# CERTIFICATION OF PELLET STOVES AND BOILERS BASED ON EN 14785 STANDARD – DESCRIPTION OF THE TEST BENCH AND PRELIMINARY RESULTS

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ABSTRACT: Residential heating systems fed with biomass represent a low environmental impact solution, also because of efficient technologies, developed in several European countries, where the products have been tested and certified. The European standards that have already been published deal mainly with efficiency, emissions and safety requirements in residential installations.
The Biomass Research Centre of the University of Perugia has realized in its laboratories a test bench for pellet stoves and boilers, based on EN 14785. The most important elements of the test bench are: a volume with thermocouples (trihedron), that surrounds the stove/boiler, to perform safety tests; a balance, on which the boiler/stove is positioned, to measure weight variation and fuel consumption during the test; a data acquisition system; a flue gases measuring and evacuation section to measure flue gases composition; and a hydraulic circuit (for thermal output measuring).
Objective of the present work is to describe the design and realization of the test bench and to report the first results obtained testing a 6 kW pellet stove.
Keywords: pellet, stove, certification

## 1 INTRODUCTION

Residential heating accounts for approximately 25-30% of the total energy demand in Italy. The use of renewables energies in this sector may represent an important opportunity to contribute to environmental sustainability and to a diversified energy system.

The energy market for buildings heating sees the lignocellulosic biomass in a position of great competitiveness with fossil fuels. In the domestic sector, stoves, fireplaces and boilers of the power of tens or hundreds of kW are currently marketed. However, at present, the Italian "fleet" is represented largely by outdated and inefficient stoves. Recently the supply of environmentally friendly combustion technologies have reached levels of efficiency, reliability and comfort very similar to those of traditional systems for gas or oil, with about 90% efficiency, compared to the old fireplaces and stoves.

Several studies and surveys at national and European level [1-2] show that the consumption of biomass for domestic heating is increasing, especially the consumption of pellets, and the number of installed units has almost doubled in the last 10 years. Being the actual market in continuous expansion, there is a need for certification of biofuels and heating equipment. Dealing in particular with heating equipment, at the moment, the market is pushing through small capacity and low cost solutions, both for boilers and stoves, that are often assembled and realized by small enterprises and sold through the great distribution channels. For this reason it becomes important to grant high performances, emissions and safety levels to align them to the existing national and international standards.

Regarding the certification of chemical and physical properties of solid biofuels, the Biomass Research Center (CRB) of the University of Perugia has realized a laboratory that has been described in previous works [3-4]. Recently a test bench for the certification of thermodynamics performances and safety requirements of pellet stoves and boilers has been realized, based on the UNI EN 14785: 2006 [5], home heating appliances fueled by wood pellets - requirements and test methods. In this paper the test bench main features and the preliminary results of performed tests are presented.

## 2 HOUSEHOLD HEATING EQUIPMENT – THE STOVE OBJECT OF THE STUDY

Pellet stove market started in Italy only in the late 90's, however at the moment Italy is the first European nation for number of facilities with approximately 1,000,000 units installed, which consume about 850,000 tons of pellets. Pellet national production is concentrated in northern Italy (about 80%) [6], keeping in mind that producers from 2003 to 2007, increased from 37 to 87 (+135%) [6-7]. In Italy, in the period 2005-2006, the sale of stoves marked a +145% respect to the period 2003-2004, while the reduced availability of pellets, with a +30% increasing rate (national production + imports) has led to an uncontrolled price increase, that has reached 400 €/ton.

The standards considered for certification equipment of household heating systems [5; 8-13] individuates two main categories of installations, depending on the power:

- appliances burning solid fuel without combustion control (stoves and fireplaces);
- installations of central heating boilers, as manual fed or automatic fed boilers, for hot water production, in a central heating circuit.

In this work the focus is on the boilers and pellet stoves.

The pellet boilers of different typologies can cover all the power used in the field of domestic, industrial or special applications. They can produce less than 10 kW, up to a power of several MW. Stoves, without the hydraulic circuit, offer the same technical features of boilers but, generally they have maximum power below 20 kW, with fuel feeding system charging from above. A stove is an equipment with closed burning chamber, normally isolated from external environment, that diffuses heat by radiation and convection.

