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## **Advanced plant upgrades using modern technology and design tools**

*Increasing the combustion capacity and the performance of existing waste to energy plants*

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### **Abstract**

The amount of municipal solid waste is still increasing and the calorific value of the waste is steadily growing. The combined result is an increasing demand for new thermal treatment capacities. An alternative solution to new waste-to-energy projects is an expansion and technical upgrade of existing incineration plants. This is an advantageous option for waste management companies because they avoid the NIMBY syndrome and the difficulties in getting permits for green field projects. Furthermore, the investment cost per tonne burned waste is less than that for a new incineration line.

This paper will present the basic ideas and principles used in upgraded projects. The core of the technology is a combination of a new furnace design, new water cooled wear zones and combustion grates and new control systems. Moreover, CFD modelling is an important tool in the design phase, and the paper gives a demonstration of the flow design process applied at Babcock & Wilcox Vølund. CFD gives the designer the possibility of checking the design for a large number of critical factors such as velocities, mixing of combustion products and secondary air, oxygen and CO concentration, temperature, surface temperature, corrosion etc. This ability is extremely valuable in the case of expansion of existing incineration plants because many of the process parameters have to be within the limits of the old plant.

## Introduction

Growing levels of waste separation and recycling are leading to slight, but significant increases in the calorific value of the "waste" materials that are left for thermal treatment. As a result, the combustion capacity at the existing plants is decreasing. The combined result is an increasing demand for new thermal treatment capacities.

In many areas of North America, Europe and Asia, the "not-in-my-back-yard" (NIMBY) syndrome has caused major problems with the development and construction of new waste handling facilities, especially waste-to-energy schemes. This social problem means that local residents are not prepared to accept the unavoidable nuisances that are inherent to nearby waste management facilities or plants.

This can be a particularly important problem in countries that still need to raise their treatment capacities (for example, for thermal treatment) significantly in order to reduce reliance on land-fill. Local opposition of this kind can dramatically delay waste-to-energy projects or, in the worst cases, lead to the refusal of planning permission.

An alternative solution to new waste-to-energy projects are expansion and technical upgrade of existing incineration plants. This is an advantageous option for waste management companies because they avoid the NIMBY syndrome. Furthermore, the investment cost per ton burned waste is less than that for a new incineration line. At the same time, the plant has to live up to a new, strict EU legislation [1].

## Basics of capacity increase

When looking for new designs of a plant there are several issues, which are essential to be considered prior to a design change. There are often bottlenecks in the system which will limit the possible capacity increase. Some of the bottlenecks can be eliminated by replacing components, while the economical consequences of other bottlenecks are too large for a feasible revamp. The main components in a waste-to-energy plant are:

- Combustion grate
- Boiler
- Air pollution control (APC) equipment
- Turbine & generator
- BOP (pipes, fans, pumps, etc.)

In this paper the main issue is to examine the plant ability of increasing the waste throughput and thereby raising its capacity. At the same time it has been under consideration that the calorific heating value of the waste is increasing. Less attention has been given to the air pollution control equipment and to the steam turbine. In the former case the most important parameter is the flue gas flow which has to be kept constantly and in the latter case surplus energy can be transferred to the surroundings.

To achieve this goal it is necessary to consider the performance of the different parts of the system with the new changes. Typically, it is possible to increase the waste throughput by 10% to 25%. The main points to be considered are as listed below:

- Ability to raise the throughput capacity of the incinerator.
- Combustion grate performance at higher capacity limited by the static and thermal grate load.

- Boiler performance after revamping. The amount of flue gas will increase as the capacity is increased. Naturally, the critical issues here are the maximum velocity in the boiler part and the temperature raise in the boiler.
- Capacity raise will change the whole flow field. Critical and high velocities are important to be avoided, if possible, to minimize the risk of corrosion and fouling. Therefore, it is important to examine the conditions near the boiler wall.

### The principle of constant flue gas amount

The amount of flue gas should not exceed the design value calculated for the maximum continuous rate **MCR**. If the amount of flue gas exceeds the design value for MCR, corrosion and fouling problems in the boiler are expected, the exit temperature of the boiler will increase, the flue gas cleaning system is unable to cope with the flow, the blowers and ID-fan are too small, etc. Therefore, it is necessary at high load to reduce the excess air number in order to lower the flue gas amount.

