Innovation with CFD

Solutions and Equipment
Why our customers choose us

According to our customers, we:

- Possess exceptional experience in our chosen technologies
- Possess unique abilities in both waste disposal and bio-fuels
- Understand the details as well as the big picture
- Have a strong environmental commitment
- Are honest and open-minded partners
- Never compromise on the end result
- Never walk away from an unfinished project, no matter how difficult it is
- Are highly competitive
- ISO 9001:2008 certified quality system

Innovation with CFD
Solutions and Equipment

_Babcock & Wilcox Vølund is one of the world's leading suppliers of equipment and technologies for converting waste and bio-fuels into thermal energy._

Our solutions uniquely combine:
- High-quality products
- Broad multi-disciplinary experience
- Use of the latest know-how within heat transfer and combustion
- Strong project management skills
Facts at a glance

- Headquarters in Esbjerg, Denmark and branch office in Copenhagen, Denmark
- 100% owned by Babcock & Wilcox Power Generation Group, Inc.

More than 500 production lines have been built based on our technologies. Many of these are still in use today.

Our companies currently employ over 10,000 people worldwide – approximately 400 are employed by Babcock & Wilcox Vølund.
A pioneer in the industry

Babcock & Wilcox Vølund has more than 80 years of experience in designing waste-to-energy and bio-fuel plants.

We have been using state-of-the-art CFD design tools since 1996. B&W Vølund uses the CFD software Fluent, which is the CFD software with the most extensive waste incineration and boiler specific reference list.

Babcock & Wilcox Vølund has developed sub-models to optimise the application of CFD to the waste-to-energy industry. These sub-models were developed in co-operation with the Sheffield University Waste Incineration Centre (SUWIC). On-going development of our sub-models is carried out in co-operation with Lunds Technical University, Aalborg University, The Technical University of Denmark and the Danish industrial research centre Force Technology.

CFD is today one of the major keystones in our technology design.

CFD is a simulation tool which uses a number of mathematical methods for handling physical and chemical phenomena. Detailed knowledge of these methods is required to carry out the analysis. A CFD analysis provides a detailed representation of the combustion process, flow field and heat transfer. The tool is therefore excellent for simulating industrial processes. The detailed chemical and physical information obtained for plants by CFD helps us create the best solution for our customers.

CFD gives B&W Valund the ability to check the design with respect to a large number of critical factors such as velocities, particle impingement, oxygen level, temperature and surface temperature. The customer will therefore receive a plant which is optimised for better environmental performance and which can provide longer and more reliable operation.

Factors such as the locations of air injection nozzles, wall heat transfer properties and local geometry features are therefore all investigated thoroughly during the design phase.

Babcock & Wilcox Vølund uses CFD analysis to deal with issues such as:

- Longer lifetime through optimum flow and temperature conditions
- Redesign due to changing calorific values of fuel
- Increasing plant capacity, in some cases by as much as 25%
- Injection of cooling water, leaching water or sludge
- Optimisation of combustion air
- Optimum burner position
- Verification of residence time
- Emission control
Innovation with CFD

CFD simulations are carried out, when designing a new plant, to determine the geometry of the furnace and boiler, positions of air inlet nozzles and burners and the expected temperature distribution.

Using CFD analysis ensures very high quality design, which B&W Vølund is recognized for.

We place great emphasis in the design phase on achieving uniform flow through the boiler, as this gives the most efficient heat transfer, lowest wear and corrosion risk and optimum retention time in which combustion can take place.

Secondary air is added via nozzles in the furnace front and back ceiling and at one or more levels in the first boiler pass. The nozzles in the first boiler pass generate the VoluMix™ system.

The VoluMix™ system generates the micro and macroscopic mixing which is required to ensure final burn-out of CO and particles.

New plant
Service Case

When a plant needs to be upgraded, we combine CFD analysis with the experience available at B&W Vølund to provide solutions to the many technical problems in the waste-to-energy and biomass combustion industry. CFD is a very efficient method for evaluating different design alternatives which otherwise are too expensive, too time consuming or impossible to test in an operating plant.

We, working with the customer, analyse the present situation at the plant and verify solutions to ensure we arrive at optimised plant operation.

For example, optimal design of the secondary air system will solve problems such as high emission levels or poor particle combustion. Optimisation of the secondary air system in many cases will also increase capacity.

The location of secondary combustion air nozzles and air jet velocity are the two major design parameters for the secondary combustion air system.

Secondary air nozzles before optimisation. The air is distributed across four locations and injected at relatively low velocities. One row of nozzles in the front ceiling, one row in the top ceiling and four nozzles on each side over the last grate.