In this paper the test bench performance will be tested on a stove charged by hand with an electronic display, through which it is possible to set the desired environment temperature. Flue gases draught is forced by a fan situated inside the stove. The spillage of flue gases, the pressure inside the combustion chamber, back burning through the fuel conveyor system, the overheating of fuel hopper and electrical safety are controlled through safety devices.

The characteristics of the stove described and analyzed in this paper are proposed in table I.

**Table I:** Characteristics of the stove object of the study (data from the technical specification of the stove)

| Characteristics | Description | |
|---|---|---|
| CE Mark | Present | |
| Norm | EN 14785 : 2006 | |
| Machine definition | Residential space heating appliances fired by wood pellets | |
| Structure | Steel and cast iron | |
| Combustion chamber | Steel and cast iron | |
| Nominal Thermal power | 6,73 kW | |
| Hourly consumption | 1,56 kg/h | |
| Efficiency | 90,98 % | |
| Flue gases temperature | 155,9°C | |
| Minimal safety distance | 200 mm | back wall |
| | 300 mm | right/left wall |
| | 0 mm | base |
| Dimensions | H x L x P = 981 x 430 x 505 mm | |
| Weight | 93,5 kg | |
| Capacity | 25 liters (about 18 kg) | |

## 3 DESIGN AND REALIZATION OF THE TEST BENCH

### 3.1 Introduction

For the above mentioned considerations the test bench design was based on the standard UNI EN 14785, that deals with pellet heaters with nominal powers limited to 50 kW.

The norm describes the test apparatus as made of a test bench equipped to monitor the following parameters:

- ambient temperature;
- maximum temperature reached on walls placed to a fixed distance from the stove external structure (trihedron);
- inlet and outlet water temperatures in the heat exchanger (if present);
- flue gas temperature;
- temperature of the fuel hopper;
- temperature of the handles and any part that needs to be touched during the operation of the stove;
- static pressure of the flue gases (draught);
- flow of water in the boiler (if present);
- total weight of the fuel and of the stove;
- concentrations of main gaseous species in the flue gases (CO, CO2, O2);
- electrical power input.

The objective is to verify that these parameters are comprised within the limits and that they comply with the statements of the manufacturer. The data besides could be processed to calculate thermal power and conversion efficiency.

Considering the above mentioned norm, the system requires that the device under test is installed, according to the manufacturer's installation instructions, on a balance surrounded by a trihedron used to measure heat radiation on close by objects. The heat generator, besides, has to be connected to an hydraulic circuit to measure heat dissipation and to a system for combustion gases spillage, that can also allow the measurement of flue gases composition and temperature.

The components essential to the bench need a proper design and engineering and are the following:

- the trihedron;
- the balance;
- the measurement sensors for the different parameters and the relative data acquisition system;
- flue gas measurement section;
- hydraulic circuit, flue gases spillage piping and heat dissipation circuit;
- the detection system of depression in the chimney and any fan that can guarantee the necessary draught. A schematic view of the layout of the test bench is presented in Figure 1.

### 3.2 The trihedron and balance

The trihedron that surrounds the measurement environment is composed of a base, a side wall and a back wall perpendicular to each other.

The base and the walls or ceiling of the trihedron must be constructed with a structure made of plywood and insulation having predetermined characteristics. The trihedron so conceived becomes the main support to help to identify the coordinates of the points in which temperature is greater; the temperatures are measured through thermocouples that satisfy the accuracy requirements specified, by the norm.

The walls are designed to contain a 18 x 18 array of sites in which thermocouples can be inserted and the total number of sensors for each wall is equal to 324, and 972 are the total sensors.

The stove must be installed on a balance to measure fuel consumption during the test, with a maximum uncertainty equal 20 g. The full scale of the balance, after assessing the weights of the boilers on the market, has been set to 600 kg and an industrial balance type BILATRON H520 + E 1005, of the capacity of 600 kg and precision of 20 g has been chosen. The dimensions of the plate are 1000 x 1000 mm.

