Computational Modeling in Anode Baking

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Abstract

Computational modeling has long been a synonym for flue optimization. Today, new tools are available which are suitable for the optimization of many other aspects in bake furnace construction as well as operation. A few examples where computational modeling can and should be used in green field projects and in bake furnace refurbishment projects include: designing the cross-over channel, dealing with cross-over firing, optimizing pitch volatile matter combustion and energy consumption. Furthermore, computational modeling may also be used in off-gas cleaning system optimization and for training purposes.

Introduction

Procedures are available in order to determine optimum anode quality obtainable from given raw materials [1, 2]. One of the important elements in anode quality optimization is the identification of the correct anode heat treatment. With flue dimensions of 5 m by 5 m or more (figure 1), it is quite a challenge to guide the hot combustion gasses through the flues in such a way that *all* anodes undergo the same optimum heat treatment, irrespective of their position in the pit.

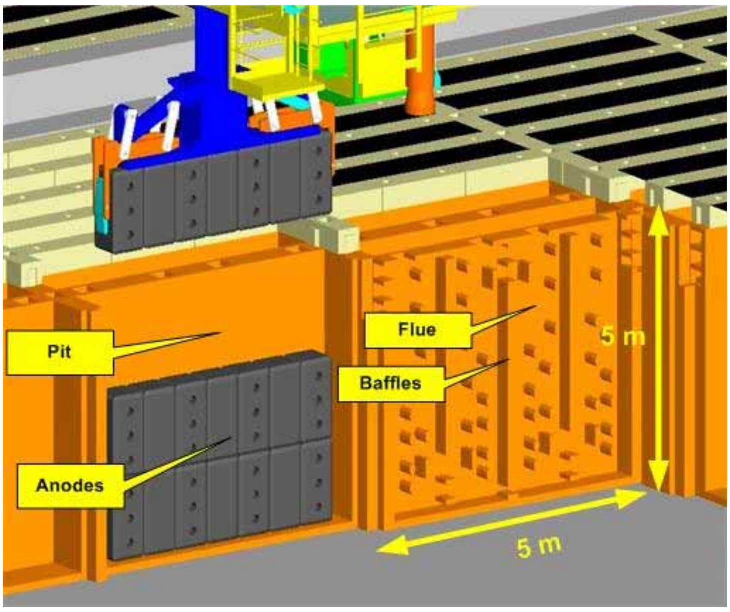


Figure 1: Modern anode bake furnace with pit/flue dimensions of approximately 5 x 5 m.

It was already established decades ago that a regular combustion gas flow distribution over the total flue surface is mandatory for identical baking treatment for *all* anodes. Today, with ‘Computational Fluid Dynamics’ (CFD) programs, it is possible to design flue configurations in such a way that poor flow distributions, as observed earlier, are avoided [3, 4] (figure 2).

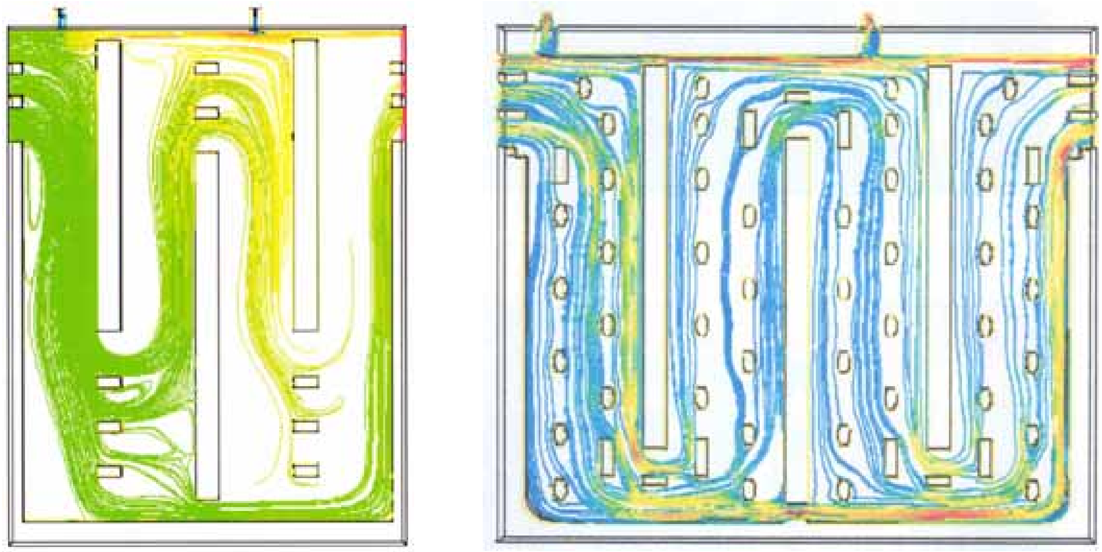


Figure 2: Poor flow pattern (left) and flow pattern optimized through application of a ‘Computational Fluid Dynamics’ (CFD) program (right).