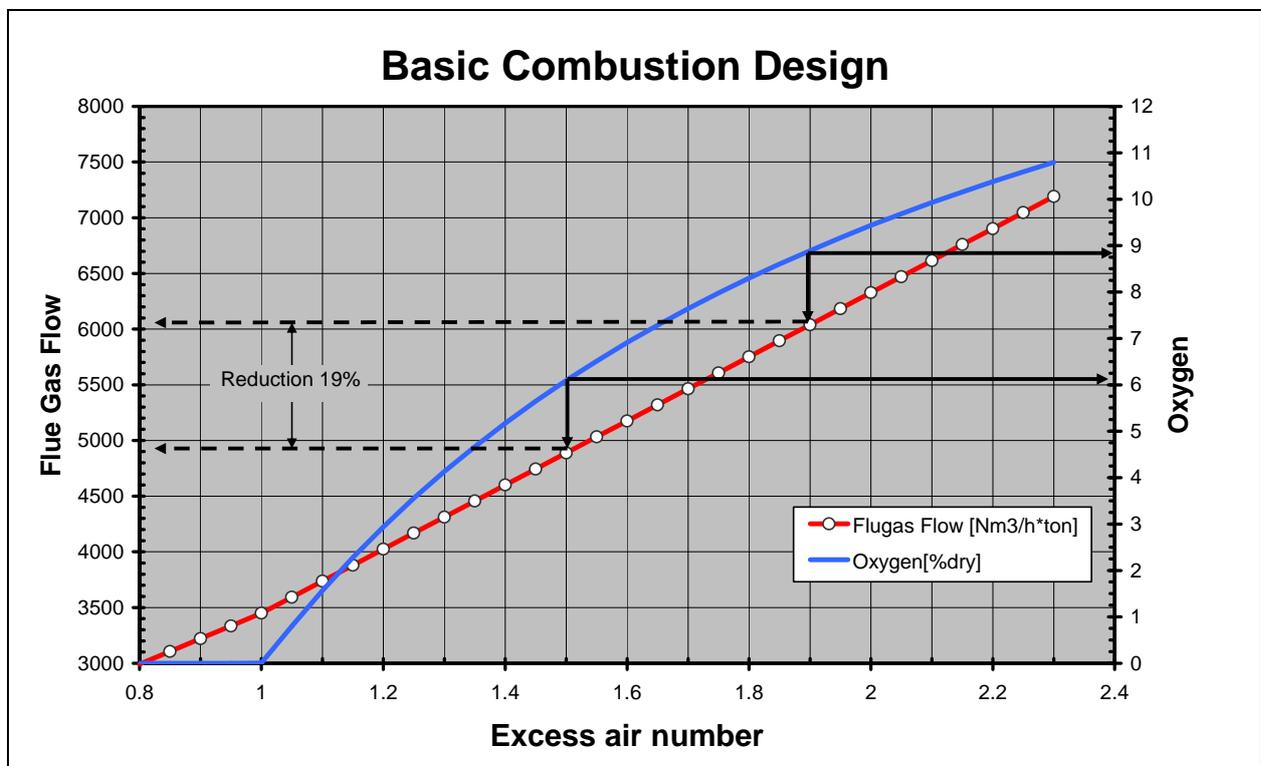


Figure 1 The principle of constant flue gas amount

Figure 1 is illustrating the basic idea. The x axis is the excess air number and the blue line without any symbols is the oxygen content in the flue gas. A typical old plant will be operated with a relative high excess air number around 1.9 corresponding to approximately 8.8 % oxygen. The red line with the round symbols is the flue gas flow per hour for 1 ton MSW. At an excess air number around 1.9 the flue gas produced per tonne waste is 6100 Nm<sup>3</sup>/h·ton.

If the excess air number is reduced to 1.5 the corresponding oxygen content is around 6 %. The flue gas flow is decreasing to 4900 Nm<sup>3</sup>/h·ton and the reduction in the flue gas flow is 19 %. This reduction can be used to increase the waste throughput as long as the excess air number is kept at the new low level.

Moreover, lower excess air number will result in a lower NO formation from the fuel bed and front part of the furnace. The changed stoichiometric rate will result in an increased flow of unburned gases into the furnace room. The energy released from the combustion process will move from fuel bed to furnace room and a large part of the furnace room will be operating under

slightly fuel-rich conditions. In that way, it is possible to stage the combustion process and reduce the  $\text{NO}_x$  formation [2, 3]. Lately, BWV has made tests with operation at oxygen levels around 4½ % - 5 % resulting in NO levels in the range 150 – 200 mg/Nm<sup>3</sup>. Another advanced is the improved overall thermal energy efficiency, because of the reduced flue gas loss [4].

