# SAGOREVANJE NISKOKVALITETNIH FRAKCIJA UGLJA LUBNICA U FLUIDIZOVANOM SLOJU

# FLUIDIZED BED COMBUSTION OF LOW GRADE FRACTIONS OF LUBNICA COAL

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**Abstract:** Domestic power industry is based on the use of coal as the dominant raw material, with limited available reserves. Consequently, low grade fuels, like coals from off-balance reserves (fine granulation coals, with high ballast and sulphur contents and low heating values) are a fuel that should be used more rationally, which implies the application of fluidized bed (FB) combustion technology. This could have a significant role in the production of heat for the industrial and agricultural sectors, and in the case of application of combustion in circulating fluidized bed, this could also have a role in electric power generation. The fact that fluidized bed boilers can burn fuels with 85% of inert materials, with effective retention of $SO_2$ by adding limestone into the furnace, and with lower NOx emissions to meet environmental standards, gives this technology significant advantages compared to other combustion technologies.

The Laboratory for Thermal Engineering and Energy of the "Vinča" Institute, for more than thirty years, has been dealing with the investigation of combustion phenomena in the FB and with the development of furnaces and boilers with this method of combustion. As part of this research, a method of examination of fuel suitability for FB combustion has been developed. The research of combustion characteristics of described fuels in the FB by the aforementioned methodology has been carried out on a laboratory semi-industrial apparatus of $200kW_{th}$ so far. In order to obtain more reliable design parameters of real plants, an industrial demonstrative boiler with FB, on which the combustion parameters of various fuels in the FB will be examined in the future, is being constructed at the moment. The paper gives a brief description of the demonstrative boiler under construction.

**Keywords:** fluidized bed, coal combustion

**Abstract:** Domaća termoenergetika zasniva se na korišćenju uglja kao dominantne sirovine, čije su raspoložive rezerve ograničene. Staga niskokvalitetna goriva, poput ugljeva iz vanbilansnih rezervi (ugljevi sitne granulacije, sa visokim sadržajem balasta i sumpora, niske toplotne moći) predstavljaju jedno od goriva koje treba racionalnije koristiti, što podrazumeva i primenu tehnologije sagorevanja u fluidizovanom sloju (FS). Ovo rešenje može imati značajnu ulogu u proizvodnji toplotne energije za sektor industrije, poljoprivrede, a u slučaju primene sagorevanja u cirkulacionom fluidizovanom sloju i za proizvodnju električne energije. Činjenica da se u kotlovima sa FS mogu sagorevati goriva i sa 85% inertnog materijala, sa efikasnim zadržavanjem $SO_2$ dodavanjem krečnjaka u ložište, i nižom emisijom $NO_x$ uz zadovoljenje standarda zaštite životne sredine, ovoj tehnologiji daje izrazitu prednost u odnosu na druge tehnologije sagorevanja.

Laboratorija za termotehniku i energetiku Instituta "Vinča" se tridesetak godina bavi proučavanjem fenomena sagorevanja u FS i razvojem ložišta i kotlova sa ovim načinom sagorevanja. U sklopu tih istraživanja razvijena je metoda ispitivanja podobnosti sagorevanja određenog goriva u FS. Dosadašnja ispitivanja karakteristika sagorevanja predmetnih goriva u FS, po pomenutoj metodologiji vršena su na poluindustrijskoj laboratorijskoj aparaturi snage 200kW$_{th}$. Radi dobijanja pouzdanijih projektnih parametara realnih postrojenja u toku je izgradnja industrijskog demo-kotla sa FS na kome će se ubuduće ispitivati parametri sagorevanja različitih goriva u FS. U radu je dat kratak opis demo-kotla u izgradnji.

**Ključne reči:** fluidizovan sloj, sagorevanje uglja

## 1. INTRODUCTION

The main energy potential of Serbia is coal. Coal reserves have to be used more rationally, especially nowadays when they are drastically reduced due to the inability to dispose of coal reserves in Kosovo and Metohija. The main part of coal is obtained by open-cast mining (about 95%), and is directly used in power plants. The characteristics of domestic lignite and brown lignite basins indicate future exploitation in complex coals series, with strong stratification of coal seams, hence oscillations of the characteristics of the coals, mined with current machinery, are inevitable. Exploitation and mining-geological characteristics of the basin, as well as the need for utilization of coal reserves with heating value below 3,500 kJ/kg, justifies the use of technology that is less sensitive to these changes, i.e. boilers with FB. The already adopted legislation on permitted emissions from thermal power plants boilers imposes the necessity to reduce emissions below the level typical for conventional boilers without desulphurization facilities and NOx reduction measures applied. At the same time, the introduction of FB combustion technology is one of the ways to increase energy efficiency and environmental acceptability of energy facilities, and the way to introduce energy technologies, the intense application of which is expected in the 21$^{st}$ century.

A significantly smaller portion of coal is obtained by underground mining, and it is mainly aimed for broad market, and less for power industry. The majority of underground coal mines is operating on the verge of profitability. There are several reasons for this, among others the reasons are the following:

- unacceptable granulation of pit coal (one of the main problems of underground mines is major content of small fractions of coal, up to 50%, which can hardly be commercially marketed for a wide range of consumers and the industry),
- often high sulphur and ballast contents, and
- intensification of environmental protection criteria.

