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METHODS FOR NOx EMISSION REDUCTION IN BFB COMBUSTION: A CFD STUDY

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ABSTRACT

Fortum and VTT have developed methods for primary NOx reduction in BFB combustion with simultaneous control of CO burnout as well as bed and furnace exit gas temperatures to minimize slagging, fouling and corrosion issues both in lower and upper part of the furnace. Computational fluid dynamics was used as a tool to systemically study features of proper air system design in such a NOx reduction strategy. In this context the CFD code Fluent and VTT's specific sub-models for BFB furnaces were applied to simulate combustion and NOx in a BFB boiler with a capacity of 175 MW fuel.

The CFD results show that if special attention has to be paid to temperature control and slagging issues in the near bed region, it's beneficial to choose secondary air elevation differently from the case with the main focus on NOx reduction. Minimum NOx emission is achieved by optimizing secondary air elevation and lower furnace air distribution. The latter is dependent on fuel properties and it can be adjusted with an additional air feed into the near bed zone. Additional air introduction combined with well-designed secondary and tertiary system to provide good mixing ensures efficient heat transfer (low furnace exit gas temperature), complete CO burnout and even temperature distribution in the upper furnace in parallel with favourable NOx performance.

Keywords: BFB, NOx, CFD, combustion, biomass, peat

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1 Introduction

Primary methods are often a cost efficient way to reduce NOx emission in furnaces. Air staging is perhaps the most commonly used method as it is easily applicable for different kind of combustion processes. However issues related to burnout, corrosion, slagging and fouling may arise in air staging cases. They should be taken into account in designing of a proper air distribution system.

Fortum and VTT have developed methods for primary NOx reduction in bubbling fluidized bed (BFB) furnaces with simultaneous control of above mentioned issues. Computational fluid dynamics (CFD) was used as a tool to systemically study features of a proper air system design. In the following CFD simulation results from a BFB furnace related to those studies are shown and analysed.

2 Air staging strategies in BFB

General idea of air staging in a BFB boiler is presented in figure 1. Primary air (1'ry) and in many cases some recirculated flue gas (FGR) are fed into the furnace from below through the bed inducing fluidization. Secondary air (2'ry) level is usually located above the fuel chutes and tertiary air (3'ry) level in the upper furnace. Based on the main air introduction levels the furnace can be divided into three combustion zones I – III. To achieve good NOx performance zones I & II are kept under-stoichiometric. Final burnout occurs in zone III.

In the NOx control methods developed by Fortum and VTT the zone I stoichiometry is adjusted by an additional air feed into the near bed region for optimal NOx reduction. In some cases additional air cannot be introduced, if special care has to be paid to control of bed temperature and low furnace slagging. In that case zone I should be operated with low stoichiometry. This leads to somewhat compromised NOx performance compared to the first option.

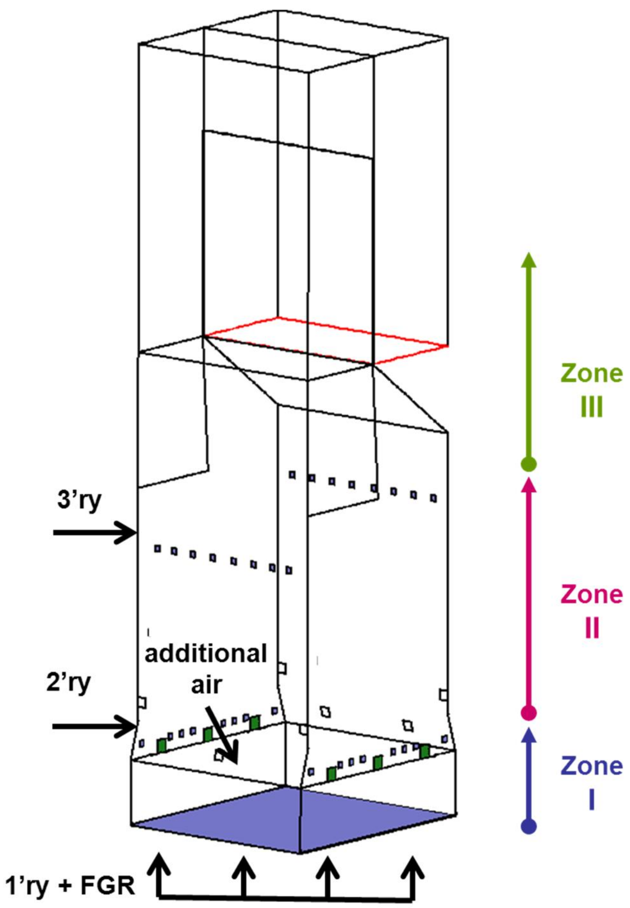

Figure 1. Air staging in BFB and the three combustion zones

3 Modelling approach and simulated cases

The commercial CFD code Fluent 12.1 equipped with VTT's specific sub-models for BFB furnaces was applied to simulate combustion and NOx in a BFB boiler. Relevant sub-models used in simulations are listed in Table 1. Detailed model description is out of the scope of this paper.

