# IMPACT OF FUEL QUALITY AND BURNER CAPACITY ON THE PERFORMANCE OF WOOD PELLET STOVE

by

**Sanja B. PETROVIĆ BEĆIROVIĆ[a*], Nebojša G. MANIĆ[b], and Dragoslava D. STOJILJKOVIĆ[b]**

[a] Energoprojekt ENTEL, Belgrade, Serbia
[b] Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

Original scientific paper
DOI: 10.2298/TSCI150310082P

*Pellet stoves may play an important role in Serbia in the future when fossil fuel fired conventional heating appliances are replaced by more efficient and environmentally friendly devices. Experimental investigation was conducted in order to examine the influence of wood pellet quality, as well as burner capacity (6, 8, and 10 kW), used in the same stove configuration, on the performance of pellet stove with declared nameplate capacity of 8 kW. The results obtained showed that in case of nominal load and combustion of pellets recommended by the stove manufacturer, stove efficiency of 80.03% was achieved. The use of lower quality pellet caused additional 1.13 kW reduction in heat output in case of nominal load and 0.63 kW in case of reduced load. This was attributed to less favourable properties and lower bulk and particle density of lower quality pellet. The use of different burner capacity has shown to have little effect on heat output and efficiency of the stove when pre-set values in the control system of the stove were not altered. It is concluded that replacement of the burner only is not sufficient to increase/decrease the declared capacity of the same stove configuration, meaning that additional measures are necessary. These measures include a new set-up of the stove control system, which needs to be properly adjusted for each alteration in stove configuration. Without the adjustment mentioned, declared capacity of the stove cannot be altered, while its CO emission shall be considerably increased.*

Key words: *pellet quality, burner capacity, combustion efficiency, CO emissions*

## Introduction

The use of renewable energy sources has been deemed to be of particular importance, not only for the reasons associated with climate changes and reduction of greenhouse gases, but for its positive contribution to the security of energy supply and support of global sustainable development goals. Almost a half of gross final energy consumed in the EU is used to generate heat, with predominant share of this energy originating from fossil fuels [1, 2]. With approximately 7 million inhabitants [3], Serbia is a country with high energy intensity and gross final energy consumption that is largely attributed to households [4]. Regulated electricity price, which is three times lower than the EU average and 40-50% lower than in EU countries with the lowest gross domestic product per capita *i. e.* Bulgaria and Romania [5], additionally encourages irrational energy use. With respect to energy sources used, Serbia traditionally relies on the use of fossil fuels, primarily locally exca-

---

[*] Corresponding author; e-mail: spetrovic@ep-entel.com

vated low quality lignite. Biomass energy, which currently accounts for 12% of gross final energy consumed, is identified as the most important national renewable energy source (RES), with 3.448 Mtoe of available annual potential or 61% of totally available RES [6]. Numerous studies as well as strategic national documents have pointed out the importance of biomass energy for the future of energy sector in Serbia, identifying the use of pellets or briquettes for space heating as one of the best ways to utilize available biomass potential in Serbia and reduce dependence on fossil fuels [7-11].

Biomass is currently mainly combusted in wood logs and pellet firing appliances. Operation of wood fired devices depends on numerous factors. It has been proven that high quality of biomass fuel is desirable for efficient combustion process and reduced pollutant emissions [12-16]. Different researchers have also shown that design and control of biomass appliances strongly depends on the quality and form of biomass fuel [17-20]. Increased popularity of wood pellets as a convenient heating fuel in the household sector across Europe has enabled pellet combustion technology to progress extraordinarily in the last decade, achieving high efficiency and reliability of combustion devices while lowering solid and gaseous pollutant emissions [21, 22]. However, a wide quality range of these devices still exists, meaning that a device must be chosen carefully and based on its intended use. Extensive experimental investigations performed had shown that emission performance of different wood combustion appliances is strongly affected by changes in fuel, appliance and operational combustion features, but had also indicated that emission of CO and gaseous hydrocarbons (CxHy) can be rather well controlled by proper technical and/or operational measures [23, 24]. Research investigations have also reported that CO and CxHy emissions are more than an order of a magnitude lower for automatically fired systems, with lowest values observed during full load operation in automated units as a result of more stable combustion process achieved through automatically maintained and controlled stationary combustion conditions [25]. Analysis performed so as to compare emissions resulting from combustion of various European wood varieties in 8 kW manually fired wood log device with emissions from 9 kW pellet stove [26] has indicated large variations among fuel types, particularly with respect to particulate matter (PM) emissions which were found to be by a factor of ten lower in case of larch and black poplar than in case of oak combustion. With respect to CO and $NO_x$ emissions from pellet stoves, tests performed on three pellet stoves varying heating power, combustion chamber size and burner pot geometry [27] have indicated that production of CO is strongly affected by the excess air and by its distribution. In the stoves examined, a low-level of CO emissions required a proper set-up to operate in the optimal range of excess air that minimizes CO production. In addition, the study has shown that the optimal range of stove operation can be enlarged as a consequence of proper burner pot design. The NO emissions were found not to be a critical issue and were not influenced by the distribution of air in the combustion chamber, their behaviour as a function of excess air was the same for all the investigated burner geometries. Numerous researchers have indicated that there is a need for energy and environmental performance of wood burning appliances to be examined in more detail [28, 29], so they can be improved and integrated into households in sustainable manner.