Exactly this non-commercial fine coal granulations, with adverse chemical composition, often prone to ignition at landfills (which is, apart from being a technical problem, also a major environmental problem), can be a very convenient fuel for local needs, and their application with the fluidized bed combustion (FBC) technology would meet environmental standards and relieve the domestic power industry to a significant extent.

The Laboratory for Thermal Engineering and Energy of the "Vinča" Institute for more than thirty years has been dealing with the investigation of combustion phenomena in the FB, and with the development of furnaces and boilers using this combustion method. As part of this research, a method of examination of fuel suitability for FB combustion has been developed. The main part of the aforementioned methodology is the investigation of fuel combustion on a semi-industrial installation in steady regimes, in order to achieve certain design parameters of a real FB utility or for other purposes [1]. By using this methodology, so far more than 20 coals of different origin and quality have been examined, with emphasis on the coals from off-balance reserves [2].

In this paper, the shortened (basic)[1] investigation of suitability of Lubnica coal for burning in the FB will be presented [3]. The Lubnica coal is obtained by underground mining and would be used for CHP plants near the Lubnica coal mines, for heating of the city of Zaječar, as well as for electricity generation.

## 2. DESCRIPTION OF THE EXPERIMENTAL FACILITY

### 2.1 Laboratory-scale experimental fluidized bed furnace

The experimental installation (Figure 1) has been dimensioned, designed and built in such a way that the results obtained during investigations on it can be used as design parameters for the construction of real-scale facilities.

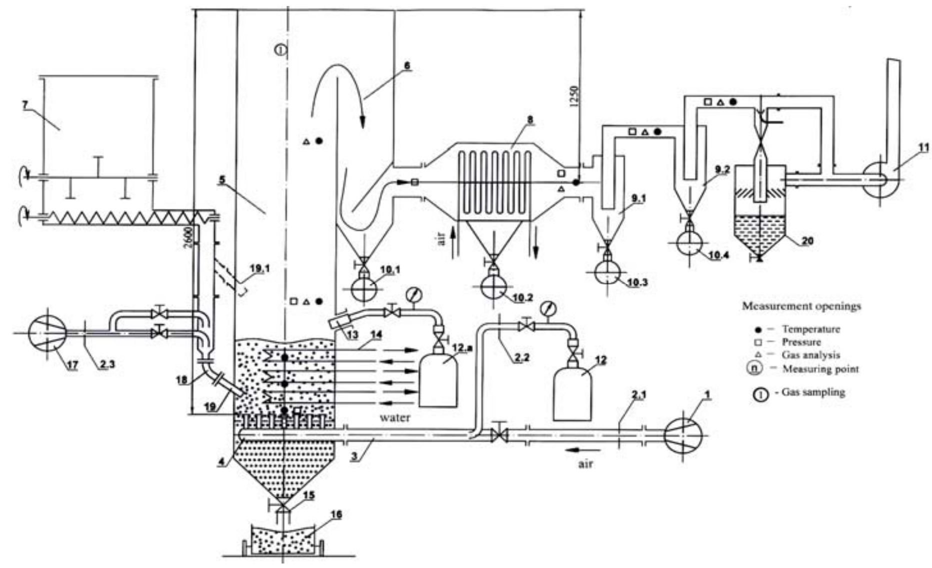



**Figure 1: Scheme of the experimental furnace with the fuel feeding system**

**Figure 2. The experimental fluidized bed furnace**

Legend:

| | |
|---|---|
| 1. Primary air blower | 11. Flue gas fan |
| 2. (2.1 - 2.3) Measuring orifices | 12. (12.a) Propane-butane flask |
| 3. Electric heater | 13. Start-up burner |
| 4. Air chamber with the air-distributor | 14. Three-part heat exchanger |
| 5. Fluidized bed furnace (1st draft) | 15. Furnace material removal valve |
| 6. Mechanical device for particle separation (2nd draft) | 16. Furnace material collector |
| 7. Fuel feeding | 17. Air blower for pneumatic transport of fuel into the bed |
| 8. Flue gases cooler | 18. The line for the visualization of the coal flow |
| 9. (9.1 – 9.2) Cyclones for particle separation | 19. Coal feeding duct into the bed (19.1 – Coal feeding duct onto the bed) |
| 10. (10.1 – 10.4) Vessels for particle disposal | 20. Scrubber (in operation only when burning toxic materials) |

[1] The shortened (basic) test implies investigations only on the semi-industrial experimental facility. These shortened investigations are done when other combustion characteristics of a fuel in the FB (ash sintering temperature in the FB, self-desuplhurization characteristics, combustion kinetics, fragmentation, etc.) are already known.