Table 1. Relevant CFD sub-models used in simulations

Turbulence	standard k-ε
Radiation	Discrete Oirdinates + WSGGM for gas radiative properties
Turb.-ch. interaction	Eddy Dissipation Model (VTT specific)
Main chemistry	Global 3-step scheme with CO and H_2 as intermediates
Fuel particles	Lagrangian tracking, VTT's sub-models for biomass and peat
Bubbling bed	Treated as boundary, VTT's freeboard-bed interaction model
NOx	Eddy Dissipation Concept (VTT) + global chemistry scheme (VTT)

The outline of the furnace in question is presented in figure 1. It has the capacity of 175 MW_{fuel}. Fuel utilized in normal operation is a mixture of forest based biomass and peat. Fuel properties and particle size distributions used in simulations are shown in figure 2. One should note that biomass particles are much larger in size. As a consequence biomass is mainly combusted in bed whereas smaller peat particles are easily captured by the flow burning during flight in the freeboard.

Fuel analysis	Peat	Biomass
Moisture [w-%]	54	52
Ultimate [w-%, dry]:		
C	55.3	51.2
H	5.5	5.6
O	31.7	38.1
N	1.7	0.4
S + ash + others	5.8	4.7
Proximate [w-%, dry]:		
volatiles	68.0	80.0
char	26.2	15.3
FR (fuel ratio)	0.39	0.19
LHV [MJ/kg, dry]	21.5	18.1

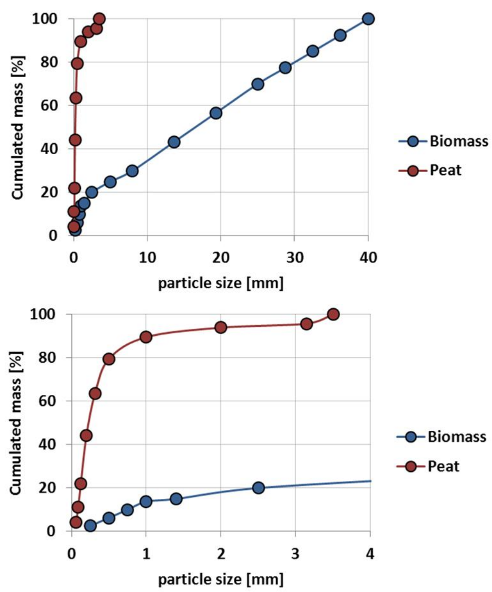

Figure 2. Fuel properties

In the beginning of the work the CFD model, especially NOx sub-model was shortly validated against plant output data in the case used as a reference for further studies. In this reference case peat-biomass ratio in fuel was approximately 30:70 by energy. Simulated NOx is well comparable to measured values. Validation result together with simulated T, O_2 and NO distributions in the furnace are presented in figure 3.