There are two side effects from this method. The rising waste throughput will result in increasing amount of ashes including fly ash which increase the risk for fouling in the boiler. Furthermore, the concentration of corrosive element such as Cl, S and heavy metal will increase and thereby the risk for boiler corrosion.

Temperature rise is another issue to be considered. When increasing the thermal input to the furnace and lowering the excess air number means that the temperature in the furnace and boiler will increase.

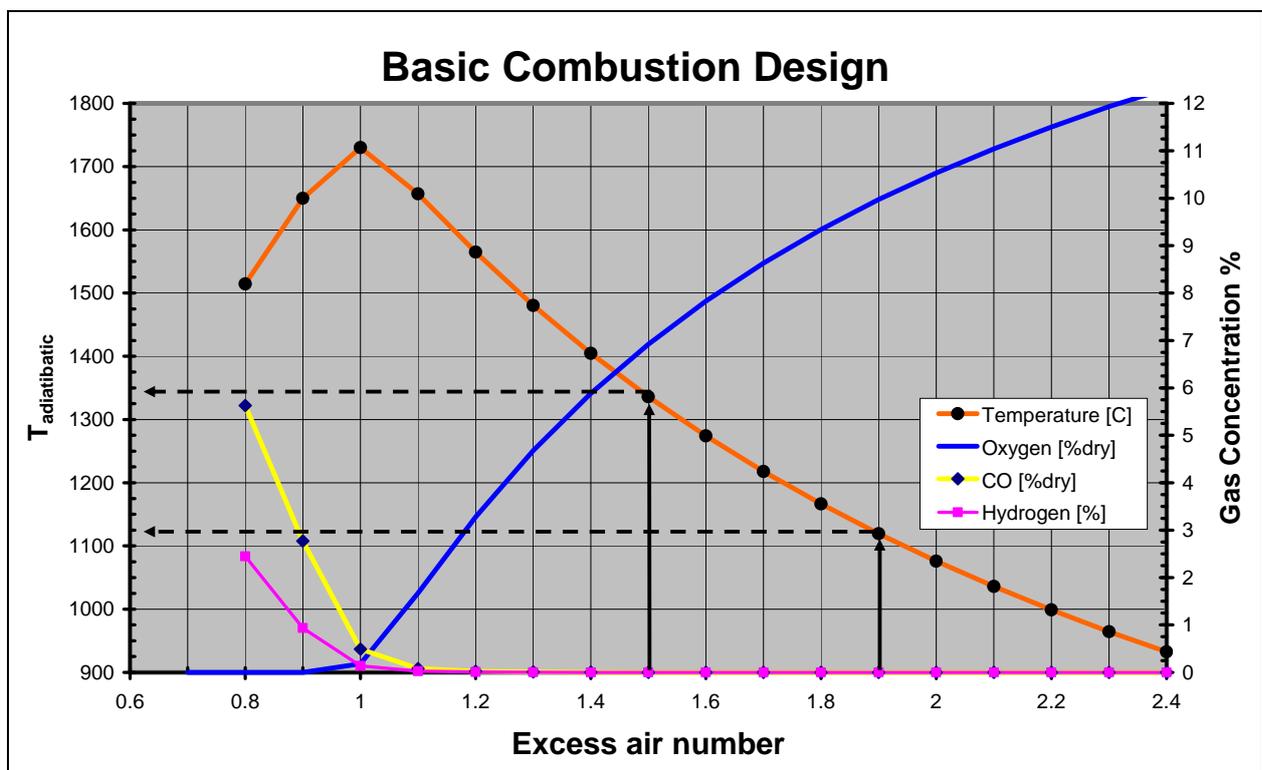


Figure 2 Adiabatic combustion temperatures as function of excess air number

In figure 2 the theoretical calculated adiabatic combustion temperature is shown as function of excess air number. The blue line is the oxygen content in the combustion product at different excess air levels. At excess air numbers less than 1 the combustion process will be incomplete and gasification processes start to be more dominating. The result can be seen in figure 2 where carbon monoxide and hydrogen starts to be present in the combustion products. These combustible gases reduce the adiabatic combustion temperature, because not all of the chemical energy is released in the process. Therefore, the maximum temperature is achieved at an excess air number of one.