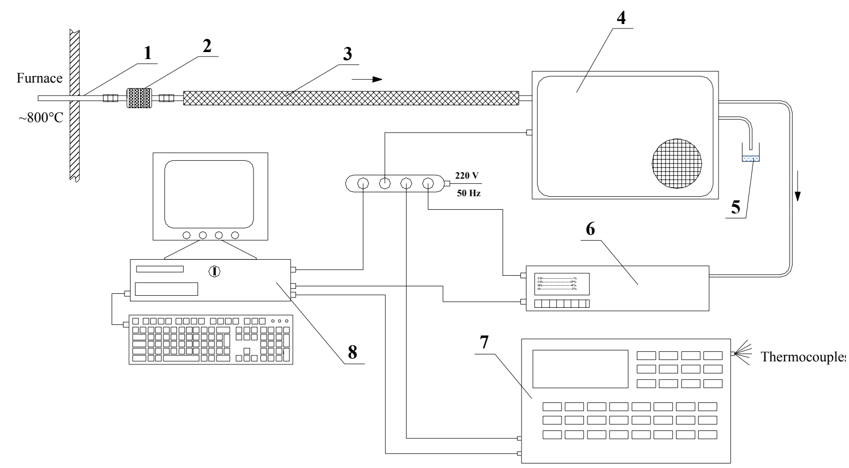
The apparatus cross-section area is 300x300 mm, the height of the first draft is 2,300 mm, while the length of the second draft is 1,250 mm. The experiments can be performed with cooling of the fluidized bed (when it is required that the excess air during the experiment remains approximately the same to that of real-scale boiler facilities) or without it (in cases when operation with lower excess air is not important, or when design parameters for hot gas generation furnaces are being determined). It is also possible to organize flue gas recirculation, or recirculation of the ash caught in the first cyclone (particle separator), as well as to introduce secondary air above the bed. One of the elements in the chain of the flue gas cleansing (aiming at separation of particles from the gaseous combustion products) is the wet scrubber with the Venturi-nozzle. The operation of the scrubber is required only in the case of operation with harmful or toxic materials, which serve as a heat source, or which should be incinerated, i.e. destroyed.

The installation enables performing experiments with fuel feeding into the bed, or onto the bed. The fuel is fed onto the bed by a mechanical feeder, and by means of the gravitational force, with maximum granulation (fuel particle size) of 30 mm. Fuel feeding into the bed is performed by pneumatic transport, where the upper size limit for fuel particles is equal to 2 mm.

The experimental furnace is shown in Figure 2. This figure shows the lower part of the furnace with the system for pneumatic transport of the coal into the bed, and the opening for the start-up and overview of the process, as well as the ash particle separator in the second draft (the cylindric vessel in Figure 2).

### 2.2 Gas analysis and temperature acquisition system

In order to meet the requirements for regular (correct) gas sampling and measurements, the gas analysis system consists of several components (Figure 3).




Legend:

1. gas sampling probe
2. coarse filter
3. heated hose - to prevent the condensation of water vapor
4. conditioner
5. condensate removal from the system
6. gas analyzer IMR 3000 P,
7. thermocouples and the acquisition system HP3852
8. special software for monitoring and registering the measured parameters

**Figure 3: Scheme of the gas analysis and temperature acquisition system**

Monitoring and recording of the measured gas composition and temperatures is performed by means of a special software, developed in the Laboratory for Thermal Engineering and Energy of the Institute of Nuclear Sciences „Vinča“. By using the software, measuring data can be recorded and continuously monitored online.

## 3. FUEL CHARACTERIZATION AND CALCULATION OF THE ADIABATIC COMBUSTION TEMPERATURE

Proximate analysis data of Lubnica coal, which was performed at the Laboratory for Thermal Engineering and Energy of the "Vinča" Institute, is given in Table 1.

| Table 1. Proximate analysis of Lubnica coal | | As received | Analytical | Dry | Dry, ash-free |
|---|---|---|---|---|---|
| **Moisture** | % | 30.81 | 16.4 | | |
| **Ash** | % | 16.16 | 19.53 | 23.36 | |
| **Sulphur total** | % | 1.68 | 2.03 | 2.43 | |
| **Sulphur in ash** | % | 0.48 | 0.58 | 0.69 | |
| **Sulphur** | % | 1.20 | 1.45 | 1.73 | 2.26 |
| **Char** | % | 40.32 | 48.72 | 58.28 | 45.56 |
| **C-fix** | % | 24.16 | 29.19 | 34.92 | 45.56 |
| **Volatiles** | % | 28.87 | 34.88 | 41.72 | 54.44 |
| **Combustibles** | % | 53.02 | 64.07 | 76.64 | 100.00 |
| **FUEL HEATING VALUE** | | | | | |
| **Higher** | kJ/kg | 14823 | 17911 | 21425 | 27955 |
| **Lower** | kJ/kg | 13625 | 16916 | 20685 | 26991 |
| **ULTIMATE ANALYSIS** | | | | | |
| **Carbon** | % | 36.58 | 44.20 | 52.87 | 68.99 |
| **Hydrogen** | % | 2.48 | 3.00 | 3.59 | 4.68 |
| **Sulphur** | % | 1.20 | 1.45 | 1.73 | 2.26 |
| **Nitrogen** | % | 0.97 | 1.17 | 1.40 | 1.83 |
| **Oxigen** | % | 11.79 | 14.25 | 17.05 | 22.24 |

The calculation of the adiabatic combustion temperature and of the theoretical combustion products volumes has been performed in order to obtain the starting basis for the calculation of the operation regime of the experimental laboratory-scale FB furnace (calculation of the needed air and fuel flow rates for achieving the desired thermal power, i.e. achieving a steady regime at the required temperature). The results of this calculation, for different excess air coefficients ($\alpha$), are given in Table 2.

