Acta Geodyn. Geomater.Vol.3, No.1 (141), 71-78, 2006

UTILIZATION OF ALTERNATIVE FUELS IN THE FLUIDIZED – BED BOILERS

Pavel KOLAT *, Bohumir ČECH, Dagmar JUCHELKOVÁ, Helena RACLAVSKÁ and Juraj LEŠKO

Vysoká škola báňská – Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava-Poruba, Czech Republic
**Corresponding author's e-mail*: pavel.kolat@vsb.cz

(*Received* October 2005*, accepted* February 2006)

ABSTRACT
The energy utilization of the alternative fuels is one of the main topics for future developments of recoverable sources in the European Union and in the Czech Republic. The aim of research is combustion tests in the fluidized-bed boiler Foster Wheeler located at Štětí. The experiments are carried out for Czech brown coal, wood, sewage sludge and wastes including analyses and recommendations for optimal thermal utilization and minimizing harmful emissions. The second step is thermal analyses of coal, alternative fuel- wood pellets and sewage sludge from treatment plant. From the results of experiments and thermal modeling it is clear that 15 % of alternative fuels can be used in the large fluidized-bed boilers located in the Czech Republic.

KEYWORDS: alternative fuels, brown coal, biomass, fluidized-bed boilers

INTRODUCTION

The power-engineering scenario of the European Union is based on the permanently sustainable development. These goals are defined in the EU primarily by the following tasks:

- Reduction of emissions of greenhouse gases within 2010 by 8% in comparison with 1990 (it corresponds to $600 \cdot 10^6$ t y^{-1} CO_2) according to conclusions adopted at the conference at Kyoto in 1998; reduction of emissions of CO_2 shall not be detrimental to economic growth of society,
- Double share of recoverable energy resources in the EU from the present 6% to 12% until 2010 – White Paper of May 1998 (including small water power plants).

Therefore, the research and development should respect these goals with emphasis on priorities among which rank primarily:

- Power engineering technologies and the measures reducing emissions of CO_2.
- Cleaner fuels by substitution or by re-treatment where the emissions of CO_2 must be reduced by 20% within 2010.

One of methods is the utilization of 6 Mtoe biofuels and fuels made of waste in combined combustion and gasification at power and heating plants. Thus utilization of alternative fuels in power engineering is one of the main goals for the development of recoverable energy resources.

MAIN GOALS OF RESEARCH

The research is focused on the field of combined combustion of brown coal and waste including biomass in the fluidized-bed boilers with atmospheric fluidized bed. Special attention will be given to emissions and possibility of the future utilization on another fluidized-bed boilers in the Czech Republic. Main goals may be outlined in the study of conditions for:

- Potential substitution of fuel with less valuable types of brown coal simultaneously with the waste and biomass, sustainability of fluidized bed combustion.
- Actual unit diagnostics development.
- Laboratory studying mechanism for combustion by differential thermo-gravimetric analysis-DTG. Figs. 1, 2.
- Raw material input analysis and dependence of combustion solid residues on raw material input.
- Combustion inaccuracy assessment in Foster Wheeler circulating fluidized bed boiler (temperatures, gaseous and solid components, velocities).
- Study of the mechanisms of fouling and deposit formation and composition. Fig. 3.
- Balance of combustion elements including heavy metals. Table 1.

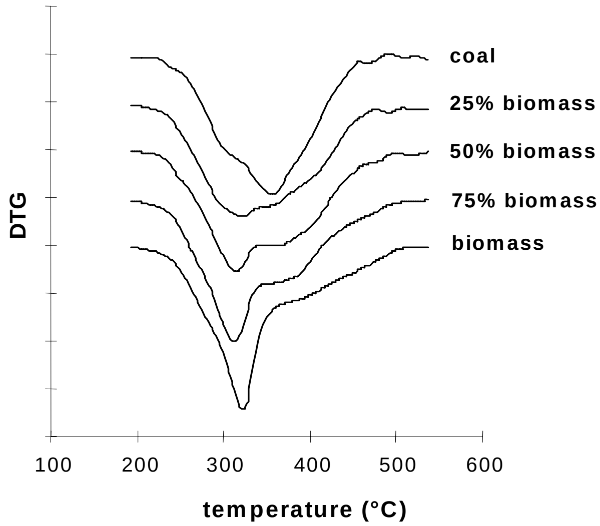

Fig. 1 DTG curves of oxidation of mixtures with various content of bio-fuel.