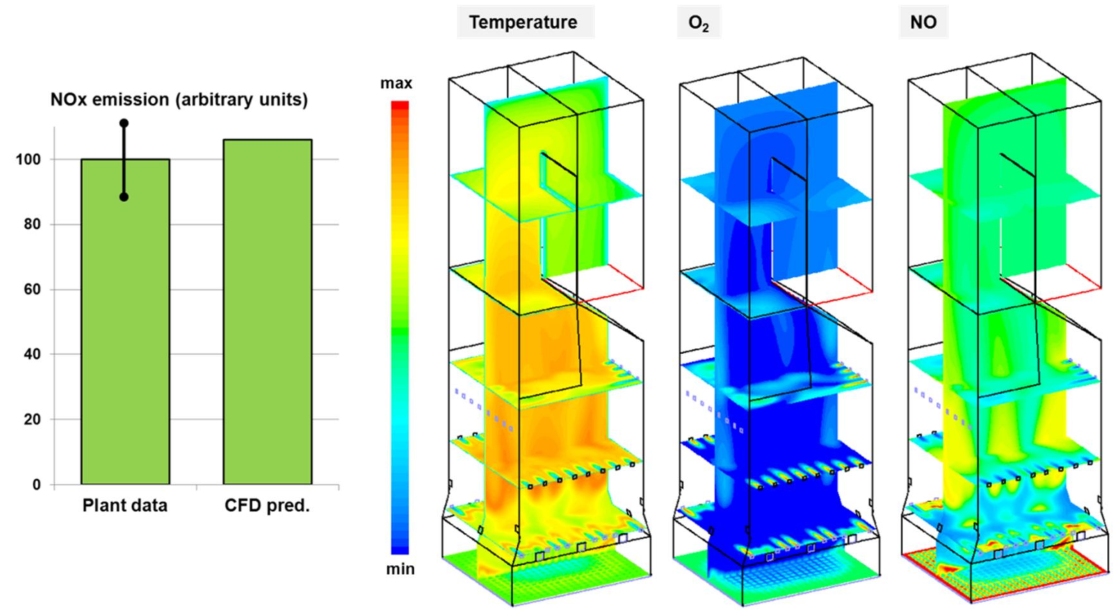

Figure 3. CFD results from the reference case (validation)

The CFD studies presented here focused on three topics:

a) Finding a proper 2'ry air elevation concerning NOx control both with and without additional air feed into zone I. Three different elevations were tested with the fuel mixture peat/bio = 30/70

b) Investigating zone I stoichiometric ratio (SR) for NOx reduction in case of additional air introduction with different fuel types (mixture, pure biomass, pure peat)

c) Testing a modification in 2'ry and 3'ry air systems to improve mixing.

Furnace exit (nose level) gas temperature (FEGT) and CO concentration were used as indicators for upper furnace fouling tendency and burnout in each case.

In all cases zone II (< 1.0) and zone III stoichiometric ratios were held equal. Zone I SR is adjusted by changing the ratio of additional air to 2'ry air.

4 Results

Two 2'ry air elevations were considered when additional air feed was off. Summary of simulation results is presented in figure 4. All values are compared to the reference case. According to the results better NOx, CO and FEGT performance is achieved, if 2'ry air is set at low position.

Simulation results obtained with different 2'ry air elevations using additional air are shown in figure 5. From the NOx point of view it seem feasible to use high position for 2'ry but the same is not necessarily true for CO and FEGT. On the other hand the zone I SR is likely to be out of its optimum in these cases. Not much additional NOx reduction is gained between the elevations 2 and 3 but at the same time CO begins to rise. As a conclusion the elevation EL-2 was chosen for further air distribution studies.