**Table 2. Calculation of adiabatic combustion temperatures for different excess air coefficients $\alpha$**

| C | H | O | N | S | A | W | HD | L0(kg/kgG) | V0(m3/kgG) |
|---|---|---|---|---|---|---|---|---|---|
| 36.58 | 2.48 | 11.80 | .97 | 1.20 | 16.16 | 30.81 | 13625. | 4.6394 | 3.5480 |

| ALFA | TGASA | VCO2 | VSO2 | VO2 | VN2 | GPSS | GCO2 | GSO2 | GO2 | GN2 | GH2O | RODG | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 1866. | 19.235 | .232 | .00 | 80.53 | 4.95 | .271 | .005 | .000 | .719 | .117 | 1.295 | 13806. | |
| 1.15 | 1703. | 16.684 | .201 | 2.79 | 80.33 | 5.64 | .238 | .004 | .029 | .725 | .104 | 1.293 | 13825. | |
| 1.30 | 1568. | 14.730 | .178 | 4.92 | 80.17 | 6.34 | .212 | .004 | .051 | .730 | .093 | 1.292 | 13851. | |
| 1.45 | 1454. | 13.186 | .159 | 6.61 | 80.05 | 7.03 | .191 | .003 | .069 | .734 | .085 | 1.291 | 13867. | |
| 1.60 | 1356. | 11.935 | .144 | 7.97 | 79.95 | 7.73 | .174 | .003 | .084 | .737 | .078 | 1.290 | 13898. | |
| 1.75 | 1271. | 10.900 | .132 | 9.10 | 79.87 | 8.43 | .159 | .003 | .096 | .739 | .073 | 1.289 | 13915. | |
| 1.90 | 1196. | 10.031 | .121 | 10.05 | 79.80 | 9.12 | .147 | .003 | .107 | .741 | .068 | 1.289 | 13932. | |
| 2.05 | 1130. | 9.290 | .112 | 10.86 | 79.74 | 9.82 | .137 | .002 | .116 | .743 | .064 | 1.288 | 13959. | |
| 2.20 | 1071. | 8.651 | .104 | 11.56 | 79.69 | 10.51 | .128 | .002 | .123 | .745 | .060 | 1.288 | 13984. | |
| 2.35 | 1018. | 8.094 | .098 | 12.17 | 79.64 | 11.21 | .120 | .002 | .130 | .746 | .057 | 1.287 | 13997. | |
| 2.50 | 971. | 7.605 | .092 | 12.70 | 79.60 | 11.91 | .113 | .002 | .136 | .747 | .054 | 1.287 | 14021. | |
| 2.65 | 927. | 7.171 | .087 | 13.18 | 79.57 | 12.60 | .107 | .002 | .142 | .748 | .052 | 1.287 | 14039. | |
| 2.80 | 888. | 6.785 | .082 | 13.60 | 79.54 | 13.30 | .101 | .002 | .146 | .749 | .050 | 1.286 | 14063. | |
| 2.95 | 852. | 6.437 | .078 | 13.98 | 79.51 | 13.99 | .096 | .002 | .151 | .750 | .048 | 1.286 | 14078. | |
| 3.10 | 819. | 6.124 | .074 | 14.32 | 79.48 | 14.69 | .091 | .002 | .155 | .751 | .046 | 1.286 | 14105. | |
| 3.25 | 788. | 5.840 | .070 | 14.63 | 79.46 | 15.39 | .087 | .002 | .158 | .752 | .044 | 1.286 | 14127. | |
| 3.40 | 760. | 5.581 | .067 | 14.91 | 79.44 | 16.08 | .083 | .001 | .161 | .752 | .043 | 1.285 | 14139. | |
| 3.55 | 734. | 5.343 | .064 | 15.17 | 79.42 | 16.78 | .080 | .001 | .164 | .753 | .041 | 1.285 | 14169. | |
| 3.70 | 709. | 5.126 | .062 | 15.41 | 79.40 | 17.47 | .077 | .001 | .167 | .754 | .040 | 1.285 | 14185. | |
| 3.85 | 687. | 4.925 | .059 | 15.63 | 79.39 | 18.17 | .074 | .001 | .170 | .754 | .039 | 1.285 | 14204. | |

# 4. RESULTS OF MEASUREMENTS IN STEADY REGIMES OF OPERATION OF THE EXPERIMENTAL FLUDIZED BED FURNACE

Experiments have been done with two different temperatures of the fluidized bed:

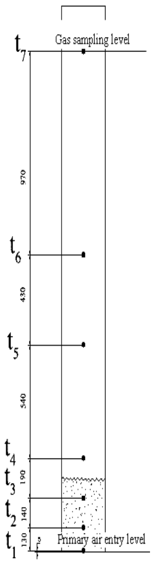
- Regime I – bed temperature 850-860°C, and
- Regime II – bed temperature 820-830°C.