### 3.3 Temperature acquisition and measuring system

The data acquisition system uses a combination of hardware and PC-based software; the system records data coming from thermocouples positioned on the trihedron, from the draught sensor on the exhaust gases duct, from the other pressure sensors and the sensor of flow on the hydraulic circuit, in addition to measurements of the flue gases characteristics (temperature, $\Delta P$, and concentration of different gaseous species).

Dealing with the hardware, the system is based on National Instruments Field Points:

- 3 modules cFP-TC-120, for thermocouples input at 16 bit, with 8 channels each;
- 3 blocks of thermocouple connectors CFP-CB-3 Compact FieldPoint, with 8 channels each;
- 1 module CFP-AI-110 general purpose acquisition, with 8 channels;
- CFP-1 block CB-1 with general purpose connectors, with 8 channels;

- 1 block VTC-1804 4-slot to connect via ethernet or serial port;
- A block PS-5 to feed 24 volts.

24 thermocouples type K were connected to the acquisition system hardware. The thermocouples are so dedicated: one for ambient temperature, one for flue gases temperature and the remaining twenty two thermocouples to measure temperatures on the three walls of the trihedron.

problems and calculation slowness. To avoid this, a simplified approach was considered, assuming steady flow condition. Once transient are over, sensors are set on a row of 18 x 18 matrix and temperature acquired, then moved to the following rows of the walls, being the distribution of the temperature function of space but not of time. To identify the end of the heating transient, a thermal IR camera was used also to identify hot spots and cold spots on the wall; the thermocouples will eventually be positioned in these points and the values will be monitored until the steady state is reached.