For a given flue configuration, properties other than the gas flow direction and velocity can also be determined, e.g. the gas temperature distribution (figure 3) and the temperature distribution in the anode middle plane (figure 4).

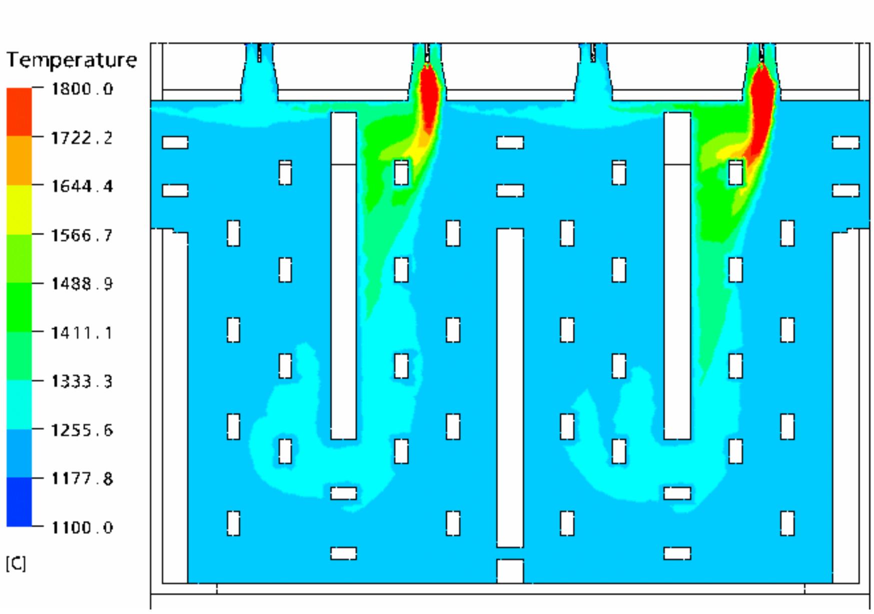


Figure 3: Calculated gas temperature distribution in a flue.

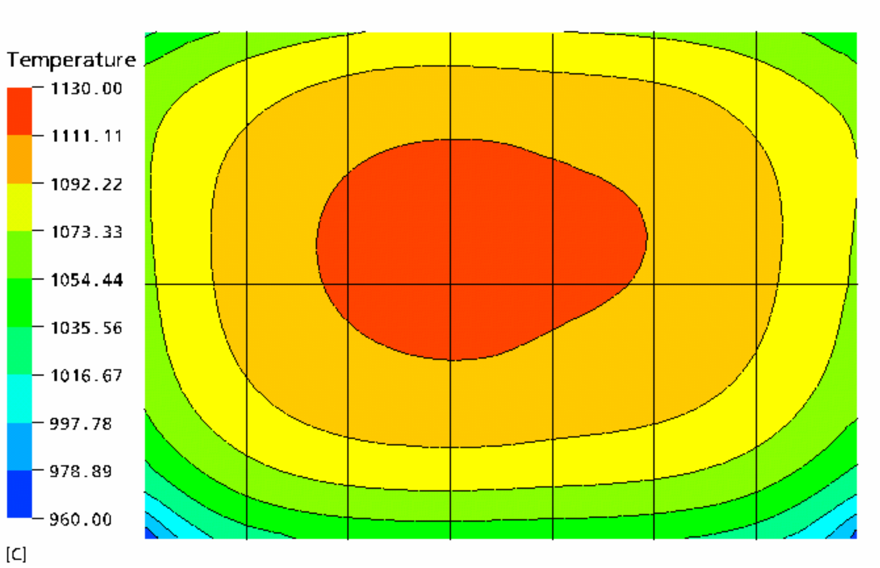


Figure 4: Calculated temperature map for the anode middle plane.

For many people, 'CFD' in bake furnace construction is simply a synonym for flue design. This statement has held true for many years. Today, however, modern CFD programs are powerful tools that can – and should – be used to optimize other aspects such as; crossover construction, energy consumption and pitch volatile matter combustion. Finally, CFD calculations can also be used as 'training tools' as they provide new possibilities in visualizing the baking process.

Crossover Channel Optimization

At both furnace ends the two furnace sides are linked by the 'crossover-channel' (figure 5).