The adiabatic combustion temperature is a theoretical maximum temperature that can be obtain if the losses or heat exchange to the surroundings is zero. In practice this is of cause unrealistic, but the curve can be used relative to estimate the difference between to excess air levels. In figure 2 the temperature difference between excess air numbers 1.5 too 1.9 is approximately 225°C. The calculations shown in figure 2 are based on the same element analysis for a typical MSW composition. In practice, the original design heating value 15 too 20 years ago is less than the actual heating values experienced today and the temperature increase is therefore higher than indicated

by figure 2. The higher heating values can cause a need to install a water cooled combustion grate [5]. Finally, the primary combustion air can be controlled without consideration to cooling of the grate bars. Moreover, water cooled combustion grates give a number of other advantages, such as lower maintenance cost, reduced amount of grate riddling and less problems with melted metal.

For design purpose the actual heat and mass balance must be calculated in order to determine the amount of energy there has to be removed in order to keep the flue gas temperature at the same levels.

To be able to keep an acceptable temperature level in the furnace there are three possible options:

- Use water injection.
- Install or increase the surface area which is water cooled
  - Water cooled wear zone in the furnace
  - Membrane baffle walls in the 2 or radiant draft in the boiler
- Flue Gas Recirculation.

Water gives approximately 4.6 times more cooling per kg than secondary air. Therefore, cooling can be achieved by replacing secondary air with water without an increase of the flue gas amount. This solution has a low investment cost, but introduce a significant heat loss as the evaporation energy cannot be recovered.

Compared to water injection, an increased evaporator wall surface will mean higher steam or energy. However, the extra steam can be a problem for the steam cycle, and water injection is a more controllable method. A water cooled wear zone above the grate is a very effective method to absorb heat from the furnace [5]. The heat transfer is typical in the range of 75 kW/m<sup>2</sup> too 100 kW/m<sup>2</sup>. The low surface temperature on the steel tubes that is a part of the wear zone will prevent that clinker is building up just above the burning waste layer. In severe cases, the clinker will disturb the combustion process and the plant has to be taken out of operation for cleaning.

Some time the flue gas temperatures in the radiant part of the boiler has to be reduced before entering the convection part in order to avoid fouling and corrosion. This can be done by introducing membrane baffle walls in the 2 or radiant draft in the boiler. The final design will be based on a detailed heat transfer calculation for the boiler and many times it will be profitably to install inline hydro boiler cleaning systems [5]. Finally, increasing the pressure part in the boiler is typical much more expensive but the long term benefit are very positive and will often give a good payback time of the investment.

Recirculated flue gas can cool the furnace without the demand for more air. However, the flow of flue gas through the boiler and electrostatic precipitator will increase. Furthermore, a flue gas recirculation system is difficult and expensive to maintain and the operator dont obtain any process advantage with the system.

As it is important to be below a maximum flue gas volume flow in the boiler, the control philosophy for the waste fired plant is very important. Today, new advanced combustion control systems are able to control the process automatic with a minimum of process variations and thereby it is possible to run the plant very close to the MCR level [5, 6].

In order to achieve the best possible design of the system, Babcock & Wilcox Vølund uses Computational Fluid Dynamics, CFD, programs as a tool for detailed engineering. CFD simulation is an effective method for evaluation of different design alternatives that are otherwise too expen-

sive, time consuming or impossible to test [5]. Computational fluid dynamics is a method used for solving the fluid flow and heat transfer equations with numerical methods.

## Expansion and technical upgrade of existing plants

In the following part of the paper, two examples of expansion and technical upgrade of existing incineration plants will be discussed. For the present analysis, the focus will be on the combustion grate, furnace and boiler.

### *Nordforbrænding NF, line 1, 2 and 3*

NF three old combustion lines have been upgraded in two steps. The objective with the first upgrade was to comply with the new EU directive for waste to energy plants [1]. The upgrade includes a new combustion control system, start-up burners and a new secondary combustion air system. A CFD calculation of the plant was carried out and the result was used to examine the flow field and heat transfer in the boiler. Moreover, the analysis was used to design and locate a water injection nozzle system in order to cool the furnace when the excess air was reduced.

