INVESTIGATIONS OF COMBUSTION PROCESS IN COMBINED COOKER-BOILER FIRED ON SOLID FUELS

by

Dragoslava D. STOJILJKOVIĆ, Vladimir V. JOVANOVIĆ, Milan R. RADOVANOVIĆ, Nebojša G. MANIĆ, and Ivo R. RADULOVIĆ

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The aim of the investigation was to make some reconstructions on the existing stove used for cooking and baking and to obtain the combined cooker-boiler which will fulfill the demands of European standard EN 12815. Implementation of modern scientific achievements in the field of combustion on stoves and furnaces fired on solid fuels was used. During the investigations four various constructions were made with different fresh air inlet and secondary air supply with the intention to obtain more complete combustion with increased efficiency and reduced CO emission. Three different fuels were used: firewood, coal, and wood briquette. A numerous parameters were measured: fuel weight changes during the combustion process, temperature of inlet and outlet water, flue gas composition (O_2, CO, SO_2, CO_2, NO_x), flue gas temperature, ash quantity etc. The result of the investigations is the stove with the efficiency of more than 75% - boiler Class 1 (according EN 12815) and CO emission of about 1% v/v. The results obtained during the measurements were used as parameters for modeling of combustion process.

Key words: *solid fuels, combustion, cooker-boiler*

Introduction

Basic aim of the investigations was development of original domestic appliance fired on solid fuel that could be simultaneously used for cooking and heating the water for central heating system and heating the space in the room where it is installed. Original design of combined cooker and water heater – MBS 90KV was used as a base for further improvements. During the realization of the investigations several prototypes of combined cooker-boiler were tested and, based on the obtained results, appropriate reconstructions were made. Afterwards, the modified constructions characteristics (thermal and environmental) were tested.

Tests of the combined cooker-boiler MBS 90KV

The tests were based on definition of test program and choice of different fuels. Definition of listed parameters was necessary to provide the same test conditions for different constructions of combined cooker-boiler.

Test procedure

The tests of combined cooker-boiler MBS 90KV were made according to the demands of regulation EN 12815. Typical test cycle for lower grill position is foreseen by this standard, that comprise:

- start up and pre-test for reaching the steady-state;
- minimum 1 hour testing for the nominal heat power when the firewood is used as a fuel, and minimum 3 hours when the coal or other fossil fuel is used for determination:
  - total efficiency, and
  - heat output,

  and
- time required to reach the steady-state.

The test rig was designed and constructed according to the demands of regulation EN 12815 (fig. 1).

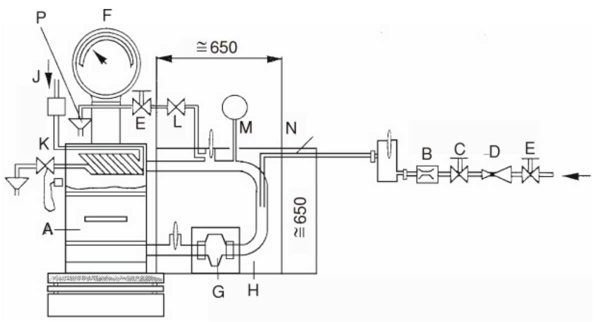

Figure 1. Test rig used for investigations
A – heating appliance, B – flowmeter, C – throttling valve, D – valve for pressure reduction, E – stop valve, F – weighing balance, G – circulating pump, H – steel reservoir, isolated with 120 mm thick mineral wool insulation or with cork pieces, J – safety device, K – thermal safety overflow device, L – overpressure valve for pressurized systems, M – expansion vessel, N – flexible junction, P – outflow

Figure 2. Combined cooker-boiler MBS 90KV on the test rig

Test fuels

Three different fuels were used for tests:

- brown coal "Banovići" (letter "u" in the test marking),
- firewood – common beech (no letter in the test marking), and
- briquette made of wood residues from furniture production (letter "b" in the test marking).

Proximate and ultimate analysis of all test fuels were made according to the regulation JUS B.H0.021. Proximate analysis was made in Fuel & Combustion Laboratory, Faculty of Mechanical Engineering, University of Belgrade, and ultimate analysis in the Institute for Chemistry, Technology and Metallurgy – Center for Chemistry. The results of these analysis (only for as received mass) for all test fuels are given in tab.1.

