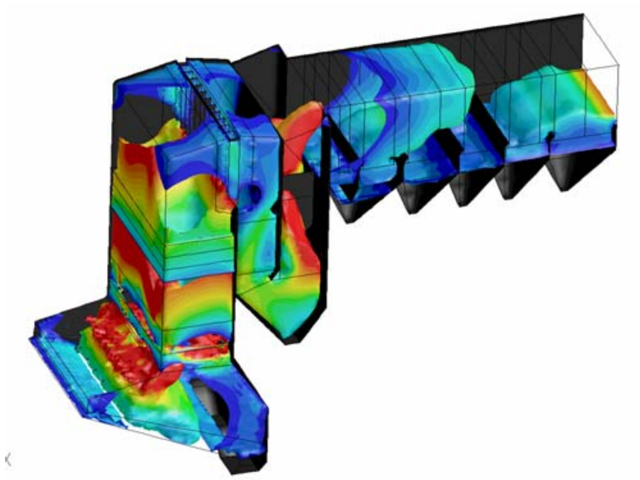
Investigation of Combustion and Flow Patterns in a Boiler

Babcock & Wilcox Vølund (BWV) design, manufacture and sell waste to energy (W-t-E) and biomass power plants. Part of the design process of boiler and furnace is a Computational Fluid Dynamics (CFD) analysis. BWV would like to investigate some improvements to the CFD modelling.



By establishing a CFD model of an existing BWV plant combined with experiments[1] and temperature and species measurements from the plant, BWV would like to gain some insight within the following areas:

Investigate choice of turbulence model (including model parameters)

BWV use the k-ε turbulence model today; the question is whether this is the right choice? Would another turbulence model give better results? How much could the results be improved by altering the model parameters and what is the calculation cost?

Build a CFD model, preferably of a test installation and compare results from different turbulence setups with measurements on the test installation.

Investigate choice of combustion model

How does the combustion model have impact on the accuracy of the temperature profiles and CO – level compared to measurements on Reno Nord? How much could the results be improved by altering the model parameters and what is the calculation cost?

Today, the employed chemical reaction model contains the main components of the flue gas: N_2, CO_2, H_2O and O_2. As it is very complex to model the combustion realistically, we have chosen to use the following simplified reaction scheme for combustion:

$$CH_4 + 1.5\ O_2 \rightarrow CO + 2\ H_2O$$
$$CO + 0.5\ O_2 \rightarrow CO_2$$
$$CO_2 \rightarrow CO + 0.5\ O_2$$

The first two reactions are limited by the mixing (the turbulence) and the reaction rate, whereas the last backward reaction is controlled by the reaction rate alone.

In the literature many authors use the reaction scheme from Jones and Lindstedt (Combustion and Flame) 73: 233-249 (1988):

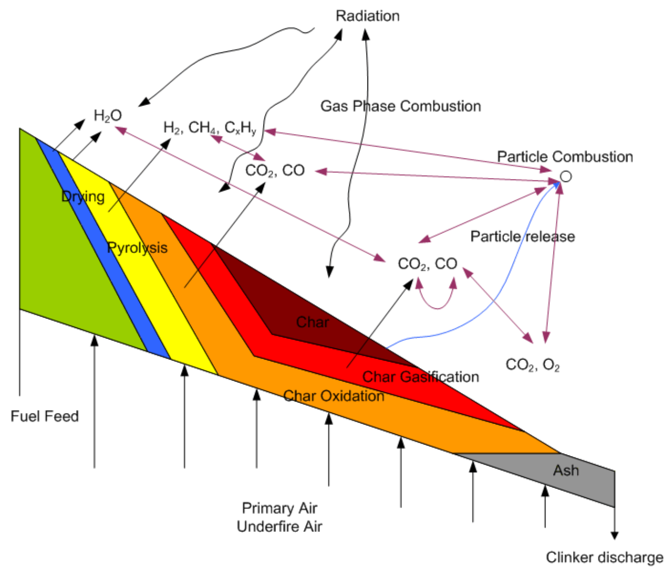
$$C_nH_{2n+2} + n/2\ O_2 \rightarrow n\ CO + (n+1)\ H_2$$
$$C_nH_{2n+2} + n\ H_2O \rightarrow n\ CO + (2n+1)\ H_2$$
$$H_2 + ½\ O_2 \leftrightarrow H_2O$$
$$CO + H_2O \leftrightarrow CO_2 + H_2$$

[1] E.g.: Experiments could be conducted on the small scale boiler at AAU - IET with LDA and PIV measurements or on the small scale batch reactor at CHEC etc.

