tried to apply CFD to study combustion and gasification issues of solid fuels, their emissions, operational parameters and other aspects like fate of nitrogen in freeboard [7-10].

Mainly the CFD models consider combustion or gasification issues in fluidized bed predict qualitative information like solid volume fraction and quantitative information like temperature profiles and heat transfer.

2. Fluidized bed systems

Bed is said to be fluidized when an evenly distributed air or gas is passed upward through a finely divided bed of solid particles. The particles which are kept on the finely divided bed remain undisturbed at low velocity. But as the air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream.

The factors on which fluidization depends are the particle size and the air velocity. Fluidized bed offers multiple benefits, such as: compact boiler design, flexibility with fuel used higher combustion efficiency and reduced emissions of noxious pollutants such as SOx and NOx [1]. Many types of fuels can be burnt or gasified in fluidized beds such as coal, coal washery rejects, biomass etc. Gasification is based on the principle of combustion. It only differs from that of combustion in such a way that gasification endo-thermal conversion technology where a solid fuel is converted into a combustible gas. The product gas consists of carbon monoxide, carbon dioxide, hydrogen, methane, trace amounts of hydrocarbons, water nitrogen and various contaminants such as char particles, ash and tars [1].Fluidized bed devices can be classified in three types on the basis of their type of flow mainly, bubbling (B), circulating (C) and pressurized bed (P). Mainly the circulating fluidized bed demand is going on increasing due to its much diversified applications. Fluidization is a complex phenomenon, and hence several authors reported kinetic models for gasifiers with various degrees of accuracy and details [12]. Fiaschi and Michelini [13] developed a kinetics model for a fluidized bed gasifier and came to a conclusion that when comparing the effect of mass transfer and surface reaction kinetics on the whole gasification mechanism, the first prevails at the start of the process due to the high temperature level and successively, when the temperature is stabilized the latter plays a dominant role.

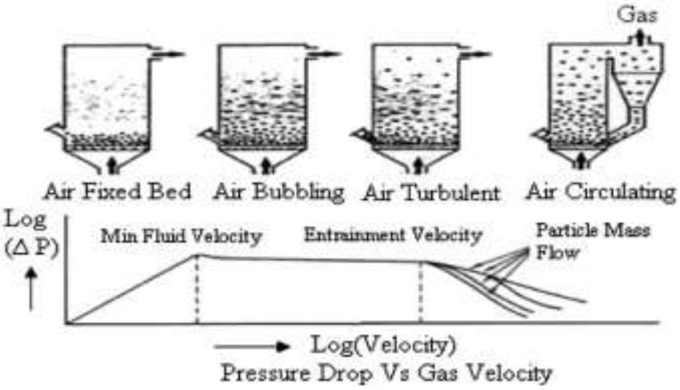

Fig-1: Principal of fluidization [11].

3. CFD modeling

In earlier period, CFD neglects the combustion and gasification as it complexes the system due to lack of advancement of computers. The first attempt to model fluidized bed device numerically which includes gasification is by Kimura and Kojima [14]. Jicheng et al. [15] also did the numerically simulation of fluidized bed coal gasifier. We have to analyze, design, and optimize the performance of fluidized bed devices which helps in the development of multidimensional combustors and gasifiers models. These multidimensional models will bridge the gap between sub-scale testing and the operation of fluidized bed furnaces by providing information about combustion and gasification processes that experimental data alone cannot provide [1]. CFD model includes the application of the conservation equations of mass, momentum and energy [19].

The figure shows a scale based classification of the model approaches used in the fluidized bed systems. By the help of this we can show the different scales for which the different models are applied. It is also used to relate the presented semi-empirical steady 3D model to other model approaches.

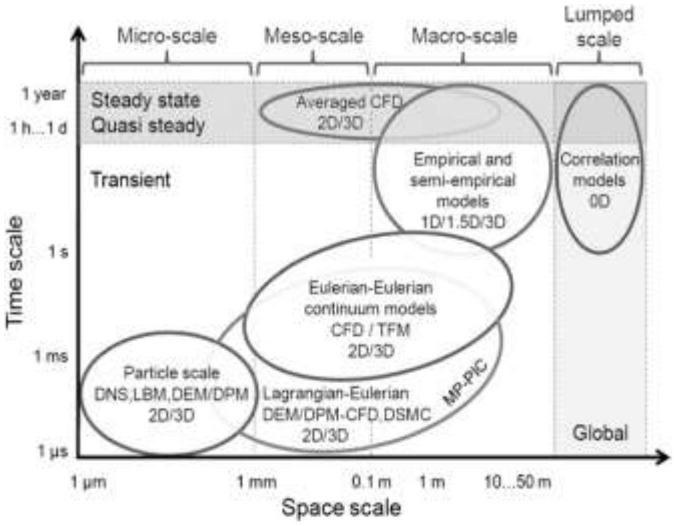

Fig-2: Scale-based classification of multiphase approaches for fluidized bed [16].