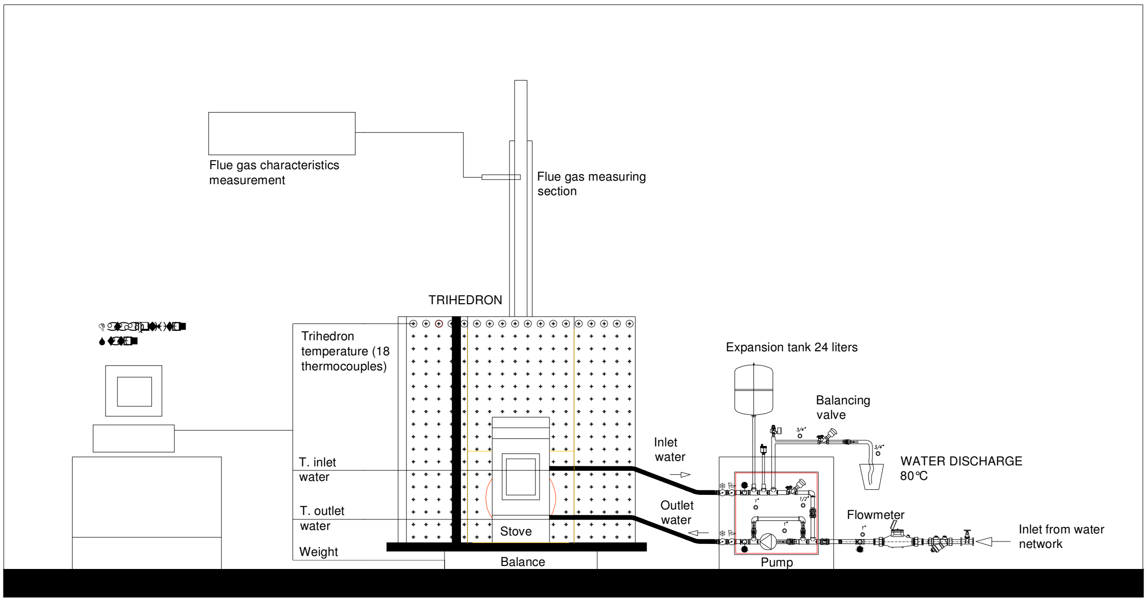


**Figure 1:** View of Test bench lay-out

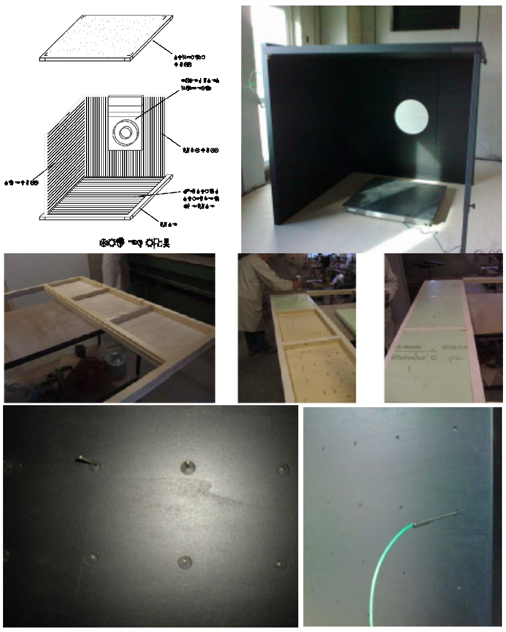

**Figure 2:** Overall view of the trihedron as built with ceiling and hole for the exit of flue gases pipe (up), particular of the layers (middle), sites for the insertion of the thermocouples (down)

The measurement and acquisition of 978 temperatures at the same time will lead to economic

The monitoring software is realized in Labview; a screen shot of the Virtual Instrument (VI) is shown in Figure 3.

It consists of several screens; in the one that is proposed, the commands for the display of thermocouples values, that measure the temperatures of the walls of the trihedron, the display of the date and the indicator marking the reaching of the maximum wall temperature, are shown.

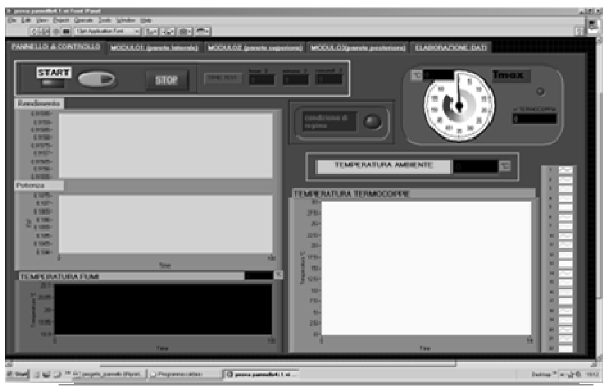


**Figure 3:** Monitoring software in Labview environment, thermocouples control panel

3.4 Flue gas section

The flue gases analysis is made through a measuring instrumentation (Testo 350) and a thermocouple (see Figure 4); the draught of the gases is measured through a static pressure transducer.

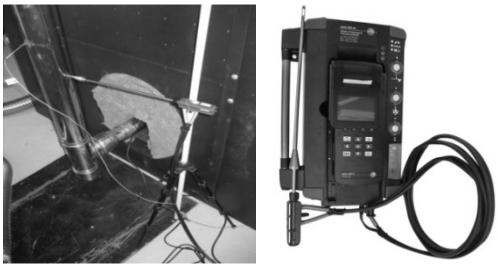

**Figure 4:** Flue gas section and flue gas measuring system

3.5 Hydraulic circuit

The hydraulic test circuit is characterized by a primary network with the expansion vase and pump and it is connected to the device under test.

