# Publication

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# *HRSG Marafiq*

# *Duct Burner*

# *CFD-Simulation*

# *Experiences*

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# *Simulation and optimisation of duct burners and operational experiences in the HRSG plant*

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## 1. INTRODUCTION

The problem of this plant (fig. 1) is based on the geometry and the gas turbine exhaust gas profile upstream the 8 natural gas duct burners. A reliable prediction of the temperature, velocity and concentration profiles upstream module #2 was the aim of this cfd-study. Especially the gradient of the temperature should be lower than 100 K for downstream processes. Moreover a good burnout of the CO should be achieved as well.

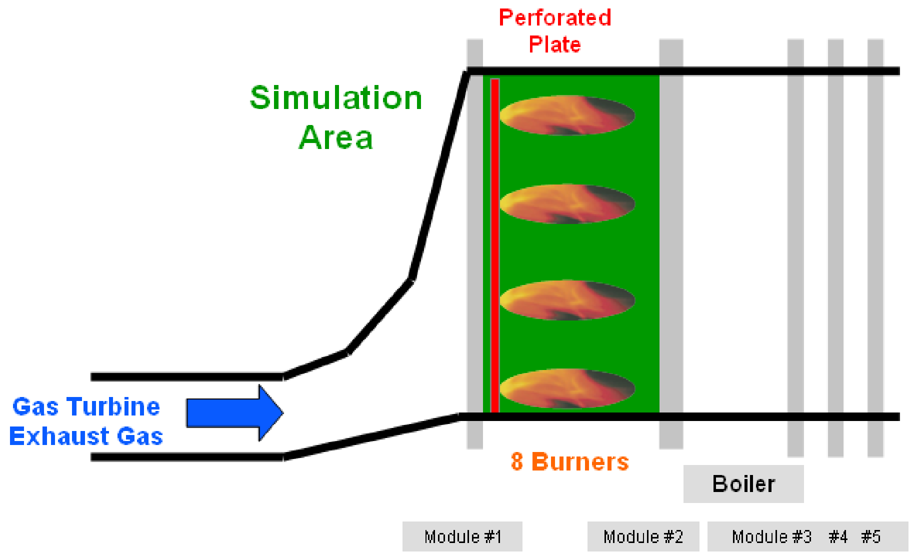


Fig. 1: Overview of the HRSG plant "Marafiq"

Because of the duct geometry the mass flow through the upper burners is quite low. The use of a perforated plate with different holes (that means different pressure losses) can minimize this effect and can increase the mass flow of the upper regions. Nevertheless very homogeneous inlet conditions can not be achieved for this plant. Therefore an optimisation of the duct burners and the combustion process based on cfd-simulations should be performed for full and partial load cases.

## 2. MATHEMATICAL MODELL FOR THE GASEOUS PHASE

Numerical modelling of industrial burners has been the subject of several studies. Simulations of pulverized coal or gas flames were made worldwide since about 20 years [e.g. 1-3]. For a general field quantity $\varphi$ the instantaneous transport equation can be written in the form:

$$\frac{\partial}{\partial t}(\rho\varphi) + \frac{\partial}{\partial x_j}(\rho\varphi u_j) = \frac{\partial}{\partial x_j}\left(D_\varphi \frac{\partial \varphi}{\partial x_j}\right) + S_\varphi \qquad (1)$$

where : $\frac{\partial}{\partial t}(\rho\varphi)$ is the transient term, $\frac{\partial}{\partial x_j}(\rho\varphi u_j)$ is the convection term,

$\frac{\partial}{\partial x_j}\left(D_\varphi \frac{\partial \varphi}{\partial x_j}\right)$ is the diffusion term, $S_\varphi$ is the source term

and: t = time, $\rho$ = density, u = velocity components, x = distance, j = coordinate direction

A generally accepted method to approximate the turbulence in flows is the time-averaging (Reynolds averaging) of the instantaneous transport equation. A turbulence model is required for the unknown correlations of the fluctuating velocity components (Reynolds stresses $\rho \bar{u}'_j \bar{u}'_j$). Very often the standard k-ε-model (requires the solution of two additional transport equations, those for the kinetic energy of turbulence, k, and its dissipation rate ε) is used for the turbulence closure. The P-1-radiation model (six flux method) was used to calculate the source term in the enthalpy balance equation where φ is substituted by the enthalpy h. For each of the chemical species, except $N_2$, a mass conservation equation is solved for the mass fraction. A two step reaction mechanism has been modelled as follows:

- $CH_4 + 1{,}5\ O_2 \rightarrow CO + 2\ H_2O$ and
- $2\ CO + O_2 \rightarrow 2\ CO_2$

The various source and sink terms in the chemical species balance were calculated by using an eddy break up model. The lower rate of the following both methods was used for the calculations:

A. Turbulence

→ "mixed = burned"

B. Kinetic

→ Arrhenius-equation

## 3. DESCRIPTION OF THE DUCT BURNERS

### 3.1 Geometry and function

As mentioned above, the temperature of gas turbine waste gases is typically not high enough to supply any downstream waste heat boiler with sufficient calorific energy.

In order to deal with this problem, Mehldau & Steinfath Feuerungstechnik GmbH have developed the COMB Ductburner. The object of the COMB Ductburner is to reheat turbine waste gases or flue gases for the purpose of operating a downstream process. Therefore the duct burner is installed as an auxiliary firing device directly into the gas turbine waste gas duct.

The COMB Ductburner consists principally of the cylindrical duct, an interior combustion chamber and the combined gas/oil burner, as can be seen in the schematic figures 2 and 3 and on a photograph (figure 4). On entering the duct, the turbine waste gas is divided into three streams which are fed into the following areas of the duct burner:

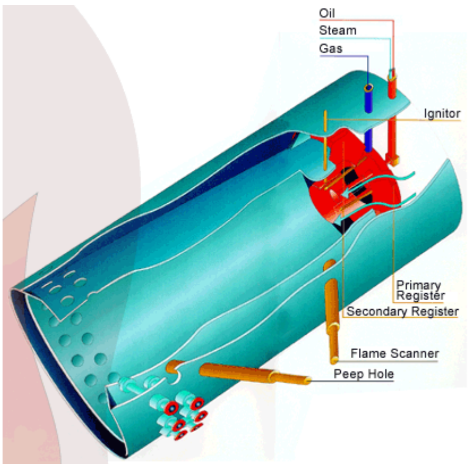


Figure 2: Duct Burner

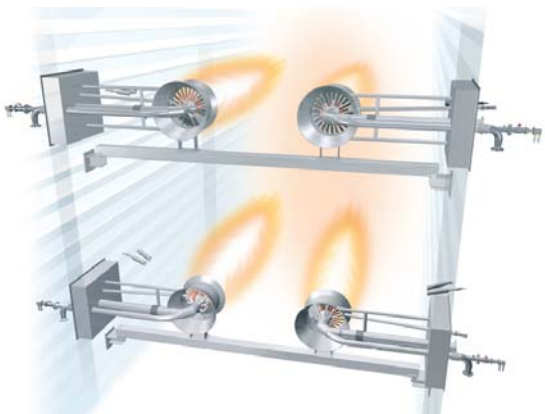

Figure 3: Concept with several duct burners

TECHNICAL DATAS:

- Range of Capacity: 5-200 MW firing capacity
- Range of Control: 10:1
- Pressure Loss Turbine Waste Gas Operation: 1.5 mbar (burner)
- Temperature Profile Downstream of Ductburner: +/- 30°C
- Turbine Waste Gas Temperatures: up to 600°C

Figure 4: Photograph of four real duct burners and the perforated plate

Because of the symmetry only one half of the plant was calculated. The generated geometry with four duct burners and the perforated plate is shown in figure 5.