In this paper, the results obtained during the investigation of the impact of fuel quality and operating parameters of pellet stove on thermal (heat output, efficiency) and environmental (CO emissions) performance of small scale household pellet stove have been presented. A novelty approach of the presented work goes to identifying necessary modifications in pellet stove configuration in order to achieve improved combustion process. The effects associated with burner capacity variation were deemed particularly interesting to examine. Although previous researchers have analysed optimization of burner geometry for specific stove configuration, they did not examine the effect of burner capacity on the performance of the pellet stove. This is particularity interesting as manufacturing cost of different capacity stoves may be reduced by keeping the stove construction unchanged and varying the capacity of the burner only. It was therefore investigated whether such simple variation in stove design may result in acceptable energy and environmental performance of the stove. Further experimental work shall focus on additional effects introduced by stove control system adjustments and analysis of joint effects achieved by modification in stove configuration and in control system settings. In addition, environmental performance of the pellet stove is planned to be additional investigated by measuring PM emissions.

## Experimental investigation

### Experimental set-up and investigation procedure

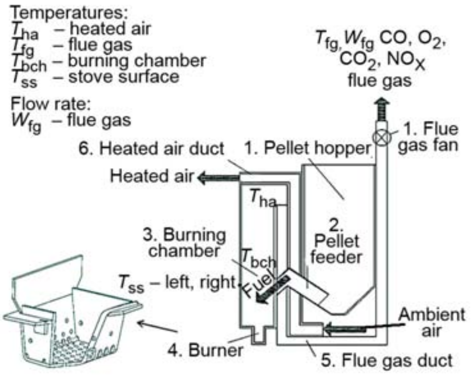

**Figure 1. Pellet stove and burner examined and performance parameters measured**

Performance of small scale pellet stove with capacity declared by the stove manufacturer of 8 kW, was evaluated in the Fuel and Combustion Laboratory of the Faculty of Mechanical Engineering, University of Belgrade, Belgrade. Experimental installation comprised test pellet stove with integrated burner (fig. 1), flue gas exhaust system, digital weighing scale, and data acquisition system. Such experimental installation enabled pellet combustion process to be examined even in more detail than minimally required by EN 14785:2006 [30]. Fuel supply rate and the combustion process were controlled automatically. Pellets loaded into a hopper were, through a vertical screw feeder, fed into the furnace *i. e.* onto a horizontal pellet burner. A fan that enables distribution of heated air into the heated room represents an integral component of the pellet stove. The system was provided with specially designed draught regulator, comprising a flue gas extraction fan and control dampers, installed in the flue duct and enabling flue draught to be controlled and maintained at desired level during the measurements performed.

Table 1 provides information on the characteristics of three different burners used in the investigation performed. In order to examine the impact of different operating parameters on energy and environmental performance of the pellet stove, thermal load of the stove (nominal or reduced) and burner capacity (6 kW, 8kW, and 10 kW) were varied, whereby keeping the flue draught at 12 ± 2 Pa as required by EN14785. Reduced load was achieved through se-

**Table 1. Characteristics of burners used in the investigation performed**

| No. | Burner capacity [kW] | Burner size, length × width × height [mm] | Burner volume [mm$^3$] | Number of openings | Total surface area of the openings [mm$^2$] |
|---|---|---|---|---|---|
| 1 | 6 | 75 × 57 × 55 | 235,125 | 45 | 883 |
| 2 | 8 | 90 × 57 × 55 | 282,150 | 65 | 1,671 |
| 3 | 10 | 105 × 57 × 55 | 329,175 | 65 | 1,671 |

lection of predefined stove settings that correspond to reduced thermal load and reduced operation of heated air fan, integrated into the stove configuration.

Burners were manufactured as rectangular-shape elements, with perforations provided on the bottom and on the front and back side walls. Perforations were provided so as to facilitate air inflow and fuel-air mixing, thereby contributing to the improved combustion process. Since bottom and side perforations enable air inflow into the burner, pellets in the burner are slightly elevated from the burner bottom, as well as from the side surfaces, and behave as some sort of fluidized bed. Therefore, there is no fixed-width pellet layer in the burner during the combustion. New pellets are periodically, in accordance with automatically set feeding rate, fed into the burner from above. The introduced pellets are falling onto an elevated, floating layer of pellets burning in the burner, with floating motion facilitated by air inflow through side and bottom perforations made in the burner.

