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Development of Advanced CFB for Clean and Efficient Coal Power

Chalmers University of Technology, founded in 1829, is an academic and postgraduate university that conducts research across a wide front within the areas of technology, natural science and architecture. The Division of Energy Technology (Department of Energy and Environment) has a long experience of research in fluidized-bed combustion and contributions from the Chalmers 12 MW CFB boiler.

Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Tel. +46 31 772 1000
Fax +46 31 772 3592
www.chalmers.se

Foster Wheeler Power Group Europe is a specialist in advanced boiler technology and associated services. Fluidized-bed boilers – and circulating fluidized-bed (CFB) boilers in particular – are at the heart of the company’s know-how and product offering. With more than 200 CFB deliveries worldwide, Foster Wheeler is the market leader in the field.

Foster Wheeler Energy Oy
P.O. Box 201
FI-78201 Varkaus
Finland
Tel. +358 (0)10 393 11
Fax +358 (0)10 393 7699
www.fwc.com

VTT Technical Research Centre of Finland is an impartial expert organisation. Its objective is to develop new technologies, create new innovations and added value thereby increasing clients’ competitiveness and competitiveness. With its know-how, VTT produces research, development, testing and information services for the public sector and companies as well as for international organizations.

VTT TECHNICAL RESEARCH CENTRE OF FINLAND
P.O. Box 1603
Fi-40101 Jyväskylä
Finland
Tel.+358 (0) 20 722 2529, fax.+358 (0)20 722 2597
jouni.hamalainen@vtt.fi

Contact
Coordinator
Dr. Jouni Hamalainen
VTT Technical Research Centre of Finland
P.O.Box 1603, FIN-40101 Jyväskylä Finland
Tel.+358 (0) 20 722 2529, fax.+358 (0)20 722 2597
jouni.hamalainen@vtt.fi

Assistant coordinator
Heidi Nevalainen
VTT Technical Research Centre of Finland
P.O.Box 1603, FIN-40101 Jyväskylä Finland
Tel.+358 (0)20 722 3676, fax.+358 (0)20 722 2597
heidi.nevalainen@vtt.fi

IsFTa is the main Greek organisation for the promotion of research and technological development aiming at the improved and integrated exploitation of solid fuels and their by-products. IsFTa was established by Presidential Decree in 1987, while since 2002, it is one of the five institutes of the National Centre for Research and Technology Hellas (CERTH).

CERTH-IsFTa
P.O.Box 39
4th km N.P. Ptolemais - Kozani
Greece
Tel. +30 2463 053842
Fax +30 2463 0 53843
www.isfta.gr

Profund process understanding
The CLEFCO project (2004-2006) of the European Union aims to promote the development of Once Through Steam Cycle (OTSC) CFB technology. This is carried out by increasing process knowledge that is essential for successful boiler design and final demonstration of multi-fuel flexibility of the process. To fulfil the development needs of OTSC CFB technology, a comprehensive understanding of CFB combustion processes must be achieved. Intensive research in laboratory, pilot and full-scale combustors is required to fulfil the above-mentioned objectives.

Chalmers University of Technology
DEVELOPMENT TOWARDS OTSC CFB

In existing CFB boilers the full potential and flexibility of the CFB process, in boiler design and controlled heat production, has not been fully exploited. This has limited the capability to configure the boiler and the steam cycle in an efficient way. Additionally, the control strategy of the units has not been refined and the characteristics of the unit's dynamic behaviour, especially with multi-fuel firing, have not been fully developed. These activities are required in order to expand the competitiveness of the concept and convince power generation industry to accept the proposed supercritical OT CFB multi-fuel concepts as the state of the art.

The strategic importance and attractiveness of the OTSC CFB design is based on multi-fuel operation, which permits a remarkable decrease in CO2 emissions when compared to a remarkable decrease in CO2 CFB design is based on multi-fuel operation, which permits a remarkable decrease in CO2 emissions when compared to a remarkable decrease in CO2.