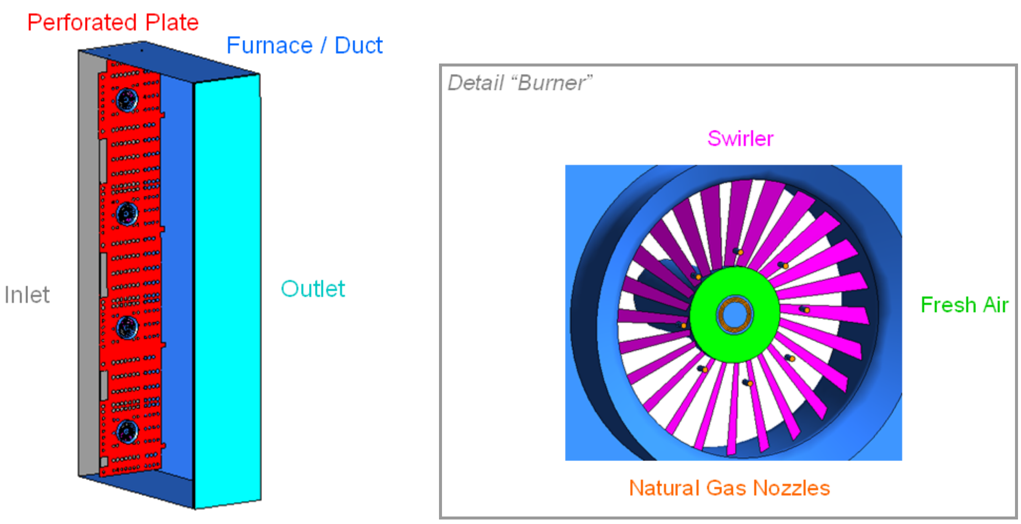

Figure 5: Simulation area with duct burners and the perforated plate

### 3.2 Operating and Boundary Conditions

The first calculated case had the following boundary conditions:

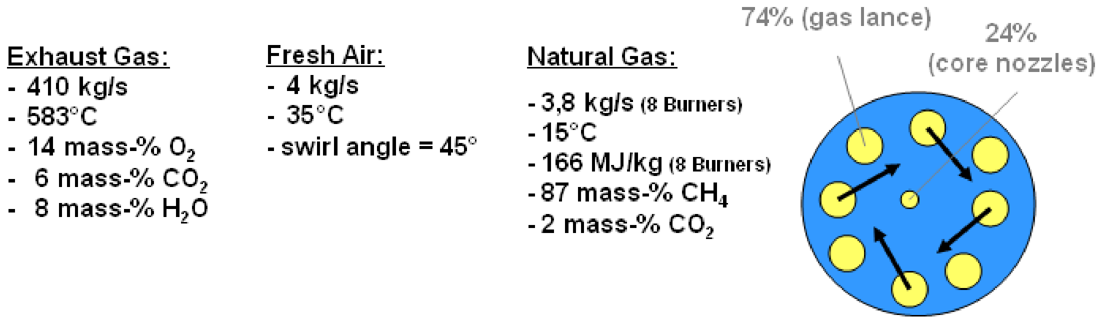


Figure 6: Boundary and operating conditions for CASE 1

As mentioned above the inlet profile of the Exhaust Gas was not homogeneous. The used profile for velocity and temperature are shown in figure 7.

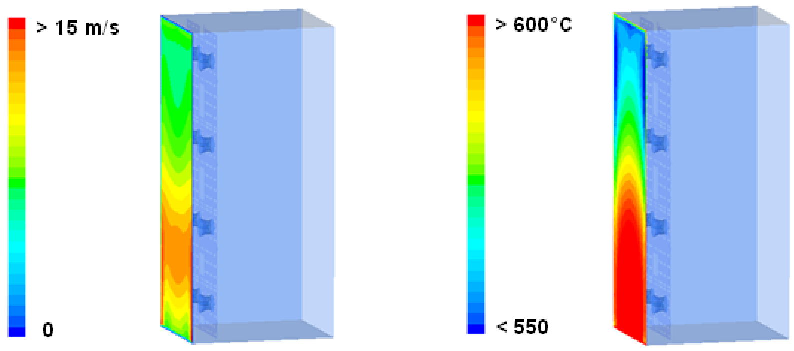


Figure 7: Exhaust Gas Profiles for CASE 1 (left: velocity, right: temperature)

Four other cases were calculated with optimised components (fig. 8):