Secondary air nozzles in the optimised case. Air is injected through two high speed nozzles in the front ceiling. Vectors indicate the direction of secondary air flow and the location of nozzles.
The velocity distribution before (left side) and after (right side) optimisation. Velocity vectors before optimisation (left) indicate bulk flow heading directly from the grate to the entrance of the boiler. A large recirculation zone occupies the front of the furnace. The entire furnace volume is therefore not used for combustion. After optimisation (right), the gas mixture leaving the grates is drawn towards the front of the furnace and mixed with air from the ceiling nozzles and burned, before leaving the furnace.

Before optimisation (left), CO combustion is not completed at furnace outlet. After optimisation (right), the secondary air system creates a vortex which draws the CO into the front of the furnace, thus enabling complete CO burnout.

Temperature distribution (°C) for the same furnace. Comparison of the temperature distributions shows that heat is concentrated at the front of the furnace (right) due to CO combustion. This further accelerates waste drying. Waste load may therefore be able to be increased, depending on the capacity of the rest of the plant.
A CFD model is based on control volumes. The furnace and boiler which are to be modelled are divided into small volumes. These volumes adjoin each other or the wall, the outlet or the inlet. The momentum, the mass and the energy conservation equations are solved for each control volume. The quality of the solution is therefore to a great extent dependent on the number, shape and position of the control volumes.

In addition to solving the momentum (Navier-Stokes), mass and energy conservation equations, the equations describing turbulence, chemical reactions, transport of particles and radiation are also solved.

A large proportion of the energy recovered from waste (between 30% to 50%) is released as combustible gases (CO, H₂, CH₄, etc.) in the furnace. Gas phase combustion is therefore also modelled to describe the entire combustion process. Incineration in the solid fuel bed is simulated using a separate empirical model that is based on test data.

Radiation contributes more than 90% of heat transfer in the furnace and the first pass of the boiler. Radiation modelling is therefore essential if a correct image of temperature and flow are to be obtained.

Particles contribute to the heat release and heat transfer. Depending on the type of feeding and grate system the heat release due to particles vary from 5% - 70% of the total heat release. For a suspension type feeding system the heat release produced by particles is high and for a pusher type system it is low. The transport and combustion of particles are therefore also modelled.

Flow

Transport of fluid is described by an impulse momentum equation for each dimension (3D) and a mass conservation equation. The impulse momentum equation (Newton’s Second Law) describes how impulse, pressure and viscosity forces influence the fluid in the cell. The impulse momentum equation for fluids is known as the Navier-Stokes equation.

Mass conservation is the other basic equation. Mass neither arises nor disappears in a control volume unless otherwise specified by the user. Combining the impulse momentum equation with the mass conservation equation allows us to create an expression for the three velocity vectors and the pressure for each cell.

Turbulence

Turbulence plays a major role in flow. When the viscous stresses in the fluid reach a specific level, the laminar flow pattern will break up and small vortexes are formed. New vortexes are formed and broken down to even smaller vortexes. The majority of these vortexes are considerably smaller than the cells in the CFD model. Turbulence in the CFD model is therefore described using a separate model.
Buoyancy

Buoyancy play a important role in thermal flow where there are large temperature differences. The flue gas is cooled as it passes along the walls in the two radiation passes. The cooled flue gas found along the walls is heavier than the flue gas in the middle of the pass. Hot flue gas will rise and cold flue gas will fall. There is therefore a balance between gravity of the cooled fluid and the amount of movement in the hot flue gas.

Heat transfer

Wall boundaries are all modelled as reflective and adjusted to the expected heat transfer, which is dependent on the covering of the boiler walls.

Heat transfer in furnaces and boilers is controlled by radiation. The majority (70-100%) of heat transfer from gas to boiler wall and gas to gas is by radiation. Radiation is modelled using the DO (Discrete Ordinates) model, which is a discrete beam model. The DO model is very suitable for situations where there are large variations in temperature and emissivity. The CFD model also includes convection and heat conduction.

Combustion

Combustion can be subdivided into a number of different phases:

- DRYING OUT
- PYROLYSIS
- IGNITION
- GASIFICATION
- COMBUSTION
- CARBON COMBUSTION
- SLAG FORMATION

The processes that take place in the fuel layer on the grate are simulated by a special standalone software program developed by B&W Vølund. The effects of the fuel layer processes are included in the model by adjusting the source terms in the modelled fuel layer.
The chemical reaction model must include the main flue gas components (N₂, CO₂, H₂O and O₂) if the thermal properties of the flue gas are to be successfully modelled. Gas phase combustion should contain the primary gasification products. The global reaction scheme in the CFD simulation is divided into the following detailed reaction scheme of three reactions:

\[
\begin{align*}
\text{CH}_4 + 1.5 \text{ O}_2 & \rightarrow \text{CO} + 2 \text{ H}_2\text{O} \\
\text{CO} + 0.5 \text{ O}_2 & \rightarrow \text{CO}_2 \\
\text{CO}_2 & \rightarrow \text{CO} + 0.5 \text{ O}_2
\end{align*}
\]

The first two reactions are limited by the mixing and the reaction rate. The last backward reaction is controlled by the reaction rate alone.