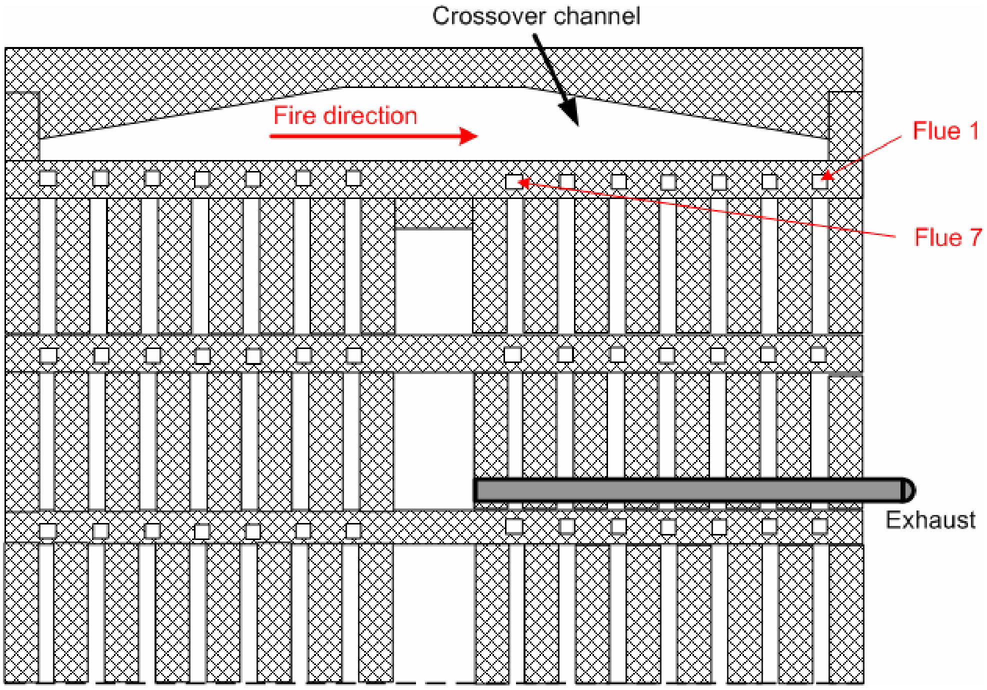


Figure 5: Crossover channel, linking the two furnace sides.

The crossover channel represents a significant heat sink. Furthermore, if the crossover channel is not properly designed, there will be unnecessary loss of pressure. CFD tools can be used to visualize and to calculate heat loss as well as loss of pressure. Figure 6 shows a comparison of an irregular flow pattern in the link between the crossover channel and headwall downstream of the channel versus an improved design depicting an improved regular flow pattern.

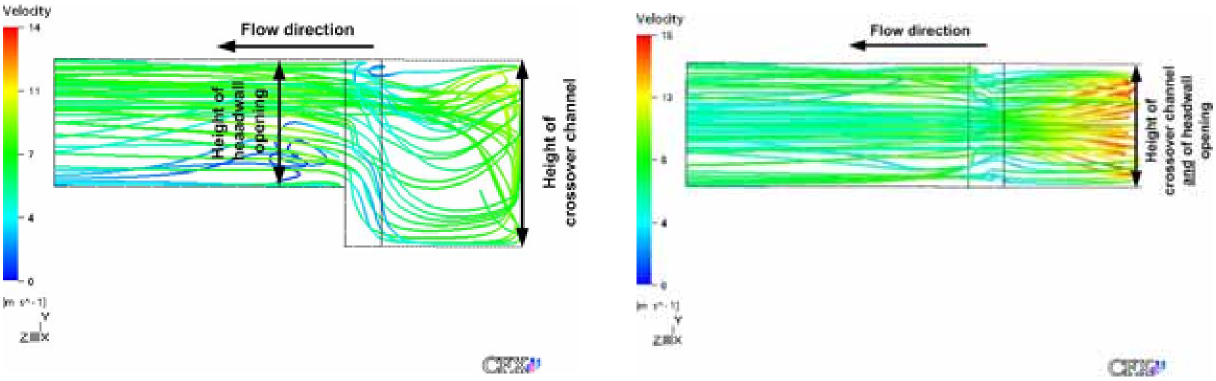


Figure 6: Crossover channel linked to the downstream headwall, with irregular flow pattern (left) and improved design [crossover channel of the same height as the headwall opening] (right).

Figure 7 shows the flow pattern on the 'upstream' side of the crossover channel. Figure 8 illustrates the temperature drop over the length of the crossover channel. Finally, in figure 9, the result of the calculation of the average temperature levels and the amount of temperature loss in kW can be seen.

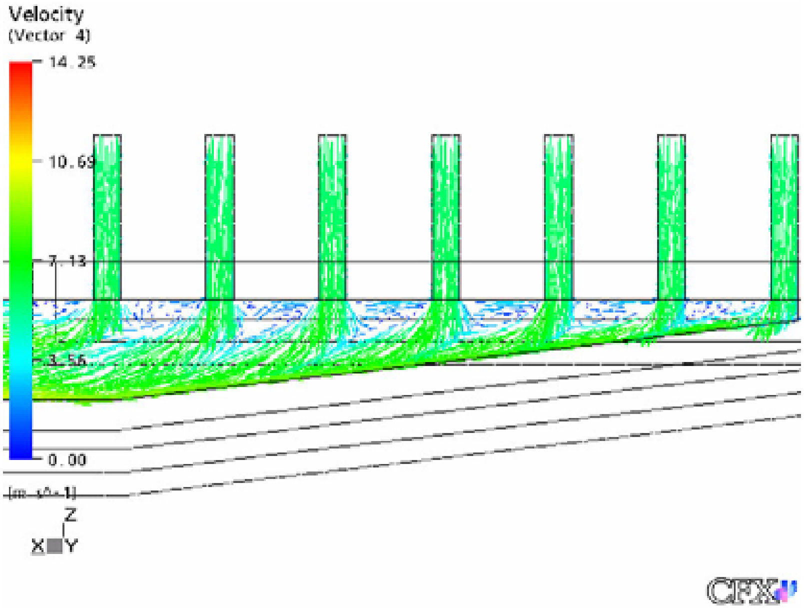


Figure 7: Flow pattern in the upstream side of the crossover channel.