The top area in the figure covers the area of steady state modeling. Due to segregation, fouling, rusting the real physical process are never steady state if the observation time is years or decades. Thus, the steady state is a virtual state, which can be reached [16] only in models, in which the number of affecting variables is limited.

Mainly the three approaches are been used for the numerical stimulation of the multiphase flow in literature. First approach is Euler-Lagragian also known as primary phase is treated as a continuum. One can calculate particle trajectories in the given interval during the primary phase flow calculations. An assumption is to be made in this model is that the volume fraction of the dispersed, secondary phase is below 10-12%, although its mass can be greater than the mass of the primary phase. Second approach is Euler-Euler approach which is considered as inter-penetrating continua. In this approach there are three models of multiphase flow; volume of fluid (VOF), the mixture model and the Eulerian model. Mostly the Eulerian model is used for the modeling of fluidized bed. Third approach is the Discrete Element method-CFD.

4. Combustion and Gasification

Combustion is defined as an exothermic oxidation process which occurs at very high temperature. For a good combustion process the main requirements are the time of reaction, temperature required for sustaining the reaction and better mixing of fuel with the oxidant. Fluidized bed fulfill all the mentioned requirement as it has excellent internal and external recirculation of hot solids at the combustion temperature which provides the fuel particles their adequate temperature and long residence time. Gasification is generally carried out by reacting fuel such as coal, biomass, petroleum coke or heavy oil with restricted amount of oxygen and often in combination with steam [1]. In order to secure our future with the benefits of the remaining energy deposits we must be able to produce energy from different sources which can be obtained and utilized from our nearby surroundings [17]. The proper conversion and right utilization of wasteful energy into useful energy is the main aim of the concerned process [18].

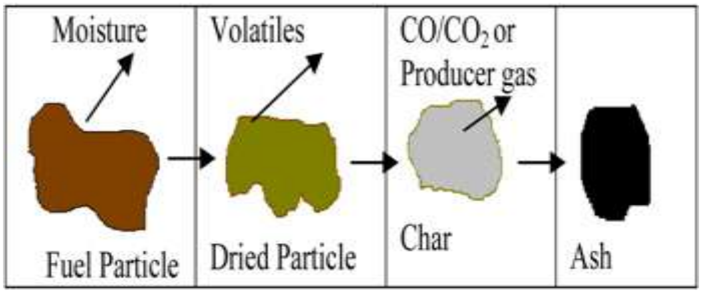

Fig -3: Stages in combustion and gasification process [1].

5. Devolatilization

Devolatilization is the process where a wide range of gaseous products is released through the decomposition of fuel. The volatile matter (VM) comprises a number of hydrocarbons which are released in steps. Devolatilization is intermediate step before combustion of particle in fluidized bed. CFD model is able to predict this stage correctly [1].

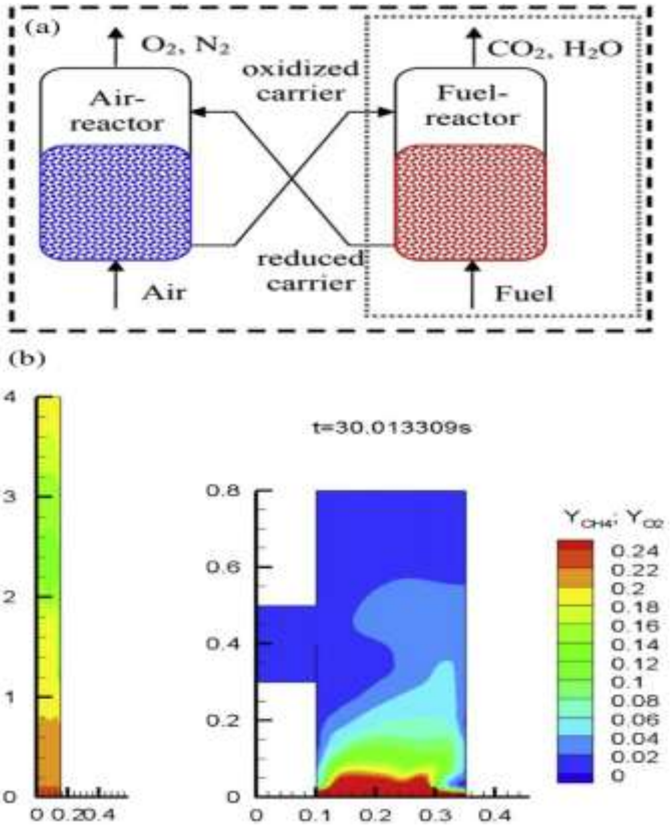

Fig-4: (a) Outline of interconnected fluidized bed chemical looping combustion systems [20]. (b) Contour plots of mass fraction of CH4 in the fuel reactor [20].

5. CONCLUSION

This paper summarizes the modeling of fluidized bed gasifier with computational fluid dynamics as a tool for the operation. The CFD modeling of fluidized bed gasifier has proved to be an efficient method in the study and analysis of the characteristics of the gasification process. The various steps involved in this process makes it a suitable and more glorified gasification type for the production of energy. Many other methods such as Artificial Neural Networks (ANN), ASPEN model are also widely considered for the modeling of different gasifiers and their operational conditions. CFD is used for the efficient designing solutions of the gasifiers and their computations.