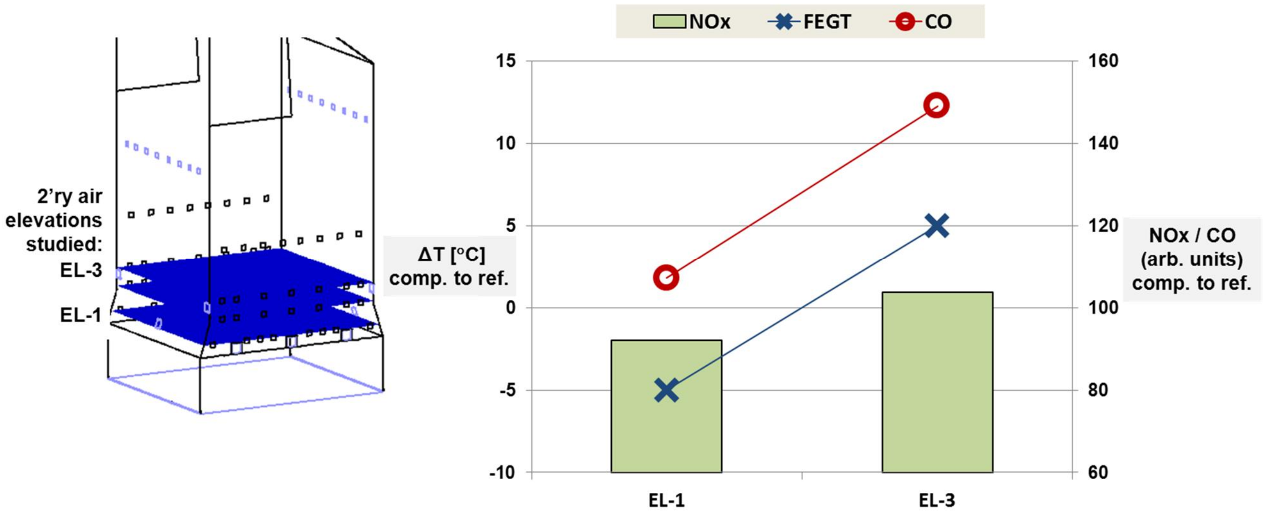

Figure 4. CFD results: effect of 2'ry air elevation, no additional air feed

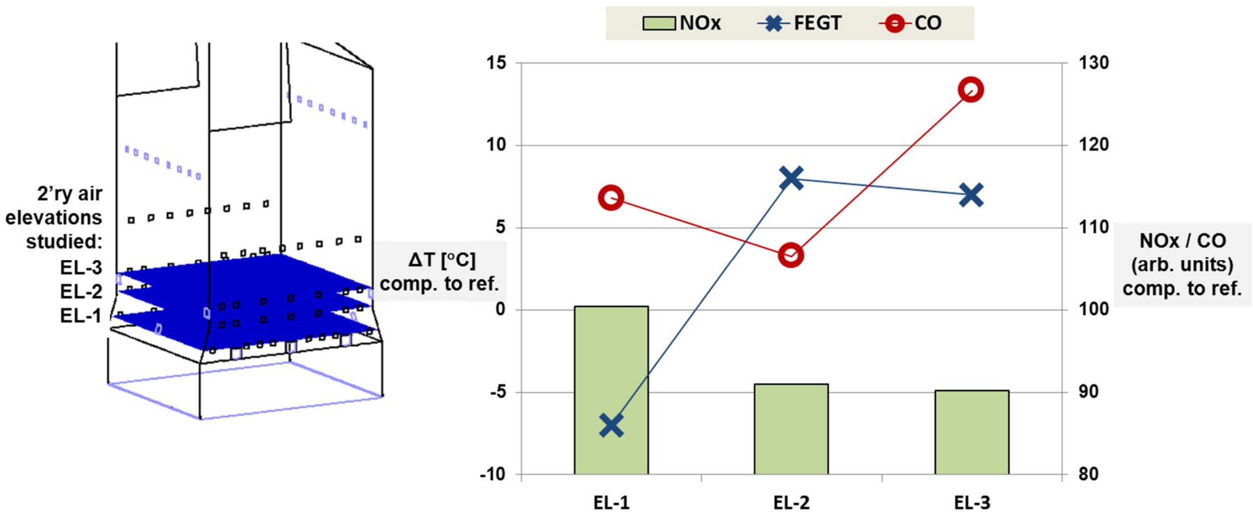

Figure 5. CFD results: effect of 2'ry air elevation with additional air feed

Zone I air distribution was studied with the chosen 2'ry air elevation EL-2. For the fuel mixture three Zone I stoichiometric ratios were tested: SR1-1 (original) < SR1-2 < SR1-3. Additional air feed was increased accordingly. The same was done for pure biomass (SR1-1 & SR1-2) and pure peat (SR1-2 & SR1-3). The results are summarized in figure 6. They indicate that by "optimizing" zone I stoichiometry (that is the amount of additional air) NOx, CO (except for peat) and FEGT can be reduced simultaneously. Optimal SR concerning NOx is likely to depend on fuel type being lower with biomass type of fuel and higher with peat. CO level is much higher in peat combustion and even increases along with the zone I SR. This is due to small particle size leading to enhanced heterogeneous combustion in the freeboard. The problem could be tackled by improving mixing at 2'ry and 3'ry air levels.