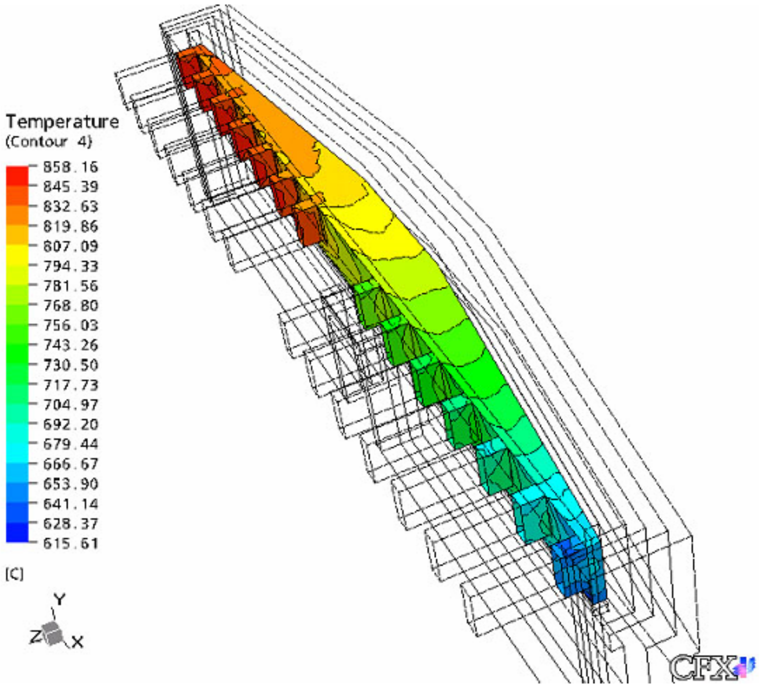


Figure 8: Temperature drop over the length of the crossover channel.

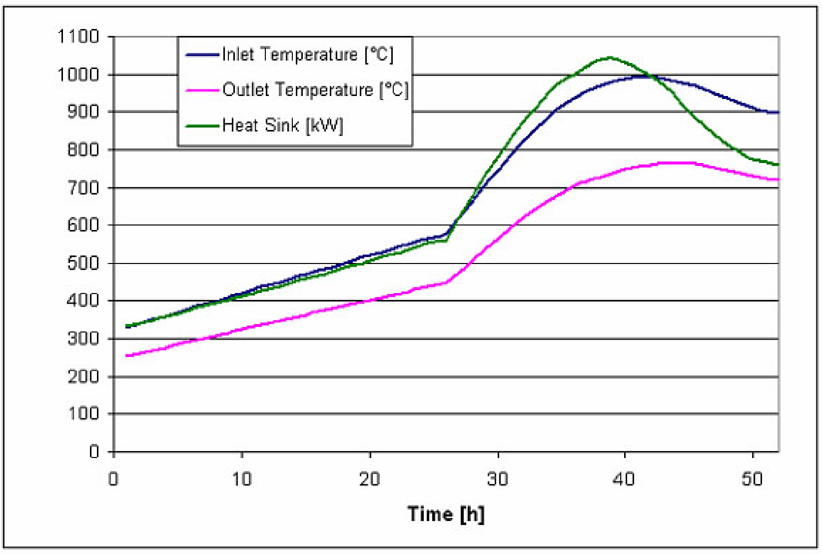


Figure 9: Crossover channel: Inlet and outlet temperature and heat sink energy over time.

Without any counteractions, the temperature drop will have a negative impact on the quality of the anodes baked in the first and second sections downstream of the crossover channel. With the information available through application of CFD tools, it is possible to design and to validate counteractions as, e.g., the application of auxiliary burners to compensate for the heat loss observed.

Energy Consumption and Pitch Volatile Matter Combustion

When comparing bake furnace energy consumption, usually only the amount of *external energy* consumed is taken into consideration, i.e. the energy supplied to the process through the burners by either gas or oil. For modern furnaces, energy consumption figures in the range of 1.7 – 2.2 GJ/ton of anodes have been reported. In older (and smaller) furnaces, typical consumption will be somewhere in the range of 2.2 – 2.8 GJ/t of anodes. The *total* energy demand for anode baking in ring type furnaces is approximately 4 GJ/ton of anodes. The difference is made up from pitch volatile matter released by the anodes during the heating-up phase. Complete pitch volatile matter combustion is a prerequisite for minimum consumption of external energy and the lowest possible impact on the environment. Pitch volatile matter combustion is a function of several variables as, e.g., pit size, pit load, flue size and under pressure applied. As an example only, figure 10 shows the relationship between the amount of oxygen in the flues, the amount of unburned volatile matter and the external energy required as a function of the draft applied to the process. Through calculations, it is possible to determine the optimum draft required for a specific flue geometry and pit load in order to minimize burner consumption and ensure complete pitch volatile matter combustion. In addition, similar calculations can be used on different flue designs in order to determine the optimum furnace design for a given pit load.