An additional subject for the project could be to evaluate the use of Eddy Dissipation Concept (EDC) for the turbulence model compared to Eddy Dissipation with Finite Rate.

Integrated bed model

The boundary conditions for the waste/fuel layer are generated with an external model. The present model calculates the released energy, mass and species from the fuel layer. The input to the bed model is air flow and distribution, fuel composition, heating value and waste volume. Because the bed model is not integrated in the CFD model the fuel layer is for instance not exposed to the heat transfer in the furnace and the chemical composition over the fuel layer.



BWV would like to have an integrated model developed and compared to the present model and compare results with measurements from a BWV plant.

Particle transport and combustion

When a boiler and furnace for a suspension feed plant for bio fuel is initially designed the preliminary characteristics for the fuel is known: Elementary analyses, type, size distribution, humidity and density. On the basis of the information a basic design of the furnace and boiler is carried out with respect to grate size, furnace dimensions, refractory and air distribution to grate and secondary air system.

To get a precise and quick answer to the retention time and burn out of the fuel it would be an advantage to use a simpler tool than CFD. State of the art CFD is relatively precise but very time consuming and costly.

Build a model of a given particle to describe particle path and retention time. The model should account for the reducing flue gas temperature through the boiler and the impact of the secondary air injection on the flow and temperature. The model should include drying, pyrolysis and combustion while density and size are reduced.

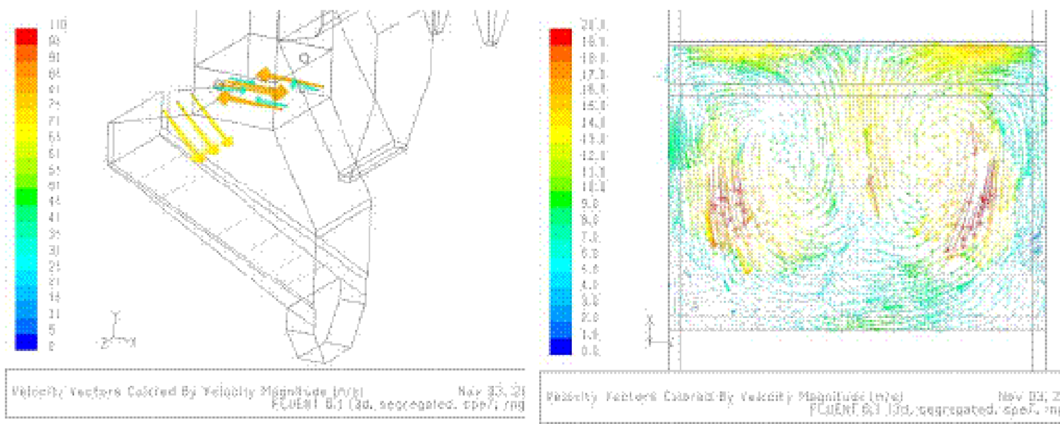
Status for NO_x models in combustion

Until this point the NO_x models have been very complex and difficult to implement on a feasible CFD model with adequate precision.
Evaluate state of the art NO_x models and test the best available model in a CFD model. Compare results from the CFD model with results from a BWV plant as well as results from experiments on the small scale batch reactor at CHEC.
Measurements from a plant can be evaluated and analysed for the influence on NO_x formation of different combustion air configurations.

Investigate ability to resolve air jets with OpenFoam

The secondary air is injected at high speed by use of nozzles. BWV would like to know how good correlation there is between the CFD model from a commercial CFD code, OpenFoam and experiments. How should the CFD model be constructed in order to capture the secondary air jets sufficiently with respect to entrainment and mixing and how good is OpenFoam compared to commercial CFD code?

Furthermore, BWV utilizes a mixing principle called Volumix™; this principle enhances mixing of the secondary air and flue gases in order to promote combustion of the combustible gases. The principle is based on special placement of the injection nozzles. BWV would like to have the principle investigated experimentally and numerically. BWV is also interested in suggestions for more optimal configuration of the nozzles.



Build a CFD model of a small scale test setup and compare results from different setups with experiments. Conduct experiments on the small test setup with LDA and PIV measurements.

Investigate the importance of the grid resolution

The common practise from BWV engineers today is to make a rather crude grid. BWV would like to get an estimate on the size of the introduced error, and a suggestion for best practice when taking results and computational time into account.

Results from an existing CFD model of a plant is validated with different strategies for refining the grid and compared with measurements from the plant.

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