These temperatures are the usual operating temperature range of industrial facilities. These are optimal temperatures, with respect to lowered $NO_x$ concentration, as well as regarding the efficiency of sulphur retention by the limestone.

The ground Lubnica coal (size $0 < d \leq 2$ mm) was pneumatically fed into the fluidized bed. Total active height of the fixed fluidized bed was ≈400 mm, while coal feeding point was at a 150 mm distance from the bottom of the fluidized bed, i.e. from the level of the air inlet.

In both regimes, the temperatures along furnace height have been measured. The thermocouples measuring temperatures $t_1$, $t_2$ and $t_3$ are placed within the fluidized bed, where the temperature $t_1$ is measured practically at the level of the primary air distributor (see Figure 4 - on the left).

## 4.1 Regime I – bed temperature 850-860°C



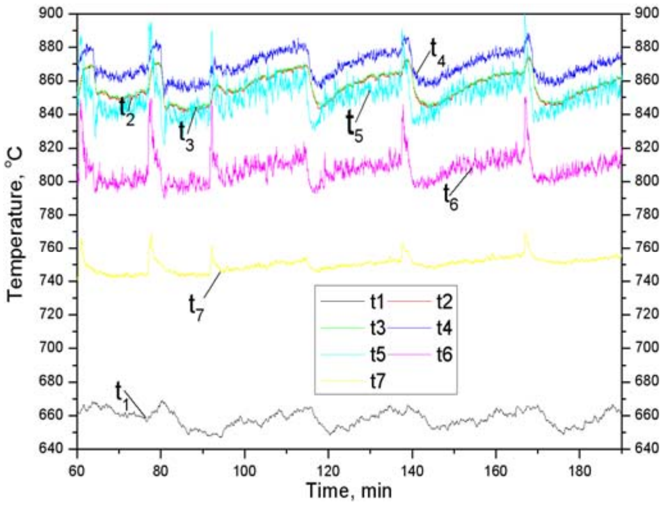



**Figure 4. Regime I – temperatures within the furnace (measured values), placement of the thermocouples in the fluidized bed furnace - on the left**

Control of the temperature in the fluidized bed in both operation regimes has been performed by stopping fuel feeding in short time-intervals, which explains uneven temperature profiles. It is easy to note that temperatures $t_2$ and $t_3$ are almost identical during the whole investigation ($t_{2sr}$=855.7°C, $t_{3sr}$=856.4°C), and the temperature $t_4$ immediately above the bed is only a slightly higher than the temperature in the bed itself, which indicates that intense combustion is occurring in the bed or in „splash“ zone. High combustion efficiency in the bed has been confirmed also by analyses of the ash collected in the separators and cyclones, as well as by analyses of the flue gas (Figure 5 and Figure 6).

The oscillations of fludized bed temperatures ($t_1$, $t_2$ and $t_3$) were in the range of ±8°C (~845-860°C) throughout the tests, while the temperature disturbances and oscillations are by far more apparent in the space above the bed. By activating the heat exchanger within the bed, temperature control could be performed even more efficiently.

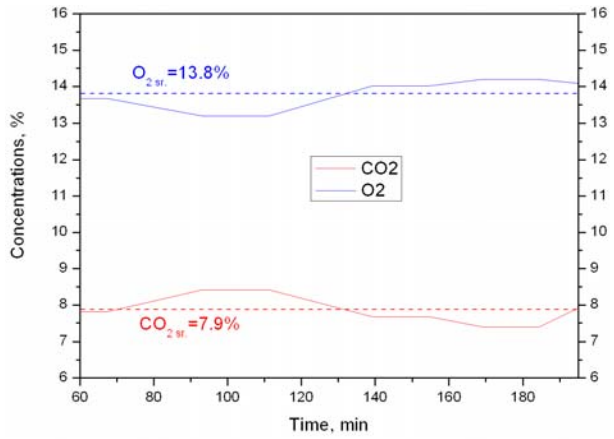



Figure 5. Regime I – concentrations of $CO_2$ and $O_2$ (measured and average values)

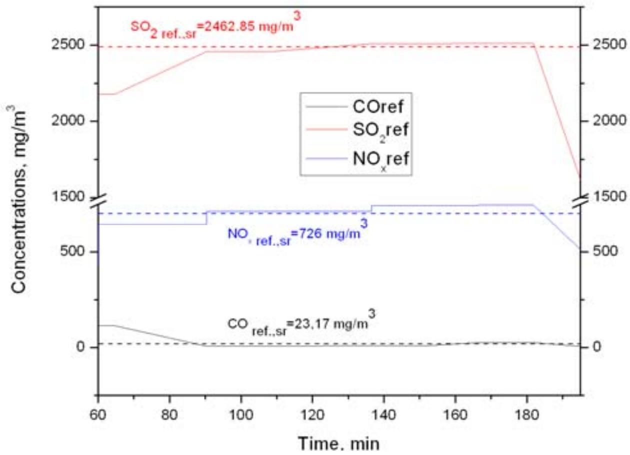



Figure 6. Regime I – concentrations of CO, $SO_2$ and NOx at reference $O_2$ content ($O_{2ref}$=7%)