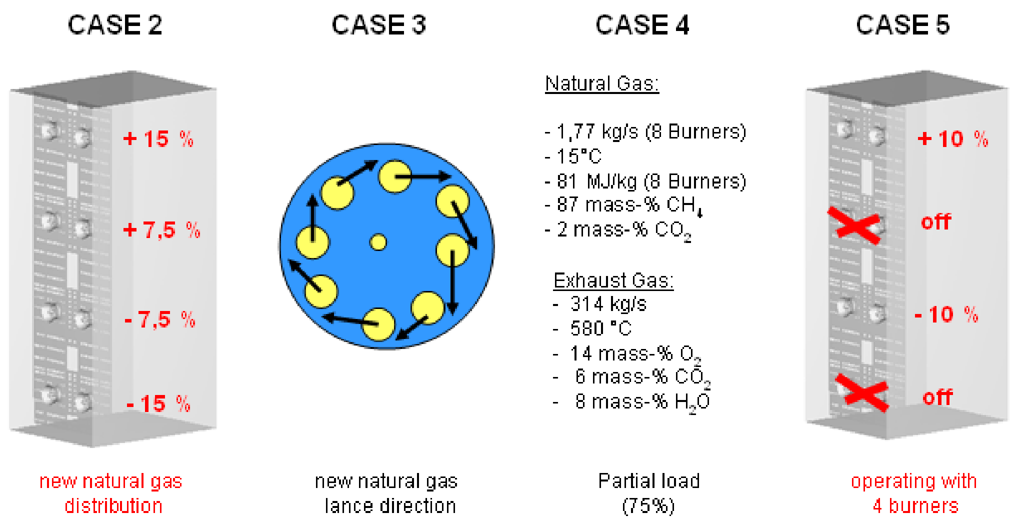

Figure 8: Differences to CASE 1

# 4. RESULTS

## 4.1 CASE 1

The simulation results for the first case are shown in fig 9.