REFERENCES

[1] Ravi Inder Singh , Anders Brink , Mikko Hupa; CFD modeling to study fluidized bed combustion and gasification; Applied Thermal Engineering 52 (2013) 585e614.

[2] W.M. Gao, L.X. Kong, P.D. Hodgson, Computational simulation of gas flow and heat transfer near an immersed object in fluidized beds, Advances in Engineering Software 38 (2007) 826e834.

[3] Y. Behjat, S. Shahhosseini, S.H. Hashemabadi, CFD modeling of hydrodynamic and heat transfer in fluidized bed reactors, International Communications in Heat and Mass Transfer 35 (2008) 357e368.

[4] N.V. Gnanapragasam, B.V. Reddy, Numerical modeling of axial bed-to-wall heat transfer in a circulating fluidized bed combustor, International Journal of Heat and Mass Transfer 52 (2009) 1657e1666.

[5] W. Wang, B. Lu, N. Zhang, Z. Shi, J. Li, A review of multiscale CFD for gasesolid CFB modeling, International Journal of Multiphase Flow 36 (2010) 109e118.

[6] X.Z. Chen, D.P. Shi, X. Gao, Z.H. Luo, A fundamental CFD study of the gase solid flow field in fluidized bed polymerization reactors, Powder Technology 205 (2011) 276e278.

[7] A Brink, S Bostrom, P Kilpinen and M Hupa, CFD modeling of the fate of biomass fuel-nitrogen in the freeboard of a 70 MW FBC-new aspects on controlling mechanisms, in: First biennial meeting, The Scandinavian-Nordic Section of the Combustion Institute 18th to 20th April 2001, Chalmers University of Technology, Goteborg, Sweden.

[8] A. Brink, C. Mueller, M. Hupa, A modified approach for predicting NOx emission trends from biomass fired bubbling fluidized bed boilers, in: Proceeding of 19th FBC conference, May 21e24, 2006.

[9] A. Brink, M. Hupa, E. Kurkela, M. Suomalainen, Minimizing NOx emission from a waste derived fuel gasifier gas combustor using CFD combined with detailed chemistry, IFRF Combustion Journal. ISSN: 1562-479X 05 (2005). ISSN: 1562-479X 1e14.

[10] R. Zevenhoven, M. Järvinen, Particle/turbulence interactions, mass transfer and gas/solid chemistry in a CFBC riser, Flow Turbulence and Combustion 67 (2) (2001) 107e124.

[11] Energy Efficiency in Thermal Utilities. A Guide Book for Energy Managers and Auditors, Bureau of Energy Efficiency, Ministry of Power, Government of India, 2005.

[12] Tigabwa Y. Ahmed1, Murni M. Ahmad∗, Suzana Yusup2, Abrar Inayat3, Zakir Khan4 Mathematical and computational approaches for design of biomass gasification for hydrogen production: A review T.Y. Ahmed et al. / Renewable and Sustainable Energy Reviews 16 (2012) 2304– 2315.

[13] Fiaschi D, Michelini M. A two-phase one-dimensional biomass gasification kinetics model. Biomass Bioenergy 2001;21:121–32.

[14] T. Kimura, T. Kojima, Numerical model for reactions in a jetting fluidized bed coal gasifier, Chemical Engineering Science 47 (1992) 2529e2534.

[15] B. Jicheng, L. Chunhao, K.C. Aoki, S. Umea, T. Kojima, A numerical simulation of jetting fluidized bed coal gasifier, Fuel 76 (4) (1997) 285e301.

[16] K. Myohanen, T. Hyppanen, A three-dimensional model frame for modeling combustion and gasification in circulating fluidized bed furnaces, International Journal of Chemical Reactor Engineering 9 (A25) (2011) 1e55.

[17] Adil Wazeer, Bhaskar Chaturvedi, Shriyash Mohril, Mahipal Singh Sankhla, Dr. Rajeev Kumar; Gasification-Contributing to the Energy Production Demands; International Journal of Engineering And Computer Science ISSN: 2319-7242 Volume 5 Issue 12 Dec. 2016, Page No. 19440-19449.

[18]. Adil Wazeer; Structural analysis of sugarcane bagasse as a feedstock in downdraft gasifier system - A review; International Journal of Research in Engineering and Innovation, Vol-1, Issue-6 (2017), 223-228.

[19] Adil Wazeer, Kaushalendra Kr. Dubey; Technological Review on Biomass Gasification Models; International Research Journal of Engineering and Technology; Volume: 05 Issue: 12; 2018.

[20]. H. Kruggel-Emden, S. Rickelt, F. Stepanek, A. Munjiza, Development and testing of an interconnected multiphase CFD-model for chemical looping combustion, Chemical Engineering Science 65 (2010) 4732e4745.