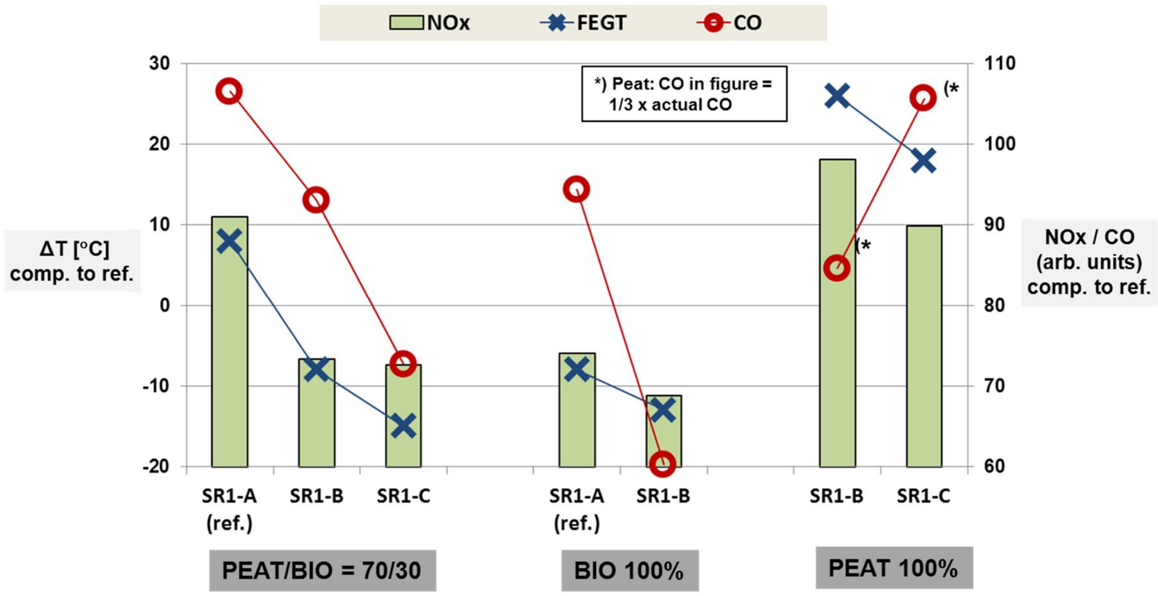

Figure 6. CFD results: effect of Zone I stoichiometry with additional air feed. SR1-A < SR1-B < SR1-C

Finally the effect of mixing was investigated by modifying 2'ry and 3'ry air nozzle systems with the "optimized" additional air feed. This was done for the fuel mixture peat/bio = 30/70. Results are presented in figure 7, where two similar cases are compared. Nose level peak temperature (Tmax) is plotted in addition to average FEGT.

The results indicate there is no drawback in NOx with the improved air system and practically no change in (average) FEGT. On the contrary peak temperature drops by some 50 degrees and CO decreases drastically indicating much more even (favourable) temperature distribution in the upper furnace and enhanced burnout.

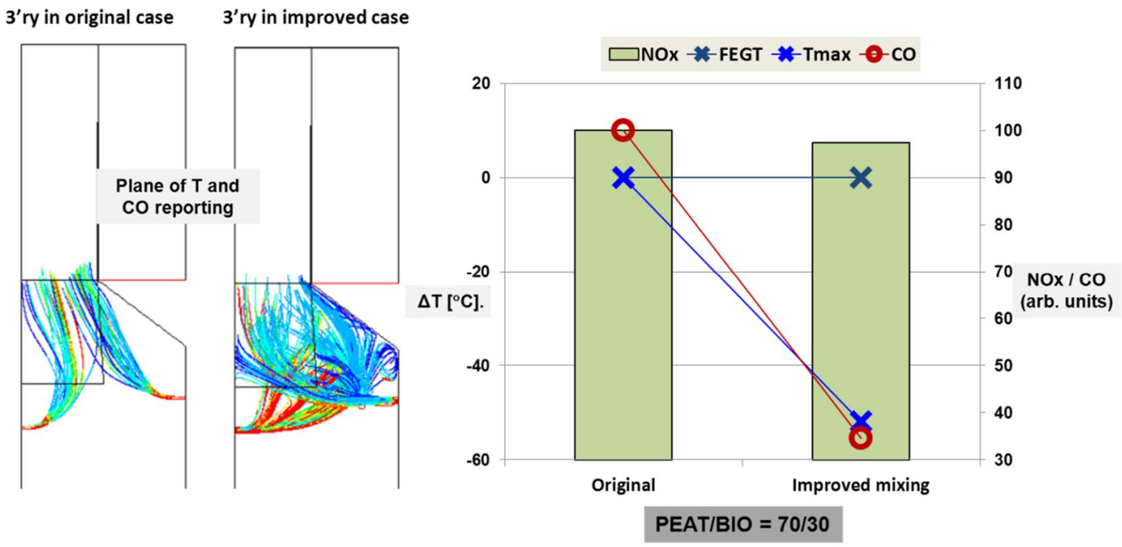

Figure 7. CFD results: mixing study

5 Conclusions

Based on the CFD simulations of a BFB boiler:

- It’s beneficial to set 2’ry air at lower position, when operating the furnace without additional air to combustion zone I
- It’s beneficial to set 2’ry air at higher position, when operating the furnace with additional air to combustion zone I
- Minimun NOx is achieved by optimizing zone I SR depending on fuel type with additional air introduction and positioning 2’ry at higher elevation. CO and FEGT can be reduced simultaneously.
- Burnout can be enhanced and upper furnace temperature distribution smoothed by paying attention to 2’ry and 3’ry systems to improve mixing. No drawback in NOx is predicted.