PROCESS CONTROLLABILITY IN STATIONARY AND DYNAMIC CONDITIONS

The dynamic and stationary characteristics of CFB furnaces have been studied with VTT’s and Chalmers’ reactors and commercial boilers fired with bituminous coal, wood and mixtures of these fuels. High volatile content and low char inventory of biomass fuels increase requirements for process control. Particularly, in the case of high efficiency large-scale CFB multi-fuel operation, the characteristics of fuel quality and mixing ratio of the fuels with respect to the CFB combustion process must be well known and taken into account both during boiler design and in methods of control. Existing stationary and dynamic models have been further developed in order to obtain a deeper understanding of the transient behaviour of the CFB process. Due to the special requirements set by the multi-fuel combustion, development of more advanced functions for describing the CFB furnace dynamics, in the control system, has been carried out. Dynamic simulation tools are widely applied in the control development and in analysis of multi-fuel boiler dynamics. Based on combustion test analyse, optimisation of CFB boiler control strategies were carried out in order to maintain low emissions of pollutants in dynamic conditions and achieve flexibility with varying coal-biomass mixtures.

EFFECTS OF MATERIAL COMMINUTION BEHAVIOUR

The size distribution of different materials can be found, if the comminution behavior of different solid materials is known. The particle size distribution (PSD) of solid materials in a CFB furnace have significant effects on boiler performance; for instance on combustion, heat transfer, emission formation and on boiler control. The accuracy of heat transfer and boiler performance calculations can be increased if particle size distributions of solid materials (ash, sand, limestone and char) can be predicted under varying fuel mixture feeding.

Study of the change of limestone PSD in VTT’s laboratory scale reactor is carried out based on a population balance model during a thermal shock and a calcination step.

MIXING OF FUEL IN THE LOWER REGION OF A CFB BOILER

A novel technique, based on phosphorescence, for particle tracking in two-dimensional fluidized beds is used to study the flow of solids in the lower region of the bed. The experiments span a range of bed heights, gas velocities, fuel-to-bed material densities and size ratios typical for fluidized bed combustors. Several fluidization regimes (bubbling, turbulent, circulating and pneumatic) are included in these trials. Dispersion is found to be larger in the vertical direction than in the horizontal, confirming the critical character of lateral fuel dispersion in fluidized-bed combustors of a large cross section. A three-dimensional FBC model for fuel concentration, that combines several fuel mixing mechanisms, has been formulated. Modelled data show a good agreement with experimental data from the Chalmers 12 MW fluidized bed boiler. Several fuel mixtures with different coal-to-biomass ratios have been tested. The importance of the dynamics of fuel particle conversion (including drying, devolatilization and char combustion) and fragmentation is confirmed by the high sensitivity revealed by the simulated results due to variations in these modelling tasks.

GAS COMPOSITION PROFILES

Measurements of gas concentrations in the freeboard show that higher coal content in the fuel mixture leads to a more homogeneous horizontal distribution of gas species. When wood chips are added to the fuel mixture, both the horizontal maldistribution and cross-axial average of CO concentrations increase. Tests with higher amounts of bed material show a more homogeneous horizontal distribution of gas concentrations. In conclusion, the combination of a low amount of bed material and a high fraction of biomass in the fuel mixture may deteriorate the combustor performance due to the increased amount of combustible gases that escape the combustion chamber. However, increasing the amount of solids in the furnace can, to some extent, counteract the lateral maldistribution of gases.

COMBUSTION RESIDUES: CHARACTERIZATION AND UTILIZATION RECOMMENDATION

To find out possibilities for end use of ash, national legislations and standards were studied by ISFTA. Knowledge was applied to ash management possibilities for coal, and co-combustion of coal and biomass. The studies were based on the ash characterization, which was carried out for ash samples collected from VTT’s and Chalmers’ CFB combustion tests.

Analyses carried out for ash samples:
- Particle size distribution
- Chemical composition
- Mineralogical composition of fly ashes

SEM image of fly ash from Sec Cyclone – Hematite. (CERTH/ISFTA)