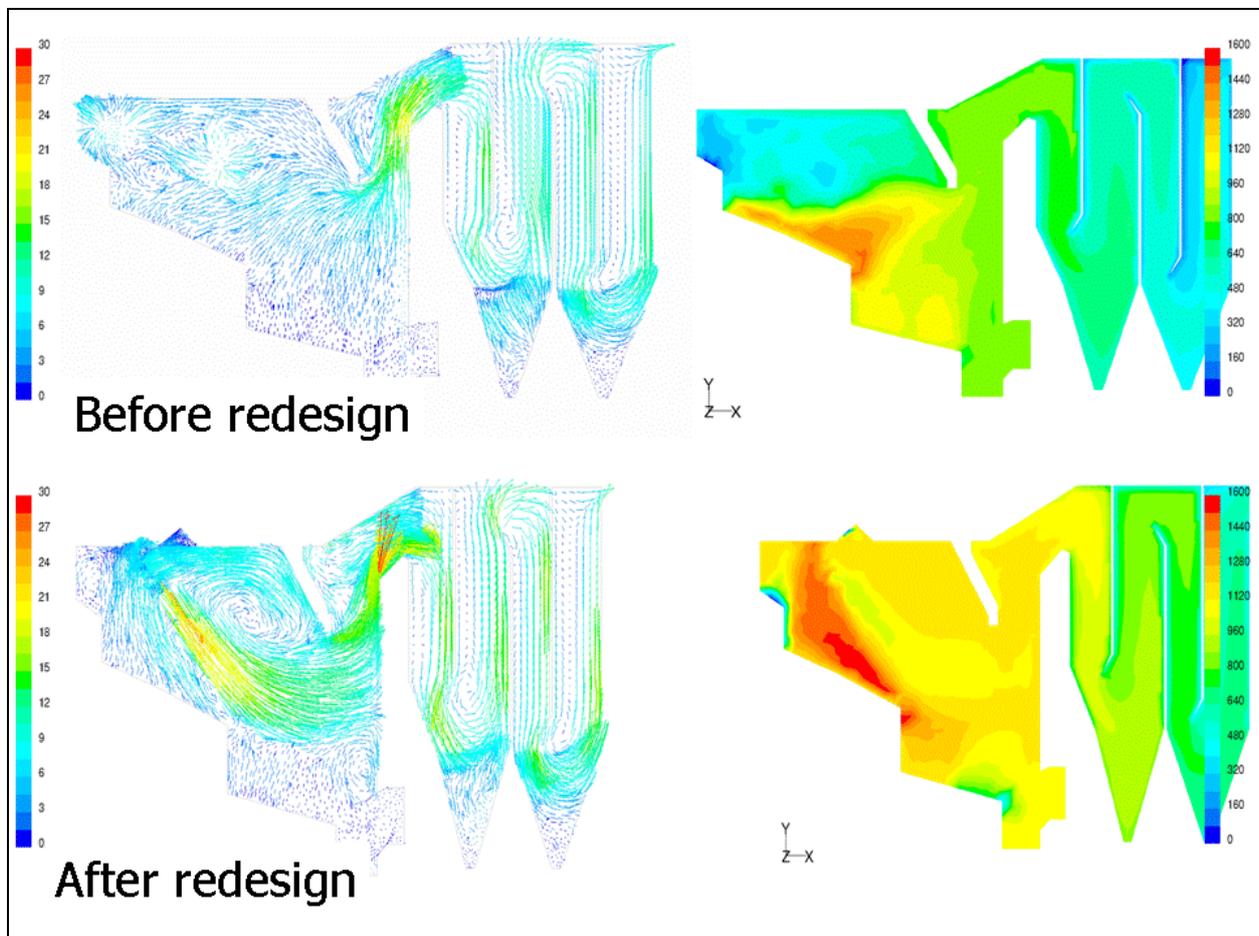
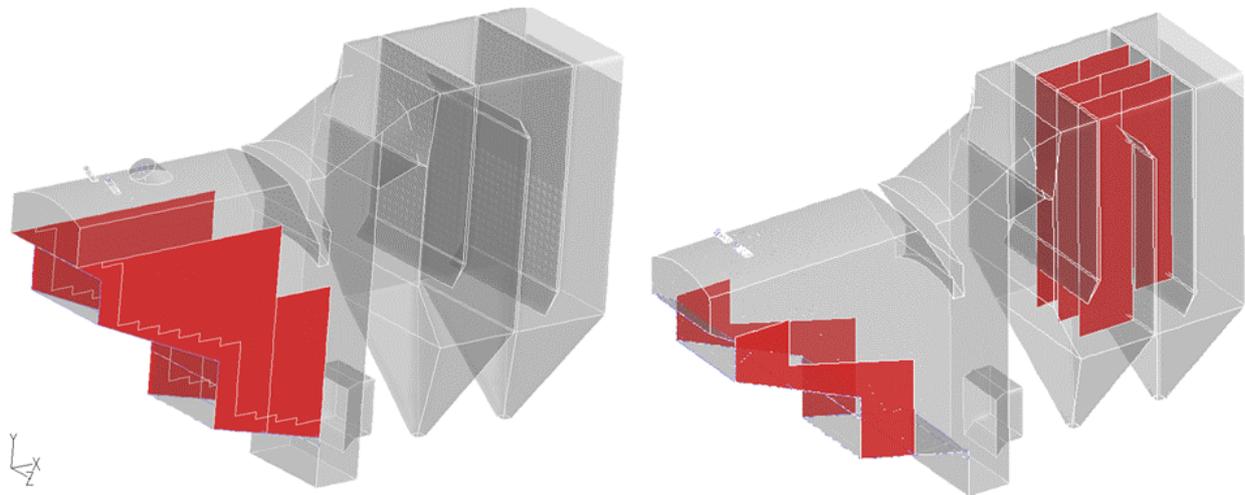