All measurements for the selected thermal load of the stove (nominal or reduced) were performed with constant fuel feeding rate. This means that pellet feeder speed and time intervals of fuel dosing into the burner were kept constant. In addition, rotation speed of air and flue gas fans were also kept constant. Operation of screw feeder is based on its operating cycles, with each 250 ms cycle comprising working period $\tau_1$, during which pellets are fed into the burner and non-working period $\tau_2$, during which no fuel is fed into the burner. Time periods $\tau_1$ and $\tau_2$ were pre-set in the stove control system in accordance with manufacturer recommendations provided for nominal and reduced thermal load of 8 kW stove and the use of 8 kW burner. Characteristic time periods equalled $\tau_1$ = 10 ms and $\tau_2$ = 240 ms for nominal thermal load, and $\tau_1$ = 6.25 ms and $\tau_2$ = 243.75 ms for reduced thermal load.

During the experiments, the following parameters were monitored and relevant data collected: pellet consumption, flue gas temperature and composition, flue draught pressure, characteristic stove surface temperatures, temperature in the furnace, and temperature of heated air (fig. 1). Fuel consumption was determined from the stove mass measurements performed using a CAS BI-II digital weighing scale. Mass of the fuel-loaded stove was measured with time increments of 5 minutes, enabling fuel consumption to be determined from the changes in the mass measured. Temperature of heated air discharged into the heated room were measured by type K thermocouples, while stove external surface temperatures (on the left and on the right side of the stove when looking from the front side of the stove) were obtained using the surface mount magnetic thermocouples. All surface measurement and heated air temperature probes were connected to TESTO 454 measuring device and central data acquisition system. Flue gas data, as well as ambient air temperature, were collected by the means of TESTO 350 gas analyser, with gas sampling probe inserted in the flue gas duct. The indicated device enabled continuous monitoring of flue gas temperature, ambient temperature, and $O_2$, CO, $CO_2$, $NO_x$ and flue gas content [31]. Measurement of $O_2$ content in the flue gas enabled excess air coefficient to be calculated. Flue draught was measured by appropriately positioned pressure probe, installed in the flue duct and connected to the same data acquisition system. All measurement campaigns were conducted with sampling rate set to 10 s. Flue gas parameters were measured as soon as the steady operation of the stove was achieved. Data collected were used to calculate performance indicators of the pellet stove: heat output, efficiency, and CO emissions. Prior to the measurements performed, all measuring devices were calibrated. Measurement accuracy was the following:

- $O_2$: ±0.2%,
- CO: ± 10 ppm when concentration is below 100 ppm; ±5% of reading, otherwise;
- $NO_x$: ± 5 ppm when concentration is below 100 ppm; ±5% of reading, otherwise;
- temperatures: ±0.1 °C (-49.9 to +99.9 °C); ±0.4 °C (+100 to +199.9 °C).

In accordance with requirements of EN 14785:2006, measurement period comprised three different phases: (1) ignition period (lasting approximately about 5-10 minutes), needed for ignition to take place and flame visualization to occur, (2) pre-test period of 60 minutes during which the system was enabled to reach steady state operation, and (3) test period of another 60 minutes used for data collection. Temperature data acquisition system, collecting data from thermocouples used to measure characteristic combustion/stove temperatures, was started at the beginning of the pre-test period, so as to enable control of temperature measurements and gradual temperature variation stabilization towards steady state operation. All performance indicators were obtained based on the data collected during 60 minutes long test period only.

### *Test fuels*

The pellets used for the investigations are classified according the standard EN 14961:2010 [32]. Pellet A is classified as A2 quality pellet, with its properties being in line with values required for the indicated quality class. Pellet B, on the other hand, due to the ash content that exceeds 1.5% m/m can only be classified as class B pellet. Heating value of pellet B is about 5% lower than the heating value of pellet A. Data presented in tab. 2 also indicate additional differences between two pellets considered. Pellet B is characterized by lower particle and bulk density than pellet A, which is associated with greater size of pellet B that causes bulk density of pellet B to be 18% higher than in case of pellet A. Thereby, pellet A is considered a better quality fuel, since it is characterized by higher heating value, lower moisture and ash content, as well as smaller size and bulk density. It is important to mention that wood pellet A was provided by the stove manufacturer. Wood pellet B was arbitrarily selected from the Serbian market in order to investigate stove performance for the commonly available type of pellet. The characteristics of the wood pellets used during the investigation are given in tab. 2.

**Table 2. Characteristics of wood pellets used in the investigation performed**

| | *Pellet A* | *Pellet B* |
|---|---|---|
| *Proximate analysis (as received)* | | |
| Type of woody biomass | beech | beech |
| Total moisture, [% mm$^{-1}$] | 6.30 | 9.85 |
| Ash, [% mm$^{-1}$] | 1.07 | 1.76 |
| Volatiles, [% mm$^{-1}$] | 78.1 | 75.28 |
| Fixed carbon, [% mm$^{-1}$] | 14.5 | 13.11 |
| High heating value, [kJkg$^{-1}$] | 18,792 | 17,928 |
| Lower heating value, [kJkg$^{-1}$] | 17,147 | 16,265 |
| *Ultimate analysis (as received)* | | |
| C, [% mm$^{-1}$] | 45.49 | 45.39 |
| H, [% mm$^{-1}$] | 6.61 | 6.30 |
| O, [% mm$^{-1}$] | 40.41 | 36.6 |
| N, [% mm$^{-1}$] | 0.12 | 0.10 |
| S, [% mm$^{-1}$] | 0.00 | 0.00 |
| *Density* | | |
| Particle density, [kgm$^{-3}$] | 1090 | 909 |
| Bulk density, [kgm$^{-3}$] | 648 | 548 |
| *Pellet size* | | |
| Diameter, [mm] | 6.4 | 6.4 |
| Length, [mm] | 14.4-27.5 | 13.2-30.7 |
| *Pellet class* | | |
| Class (EN 14961:2010) | A2 | B |