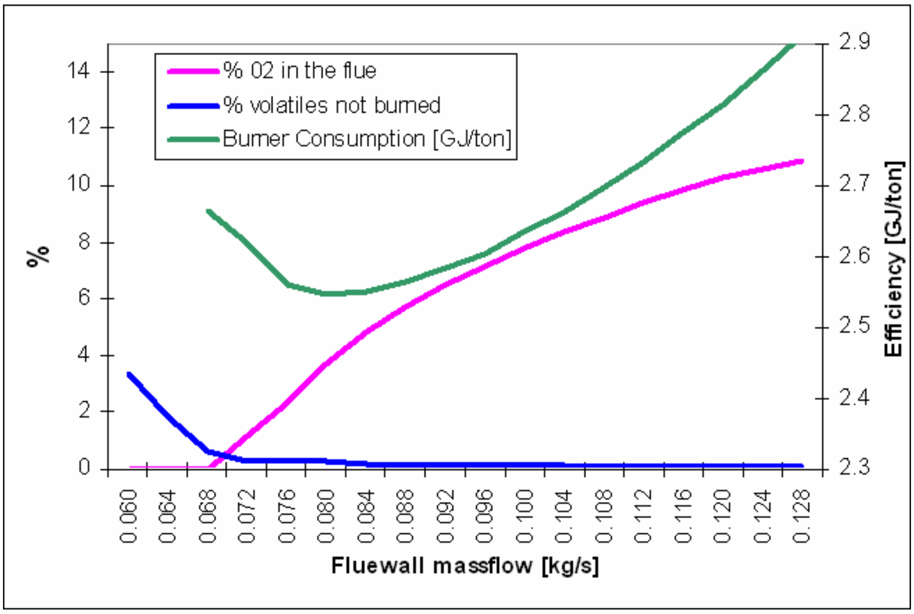


Figure 10: Relationship between oxygen content in the flue, unburned volatiles and external energy required as function of the draft applied.

Off-gas System: Draft Loss Optimization

Modeling should not be restricted to the anode bake furnace. Draft loss optimization in the off-gas system is similarly important; from the exhaust manifold through to the off-gas cleaning installation and to the stack. Application of CFD tools enhances the design of the off-gas piping system in such a way that unnecessary pressure drops can be avoided. This may be of special interest if an existing furnace is modified in order to increase the capacity. If the fans are unable to supply the required under pressure for the modified system, proper furnace operation is simply impossible. In visualizing the existing system or by creating a visual model of the proposed new installation as shown in the figure 11, it would be possible to identify any flow irregularities. These can therefore be avoided or corrected.

Figure 11: Irregular flow patterns resulting in undesirable pressure drop.

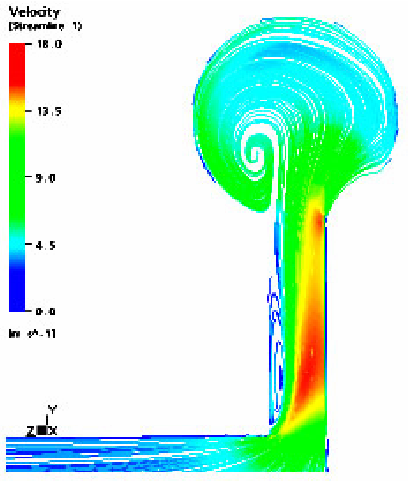


Figure 12 shows a comparison of system under pressure on different furnaces and plants as well as the pressure drop over the exhaust manifold. Even though there will always be a significant pressure drop at the exhaust manifold, it is obvious that in certain plants there is some leeway for improvements.