Figure 3 Flow field and flue gas temperature before and after redesign of secondary air system SA

The old furnace design was made with 4 side wall secondary nozzles where as the new CFD design is with 2 powerful nozzles in the furnace ceiling. The result is a large vortex in the furnace that mixes the flue gases very well and thereby creates a much more uniform temperature distribution in the furnace. Before redesign of the secondary air system the upper part of the furnace was cold and an ineffective part of the heat uptake in the furnace. The secondary air jets picks up hot gas from the top of the bed and moves it forward in furnace as designed. In this way, good ignition and drying conditions have been created in the front of the furnace resulting in a fast and stable ignition process.

The result was a achieved and the plant emissions and residence time requirement could fulfil the EU directive. Furthermore, the capacity for each line was increased from 2.65 t/h too 3.0 t/h.

The second steep was further increase of throughput and on the same time lower the temperature profile in the boiler. The maximum capacity of the combustion grate was calculated to be 3.4 t/h waste with a heating value of 10 MJ/kg. In order to obtain both goals it was necessary to re place the water injection nozzle system with water cooled wear zones and baffle membrane walls I the boiler.



**Figure 4** Two different design options – the red areas are new extra water cooled membrane walls.

Figure 4 illustrates two different design strategies for the upgrade, one with extended large water cooled wear zones in the furnace and one with smaller wear zones in the furnace combined with 3 baffle membrane walls in the second and third radiant pass of the boiler. In both cases the extra heat uptake was the same and designs in order to balance the extra waste throughput. Both cases were simulated with the CFD tool. The case with the extended large water cooled wear zone was rejected because of the EU directive demand of 2 second of resident time above 850°C. The heat uptake in the furnace became to high and the cooling of the flue gases were to rapid.

Case	MSW	H <sub>o</sub>	Q	Flue gas	O <sub>2,drv</sub>	T <sub>res</sub>	T <sub>rad-b</sub>
Unit	ton/h	MJ/kg	MW	Nm <sup>3</sup> /h	%	sec	°C
<b>Old design</b>	<b>2.30</b>	<b>11.1</b>	<b>7.09</b>	<b>21726</b>	<b>12.3</b>	<b>~1</b>	<b>386</b>
<b>1 Redesign</b>	<b>3.00</b>	<b>11.1</b>	<b>9.24</b>	<b>20598</b>	<b>9.2</b>	<b>2.5</b>	<b>597</b>
<b>2 Redesign</b>	<b>3.40</b>	<b>10.0</b>	<b>9.44</b>	<b>18321</b>	<b>7.2</b>	<b>2.1</b>	<b>511</b>

**Table 1** Main process data for the upgrade of the Nord Forbrænding NF plant

In table 1 the overall process data are shown for 1 line. The capacity for each line has be increased from 2.3 too 3.4 t/h or more than 47% and at the same time the flue gas flow have been kept at a lower level than the original operating condition. In the second upgrade it can be noticed that the outlet temperature of the radiant part of the boiler is slightly reduce despite of the lower excess air. By upgrading all 3 lines the total yearly capacity has been increased with 26400 tonne.

### Amagerforbrænding AF line 4

AF4 is one out of four combined rotary kiln and combustion grate plants built in 1990 and the first three was built in the early 1980. The four lines are equipped with steam boilers and turbine (48 bars, 380 °C) for electricity production.