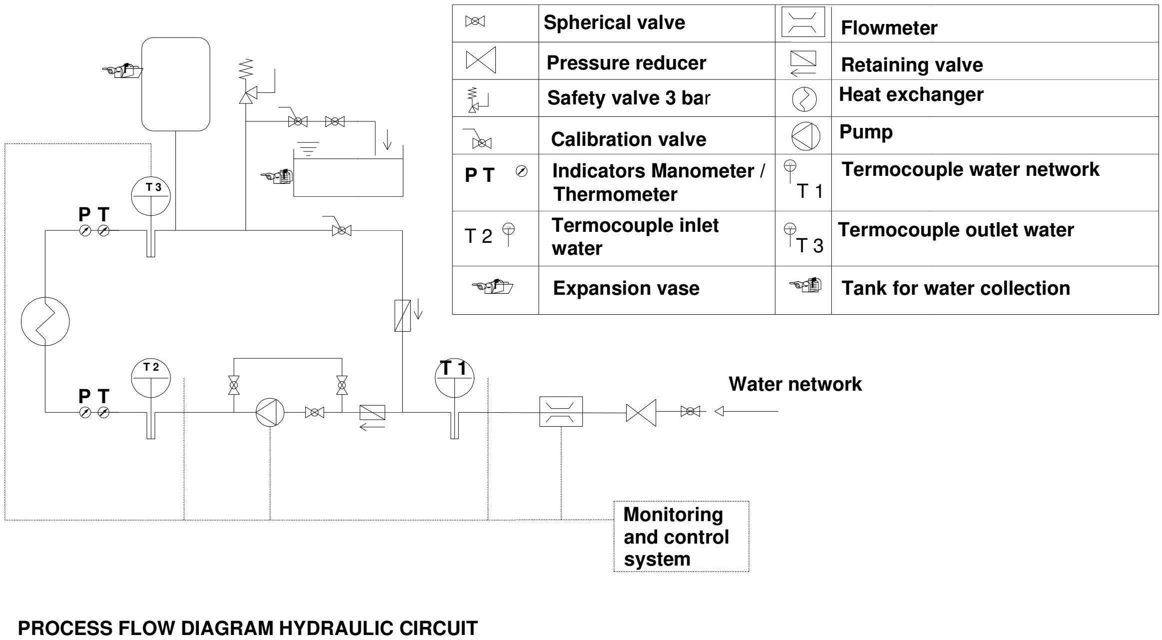


**Figure 5:** Process flow diagram of the hydraulic circuit

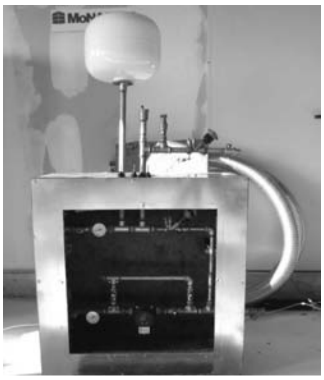

**Figure 6:** Hydraulic circuit

The measuring section is based on a flowmeter with electromagnetic sensor, type ISOMAG®MS501, and two thermocouples located in the inlet and outlet of the heat generator (see Figure 5). The entire circuit is contained within a box made of steel and equipped with removable door with dimensions of 900 mm x 900 mm x 550 mm insulated inside with a layer of 120 mm of mineral wool (see Figure 6).

During the tests in this work the stove described in Table 1 has been used, this means that being not present an heat exchanger, the hydraulic circuit was not used in the trials in question.

## 4 TEST PROCEDURES, PRE-TEST AND NOMINAL POWER TEST

4.1 Test conditions

According to the standard, the stove must be connected to the flue gas measuring section so that the temperature, the composition and the flue gas draught can be measured.

The test at rated thermal performance must be made according to the settings specified by the manufacturer.

The test is divided into two parts:

- a period of starting and one or more pre-test periods;
- the trial period.

The cold start test may be followed by another test, provided that the ash is removed. If the test is started at ambient temperature, the nominal power test period must be preceded by the initial ignition and a pre-test period. The duration of the pre-test period should be sufficient to ensure the establishment of the steady state.

Among the safety tests are comprised:

- temperatures of adjacent combustible materials control;
- operating tools safety test;
- test of combustion gas spillage;
- temperature in the fuel hopper control;
- safety against back burning through the fuel conveyor system;
- safety against overheating the boiler water;
- thermal discharge control;
- strength and leaktightness of boiler shells;
- electrical safety.

In the present work only the temperatures of adjacent combustible materials safety test was performed, because the heating apparatus tested is a pellet stove and not a boiler.

4.2 Thermocouples positioning using software

7 thermocouples have been installed for each wall into hottest and coldest points, to verify that the steady state has been reached. The panel presented in Figure 3 can be used in its functionality also to determine the highest temperature measured in a wall of the trihedron. For each wall there is a screen (see as an example "Sidewall", in Figure 7) that presents and indicator for each site that can be filled with a thermocouple so that 324 values can be obtained, corresponding to an array of holes 18 x 18 that were build using 18 measurements made with 18 sensors in a row (see Figure 8). As explained above, 22 thermocouples are available, so the program creates an array of 18 elements (4 thermocouples are not considered) in order to take the values of all the thermocouples.

