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CFD simulation of heating a Cu pipe with a safe H₂/O₂ flame

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Abstract. As part of the EU/SME project SafeFlame (www.safeflameproject.eu) the heating of a Cu pipe by a H₂/O₂ flame has been modeled and the results are compared to experiments. CFD (Computational Fluid Dynamics) modeling has been utilized to study the flow and combustion in the flame and the heat transfer from the flame to the pipe. The simulation results are compared with the measured temperature history of the pipe at different locations and with the visual flame. The influence of distance between the burner and the pipe and of using two opposite H₂/O₂ flames on the heating rate of the pipe has been investigated. Reasonable agreement between modeling and experiments has been obtained. The reasons for differences between modeling and experimental results are discussed.

Introduction

The development of safe hydrogen/oxygen burners for brazing is challenging. For safe operation, flame lift off and flash back has to be avoided and a stable flame for different power output has to be guaranteed. Moreover, a flame shape giving high enough heat transfer at proper distance from burner nozzle is required. Consequently, it is important to understand the flame behaviour at different power outputs.

This paper describe the application of CFD modelling to study the heating of a Cu pipe by a H₂/O₂ flame. In the next section the cases simulated are presented. Then the modelling approach is described. After that the simulation results are presented and compared to experiments, and discussed.

Heating cases simulated

In this work the heating of a Cu pipe was simulated with three burner alternatives. The distance between the burner and the pipe was varied for one burner. The cases are defined in Table 1. In the 3-hole burner the injection of H₂ and O₂ is through three openings in a line.

Table 1. Burner cases for brazing studied through simulation. Flames heating a straight copper pipe of length 200 mm at 15 or 30 mm distance from the burner. O₂ volume flow rates are half of the H₂ flow rates to have stoichiometric conditions.

Burner	H ₂ flow rate [l/min]	Cu pipe diameter [inches]	Distance between burner and pipe [mm]
1-hole burner	6	5/8"	15 and 30
3-hole linear burner (horizontal direction)	9	7/8"	30
3-hole linear burner (vertical direction)	9	7/8"	30

The heating of the Cu pipe was measured at ITM Power in Sheffield by thermocouples located on the back side of the pipe with respect to the burner and shown in Fig. 1.

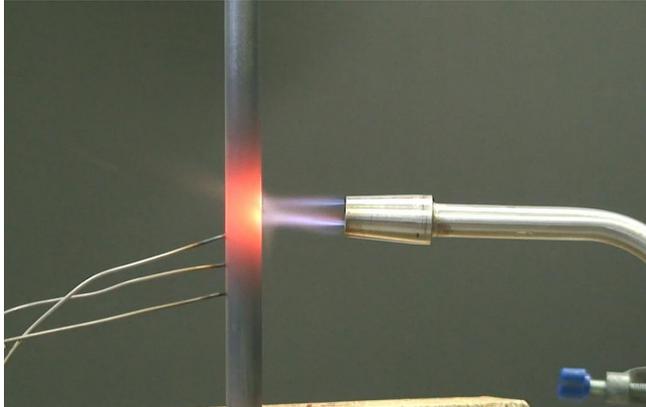


Figure 1. Experimental setup for the heat transfer tests at ITM Power. Flame heating a copper pipe of length 200 mm. The thermocouples are located at the back of the pipe at distances 10mm, 20 mm and 30 mm below the centreline of the burner head.

Modeling approach

In the CFD simulations the commercial Fluent (version 12.1.2) code was utilized. For the H_2/O_2 reaction kinetics a 12 step San Diego mechanism was used [1] and solved with Fluent's stiff chemistry equation solver. Constant properties of Cu were used: density 8940 kg/m^3 , specific heat 381 J/kgK , thermal conductivity 340 W/mK and surface emissivity 0.1. The sensitivity of the results on the surface emissivity was studied by changing the emissivity from 0.1 to 0.8.

The simulations were done in two steps to minimize the computational time: In the first step the steady state flame impinging the pipe was computed without heat transfer to the pipe. In the second step the transient heating of the pipe was computed with fixed flame shape but allowing cooling of the flame due to the heat transfer.