Table 1. Proximate and ultimate analysis of test fuels

	Fire-wood	Coal	Briquette
Proximate analysis			
Total moisture, [% m/m]	8.23	12.42	9.76
Combustibles, [% m/m]	91.00	78.05	89.87
Ash, [% m/m]	0.77	9.52	0.37
Volatiles, [% m/m]	75.07	38.93	76.06
Fixed carbon, [% m/m]	15.94	39.12	13.80
High heating value, [kJ/kg]	18031	21143	17420
Low heating value, [kJ/kg]	16624	19724	15782
Ultimate analysis			
Carbon, [% m/m]	43.43	56.47	46.05
Hydrogen, [% m/m]	5.34	4.73	6.19
Nitrogen, [% m/m]	0.45	1.35	0.67
Sulphur, [% m/m]	–	1.40	0.21
Oxygen$^{\text{as the difference}}$, [% m/m]	41.79	14.10	36.73

Constructions of combined cooker-boiler MBS 90KV

During the investigations different constructions of combined cooker-boiler MBS 90KV were tested:

- CONSTRUCTION 0 – Basic construction made by modification of classic solid fuel cooker MBS 90. Modification was primarily made on the firebox, which was increased in depth providing the space for insertion of heat exchanger in the upper zone. Other construction elements of the original cooker were not altered.
- CONSTRUCTION 1 – The firebox grill was lowered related to the basic prototype. Air inlet from the front side was closed. Position and dimensions of the ashtray are such that in the working position it is completely blocking rear side air inlet (which is the only air inlet for both primary and secondary air). In this way the airflow is allowed only along the sidewalls of the ashtray providing the primary air to the grill. This construction is marked as Model 0.
- CONSTRUCTION 2 – Ashtray height was reduced for 15 and 25 mm respectively, to allow air entrance in the air plenum beneath the firebox. The first modification was named Model 2 and the second one Model 1.
- CONSTRUCTION 3 – The secondary air supply was modified in a such a way that the direct flow upwards was blocked and redirected under the firebox grill. This modification was named Model 1a.
- CONSTRUCTION 4 – Firebox grill was moved backwards, to the rear wall, and the secondary air grill was placed on the front firebox wall instead on the back. This modification was named Model 1b.

Test results

Test results for all measured characteristics for one specific test (Test 1bu – boiler construction 4 with brown coal "Banovići" as test fuel; Report no. 12-54-12.01/2002) are given in the following figures as follows:

– fuel weight changes during the combustion process (fig. 3),

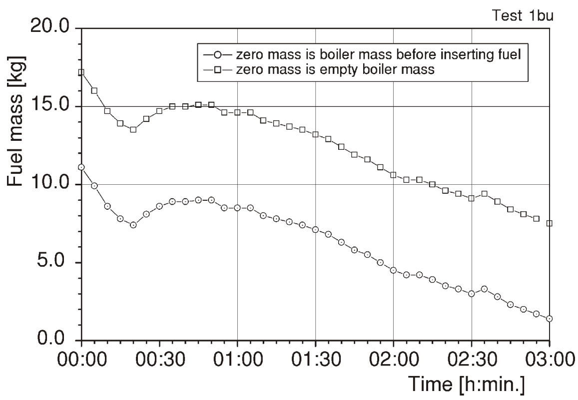

Figure 3. Fuel weight changes during the combustion process

– temperature measurements (water temperature at the inlet and outlet of the boiler and temperatures of the boiler body) (figs. 4 and 5), and
– flue gas composition (fig. 6).

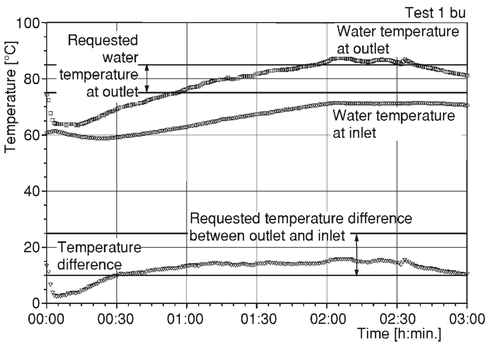

Figure 4. Water temperatures at the inlet and outlet and temperature difference

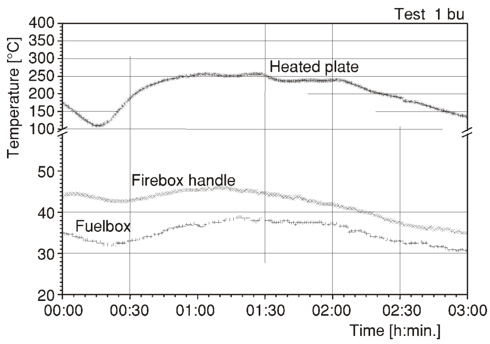

Figure 5. Temperatures of different part of boiler body

Discussions

Results obtained during the experiments were classified in 3 groups:
- thermal characteristics,
- functional characteristics, and
- environmental characteristics.

Thermal characteristics

Thermal characteristics that were determined during the tests were:
- nominal total heat output,
- heat output to the central heating water,
- heat output to the ambient, and
- total efficiency of the combined cooker-boiler.