**Particles**

Particle substances are carried away from the fuel layer during combustion. These solids or particles contain combustible material which can be seen in the furnace as visible yellow flames.

These particles will follow the flow, combustion and consuming oxygen and releasing heat and combustion products. These particles will also change the radiation properties of the gas. Consequently, the optical thickness of the gas will increase giving higher levels of radiation. Further particles impinging on the heated surface are a corrosion factor.

**Combustion Air**

Combustion air is subdivided into four main groups:

- PRIMARY AIR
- SECONDARY AIR
- TERTIARY AIR
- COOLING AIR

The volume of primary air needs to be adjusted so that there is sufficient air at the grate.

Secondary air is added via nozzles at the furnace front and back ceiling and in the first boiler pass.

The secondary air system must be designed so that it can handle CO released from across the entire grate, because dry fuel will gasify at the front end of the furnace while wet low quality fuel will gasify in the middle of the furnace. It can furthermore be expected that irregularities in the fuel will cause increased short time CO release from all parts of the grate.
Gas phase burn-out is principally controlled by four factors:

1. TEMPERATURE
2. CONCENTRATION OF $O_2$
3. TURBULENCE
4. RETENTION TIME

Flue gas temperatures must be above 800 °C for high chemical reaction rates for the combustion of CO to be achieved.

Turbulence is very often the parameter which has the greatest influence on CO burn-out. CO and $O_2$ must therefore be brought together for CO combustion to take place. The reaction between CO and $O_2$ to form $CO_2$ takes a few milliseconds. Microscopic pockets of CO rich areas, $O_2$ rich areas and $CO_2$-rich areas are created in the flue gas. Both micro and macroscopic mixing is therefore required to bring these pockets of CO and $O_2$ together.

Secondary air nozzles are required to create about this mixing (= turbulence). Secondary air will add ‘mixing energy’ to the furnace area – the more energy added, the better the burn-out. The location and the number of nozzles is an important factor, as we want mixing to be carried out in the correct areas.

Wood chips burning in suspension. Coloured according to particle diameter and state of combustion.
As the process requires a certain reaction time, residence time is an important factor in the determination of the degree of burn-out. Residence time however primarily influences processes which are diffusion controlled – i.e. particle combustion. After particle gasification, there is a comparatively long sequence in which the remaining solid carbon content is combusted. If oxygen is present, it will diffuse towards the surface of the particle where it reacts with the carbon releasing CO and CO$_2$. It is therefore important that particles have a long residence time in the presence of oxygen and sufficiently high temperatures (>800 °C) if a high degree of burn-out is to be achieved. This is primarily secured by the flow pattern in the furnace and 1. pass of the boiler.
Lectures and publications


Ole Hedegaard Madsen; NUMERICAL MODELLING OF FURNACES AND BOILERS, Copenhagen Waste & Water 97, Copenhagen, Denmark, 1 - 4 April 1997.

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Kenneth Jørgensen, Ole Hedegaard Madsen; MODERN CONTROL SYSTEMS FOR MSW PLANTS, Second International Symposium on Incineration and Flue Gas Treatment Technologies, Sheffield University, UK, 4-6 July 1999.


Ole Hedegaard Madsen; NEW TECHNOLOGIES FOR WASTE TO ENERGY PLANTS, 4th International Symposium on Waste Treatment Technologies, Sheffield, UK, 29 June – 2 July 2003.


Long reference list

CFD analysis provides a detailed representation of the combustion process, flow field, and heat transfer. The detailed chemical and physical information obtained for plants by CFD helps us create the very best solution for our customers.

We have been using the CFD design tool on more than 120 projects since 1996. We use CFD when we design new plants and in our service business when upgrading older plants.
Babcock & Wilcox Vølund is one of the world’s leading suppliers of equipment and technologies designed to convert waste and bio-fuels into thermal energy.

Founded in 1898 and headquartered in Esbjerg, Denmark, the company is 100% owned by Babcock & Wilcox Power Generation Group, Inc. in Barberton, Ohio, USA.

Our companies currently employ over 10,000 people worldwide of which over 400 are employed by Babcock & Wilcox Vølund.