### *Test regimes*

Eight different regimes have been examined during the measurement campaigns, each characterized by pellet quality used, capacity of the burner installed in the stove and thermal load applied (nominal or reduced). Identification (ID) label attributed to each operating regime examined is shown in tab. 3.

**Table 3. ID labels of operating regimes examined**

| Pellet type | Heat load | Burner capacity [kW] | Regime ID | Pellet type | Heat load | Burner capacity [kW] | Regime ID |
|---|---|---|---|---|---|---|---|
| A | Nominal | 8 | PA-N-B8 | B | Nominal | 8 | PB-N-B8 |
| A | Reduced | 8 | PA-R-B8 | B | Reduced | 8 | PB-R-B8 |
| A | Nominal | 6 | PA-N-B6 | B | Nominal | 6 | PB-N-B6 |
| A | Nominal | 10 | PA-N-B10 | B | Nominal | 10 | PB-N-B10 |

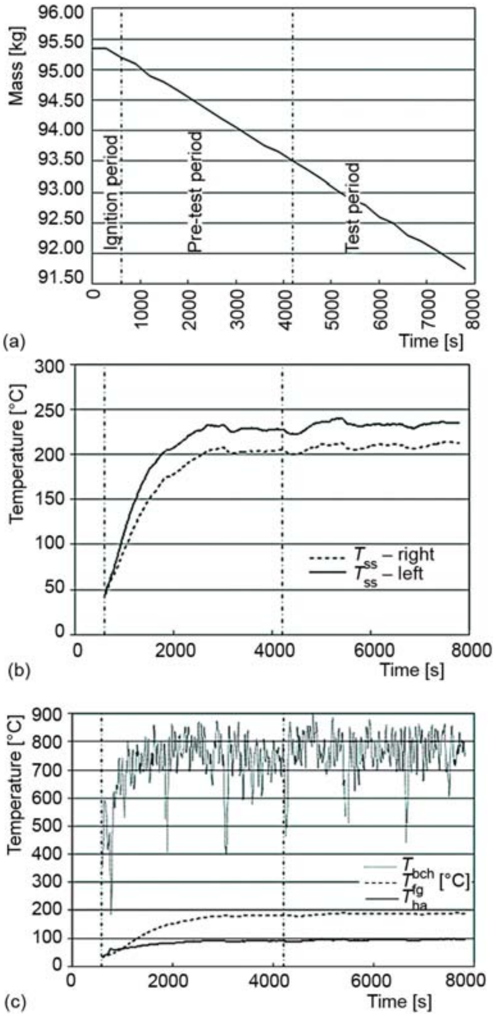

**Figure 2. Continuous measurement performed during PA-N-B8 regime**

## Results and discussion

### *Energy performance*

Test results obtained during measurement campaign associated with one specific regime (PA-N-B8) are given in fig. 2 as:

- fuel weight changes during characteristic periods of the combustion process, indicative of fuel consumption rate, fig. 2(a);
- temperature measurements of stove surfaces, right and left side, fig. 2(b);
- temperature measurements of flue gas, heated air and temperature in the burning chamber, fig. 2(c).

Data presented in tab. 4 show summarized results of the stove energy performance analysis, indicating the important parameters of each regime examined, as well as related heat output and efficiency values. Thermal efficiency of the stove was calculated based on the expression:

$$\eta = 100 - (q_a + q_b + q_r)\ [\%] \tag{1}$$

where $q_a$ is the proportion of the losses through specific heat in the flue gases, $q_b$ – the proportion of the losses through latent heat in the flue gases, and $q_\mathrm{r}$ – the proportion of the heat losses through combustible constituents in the residues. Expressions for $q_a$, $q_b$, and $q_\mathrm{r}$ are defined in EN 14785:2006 and shall not be presented herein for the sake of brevity. Energy losses through specific heat represent thermal losses lost as a result of flue gas temperature which is higher that the ambient temperature. Energy losses through latent heat in the flue gases represent chemical losses of the combustion process and depend on the content of carbon in the fuel, as well as CO and $CO_2$ in the flue gas. Energy losses through combustible constituents in the residues are a direct consequence of the unburned carbon in the solid combustion residues.