Simulation results

Simulation results are shown in Figures 2-5 and compared to experiments in Figures 6 and 7. The experimental set up is illustrated in Fig. 1. Figures 2-4 show the simulated flame impinging the copper pipe for the three cases studied with 30 mm distance between the burner and the pipe.

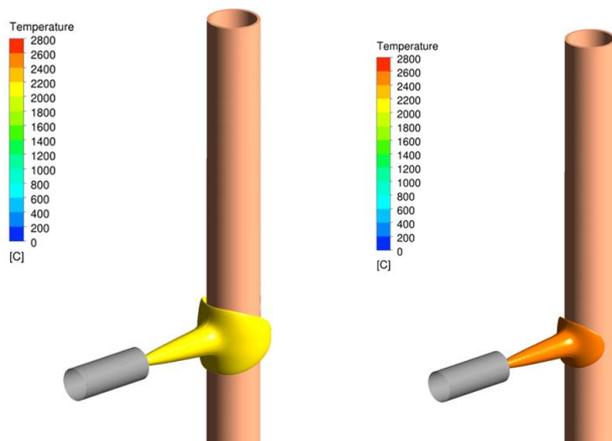


Figure 2. Simulated temperature isosurfaces 2163 °C (left) and 2500 °C (right) for the single hole burner at 30 mm distance from the pipe. Pipe diameter 5/8". H_2 flow rate 6 l/min.

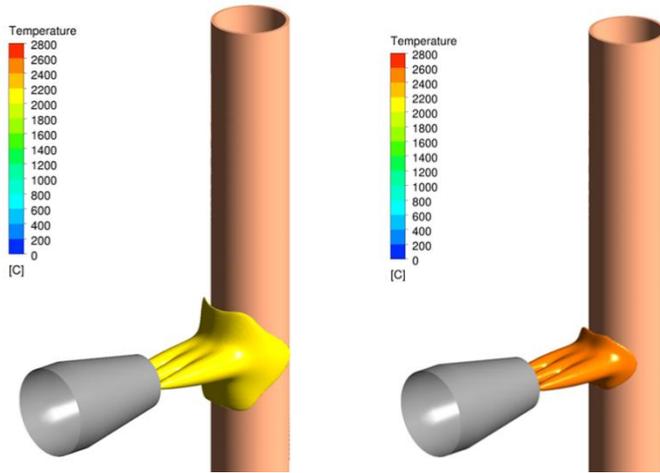


Figure 3. Simulated temperature isosurfaces 2163 °C (left) and 2500 °C (right) for the 3- hole linear burner horizontally at 30 mm distance from the pipe. Pipe diameter 7/8". H₂ flow rate 9 l/min.

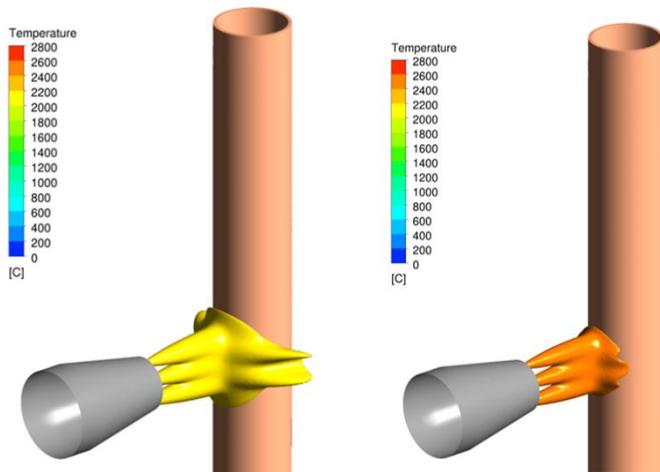


Figure 4. Simulated temperature isosurfaces 2163 °C (left) and 2500 °C (right) for the 3- hole linear burner vertically at 30 mm distance from the pipe. Pipe diameter 7/8". H₂ flow rate 9 l/min.

In Fig. 5 the computed temperature of the Cu pipe is shown at various times for the single hole and the three hole burner cases. The sensitivity of the results on the surface emissivity was studied by changing the emissivity from 0.1 to 0.8 resulting in about 10-30 °C lower temperatures at the monitoring points after 10 s heating.

The simulated temperature of the pipe during heating is compared with measurements in Figures 6 and 7.