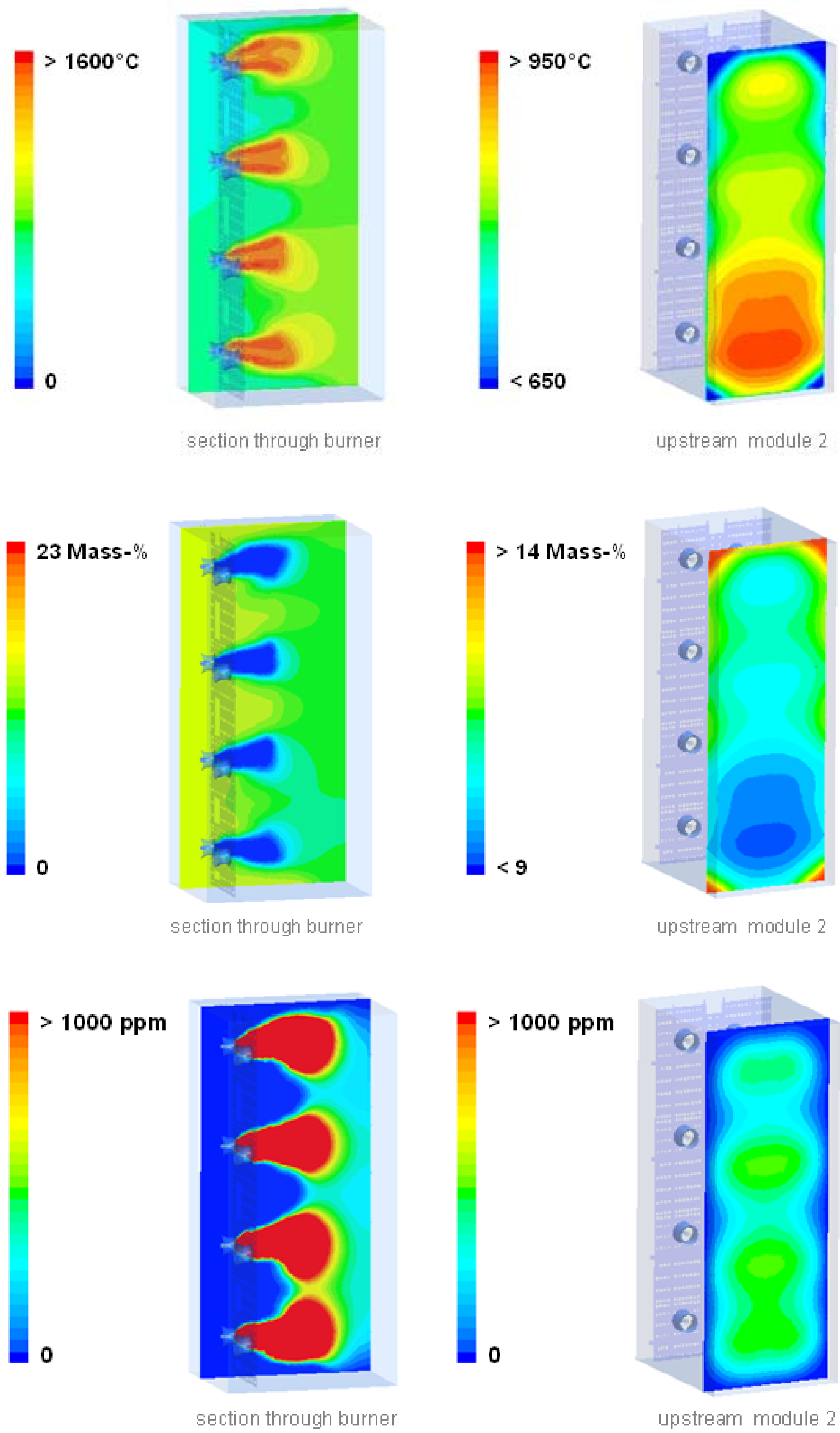

Figure 9: Temperature, Oxygen and CO Distributions, CASE 1
It can be recognized that the temperature gradient is very high upstream module #2 (higher than 100 K). This is caused by the inlet profile and the duct geometry upstream the 8 burners. Moreover the CO values at the end of the furnace are quite high (~ 500 ppm) which indicates that the combustion process should be optimized.