The obtained results show that capacity of the stove declared by the manufacturer was not achieved. Stove examined was declared to have capacity of 8 kW, when using 8 kW burner and pellet of recommended quality *i. e.* pellet A. However, measurements and calculations performed have determined that actual heat output of the stove in the specified case equalled 6.67 kW (tab. 4). Heat output of the examined stove was reduced by 1.13 kW *i. e.* 16.9% when pellet B was used, which is caused by lower quality, higher particle, and bulk density of pellet B. This again proves how important it is to use the fuel whose characteristics as a minimum match those specified by the manufacturer of pellet combustion device.

**Table 4. Parameters showing energy performance of the stove examined**

| Regime ID | Fuel consumption [kgh$^{-1}$] | Flue gas temperature [°C] | $O_2$ content in flue gas [% vv$^{-1}$] | Excess air coefficient | Heat output [kW] | Efficiency [%] | CO emission [mgm$^{-3}$] |
|---|---|---|---|---|---|---|---|
| PA-N-B8 | 1.75 | 177.7 | 15.40 | 3.75 | 6.67 | 80.03 | 332 |
| PA-R-B8 | 1.10 | 132.5 | 17.53 | 6.05 | 4.02 | 76.77 | 1285 |
| PB-N-B8 | 1.60 | 160.9 | 16.56 | 4.73 | 5.54 | 76.69 | 636 |
| PB-R-B8 | 1.00 | 126.2 | 17.97 | 6.93 | 3.39 | 75.05 | 1486 |
| PA-N-B6 | 1.75 | 175.4 | 15.55 | 3.85 | 6.64 | 79.61 | 562 |
| PA-N-B10 | 1.75 | 176.0 | 15.78 | 4.02 | 6.55 | 78.56 | 787 |
| PB-N-B6 | 1.65 | 169.1 | 16.06 | 4.25 | 5.80 | 77.86 | 554 |
| PB-N-B10 | 1.65 | 167.7 | 16.19 | 4.36 | 5.78 | 77.54 | 590 |

Results presented in tab. 4 indicate that fuel consumption of pellet A is higher than in case of pellet B for the same thermal load of the stove. This difference equalled about 9% for nominal and 10% for reduced thermal load when 8 kW burner was used. In case of 6 kW and 10 kW burners, the difference equalled 6% for nominal thermal load. As pellet feeder speed and time intervals of fuel dosing into the burner were kept constant for all regimes with the same thermal load (nominal/reduced), the difference observed in fuel consumption is attributed to differences in pellet characteristics, namely bulk and particle densities. In the same time, since rotation speed of air and flue gas fans were also kept constant for nominal/reduced thermal load regime, quantity of air introduced in the burning chamber was the same for all nominal *i. e.* reduced load regimes. Thereby, the indicated difference in fuel characteristics and associated combustion process specifics were identified as the reason behind the 26% higher excess air coefficient recorded in case when pellet B was used during nominal thermal load regime. In the same time flue gas temperature was 10% lower for the same regime when pellet B was combusted.

During reduced thermal load, excess air coefficient was 14% higher when pellet B was combusted, while flue gas temperature was observed to be 5% lower. This enabled higher heat output and higher efficiency to be achieved with the use of pellet A. Similarly, in case of 6 kW burner and nominal load of the stove, indicated differences in excess air coefficient was found to be 10% while flue gas temperature difference was 4%. In case of 10 kW burner and nominal thermal load of the stove, excess air coefficient was found to be 8%

higher in case of pellet B, with flue gas temperature being 5% lower. It can be concluded that all cases considered have shown that the use of pellet A, as a fuel having advantageous characteristics when compared to pellet B, results in higher heat output and higher efficiency of the stove examined.

Results obtained point out to the conclusion that different burner capacities do not affect heat output and efficiency of the stove to high extent. In case of pellet A, the use of 6 kW and 10 kW burner in nominal load, without any type of adjustment in control of the process (flue gas fan speed of rotation and similar), resulted in heat outputs of 6.64 and 6.55 kW, respectively, which is very close to 6.67 kW output measured when 8 kW burner was used. The best stove performance is accomplished when control system of the stove, defining and controlling combustion in the stove, operated in accordance with its set-up conditions defined by the stove manufacturer for burner capacity corresponding to the nameplate stove capacity and the use of recommended fuel quality. Results indicate that replacement of the burner only is not sufficient to proportionally increase/decrease the capacity of the same stove, meaning that additional measures are necessary. These measures include new set up of the stove control system, which needs to be properly adjusted for each alteration in stove configuration. In case of three regimes performed with pellet B, the highest efficiency of 77.86% is achieved with 6 kW burner, which may be attributed to compromised pellet quality and relatively low excess air in the combustion chamber. However, the use of pellet B in regime with 8 kW burner was associated with less favourable combustion process features, resulting from the high excess air in the combustion zone attributed to the factors mentioned previously. This confirms that performance of pellet stove, confirmed to be satisfactory for one particular fuel quality, shall exhibit different, even considerably compromised performance, if fuel of another quality is used. Again, control system needs to be adjusted so as to take into account different fuel characteristics from those recommended by stove manufacturer.