Regulation EN 12815 doesn't have strict limits for the nominal heat output and ratio of heat output to the central heating system and ambient. However, total efficiency is strictly defined and, depending on it, all appliances are classified in 4 classes given in tab. 2.

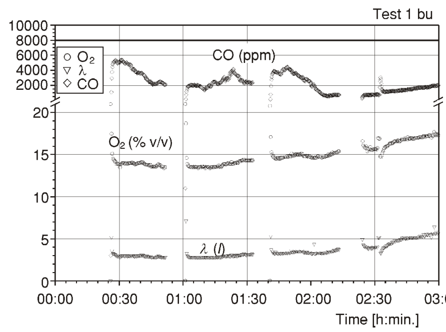

Figure 6. Flue gas composition

Table 2. Classes of appliances

Appliance class	Total efficiency [%]
Class 1	more than 75
Class 2	from 70 to 75
Class 3	from 65 to 70
Class 4	from 60 to 65

Nominal heat output, heat output to the water for central heating system, heat output to the ambient air and total efficiency are given in tab. 3. Experimental results from the tests of final model (adopted for production) for different fuel types are given on fig. 7 (nominal heat output) and fig. 8 (total efficiency).

Based on the classification given in tab. 2, combined cooker-boiler MBS 90KV is an appliance of Class 1 (efficiency grater than 75%).

Table 3. Nominal heat output and efficiency for different models

Test	Nominal heat output [kW]	Heat output to the water [kW]	Heat output to the ambient [kW]	Total efficiency [%]
Firewood				
0	20.01	5.85	14.16	74.83
1	22.05	7.50	14.55	74.60
2	19.64	7.10	12.54	73.58
1a05	18.09	5.40	12.69	79.23
1a10	20.50	6.14	14.36	74.58
1b05	17.84	6.92	10.92	74.69
1b10	20.39	6.75	13.64	76.12
1b15	22.17	7.36	14.81	70.01
Coal				
1bu10	16.13	5.87	10.26	80.32
Briquette				
1bb05	15.70	5.79	9.91	80.85
1bb10	18.38	6.13	12.25	74.06

Note: first digit and first letter are model mark, second letter is mark of test fuel used (no letter – firewood, u – coal, and b – briquette), last two digits are mark of draught in flue gas duct

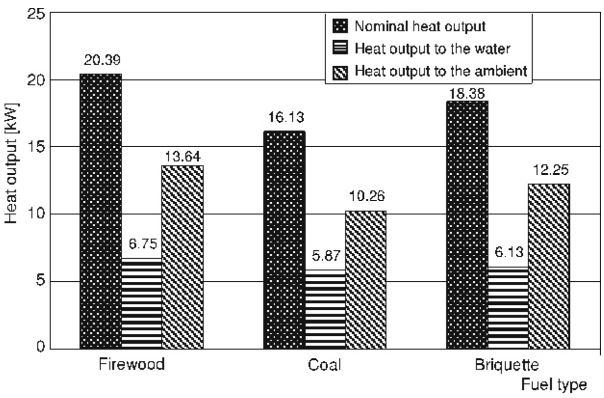

Figure 7. Heat outputs for all test fuels (final mode 1)

Functional characteristics

Functional characteristics are defining heating of the water for central heating system. Determination of these characteristics comprised measurement of:

– water temperature at the outlet of the boiler, and
– temperature difference between outlet and inlet.

Values for these temperatures defined in regulation EN 12815 are given in tab. 4. Time period when those values are satisfied was just recorded as requested by this regulation.

Measurement results for different models and all three fuels are given in tab. 5.

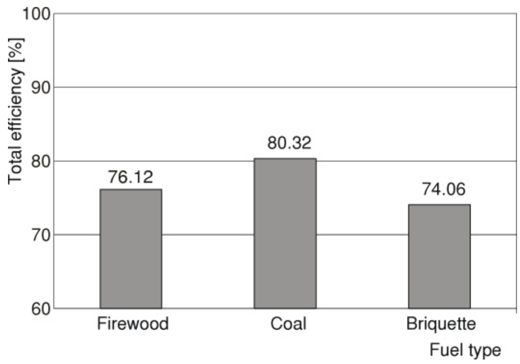

Figure 8. Total efficiency for different fuel types (final model)

Table 4. Requested values for temperatures

Requested water temperature at outlet [°C]	Requested temperature difference between outlet and inlet [ºC]
80 5	from 10 to 25

Table 5. Measurement results for the functional characteristics

Test	Outlet water temperature [°C]	Temperature difference [°C]
	Firewood	
0	78.6	13.3
1	88.2	16.9
2	83.5	14.6
1a05	76.3	13.1
1a10	71.9	11.5
1b05	80.5	14.5
1b10	78.0	14.4
1b15	87.2	15.7
	Coal	
1bu10	78.7	12.4
	Briquette	
1bb05	75.3	12.2
1bb10	76.3	13.1