The software then provides an output array of LEDs, in which the seven hottest spots of the wall are highlighted (see figure 9).

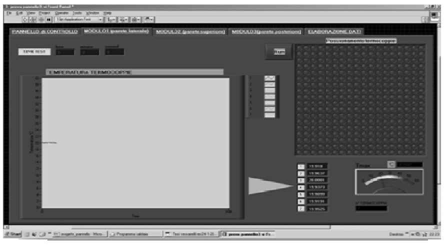

**Figure 7**: Software module “Sidewall”

**Figure 8:** First array of 18 thermocouples sampled with a 18 x 18 – back wall

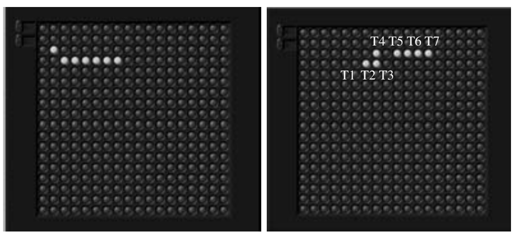


**Figure 9**: Side wall (left) and back wall (right) with indicated the hottest points

5.3 Thermocouples positioning using the thermocamera

The FLIR P620 IR (see Figure 10) camera was used, as it has been said to verify the hot and cold points in which the thermocouples are positioned, to verify steady state, but also during the test to gather further qualitative and quantitative information on the hottest places in the walls of the trihedron. In Figure 11 the diagrams of the temperatures respectively in the side, and back wall, are presented.


**Figure 10**: FLIR P620 IR thermal camera

It can be notied from Figure 11, as the highest temperatures can be found on the upper part of the side wall (picture on the left), while in the lower part, that is more far from the stove, the temperatures decrease. In the back wall (picture on the right) the highest temperatures are on the part above the stove, with the highest intensity in the angle of the trihedron where the side wall, the back wall and the upper wall meet. The measures done with the thermocamera are realized inside the trihedron using a high sensitivity sensor while problems due to the interference of the stove body are visible. On the other hand the thermocouple array (introduced in paragraph 5.2) is composed by values sampled in discontinuous sites, dislocated along the trihedron (no interference of the stove is visible).

Hence the graphs obtained from the thermocamera can not be compared with the measures derived from an array of 18 x 18 thermocouples, although the two measured thermal fields (reported in Figures 11 and 12-13) have a similar trend, as it can be seen from Figures 12 and 13, obtained from the interpolation of the temperature values contained in a matrix of 18 x 18 thermocouples. Figure 11 shows also that the stove (bottom right in the left picture and in bottom part of the right picture) was insulated with rockwhool to avoid that its high surface temperatures could change the measuring scale of the thermal field in the walls. In Figure 13 the cold area at the left of the wall represents an external area with respect to the measuring environment, because the side wall is inserted in ¼ of the total length of the back wall and it has to be at a constant distance from the stove, as declared by the manufacturer (that is 30 cm, as presented in Table 1).