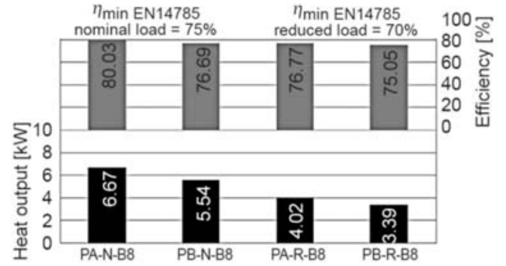

**Figure 3. Energy performance indicators of the pellet stove for different operating regimes**

Energy performance indicators of the pellet stove, obtained for eight different operating regimes examined, are presented in fig. 3. In general, the highest efficiency, η, of 80.03% was measured in case of nominal load and use of pellet A, where as the use of pellet B in the same operating regime resulted in reduced stove efficiency of 76.7%. However, efficiency values obtained for both type of pellet used were above 75%, which is a minimum permitted by EN 14785. The difference in stove efficiency resulting from the use of different pellets in case of reduced heat load was found to be 1.7%, whereby the stove performance was deemed generally acceptable for both pellets since the efficiency exceeded minimally required 70% for reduced thermal load.

The heat output *lost* as a result of lower quality pellet was found to be 0.63 kW, which is still 15.7% lower than the related heat output achieved with the use of pellet A. In addition, it has been observed that the heat losses through specific heat in the flue gases $q_a$ [28], reaching 20-24%, represented the most dominant type of heat losses in the process examined. Heat losses through latent heat in the flue gases, $q_b$, were observed to be less than 1% in all cases examined and losses through combustible constituents in the residues, $q_r$, were found to be negligible (as expected, due to the very low pellet's ash content).

Effects of burner capacity variation were deemed particularly interesting to examine bearing in mind a possibility for manufacturers to use the same stove construction when manufacturing different nameplate stove capacities, with only variation being in the capacity of the burner. This would significantly reduce stove production costs, enabling serial production of different capacity stoves. Three different burners were examined for the stove with declared capacity of 8 kW, each tested for nominal thermal load and the two pellet types defined earlier. Results obtained are presented in fig. 4. Doted rectangular line denotes the use of 8 kW burner *i. e.* burner capacity corresponding to the stove capacity declared by the manufacturer. As seen in the fig. 4, experiments failed to confirm that the use of alternative burner capacity reflected on the stove heat output, showing only slight change as a result of this alternation in stove configuration.

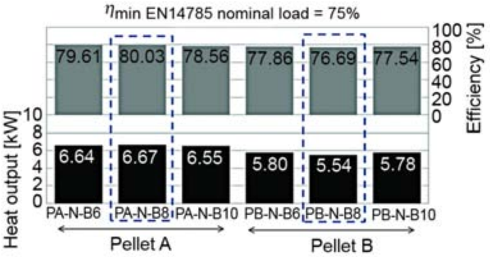

**Figure 4. Effect of burner capacity on energy performance of the pellet stove**

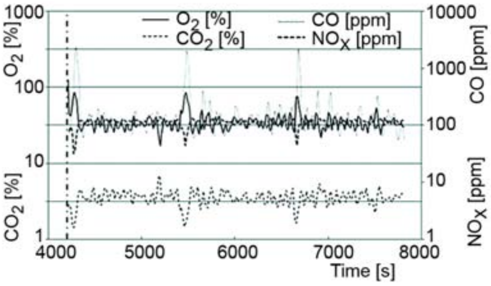

**Figure 5. Emissions from the pellet stove for PA-N-B8 regime**

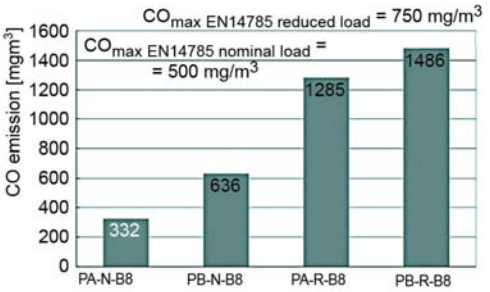

**Figure 6. The CO emission of the pellet stove for different operating regimes**

### *Environmental performance*

Figure 5 presents environmental performance data measured for the regime PA-N-B8, corresponding to thermal performance measurement data presented in fig. 2. Flue gas components measured included $O_2$, $CO_2$, CO, and $NO_x$. Analysis performed showed that higher CO content in the flue gas is measured in case of pellet B, which is indicative of incomplete combustion, associated with lower combustion temperature, higher moisture content of pellet B and higher excess air in the combustion zone, caused by less favourable characteristics of pellet B. Obtained CO measurements are presented in tab. 4, given for 13% $O_2$ as required by EN 14785. Data presented in fig. 6 indicate that only in case when pellet A was fired at nominal thermal load CO emissions were below emission limit values defined by 14785. In all other cases, when pellet A was used at reduced thermal load and when pellet B was fired both at nominal and reduced load, CO emission limit values were exceeded. With respect to $NO_x$ emissions, it was concluded that for pellet A, $NO_x$ emissions ranged from 84 to114 ppm, while for pellet B they varied from 37 to 54 ppm. Lower emissions in case of pellet B result from lower temperatures in the furnace. Although measured, $NO_x$ emissions were not able to be compared with emission limit values since the ones are not specified or limited by EN 14785.