The pipe heats much faster according to the simulations than in the experiments. The reasons for this discrepancy are discussed in the next section.

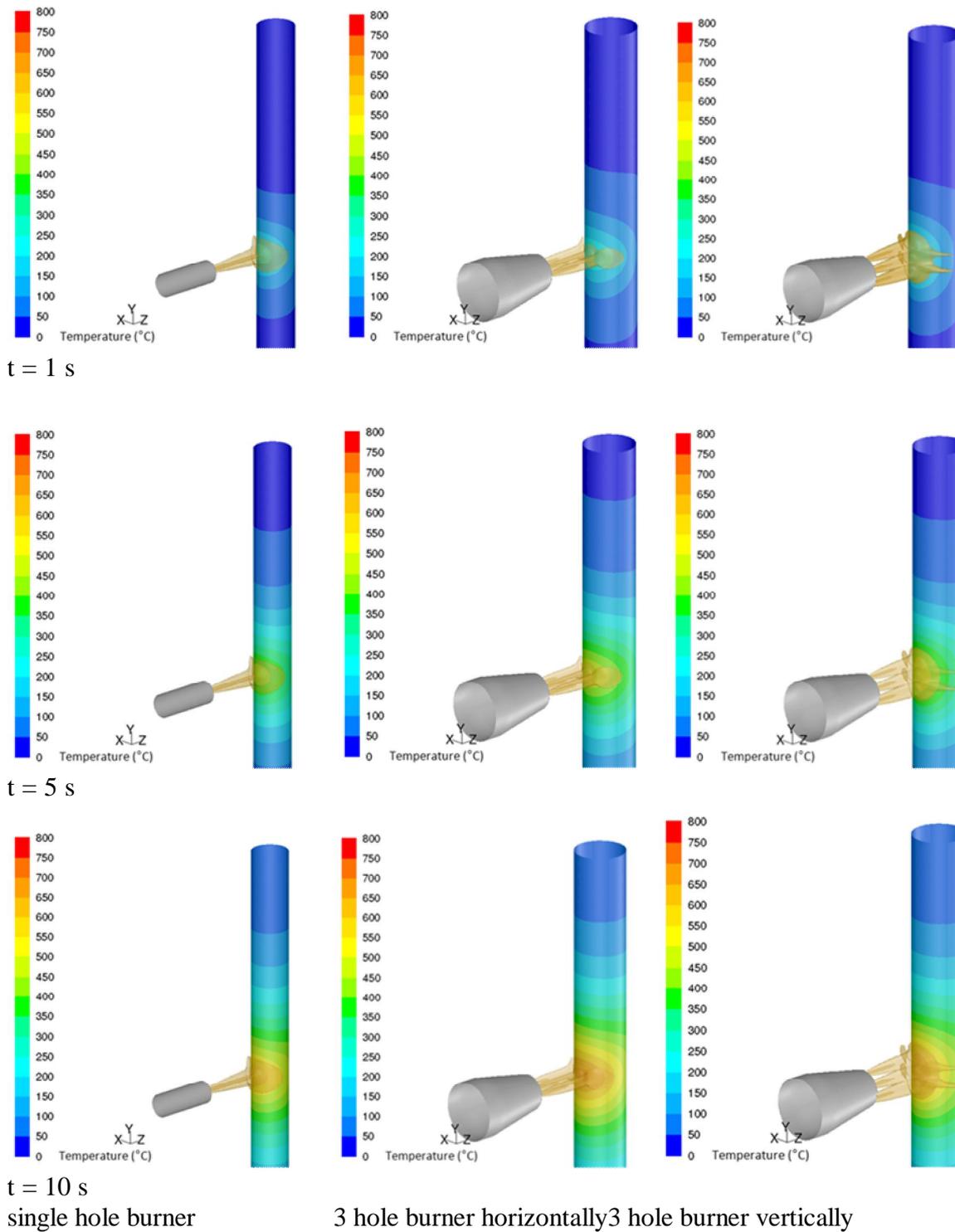


Figure 5. Surface temperature of copper pipe of length 200 mm during heating. Distance between burner and pipe is 30 mm. Pipe diameter 5/8" (single hole burner) or 7/8" (3-hole linear burner). H_2 flow rate 6 l/min (single hole burner) or 9 l/min (3-hole burner).