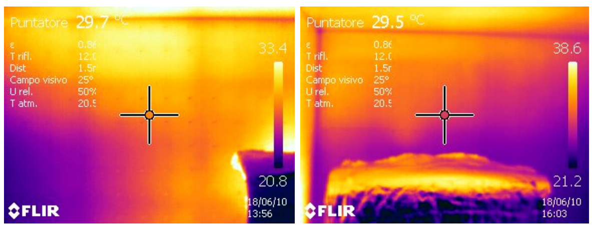


**Figure 11:** Temperature distribution on side wall (left) and back wall (right) obtained from IR camera

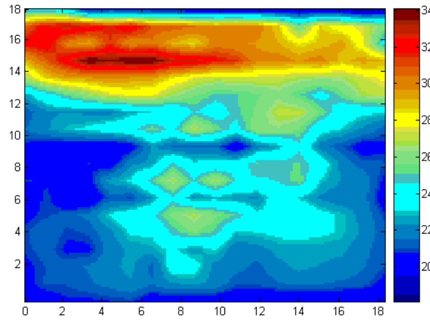

**Figure 12:** Interpolation of the temperatures measured by thermocouples on the side wall

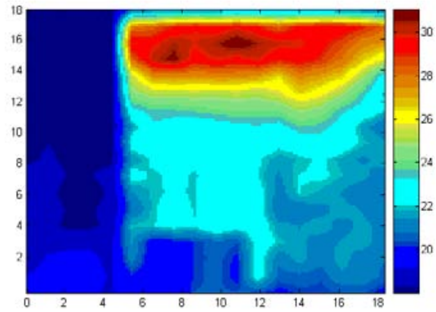

**Figure 13:** Interpolation of the temperatures measured by thermocouples on the back wall

The thermocamera gives therefore a qualitative confirmation on the positioning of the hottest zones in the trihedron and it could be employed to complete the analysis realized through the matrix of 18 x 18 thermocouples, sampled in different moments, once the steady state has been reached. The presented methodology has the advantage of giving accurate measures, using a low number of acquisition channels.

## 5 RESULTS

### 5.1 Characterization of the used fuel

Before the performance tests of the stove, the most important characteristics of the used fuel have to be measured.
The pellets used for the test is beech wood type certificate first class. The results of the analysis of fuel and ash are reported in Table II.

**Table II:** Results of the analysis on a sample of the used wood pellet

| Parameter | Value | Unit of measurement |
|---|---|---|
| Moisture | 7.5 | % |
| Volatiles | 82.12 | % |
| Ashes | 0.65 | % |
| Fixed carbon | 9.72 | % |
| LHV d.b | 20,170 | kJ/kg |
| C | 42.29 | % |
| H | 6.22 | % |
| N | 0.28 | % |
| Residual weight of the nominal test | 21.9 | g |
| Residual weight of the pre-test | 5.66 | g |

### 5.2 Pre-test results

In the pre-test the 24 available thermocouples were installed to measure ambient temperature. Of these only two were installed in specific points:

- the probe placed to measure ambient temperature at a height of 0.5 m and at a distance of 1.2 m from the heating apparatus;
- the probe to measure the temperature of the flue gases, is inserted into the site created in the flue gas measurement section.

All other thermocouples were placed in side, back and superior wall, in the points where initially it was verified to have the highest temperatures, through the use of the thermocamera and preliminary tests. After that the fuel load required in the pre-test was calculated, some basic parameters were recorded, such as:

- the stove weight;
- the pre-ignition load;
- the stove weight after ignition and during the test.

Once completed the pre-firing controls, the stove has been started. The data acquisition system was started, when the flame was ignited in the burning chamber.

The recorded temperatures for the pre-test period are shown in Figures 14 and 15. The pre-test period lasted 1 hour and 9 minutes, during this period the flue gas temperature and those measured by the thermocouples placed on trihedron increased gradually, until reaching constant values. After the temperature of the flue gas had settled on a stable value within 5 °C, it was decided to terminate the test and record the final values. It can be seen in figure 14 that the temperature of the flue gases was stabilized after about the 22nd minute and the maximum value reached is 175 ° C.

Ambient temperature was constant both during the pre-test and during the nominal power test, around a value of about 14 °C.

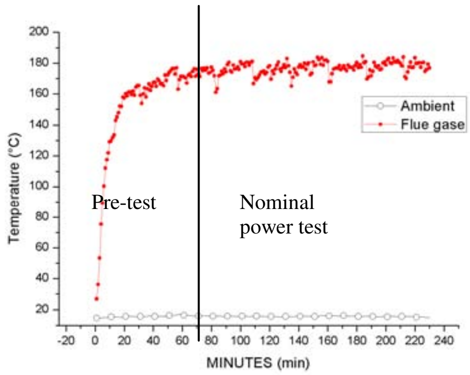


**Figure 14:** Flue gases and ambient temperatures

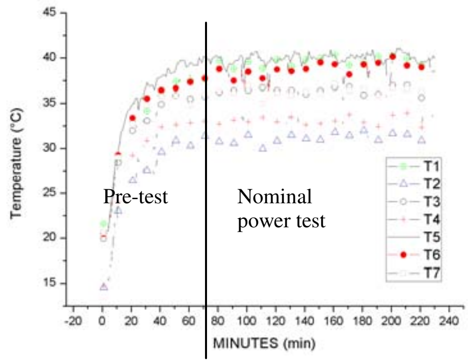


**Figure 15:** Temperatures measured by the thermocouples on the back wall

### 5.3 Nominal power test results

During the test at nominal output the flue gases temperature remains fairly constant around the range of 160-175 ° C (see Figure 14).