The CO emission measurements associated with the use of different capacity burners, as presented in fig. 7, point out to the conclusion that requirements of the relevant standard with

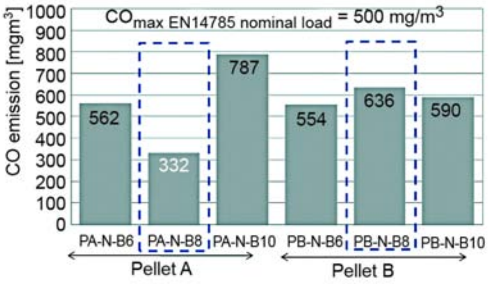

**Figure 7. Effects of burner capacity on CO emission of the pellet stove**

respect to CO emission limit values were met when pellet A and 8 kW burner was used. Use of alternative burner capacities has caused CO emissions to peak above the maximal permissible level. Therefore, data obtained imply that although burner capacity did not impact heat output of the stove in any considerable manner, it significantly affected related CO emissions. As far as the pellet B is concerned, neither of the burner capacities enabled measured CO emissions to be lower than emission limit values of 500 mg/m3 for nominal thermal load.

## Conclusion

The paper presents results of the research investigation performed in order to examine thermal (heat output, efficiency) and environmental (CO emissions) performance of 8 kW household pellet stove, associated with changes in fuel quality and operating parameters of the stove. Measurements were performed for two different wood pellets as well as three different burner capacities, as well as for nominal and reduced thermal load of the pellet stove, all in order to identify necessary modifications in pellet stove configuration in order to achieve improved combustion process. Results obtained indicate that the pellet quality, as well as pellet physical properties, significantly affects performance of the pellet stove. Although it would be expected that less quantity of higher quality fuel would be consumed to achieve certain heat output when compared to lower quality fuel, consumption of higher quality pellet (pellet A) was found to be 9% higher for nominal and 10% higher for reduced thermal load than when lower quality pellet (pellet B) was used for the same operating regime. This irregularity was attributed to differences in pellet characteristics, namely higher bulk and particle densities of higher quality fuel, indicating that apart from composition and heating values, pellet physical properties also significantly attribute to combustion process features. The results also showed that capacity of the stove as declared by the manufacturer was not achieved. Stove examined was declared to have capacity of 8 kW, when using 8 kW burner and pellet of recommended quality *i. e.* higher quality pellet of the two examined (regime PA-N-B8). However, measurements and calculations performed have determined that actual heat output of the stove in the specified case equalled 6.67 kW. Heat output of the examined stove was additionally reduced by 16.9% in nominal load and 1.7% in reduced load regime when lower quality pellet was used. As far as CO emissions are concerned, in case of nominal load and use of better quality pellet, CO emissions were below the emission limit value. With respect to the burner capacity variations, data obtained indicate that modification in burner capacity practically did not affect heat output of the stove, but affected related CO emissions. It is therefore concluded that replacement of the burner only is not sufficient to increase/decrease the nameplate capacity of the same stove. Further investigation will examine alternative set-up of the stove control system, which needs to be properly adjusted for each alteration in stove configuration. Without the adjustment, heat output of the stove shall not be altered, while environmental performance shall be considerably compromised. Further experimental work shall focus on the additional effects introduced by stove control system adjustments and analysis of joint effects achieved by modification in stove configuration and in control system settings.

## References

[1] ***, European Renewable Energy Council (EREC), Renewable Energy in Europe – Markets, Trends and Technologies, Publication Office of the European Union, Luxemburg, 2010

[2] Klaus, T., *et al., Energy Target 2050:100% Renewable Electricity Supply*, Federal Environment Agency, Dessan Rosslan, Germany, 2011

[3] ***, Comparative Overview of the Number of Population in 1948, 1953, 1961, 1971, 1981, 1991, 2002 and 2011, Statistical Office of the Republic of Serbia, Belgrade, 2014, ISBN978-86-6161-109-4

[4] ***, Energy Balances of the Republic of Serbia for 2014, Official Gazette of RS, No. 115/13, Belgrade, 2014

[5] ***, Eurostat, http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database, data retrieved in September 2014

[6] ***, Draft Serbian Energy Sector Development Strategy until 2025, with Projections until 2030, http://www.srbija.gov.rs/vesti/dokumenti_sekcija.php?id=45678, data retrieved in September 2014

[7] Perakis, C., *at al.,* Biomass Potential for Future Investments in Serbia, *Proceedings*,19th European Biomass Conference and Exhibition – From Research to Industry and Markets, Berlin, 2011

[8] Glavonjic, B., *at al.*, Wood Pellets Market in Serbia – Production and Opportunities for Utilization, 19th European Biomass Conference and Exhibition from Research to Industry and Markets, *Proceedings*, Berlin, 2011