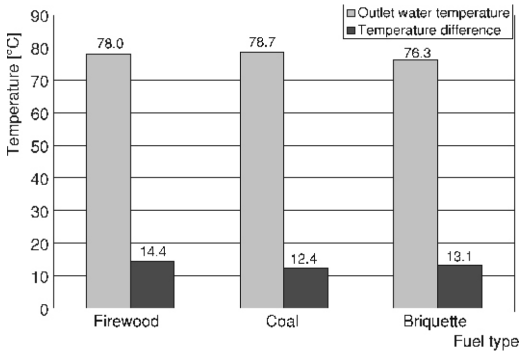

Figure 9. Outlet water temperature and temperature difference for different fuel types (final model)

Comparative values of outlet water temperature and temperature difference for all three test fuels are given on fig. 9.

Environmental characteristics

Under environmental characteristics only carbon monoxide (CO) emission level is defined. Based on the value of CO emission all appliances are, according to the EN 12815 classified in three classes given in tab. 6.

Table 6. Classes of appliances based on CO emission

Appliance class	Maximum permitted CO content, calculated at 13% v/v O_2 content in flue gas [% v/v]
Class 1	less than 0.3
Class 2	from 0.3 to 0.8
Class 3	from 0.8 to 1.0

Results of the CO emission measurements are given in tab. 7, and comparative CO emissions (calculated on 13% v/v O_2 content in flue gas) for all test fuels are given on fig. 10. The adopted final version was the best, fired on coal. It is Class 2 appliance based on classification given in tab. 6 but it was slightly above the limit for the

Table 7. Results of CO emission calculated at 13% v/v O_2 content in flue gas

Test	CO emission [% v/v]
Firewood	
0	1.78
1	1.93
2	2.27
1a05	1.85
1a10	1.58
1b05	1.35
1b10	1.24
1b15	2.14
Coal	
1bu10	0.31
Briquette	
1bb05	1.71
1bb10	1.74

Class 1. Firing this appliance on firewood and briquettes from wood didn't reach even the limit of Class 3. This will be the principal target for further development of this appliance.

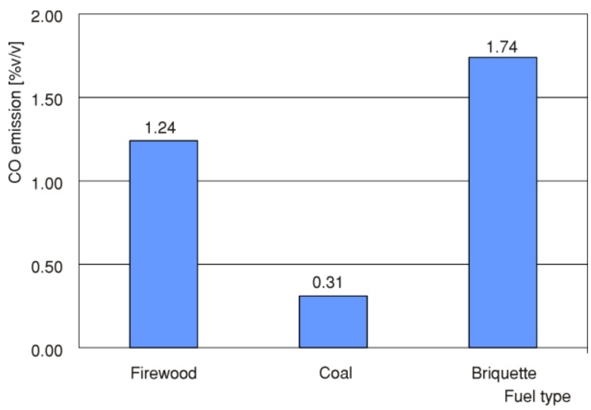

Figure 10. CO emission calculated at 13% v/v O_2 content in flue gas for different fuel types (final model)

Conclusions

Heating appliances fired on solid fuel could be a part of past but definitely a part of the future, especially having on mind that the biomass is renewable energy source with zero CO_2 balance. The importance of this type of heating appliances is emphasized by the adoption of the latest European regulation in this field EN 12815. This regulation has brought clear test procedures and strict limits for heating appliances fired on solid fuel.

Combined cooker-boiler MBS 90KV produced by the Company Milan Blagojević a. d., Smederevo, Serbia, is one of the newest products on the Serbian market. The results from the tests made completely according to the demands of EN 12815 during its development are presented in this paper. Based on these results it can be concluded that:

- total efficiency required by Class 1 was achieved (more than 75%) when fired on firewood and coal while slightly below this limit (Class 2) when fired on briquette made of wood residues from furniture production,
- nominal heat output of 16 kW was reached firing on coal, and even 20 kW fired on firewood,
- heat output to the water for central heating system was about 6 kW for all test fuels,
- CO emission of a Class 2 appliance was reached firing on coal (0,31% v/v),
- CO emission was above the highest permitted limit when fired on biomass (firewood and briquette both), and
- further improvements in biomass combustion (reconstruction of firebox) are needed to reduce the CO emission.

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Authors' address:

D. D. Stojiljković, V. V. Jovanović, M. R. Radovanović,
N. G. Manić, I. R. Radulović
Faculty of Mechanical Engineering, University of Belgrade
16, Kraljice Marije, 11000 Belgrade, Serbia

Corresponding author (D. Stojiljković):
E-mail: dstojiljkovic@mas.bg.ac.yu

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