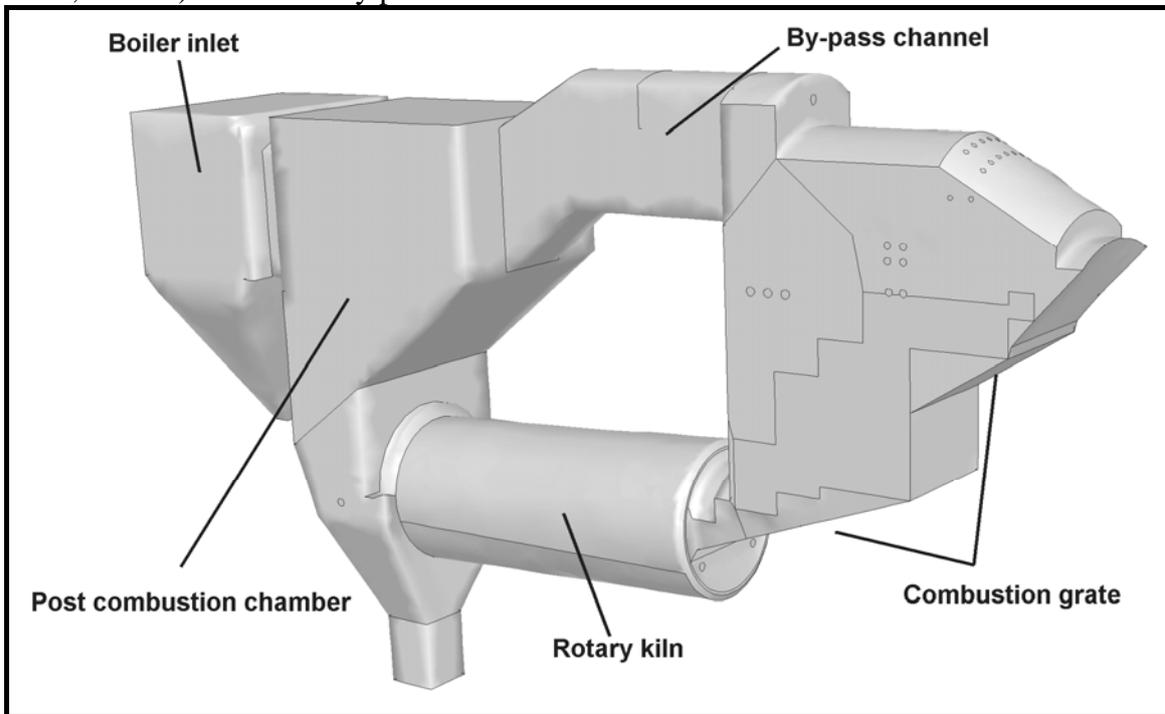


Figure 5 AF4 plant layout before rebuilding

Figure 4 shows the plant as it was set up in Fluent for the CFD analysis. The main reason for redesigning the AF4 was to increase the throughput capacity and the target was an increase of 25%.