### 4.2 CASE 2 (New Natural Gas Distribution)

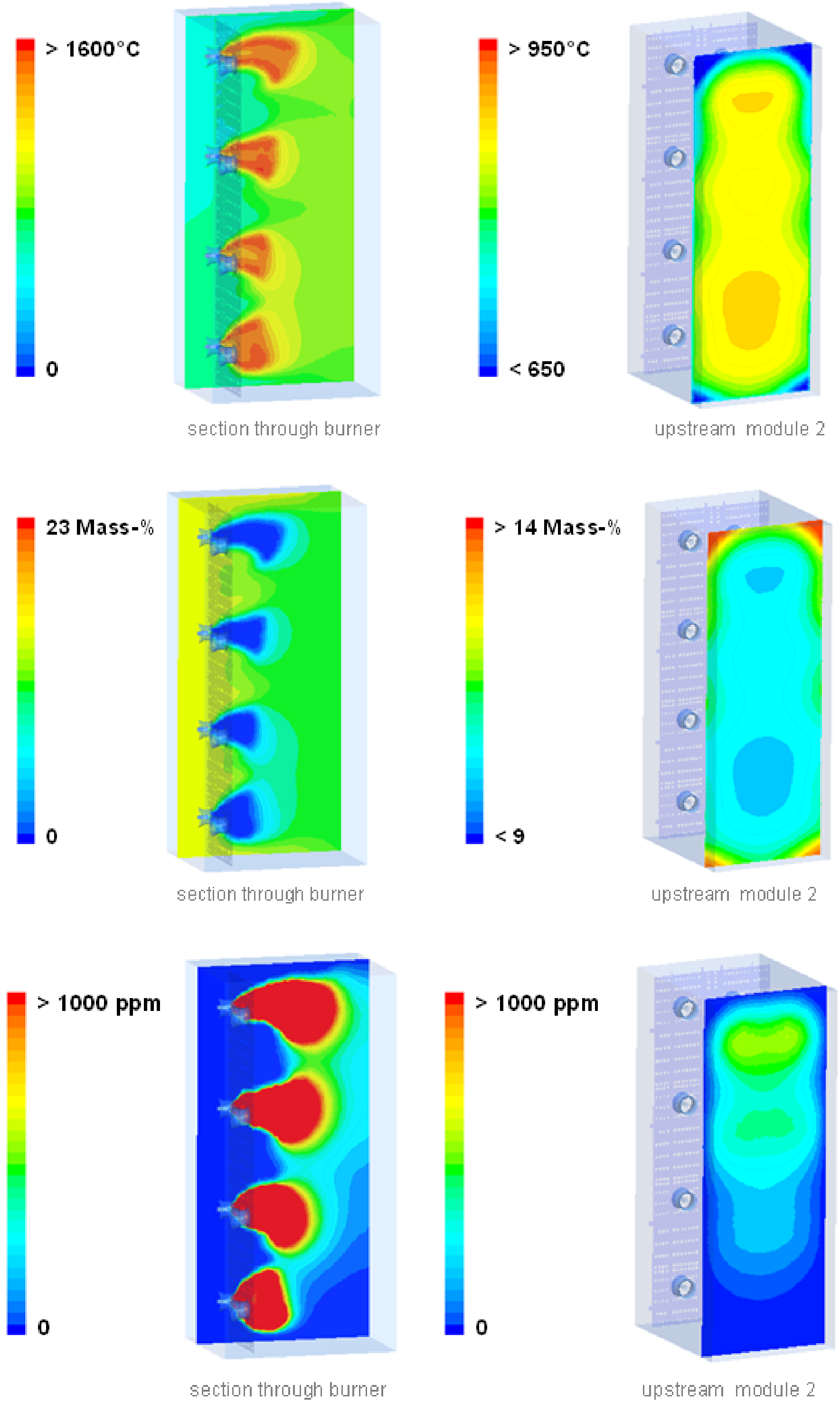

Figure 10: Temperature, Oxygen and CO Distributions, CASE 2

Due to the duct geometry and the gas turbine profile the natural gas distribution was modified (lower fuel mass flow through the upper burners). With this modification the requested temperature gradient (< 100 K) upstream module #2 could be achieved. But the combustion concept has not changed compared to CASE 1 and therefore higher CO concentrations were calculated anymore. An improvement of the mixing between CO and Oxygen was necessary and therefore a modified natural gas injection angle was analysed.

### 4.3 CASE 3 (New Gas Lance Direction / New Injection Angle)

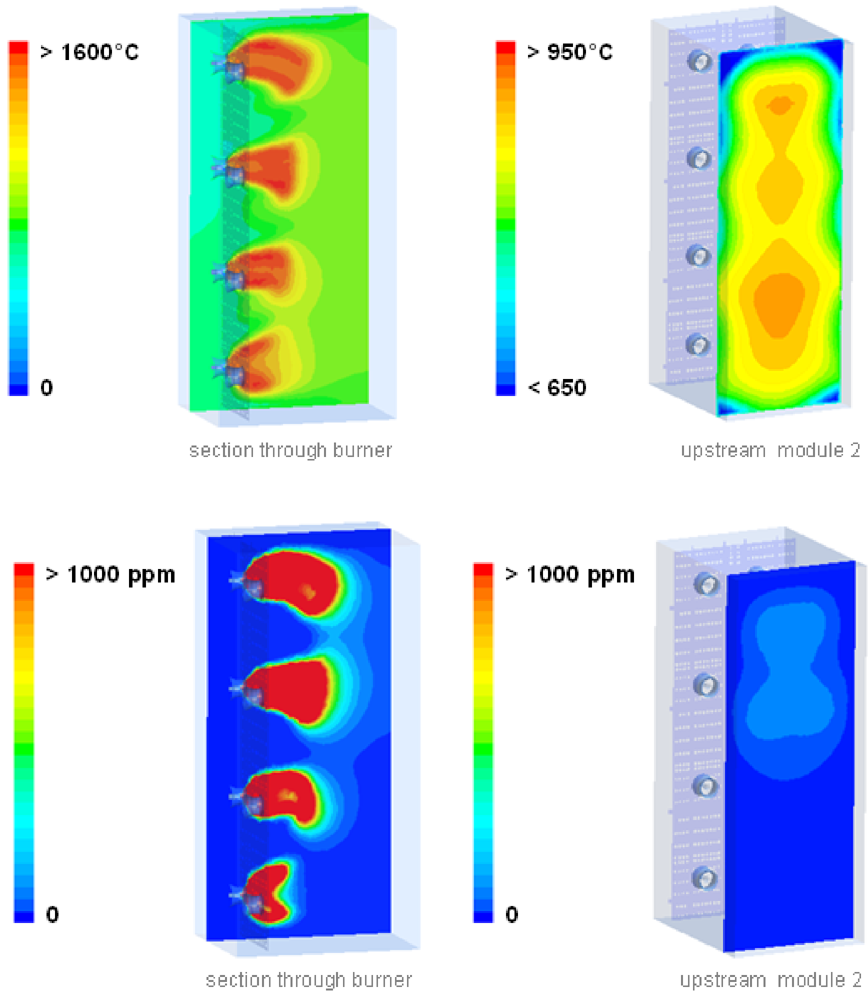


Figure 11: Temperature and CO Distributions, CASE 3

The temperature gradient is still low enough for this CASE 3. With the modified natural gas injection angle (more to outer regions / not to the core) the combustion process was optimized. CO as an indicator for the burnout could be decreased significantly (mean concentration < 50 ppm). With this improved concept several other studies (f.e. partial load) were performed. CASE 4 represents a typical partial load (75%) and CASE 5 shows predictions for an operating with only 4 burners.