Average oxygen content in the combustion products in Regime I (Figure 5) corresponds to the value of excess air coefficient $\alpha_{av}$ = 2.91. This value matches quite well with the value of $\alpha$ required for achieving the adiabatic combustion temperature of 850°C (Table 2). Concentrations of CO, NOx and $SO_2$ in the combustion products (Figure 6) have been averaged as well and recalculated to the reference value of 7% $O_2$ in the combustion products, which is stipulated by relevant legislation. A drastic decrease of $SO_2$ concentration in the final part of the investigation is a consequence of direct limestone feeding onto the bed through the hole at the top of the furnace. This confirms the positive effects of limestone feeding into/onto the fluidized bed and the suitability of the fluidized bed, considering the possibility of $SO_2$ emission reduction. These effects could not have been quantified completely, due to the lack of data regarding the analysis of the limestone fed to the fluidized bed.

### 4.2 Regime I – bed temperature 820-830°C

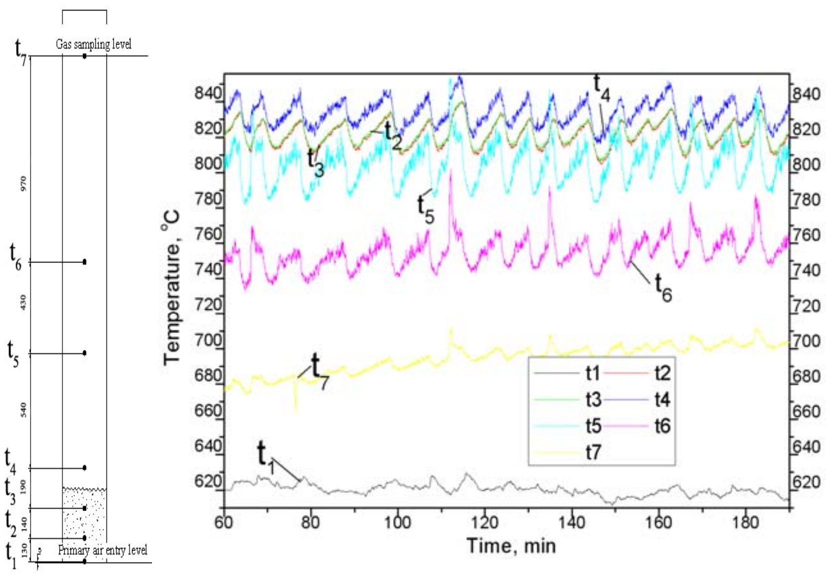



Figure 7. Regime II – temperatures within the furnace (measured values), placement of the thermocouples in the fluidized bed furnace - on the left

Since the speed (number of rotations) of the feeding system worm was close to minimum, switching from Regime I to Regime II, i.e. lowering the temperature to 820-830°C, was achieved by more frequent switching off of the feeder, hence oscillations of all temperatures were more obvious than in Regime I. Average values of bed temperatures $t_2$ and $t_3$ were almost the equal one to another, as it was in Regime I, due to uniform fluidization ($t_{2av}$ = 821.4°C, $t_{3av}$ = 822.3°C), which can be observed from the diagram in Figure 7.

Average $O_2$ concentration of 13.9% (Figure 8) corresponds to the average excess air coefficient of 2.96. This value matches quite well with the value of $\alpha$ required for achieving the adiabatic combustion temperature (from the calculations - Table 2). This is considered as a quite good result, taking into account that combustion was controlled by fuel feeding.

Regime II proved to be more favourable than Regime I, from the point of view of combustion completeness (efficiency), more exactly CO emission, which was cut to half in comparison with Regime I (Figure 9). The emission of $NO_x$ was slightly higher than in Regime I. The concentration of $SO_2$ in the flue gases was higher in the beginning of the investigation than in Regime I, but it was decreased by introducing the limestone into the bed. In Figure 9, moments of limestone introduction can be clearly seen, as well as its long-term influence on $SO_2$ concentration reduction.