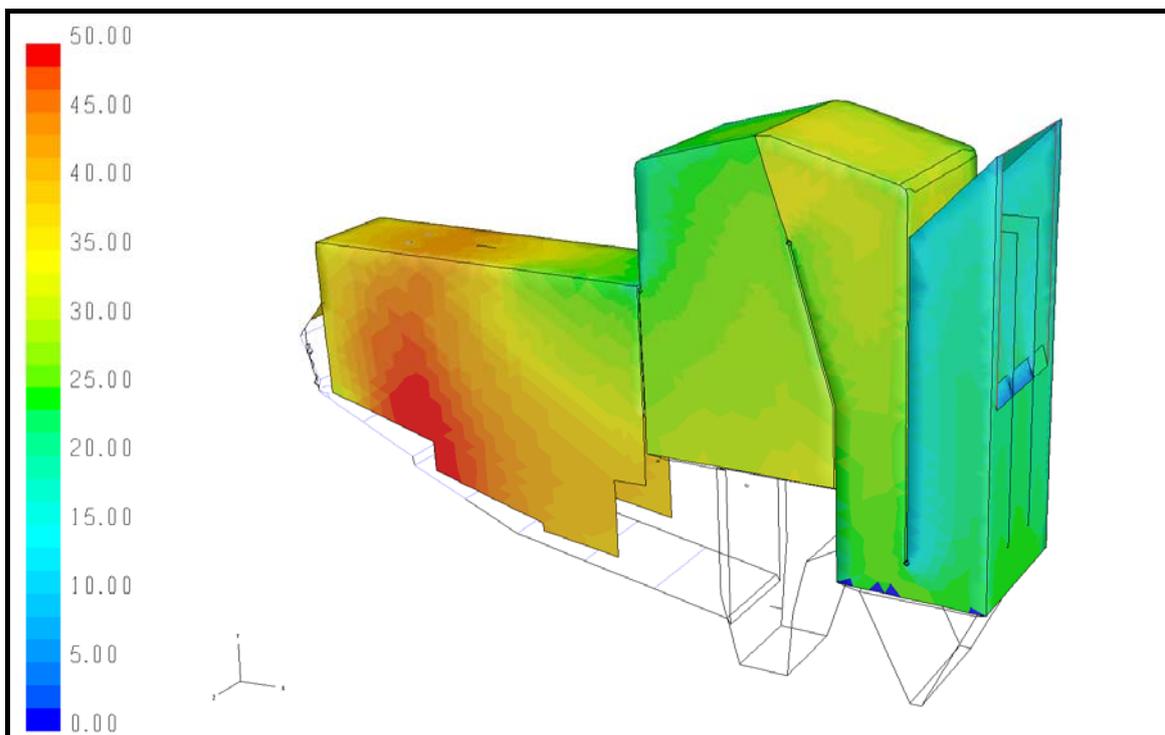


Figure 6 The new water cooled furnace and boiler construction. The surface colour mapping is showing the heat load expressed in kW/m<sup>2</sup>

In the new design the rotary kiln has been removed and replaced with new combustion grates. The by-pass channel has been removed and the furnace was expanded and made of water cooled evaporator walls protected by refractory. The secondary air system and the inlet conditions to the post combustion chamber were redesigned by CFD modelling. Finally, the economizer was expanded in order to lower the outlet temperature out of boiler and thereby raise the thermal efficiency.

In table 2 the old design data and the new design data are listed. Furthermore, the process values measured during the guarantee test are shown in the last row. At the function and guarantee test the plant was actually operating at 110% load. The results in table 2 demonstrate that the throughput is increased; the achieved capacity is 16 ton/h corresponding to an increase of 33%. The new water cooled furnace made it possible to operate the plant at very low oxygen level without high temperatures or CO problems. The result is a low flue gas flow that easily can be handled by the old boiler parts and the existing flue gas cleaning system.

Case	MSW	H <sub>0</sub>	Steam	Flue gas	O <sub>2,dry</sub>	LOI	Efficiency
Unit	ton/h	kcal/kg	ton/h	Nm <sup>3</sup> /h	%	%	%
Old design	12	2500	37	85600	12.3	< 3	79.6
New design	15	2500	51	80300	7.45	< 2	84
Guar. Test	17.7	2270	56	65790	6.2	1.4	85.4

**Table 2 Main process data for the upgrade of the Amager Forbrænding AF line 4**

Subsequently, Babcock & Wilcox Vølund was upgrading the remaining three old lines with the same concept. The final result gave Amagerforbrænding a new extra throughput capacity of 16 ton/h and a significantly higher steam production. The extra steam flow will be used in a new turbine.

## Conclusion

An alternative solution to new waste-to-energy projects is an expansion and technical upgrade of existing incineration plants. The main reason for redesign is to increase the throughput capacity and compensate for the rising calorific value. Babcock & Wilcox Vølund has demonstrated that it is possible to reach an increase of 25% - 30%.

The paper gives a demonstration of the working process applied at Babcock & Wilcox Vølund. CFD gives the designer the possibility of checking the design for a large number of critical factors such as velocities, oxygen concentration, temperature, surface temperature etc. This ability is extremely valuable in the case of expansion of existing incineration plants because many of the process parameters have to be within the limits of the old plant.

## Acknowledgement

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## References

1. European Integrated Pollution Prevention and Control Bureau; Reference Document on the Best Available Techniques for Waste Incineration, July 2005, Sevilla, Spain <http://eippcb.jrc.es/pages/BActivities.cfm>
2. Starley G.P., Bradshaw F.W., Carrel C.S., Pershing D.W., Martin G.B.; The influence of Bed-Region Stoichiometry on Nitric Oxide Formation in Fixed-Bed Coal Combustion. Combustion and Flame 59, p 197-211, 1985.

3. Vogg H., Merz A., Hunsinger H., Walter R.; Primäre NO<sub>x</sub> Minderung - Der Schlüssel für eine kostengünstige Abfallverbrennungstechnologie, Chemie Ingenieur Technik 68, p 147, 1996.
4. Ole Hedegaard Madsen, Siegfried Binner, Jens Christian Jensen; Thermal Optimization and Pollutant Control in MSW Incineration Plants, Pollution Control '97, International Conference on Pollution Prevention and Control, Bangkok, Thailand, 12-14 November 1997.
5. Ole Hedegaard Madsen; Next Generation of Waste Fired Power Plants, NAWTEC 15, Miami, USA, 21 – 23 May 2007.
6. Ole Hedegaard Madsen and Jacob Munch Jensen; Practical test of ACC systems for Waste to Energy plants, 3rd International Conference on Combustion, Incineration/Pyrolysis and Emission Control, Hangzhou, China, 21 – 23 October 2004