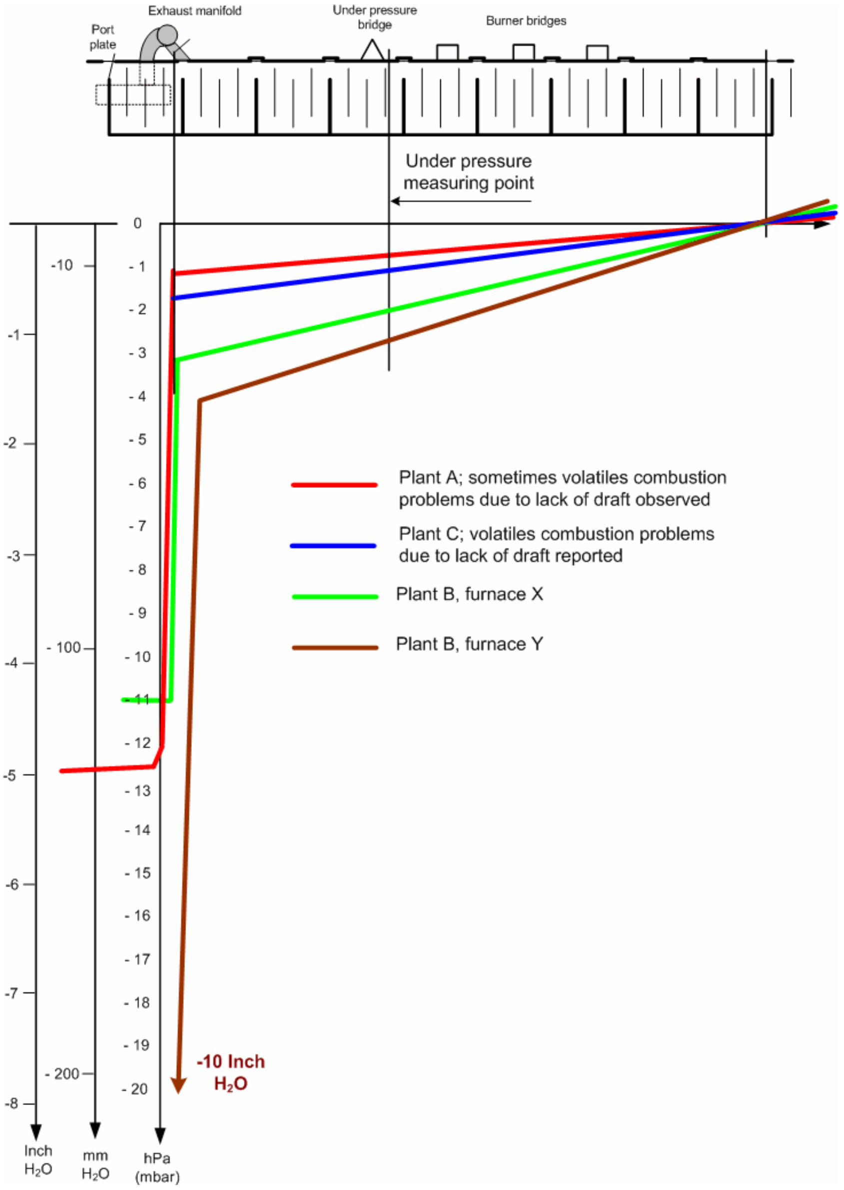


Figure 12: Comparison of system under pressure and under pressure drop at the exhaust manifold for different furnaces and plants.

Emission measurements support

CFD calculations may also help in solving ‘exotic’ problems linked to off-gas sampling in stacks. In the relevant international standard [5] it states that a ‘straight’ tube of at least 5 stack diameters upstream of the sampling point and 2 – 5 stack diameters downstream of the sampling point is required. Therefore, the sampling point will often be found somewhere half way up the stack, or 20 – 25 meters above ground level (figure 13). It is also stipulated in the standard that a ‘regular’ velocity distribution in the stack should be achieved with velocity variations over the stack surface of not more than a ratio of 1 : 3; a minimum versus maximum gas velocity. In reality, however, even a negative or ‘reverse’ flow as shown in figure 14 has been observed. In this scenario, it is impossible to achieve the required emission measurements as stipulated in the relevant standard.

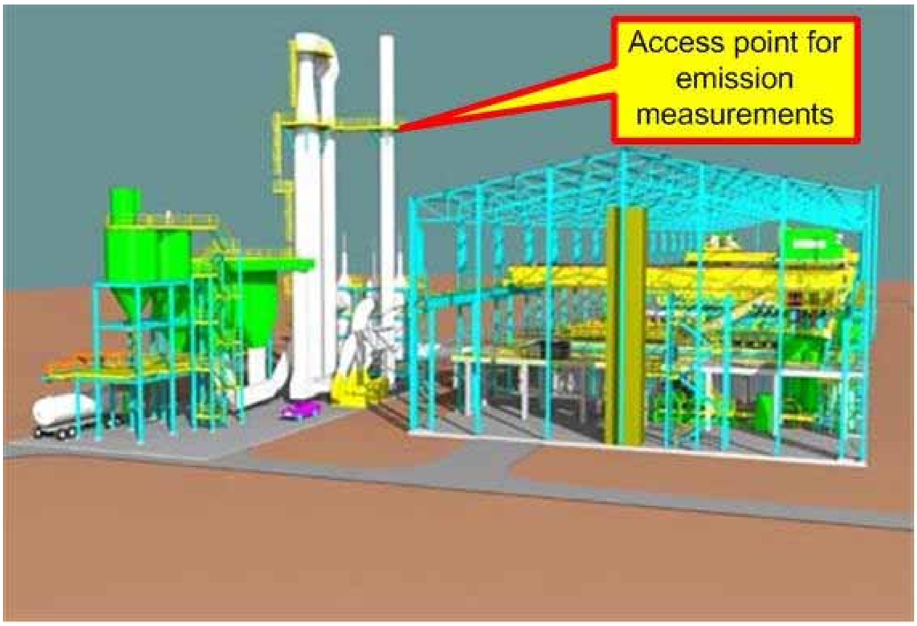


Figure 13: Access point for emission measurements on a bake furnace stack; 20 m above ground.