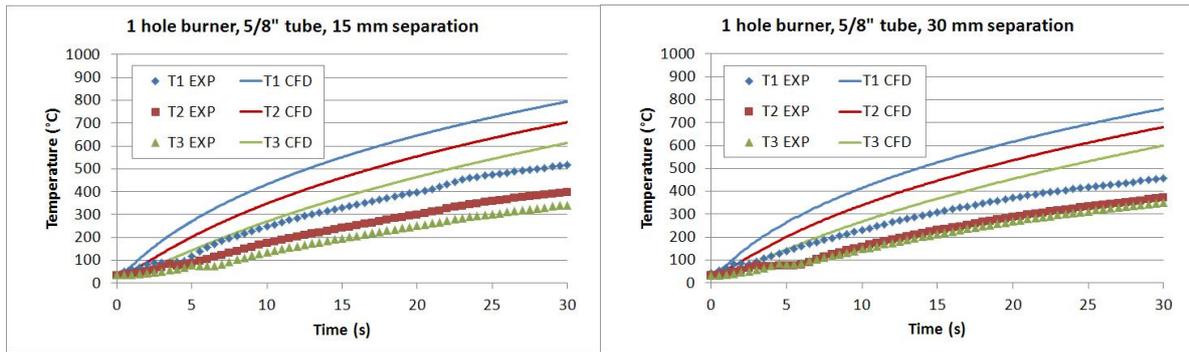


Figure 6. Computed ('CFD') and measured temperature of pipe at 10 mm (T1), 20 mm (T2) and 30 mm (T3) distance below the centreline of the burner head. Diameter of pipe is 5/8", H₂ flow rate 6 l/minute, distance between burner and pipe is 15 mm or 30 mm.

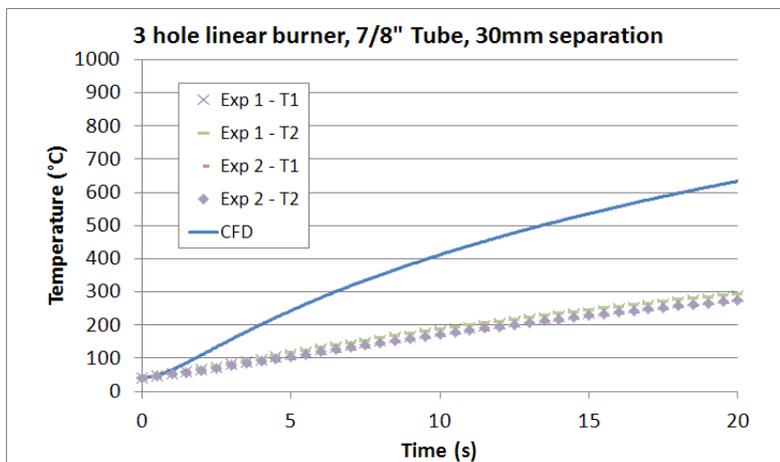


Figure 7. Computed ('CFD') and measured (Exp) temperature of pipe at 10 mm distance below the centreline of the burner head (thermocouples T1 and T2 are next to each other at same level, not to be confused with T1 and T2 in Fig. 6). Diameter of pipe is 7/8", H₂ flow rate 9 l/minutes, 3-hole linear burner horizontally. The experiments were repeated (Exp1, Exp 2) giving essentially the same results.

Discussion of results

The simulations show a clearly faster heating of the Cu pipe as compared to experiments. However, earlier simulations of the free H₂/O₂ flame shapes and lengths agree well with the observed flames as can be seen in Figures 8 and 9. The essential point in these comparisons is that the same value of OH concentration and, also that of temperature (not shown) correspond to the visual flame for all H₂ flow rates. Similar results were obtained with other flow rates and for the three hole burner with these same values of OH and of temperature.

Based on the encouraging results of the free flame simulations we expect that the flame length is correctly predicted also in the cases of heating a Cu pipe. The probable reason for the discrepancy between the simulated and measured heating rates is that in the heating experiments the flames are not stationary but fluctuate around the pipe whereas in the simulations a stable symmetric flame is assumed. In Figures 10 and 11 snapshots from videos show the fluctuation of the flame in the experiments.