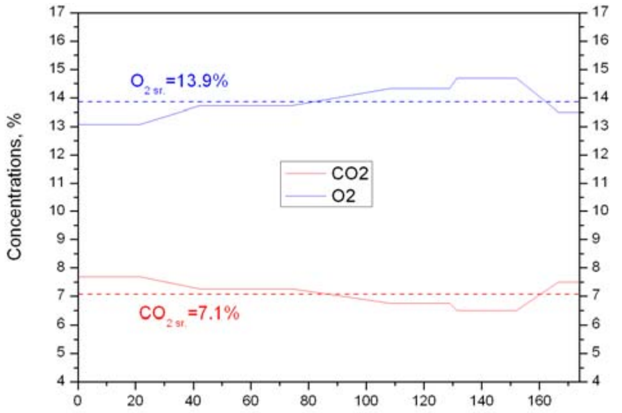



**Figure 8. Regime II –$CO_2$ and $O_2$ concentrations (measured and average values)**

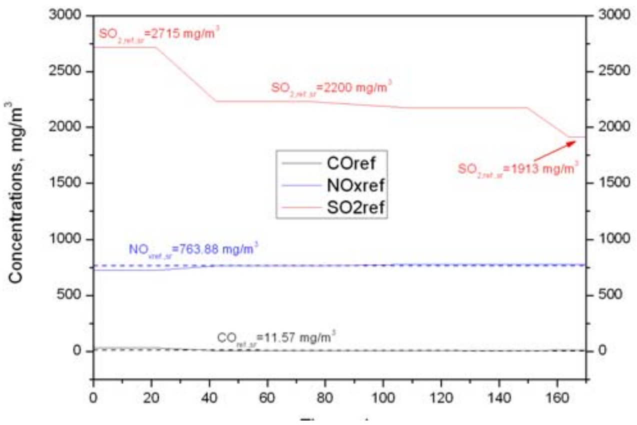
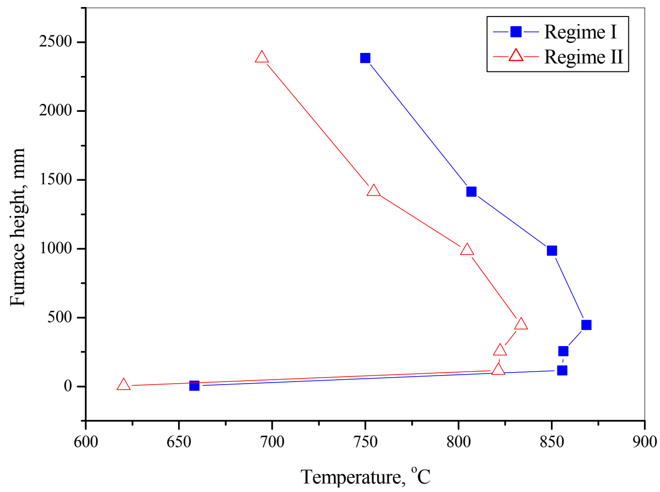



**Figure 9. Regime II – CO, $SO_2$ and NO concentrations, at the referent $O_2$ content ($O_{2ref}$=7%)**




Comparison of average temperature profiles along furnace height, showed in Figure 10, enables comparison of the regimes. Temperature profiles are very much alike, because of the control method used, as well as due to the design characteristics of the furnace itself.

**Figure 10. Change of average temperature along furnace height, for both working regimes**

*Table 3. Mass balance of the operationof the experimental FB furnace in both working regimes*

| Regime | Fuel mass flow rate | Total mass of the coal used | Collected ash | | | | Primary air flow rate | Secondary air flow rate | Average temperature of the active part of the FB |
|---|---|---|---|---|---|---|---|---|---|
| | kg/h | kg | kg | | | | kg/h | kg/h | °C |
| | | | Separator 1 | Separator 2 | Cyclone 1 | Cyclone 2 | | | |
| I | 7.77 | 31.5 | 2.32 | 1.05 | 0.71 | 0.29 | 71.53 | 18.23 | 856.0 |
| | | | ∑: 4.37 (86% of the ash)<br>Went out through the chimney: 0.65: 0.65 (14% of the ash) | | | | | | |
| II | 8.00 | 29.74 | 1.9 | 1.95 | 0.5 | 0.45 | 67.44 | 18.23 | 821.8 |
| | | | ∑: 4.8 (83% of the ash)<br>Went out through the chimney: 0.74: 0.74 (17% of the ash) | | | | | | |

The data on the amounts and mass flow rates of the fuel and air, as well as of the ash collected in separators and cyclones, are given in Table 3. It should be pointed out that, in both working regimes, the mass of the bed material was almost the same before and after the experiment, which showed that was no ash retaining in the bed. On the basis of measured masses of the ash collected in the separators and the cyclones, as well as on the basis of the proximate coal analysis (ash content in the coal, Table 1), the mass fraction of the fly ash particles emitted into the athmosphere through the chimney was determined.

*Table 4. The results of examining of the fly ash*

| | | | Separator 1 | Separator 2 | Cyclone 1 | Cyclone 2 |
|---|---|---|---|---|---|---|
| Regime I | Ash | % | 98.69 | 97.22 | 98.08 | 96.92 |
| | Combustible | % | 1.31 | 2.78 | 1.92 | 3.08 |
| | Average particle diameter, calculated on total sample mass | $\mu m$ | 157.99 | 91.66 | 44.52 | 42.78 |
| Regime II | Ash | % | 98.77 | 96.98 | 97.87 | 96.96 |
| | Combustible | % | 1.23 | 3.02 | 2.13 | 3.04 |
| | Average particle diameter, calculated on total sample mass | $\mu m$ | 159.17 | 93.88 | 38.91 | 38.59 |

The investigation of fly ash samples, collected in separators and cyclones, from both working regimes (see Table 4), showed a very low content of combustible matter (mostly< 3%). This proved that most particles almost completely burnt out in the furnace itself.

