Velocity measurements and sampling inside a wood open fire-place to optimize the combustion performances

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INTRODUCTION

Wood combustion is one of the main objectives in burning renewable sources [1]. The interest in expanding this market, while reducing the environmental impact lead the manufacturers of different wood stoves to optimize the combustion chamber reducing pollutant emission and increasing global efficiency.

The design of these stoves is still empirical and it is based on the know-how of the industrial partners. The aim of this paper is to present how it was possible to optimize the heat exchange inside a wood open fire place using recent Laser Doppler Anemometry equipment. Moreover, samplings of the flue gas were performed in different operation condition and at different delay from the wood charge in order to measure the particulate emission.

EXPERIMENTAL SET-UP

The product presents itself as a classical wood stove, whose wall are used as heat exchanger for the heating water circuit. Those stoves are divided in two parts: the combustion chamber, where wood is inserted, and on the top of the stove is inserted the water/exhaust gas exchanger also for heating. Moreover, there are two independent water circuits for heating and sanitary water. The figure 1 represents a typical wood open fire place.

Fig. 1 View of classical wood open fire place.
Two different prototypes were designed and equipped with optical accesses. The combustion chamber geometry is the same for both the stoves while the water/exhaust gas exchanger geometry was modified. The figure 2 presents the two configurations of the exchanger.

![Diagram of wood stoves with heat exchanger](image)

*Fig. 2 Partial cross-section of the wood stoves with the heat exchanger.*

The two stoves were prepared according to the UNI norm [2] in order to calculate the global efficiency. Moreover, following the norms, it was possible to compare the performances of the stoves keeping constant the combustion parameters and the operative conditions. Continuous temperature measurements of the water circuit and at the exhaust were performed. Stable gases (CO, CO₂, NOₓ, HC, O₂) were measured every five minutes. 2 D velocity profiles were obtained using a DANTEC BSA Phase Doppler Particle Analyzer configured for back scattering measurements. Measurements were performed along a wood charge of 10 kg. The duration of a wood combustion charge was about 50 minutes. Wood had relative moisture of 30% and a net heating value of 2800 kcal/kg.

**RESULTS AND DISCUSSIONS**

The figure 3 represents a typical differential temperature (T<sub>out</sub> – T<sub>in</sub>) profile during a combustion charge. The dot lines represent the range of acceptable value for efficiency calculation.

![Differential temperature profile](image)

*Fig. 3 Typical differential temperature profile.*

![Gas concentration profiles](image)

*Fig. 4 Typical gas profiles.*
Figures 3 and 4 are representative of both prototypes since there were no significant profile differences between the two prototypes. In fact, the global efficiency of prototype I is 74.4% while for the second one it is about 74.8%. For both the stoves there is a sharp increase of the CO emission after about 30 min from the wood charge, while NOX concentration at the stack is about 40 ppm for the first 30 min. NOX emissions are mainly due to nitrogen present in the wood. The total soot emissions of both prototypes have similar value of 60 mg/Nm³. The average exhaust gas temperature was about 250°C.

An interesting result concerns the heating rise time of the water. In fact, the starting conditions are important for such products. We measured the time elapsed for the water to pass from 15°C to 60°C. For the first prototype this time is about 1 hr, while for the second prototype (with cylindrical exchanger) this time is about 25 min. This phenomenon can be explained by the different geometry of the water/gas exchanger and their position respect to the combustion place.

A complementary explanation could be given by the velocity study. Indeed, the study concerned the measurement of the velocity flow fields in the front panel, the rear panel and lateral panel of the prototypes (fig. 5) in order to get information about the heat exchange between exhaust gases and the water exchanger.

The 2D velocity profiles were measured in back scattering at different depths inside the stove. The measurements obtained viewing from the rear panel are not presented here since they are similar for both prototypes and are not relevant. The analysis of the front panel measurements indicates that the gases pathways are different for the two prototypes. In fact, for the first prototype, an important part of the flue gas passes between the exchanger and the external wall as presented in figure 6, while for the second prototype most part of the gases passes between the two cylinders.
Figure 7 evidences that, for the prototype I, gases passes regularly between the external wall of the stove, while for the second prototype gases are detected only on the right part and partially on the left part of the stove. The results obtained on the lateral panel presented in figure 8 confirm the gases pathway hypothesis for prototype II. No results are available for the prototype I due to the impossibility to insert optical accesses.

CONCLUSIVE REMARKS

The optimization of the geometry and heat exchanger of a wood open fire-place was performed using Phase Doppler Anemometry. Gas sampling analysis evidenced that the global efficiency depends only on combustion chamber and not on heat exchanger. The global efficiency of such product is about 75%. This work also evidenced that position of the exchanger respect to the flame is important for heat exchange.

REFERENCES

2. UNI 9841 – EN 13229 Norm.