[9] Glavonjić, B., Consumption of Wood Fuels in Households in Serbia – Present State and Possible Contribution to the Climate Change Mitigation, *Thermal Science, 15* (2011), 3, pp. 571-585

[10] ***, Biomass Action Plan for the Republic of Serbia 2010-2012, Official Gazette of RS, No. 56/2010, Belgrade, 2010

[11] ***, Renewable Energy National Action Plan, Official Gazette of RS, No. 53/2013, Belgrade, 2013

[12] Fiedler, F., The State of the Art of Small-Scale Pellet-Based Heating Systems and Relevant Regulations in Sweden, Austria and Germany, *Renewable and Sustainable Energy Reviews, 8* (2004), 3, pp. 201-221

[13] Dias, J., *et al.*, Test of a Small Domestic Boiler Using Different Pellets, *Biomass and Bioenergy, 27* (2004), 6, pp. 531-539

[14] Vinterback, J., Pellets 2002: The First World Conference on Pellets, *Biomass and Bioenergy, 27* (2004), 6, pp. 513-520

[15] Garcia-Maraver, A., *et al.*, Relationship between Fuel Quality and Gaseous and Particulate Matter Emissions in a Domestic Pellet-Fired Boiler, *Fuel, 119* (2014), 6, Mar., pp. 141-152

[16] Arranz, J. I., *et al.*, Characterization and Combustion Behaviour of Commercial and Experimental Wood Pellets in South West Europe, *Fuel, 142* (2015), Feb., pp. 199-207

[17] Kristensen, E. F., Kristensen J. K., Development and Test of Small Scale Batch-Fired Straw Boilers in Denmark, *Biomass and Bioenergy, 26* (2004), 6, pp. 561-569

[18] Eskilsson, D, M., *et al.*, Optimisation of Efficiency and Emissions in Pellet Burners, *Biomass and Bioenergy, 27* (2004), 6, pp. 541-546

[19] Limousy, L., *et al.*, Gaseous Products and Particulate Matter Emissions of Biomass Residential Boiler Fired with Spent Coffee Grounds Pellets, *Fuel, 107* (2013), May, pp. 323-329

[20] Bafver, L. S., *et al.*, Particle Emissions from Pellet Stoves and Modern and Old-Type Wood Stoves, *Biomass and Bioenergy, 35* (2011), 8, pp. 3648-3655

[21] Miguez, J. L., *et al.*, Review of Technology in Small-Scale Biomass Combustion Systems in the European Market, *Renewable and Sustainable Energy Reviews, 16* (2012), 6, pp. 3867-3875

[22] Qiu, G., Testing of Flue Gas Emissions of a Biomass Pellet Boiler and Abatement of Particle Emissions, *Renewable Energy, 50* (2013), Feb., pp. 94-102

[23] Boman, C., *et al.*, Emissions from Small-Scale Combustion of Biomass Fuels – Extensive Quantification and Characterization, Energy Technology and Thermal Process Chemistry, Umea University, Arrhenius Laboratory, Stockholm University, Stockholm, 2005

[24] Luisser, M., Schmidl, C., Emissions from Small Scale Pellets Stoves and Boilers, *Proceedings,* Australian Combustion Symposium, Sidney, Australia, 2007

[25] Schmidl, C., *et al.*, Particulate and Gaseous Emissions from Manually and Automatically Fired Small Scale Combustion Systems, *Atmospheric Environment, 45* (2011), 39, pp. 7443-7454

[26] Kistler, M., *et al.*, Odor, Gaseous and $PM_{10}$ Emissions from Small Scale Combustion of Wood Types Indigenous to Central Europe, *Atmospheric Environment, 51* (2012), May, pp. 86-93

[27] Petrocelli, D., Lezzi, A. M., CO and NO Emissions from Pellet Stoves: an Experimental Study, *Journal of Physics: Conference Series, 501* (2014), Con., 1, pp. 165-1712

[28] Carvalho, R. L. T., *et al.*, Energy Performance of Portuguese and Danish Wood-Burning Stoves, *Proceedings,* World Renewable Energy Congress, Linkoping, Sweden, 2011, Vol. 3, pp. 92-100

[29] Moran, J. C., *et al.*, Experimental Modelling of a Pilot Lingocellulosic Pellets Stove Plant, *Biomass and Bioenergy, 27* (2004), 6, pp. 577-583

[30] ***, ONORM EN 14785:2006, Residential Space Heating Appliances Fired by Wood Pellets – Requirements and Test Methods, Austrian Standards Institute, Wien, 2006

[31] Manić, N., Optimisation and Modelling of Biomass Pellet Combustion in Small Scale Pellet Stove for Household Heating, Ph. D. thesis, University of Belgrade, Belgrade, 2011

[32] ***, ONORM EN 14961:2010 – Part 2, Solid Biofuels – Fuel Specifications and Classes – Part 2: Wood Pellets for Non-Industrial Use, Austrian Standards Institute, Wien, 2010

Paper submitted: March 10, 2015
Paper revised: May 5, 2015
Paper accepted: May 5, 2015