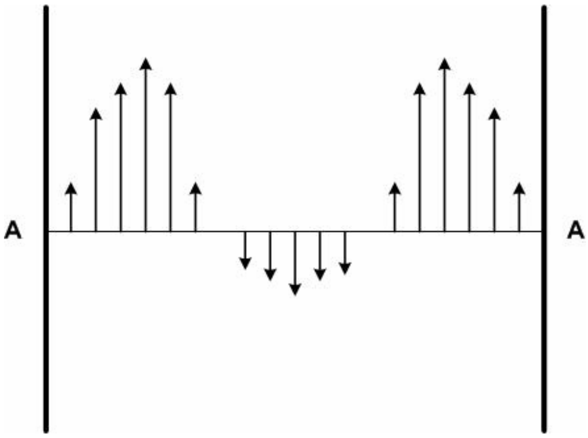


Figure 14: Irregular off-gas velocity distribution measured in a bake furnace stack, with ‘negative flow’ in the center of the stack, preventing correct emission measurements.

The flow distribution presented in figure 14 has been measured in a stack with a *tangential* connection between the off-gas pipe and the stack (figure 15).

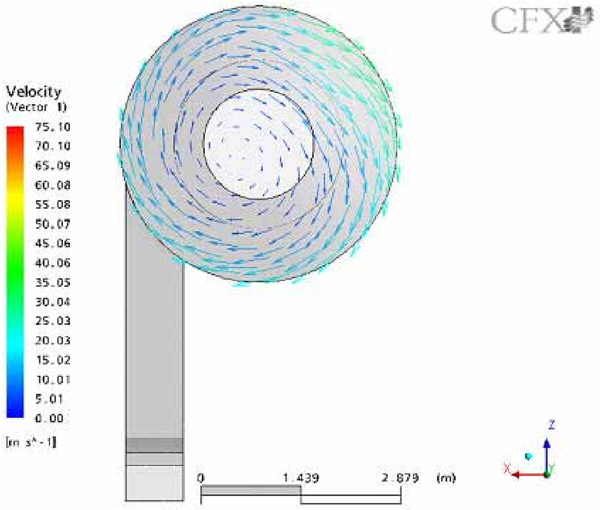
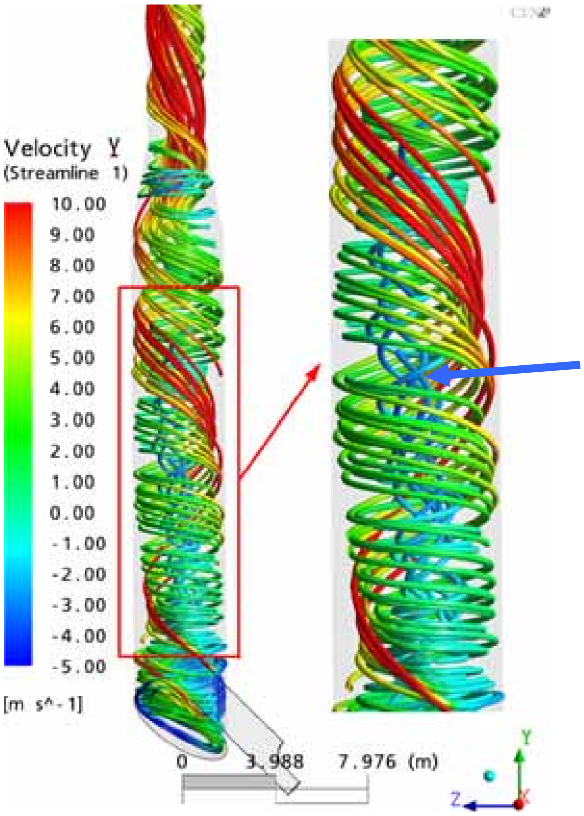


Figure 15: Gas inlet configuration for the stack with 'reverse flow' as shown in figure 14.

Based on the flow calculations shown in figures 16 and 17, the velocity distribution in figure 14 could be confirmed. Modeling the system in the design phase will help avoid such problems. In the case of existing plants, calculations can be used to determine the required counteractions in order to end up with a flow pattern that meets with the requirements stipulated in the relevant standards.



Reverse flow (shown in blue) in the (-Y) direction in the center of the stack

Figure 16: Streamlines with 'reverse flow' in the center of the stack shown in figures 14 and 15.

