5-Minute CFD of Flameless Oxidation

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Abstract: **This article should stimulate a discussion about the role of CFD simulations for flameless oxidation with the goal to increase trustworthiness of the results of CFD. It is proposed to drastically reduce the complexity of the cases to achieve results in less than 5 minutes. These calculation could be performed as an alternative or addition to existing calculations.**

Keywords – flameless oxidation, FLOX®, CFD, industrial furnaces,

I. INTRODUCTION

CFD is widely used to model burners and furnaces. The largest drawback of these simulations is their lack of trustworthiness despite enormous efforts in form of intellectual and computer power. Possible sources for deviations in the results are:

- unknown or wrong boundary conditions
- code errors
- input errors
- insufficient models
- unit conversion errors
- numerical errors
- not fully converged solution
- …...

CFD simulations in the field of combustion are generally very complex and grid generation as well as numerically solving the equations can take days, weeks or even months on powerful computers [1] [2]. In addition to the high cost of such calculations, there is usually no time to perform many reruns of the simulation.

Flameless oxidation has some unique features and this article will propose how to perform meaningful simulations which require CPU time of less than 5 minutes.

II. FLAMELESS OXIDATION

Flameless Oxidation was first developed to suppress thermal NOx formation in burners for heating industrial furnaces using preheated combustion air [3]. While this technique is applied in large numbers now, there are a number of other applications emerging in the fields of biogas, coal, gas turbines, Stirling engines, hydrogen reformers and others.

Flameless oxidation is defined as:

Flameless oxidation is stable combustion without a flame and with defined recirculation of hot combustion products

- for gaseous, liquid and solid fuels
- with and without air preheat
- with and without fuel preheat
- for lean, near stoichiometric and rich combustion (e.g. l = 0.3 – 3)
- for diffusion, partially premixed and premixed combustion

and:

- it is not necessary to use preheated air
- it is not necessary to operate with low oxygen levels
- no catalysts are required
- there is no need for large combustion chamber volumes
- separate injection of fuel and air not required

Besides the advantage of minimized thermal NOx-formation, flameless oxidation offers some other features like:

- temperature uniformity
- robustness
- simplicity
- fuel flexibility

which makes it an attractive alternative to combustion with flames even in applications where thermal NOx is not an issue. In order to tap the full potential of flameless oxidation, CFD can be a very valuable tool if the results are reliable and could be obtained with reasonable effort.

III CFD - MODELLING OF FLAMELESS OXIDATION

The absence of flames makes modelling of flameless oxidation much easier compared to modelling of flames. In addition, the geometry of FLOX®[1] burners is usually much simpler compared to flame burners which often include swirl blades, bluff bodies and other parts which require a high level of geometric detail.

Reaction models which were developed for flames should be critically inspected about their suitability to model flameless oxidation economically and accurate. Depending on the flameless oxidation burner design, the reaction progress may be more mixing or kinetically controlled. Practical experience confirms, that the temperature of the recirculating products of combustion is a very important parameter. Therefore, in a first step it is proposed to use a simple Arrhenius approach for the reaction of the species fuel and oxidizer to product [4][5].

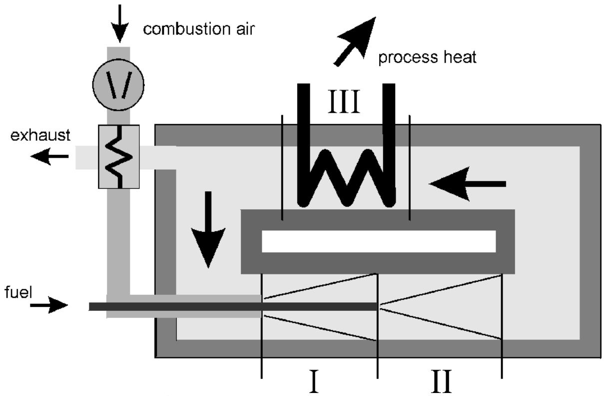

Figure 1: FLOX® schematic

Figure 1 shows a schematic of a possible FLOX® process with step I, the mixing of air and combustion products, step II the mixing with the fuel, step III the heat extraction and the recirculation. For a real FLOX® burner, steps I and II occur simultaneous in most cases. Recirculating of combustion products is critical for flameless oxidation but requires a lot of effort regarding grid generation and CPU time for calculating the correct heat transfer within the furnace from the combustion products to the load, the furnace walls and other possible heat sinks. In a real furnace, the furnace temperature and thus the temperature of the recirculating combustion products is controlled by the furnace temperature controller.

This leads to the idea that it is not really necessary to simulate all details of the heat transfer if the main point of interest is the reaction zone of the burner.