## 5. CONSTRUCTION OF AN INDUSTRIAL DEMONSTRATIVE BOILER

In order to obtain more reliable design parameters of real utilities, within the scope of the project supported by the Ministry of Science and Technological Development (Project TR18219), the construction of an industrial FB demo-boiler, in which the parameters of combustion in the FB will be investigated (with the emphasis on low-grade fuels and waste materials, which are difficult or impossible to burn in conventional boilers) is ongoing. With its construction, the opportunity has risen for the first time to include an industrial boiler into the experimental basis of burning the waste materials in the FB. This boiler will be installed within the grounds of the boiler factory TIPO-KOTLOGRADNJA from Belgrade. The maximum capacity of the boiler should be 300 kW, and the boiler is intended to be a warm water one, and operate in the regime of 90/65 $^0$C. Due to the anticipated significant removal of solid particles from the FB (fuel ash and inert material of the FB), which eventually may be deposited in the heat exchanger pipes (first and second "draft" pipes), the boiler is foreseen to be designed as a vertical structure. A scheme of the boiler with the basic dimensions is given in Figure 11, while the images showing different stages of assembly of the FB boiler are given in Figure 12-Figure **16**.

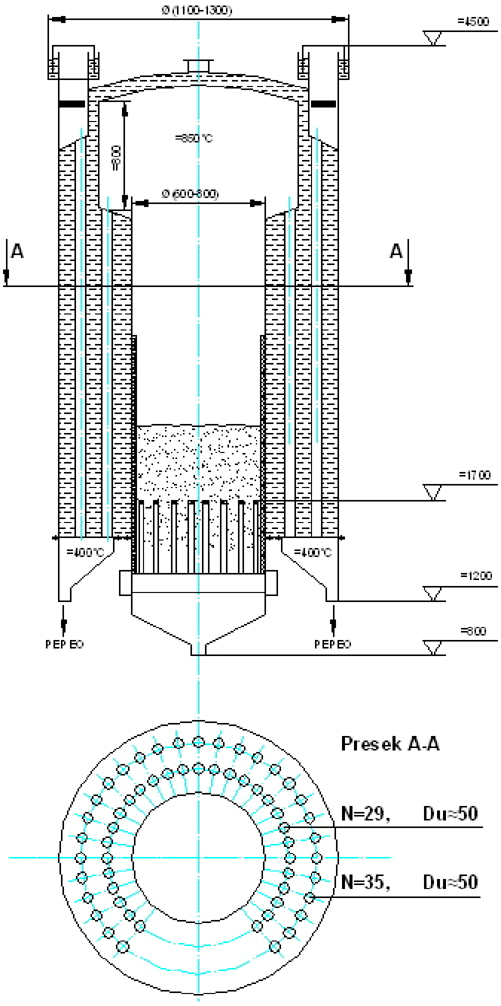



**Figure 11. Schematic of industrial FB demo-boiler**

**Figure 12. Lower flange / FB bottom under construction**

**Figure 13. Installation of bubble caps for fluidization onto the fluidization air distributor**

**Figure 14. Mounting of the fluidization fan onto the fluidization air/gas distributor**

**Figure 15. Installation of the furnace shell onto the air distributor**

**Figure 16. Distributor appearance, observed from the top of the furnace**

## 5. CONCLUSION

The conclusions on the investigation of suitability of Lubnica coal for burning in the fluidized bed focus on combustion quality, which implies combustion completion, i.e. combustion efficiency, as well as satisfying the environmental protection criteria.

As it can be seen from the presented results of measurements (diagrams, Figure 6 and Figure 9.), carbon monoxide (CO) concentration in the flue gas was considerably lower than the maximum allowable limit stipulated by relevant legislation[2] (CO << $250 mg/m^3$). This also implies that losses due to unburnt matter in the gaseous products were negligible. The amount of unburnt matter in the fly ash is also negligible [3].

A comment on the combustion quality, with respect to meeting the regulations on the environmental protection, is less favourable to some extent. The concentration of $SO_2$ by far overcomes the maximum permitted limits. During the experiments it was shown that the concentration and emission of sulphur-dioxide could be lowered, relatively easily, by adding limestone. In addition, nitric oxides' concentration in the flue gases was higher than expected. The basic reason for that was high excess air during the experiments, due to the method of controlling fuel feeding. In real conditions, on a real boiler with circulating fluidized bed, lower $NO_x$ concentration is expected. Nevertheless, a way for additional decrease of the concentration of nitrogen compounds in the flue gases has to be provided, by adding ammonia or in some other way.

Generally, it can be stated that the investigated coal is suitable for burning in bubbling, as well as in circulating fluidized bed. It is sufficient to use the advantages of the fluidized bed technology, and simple design solutions, so as to meet the law requirements regarding pollutant emissions.

Considering the size of off-balance reserves of lignite in Serbia, as well as large percentage of non-commercial coals from underground mines (about 60% of fine coal fractions), it is possible to build a modern, efficient and environmentally friendly boilers with fluidized bed combustion, for production of energy (heat and electricity) in industry and district heating systems, by combusting coals which can not be burnt in other boiler types, or which can not be burnt efficiently and meet the required environmental standards [2].

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[2]According to the "*Rulebook on maximum allowed emissions, the method and schedules of measurements and recording*" (Official Gazette of the Republic of Serbia 54/92), the emission limits for boilers with thermal power of the furnace in the range of 1-50MW with FB combustion are:

- CO-250 $mg/m^3$,
- $SO_2$ -2000 $mg/m^3$, and
- $NO_2$- 1000 $mg/m^3$.

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