The average gas temperature is found to be 168.7 °C, even if from Table I it can be inferred that the flue gases temperature declared by the manufacturer is about 155.9°C. The average ambient temperature during the nominal test settles at about 13.8° C.

Dealing with the temperatures recorded by thermocouples during the nominal power test, the maximum temperature reached by the sides of the trihedron stands at a value equal to 32.4 ° C, which is well below the limits set by the legislation. This implies that the temperature of the walls of the trihedron does not exceed in any case the temperature of 65 ° C.

Regarding the performance data collected, these should be compared with the rating of the stove. In relation to the nominal power, test data show a reading equal to 7.34 kW, 0.61 kW higher than the maximum power stated by the manufacturer.

The efficiency instead, reaches a value of about 82.9% and shows a decline of 8.1%, respect to the value indicated by the manufacturer (see Table 4).

The average values of $CO_2$ and CO emissions are about respectively: 5.60% and 209 ppm.

**Table III:** Pellet stove performances

| EFFICIENCY CALCULATION | | |
|---|---|---|
| η | $100-(q_a+q_b+q_r)$ | |
| Thermal losses in the flue gases (QA), | 3405.40 | kJ/kg |
| Percentage value of the flue gases thermal losses ($q_a$) | 16.88 | % |
| Chemical losses in the flue gases (QB) | 38.45 | kJ/kg |
| Percentage value of the flue gase chemical losses ($q_b$) | 0.19 | % |
| Losses due to the combustion residual (QR) | 4.36 | kJ/kg |
| Percentage value of the losses due to combustion residual ($q_r$) | 0.02 | % |
| η | 82.90 | % |
| POWER CALCULATION | | |
| P | 7.34 | kW |

**Table IV:** Comparison between the measured parameters and those declared by the manufacturer

| Parameter | Measured | Declared | Percentage Error |
|---|---|---|---|
| Fuel consuption | 1.58 kg/h | 1.56 kg/h | 1.1 % |
| LHV | 20,168 kJ/kg | ≥ 16,900 kJ/kg | / |
| Flue gases temperature | 169 °C | 156°C | 7.6% |
| Power | 7.34 kW | 6.73 kW | 8.3% |
| Efficiency | 82.90 % | 90.98% | 8.9% |

## 6 CONCLUSIONS

In the present paper the test bench for the certification of pellet stoves made at the Biomass Research Centre (CRB) of the University of Perugia is described and the results of a first experimental test campaign are illustrated.

The test bench is composed by: a trihedron, inside which a heat generator is installed, in which holes are present that can host thermocouples used to monitor temperature at a certain distance from the external structure of the heat generator, this is done for safety purposes; a balance on which the heat generator is placed, used to monitor the weight and so the consumptions in exercise phase; a data acquisition system (composed by modules that can be programmed and thermocouples as measuring sensors); a measuring section of the concentration of the main substances present in the flue gases; an hydraulic test circuit (composed by control and safety valves, a pump, connected to water inlet and outlet pipes, and a bypass circuit) for the generators of hot water; a system to monitor flue gases draught and a vent that grants flue gases spillage.

The test bench will be used to certify pellet stoves with a maximum weight of 500 kg and a maximum power of 50 kW and pellet/chips fed boilers with a maximum weight of 500 kg and a maximum power of 300 kW. The simplified test methodology comprehends a pre-test phase, necessary to reach steady state condition, and a following nominal power test, during which process parameters and temperatures are measured in different moments, but without influence on the trends, being the transitory phase completed.

Finally a preliminary test was performed to characterize the performance of a pellet stove. The hydraulic circuit has not been tested because no hot water was produced. The obtained results show that, regarding nominal power test, the data indicate a value of the measured power equal to 7.34 kW, 0.61 kW higher respect to the maximum power declared by the manufacturer. The efficiency instead, is about 82.9%, this shows a reduction of 8.1%.

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