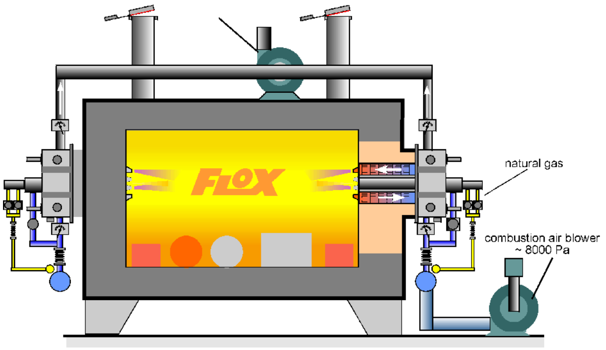

Figure 2: furnace heated with FLOX® burners

A typical CFD domain of a furnace (Figure 2) is shown in Figure 3 which includes the inside of the furnace and the furnace wall represent the boundary walls of the domain. Depending on the level of detail, a computational grid can easily have 100000 cells and more

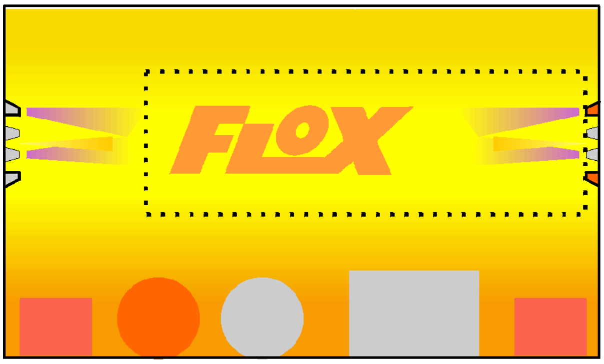

Figure 3: CFD domain

Choosing the dotted line as boundaries for the domain leads to a significant reduction in grid cells by several orders of magnitude. This correlates to calculating only steps I and II in the schematic of Figure 1. The side borders of the domain are defined as open (zero pressure) boundaries with defined inflow conditions. This approach can drastically reduce the time for setting up the modelling case and the CPU time but still deliver realistic results.

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1 FLOX® - registered trade mark of WS Wärmeprozesstechnik GmbH, Renningen

The most simple FLOX® burner is a premixed one nozzle burner. Such a burner can be calculated using a 2-D cylindrical grid using only a few hundred grid cells. If a 3-D cartesian grid is preferred, such a burner could also be approximated by a burner with a quadratic nozzle. The results of these two configurations, shown as temperature fields in Figure 4 were calculated in a few minutes and correlate well with measured data.

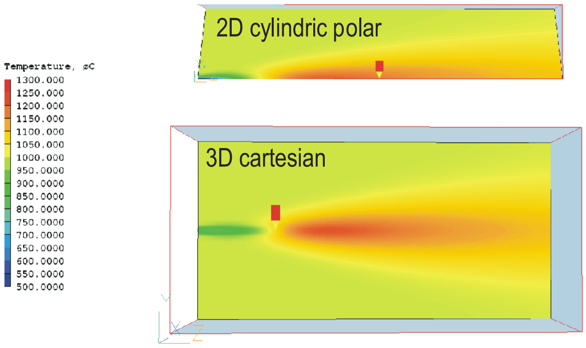

Figure 4: comparison of 2D and 3D grid

Variations can include:

- air preheat temperature
- furnace temperature (inflow conditions)
- burner capacity
- fuel
- turbulence inlet intensity
- excess air ratio
- burner nozzle diameter
- obstacles within the jet (e.g. thermocouples)

using different models like:

- reaction models
- turbulence models
- radiation models (or none)
- grids and others

If all these parameter variations could be reproduced by the CFD model the level of trust in the model improves significantly.

The equations can also be formulated as a quasi-2D or quasi-3D cases if there is no influence against the flow direction. This speeds up the calculations even further.

IV CONCLUSIONS

When choosing the right boundary conditions, fast (5-minute) CFD can be a very valuable tool to model certain burner configurations but also to proof the validity of submodels. That makes fast CFD an attractive substitute or supplement to complex calculations for both, industrial applications and accademic approaches.

Being able to repeat and compare results within very short time helps to obtain a deeper understanding of the process as well as the modelling and also to eliminate errors.

Besides the proposed simplifaction of the modeling, the following leads to a further credibility of CFD – modeling:

- it should be possible to have results of a modelling case being checked by a colleague in less than a day, preferably using a different CFD-code
- all boundary conditions and descriptions of the modelling case should fit on one page
- experimental set-ups should be designed accordingly

A goal for the future is real time simulation of unsteady combustion processes using a thermocouple to define the inflow conditions and other sensors to define the burner operation.

V REFERENCES

[1] L. Porcheron, L. Ferrand, E. Masson, F. Aguilé, A.Quinqueneau, D. Honoré, M. Boukhalfa, High Temperature Air Combustion burner : semi-industrial scale experiment and CFD simulation, HTACG2005, Essen

[2] M. Flamme, R. Giese, U. Konold, M. Brune, A. Scherello, W. Diemar, Optimization of a Roller Hearth Furnace for a CSP Plant, HTACG2005, Essen Germany

[3] Wünning J., Flammenlose Oxidation von Brennstoff mit hochvorgewärmter Luft, Chem.-Ing.-Tech. 63 (1991), Nr. 12, page 1243-1245

[4] Wünning J.G., Flammlose Oxidation von Brennstoff, Dissertation, Aachen, 1996

[5] Wünning J.A., Wünning J.G., Flameless Oxidation to Reduce Thermal NO-Formation, Prog. Energy Combust. Sci. Vol. 23, page 81-94, 1997