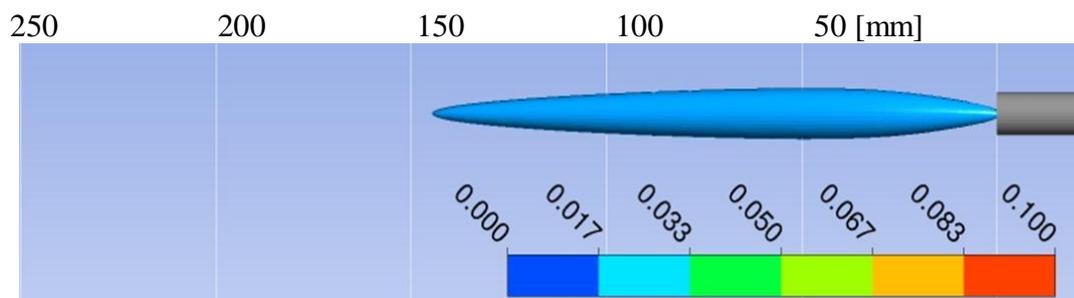


Figure 8. Comparison of simulated free flame with visual flame for single hole burner with H_2 flow rate 4.5 liters per minute. Visual flame taken from video of experiments. Simulated results show surface of constant OH-concentration (mole fraction 0.017).

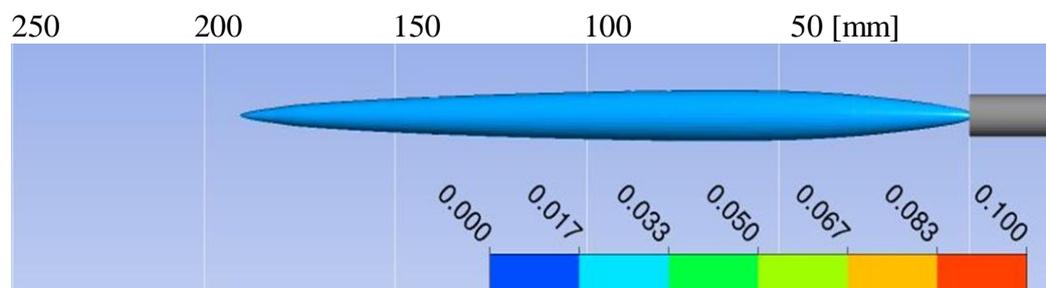


Figure 9. Comparison of simulated free flame with visual flame for single hole burner with H_2 flow rate 6 liters per minute. Visual flame taken from video of experiments. Simulated results show surface of constant OH-concentration (mole fraction 0.017).

The fluctuation of the flames in the experiments is related to the formation of Karman's vortex street behind the cylinder at the prevailing flow conditions. The steady state flow simulations can't capture this phenomenon and, consequently, predict a too effective heat transfer. A time dependent flow simulation would require a considerable longer computing time and it was not possible within the schedule of the project.

From the practical point of view, effective heat transfer from the flame to the pipe is desired. A flame wrapping around the pipe would be beneficial but the Karman vortex street type flow occurs between Reynolds numbers about 60 and 5000. At higher Reynolds numbers the flow would become turbulent and heat transfer would be enhanced.



Figure 10. Snapshots of flame heating a copper pipe (above) showing fluctuations of the flame. Single hole burner, distance between burner and pipe of diameter 5/8" is 15 mm, H₂ flow rate 6 liters per minute.



Figure 11. Snapshots of flame heating a copper pipe (above) showing fluctuations of the flame. Single hole burner, distance between burner and pipe of diameter 5/8" is 30 mm, H₂ flow rate 6 liters per minute.

Summary

The heating of a Cu pipe with burners for H₂/O₂ flames has been investigated through simulation. For the free flame cases the simulations agree well with the visual flames in the experiments. For the cases where the flame heats a copper pipe, the simulations predict a faster heating of the pipe than observed in the experiments. The reason of this discrepancy is discussed.

Simulations support the development of the H₂/O₂ burner for brazing and increase the understanding of the flame and heating processes. The results raise the question of proper flow conditions for most effective heat transfer from the flame to the pipe.

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