### 4.4 CASE 4 (75% Partial Load)

The calculated temperatures for a partial load case are shown is fig. 12.

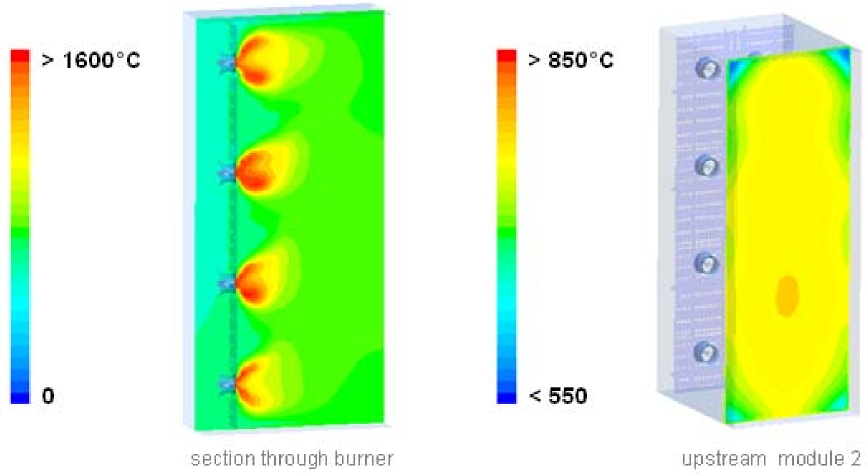


Figure 12: Temperature Distributions, CASE 4

Based on the optimized combustion concept (modified natural gas mass flows and injection) the predicted temperature distributions for 75% partial load are still homogeneous enough.

### 4.5 CASE 5 (Operating with 4 Burners)

Some partial load cases are defined for an operating with 4 or 6 burners. Fig. 13 shows the predicted values for an operating with only 4 burners.

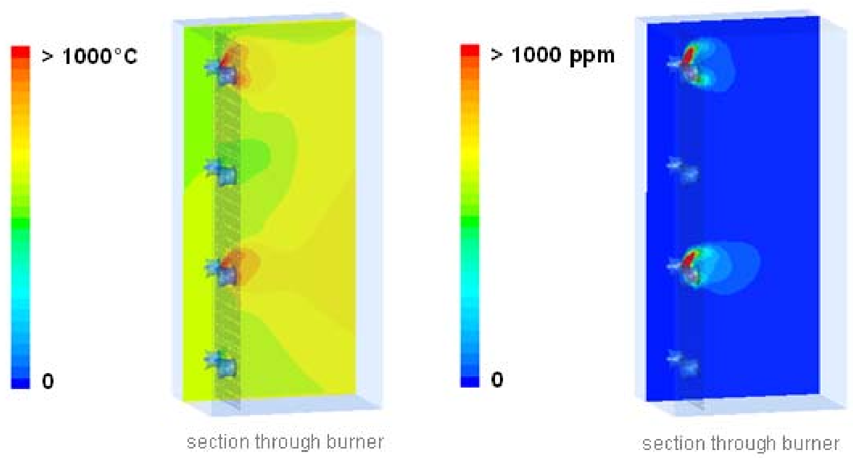


Figure 13: Temperature and CO Distributions, CASE 5

The problem for this case is the quite low temperature level. If the local temperatures are too low, the activation energy is missing and the system "produces" high CO concentrations. But based on the simulation results no risk for higher CO values was determined and the temperature gradient was also low enough for the downstream processes.

## CONCLUSION

Based on the CFD simulation results "Mehldau und Steinfath Feuerungstechnik GmbH" delivered 8 duct burners with a maximal capacity of 22,5 MW per burner for the heat recovery steam generator (HRSG) plant Marafiq IWPP. The plant was installed from 2007 to 2009 and at the end of 2009 the first experiences have confirmed the good predicted combustion results. The ignition worked without any problems and a stable condition could be found out for a full load case. Moreover the requested emission limits were directly achieved and therefore no rework, modifications or fine-tuning were necessary.

## REFERENCES

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