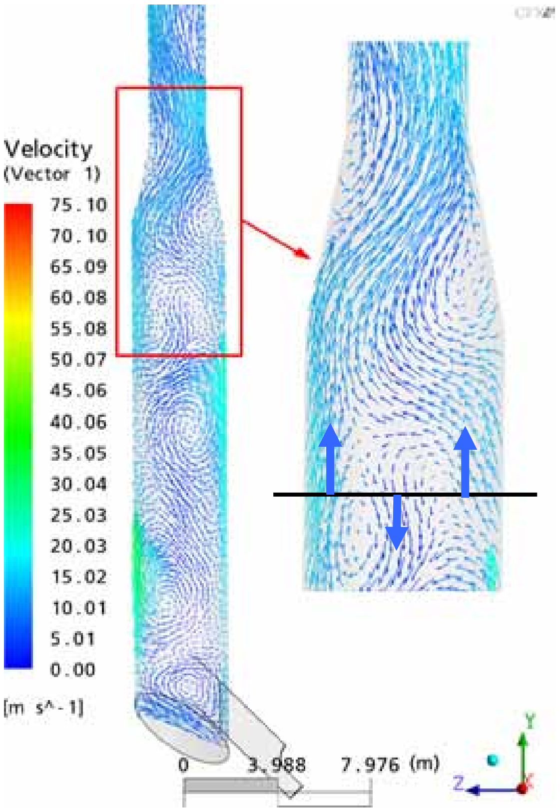


Figure 17: Velocity vectors with ‘reverse flow’ in the ‘Y’ –direction in the center of the stack shown in figures 14 and 15.

Training Support

In an anode bake furnace (figure 18), the loading and unloading of anodes (figure 19) is about all that one can see. The baking process as such, is virtually invisible.

Figure 18: Anode bake furnace in operation

Figure 19: Unloading anodes from a pit in an anode bake furnace.

Experience shows that many operators have difficulties in assessing how the heat wave progresses in the furnace. Today it is possible to visualize the baking process in a 3-dimensional model showing the move of the fire front in the direction of the exhaust manifold and the penetration of the heat wave from the flue cavity through the flue walls and the packing material into the anodes in the pit. Even the pitch volatile matter can be easily seen. Figure 20 shows two 'snapshots' taken at the beginning and at the end of a fire cycle. In a computerized presentation it is possible to present an animated heat wave movement.

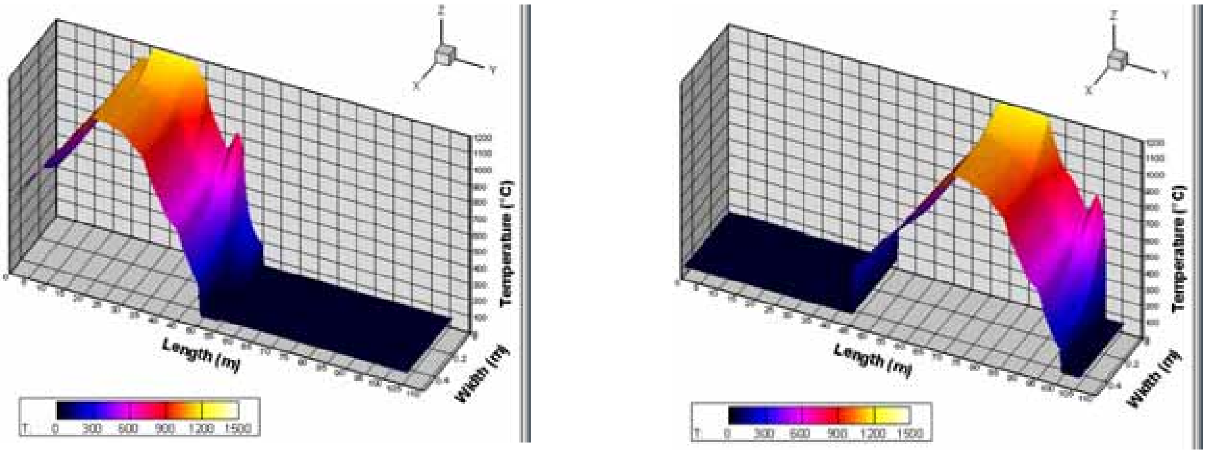


Figure 20: Snapshot of heat wave in an anode bake furnace, shortly after the beginning and at the end of a new fire cycle. 'Length' in meters is the direction of the fire front. One unit (5 m) equals one section. 'Width' is from the flue wall surface (Y-Z axis) in the direction of the flue wall, packing material and anode surface.

Conclusions

Operating a sub-optimum anode bake furnace results in extra operating cost and has a negative impact on anode quality and on the environment. Computational Fluid Dynamics (CFD) programs and heat transfer calculations are powerful tools in achieving the following goals:

- Optimum temperature distribution in the flue
- Minimizing the negative impact of the crossover channel
- Full pitch volatile matter combustion and minimum fuel consumption
- Minimizing pressure losses in the off-gas piping system
- Correct off-gas sampling
- Process visualization for training purposes.

Such tools can be successfully applied not only in green field projects, but also in evaluating and realizing bake furnace refurbishments. In avoiding mistakes, the rewards derived from CFD calculations are extremely attractive.

References

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