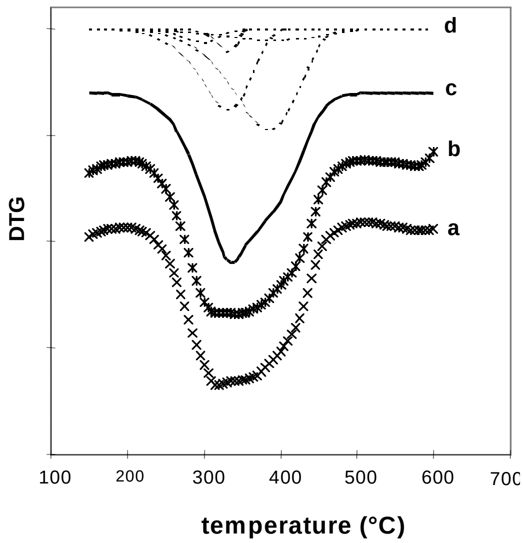

Fig. 2 DTG curves of oxidation for pilot plant (a) and laboratory (b) coal mixtures with biofuel (15%) and their comparison with theoretical curve (c) and its breakdown for individual processes (d).

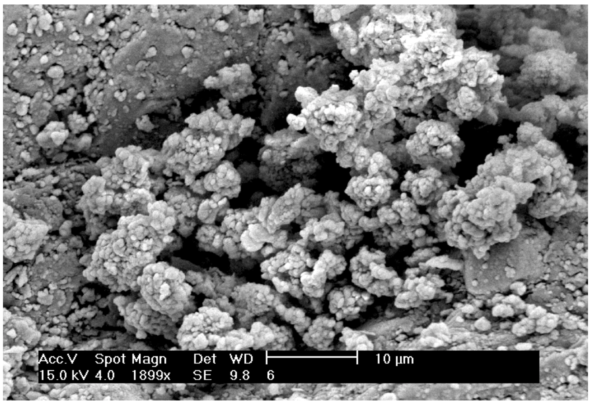

Fig. 3 Solid specimens sampled at various combustor levels for verifying condensation-evaporation model and fouling conditions by scanning electron microscopy

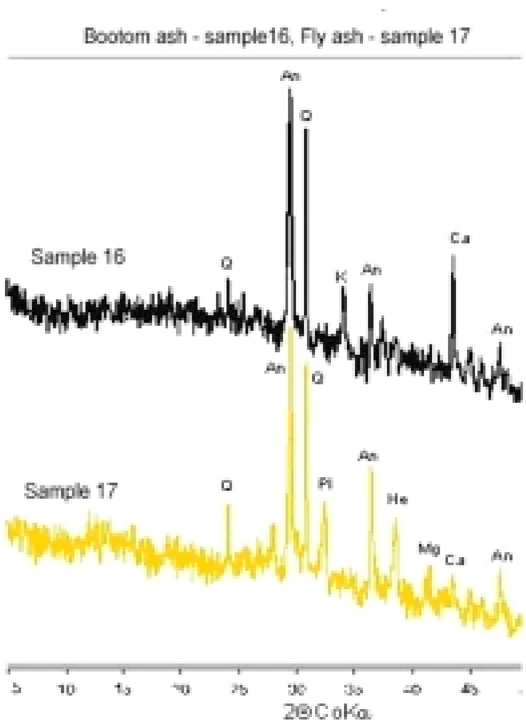

Fig. 4 Powder diffraction analysis of the fluidized bed ash and filter ash.

- Verification of a redistribution mode for choice of elements btween the fuel and solid by-products of combustion.
- Quantitative phase analysis and strucural analysis of substance especially minerals by employing rtg. diffraction methods. Fig. 4.
- Atomic absorption spectrometry.
- Balance for volatile elements (chlorine, sulfur, mercury and selenium), semi-volatile elements (vanadium, nickel, cobalt, and arsenic) and some non-volatile elements (chromium and tin).
- Leaching tests for combustion solid products.
- Long-termformation on thermal exchanger walls.
- Saturation sludge dosing as a sorbent. Figs. 11, 12.

Table 1 Heavy metals concentration during combustion tests

	Exam "1"	Exam "2" [μg.m$^{-3}_{N\ dry}$]	Exam "3"	Exam "1"	Exam "2" [μg/m$^3_{N\ dry}$] calculated at 6% O_2	Exam "3"
As	3.03	1.79	2.06	3.38	1.94	2.26
Al	10058.28	20669.75	14099.04	11217.42	22353.73	15448.18
Cd	1.63	0.74	0.70	<2.00	0.80	0.77
Co	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Cr-total	5.77	8.02	6.81	6.43	8.68	7.46
Cu	44.69	31.08	41.76	49.84	33.61	45.75
Ni	13.16	4.17	2.62	14.68	4.51	2.87
Pb	15.34	11.88	18.69	17.10	12.85	20.48
Sb	133.13	154.32	73.80	148.47	166.89	80.86
Se	2.12	1.64	1.28	2.36	1.77	1.40
Sn	2.67	1.60	1.09	2.98	1.74	1.19
Tl	<0.80	<0.80	<0.80	<0.80	<5.00	<5.00
V	7.24	9.07	7.09	<0.30	9.81	<0.30
Zn	3588.96	10992.28	6781.15	4002.55	11887.83	7430.04
Hg	0.68	0.90	0.64	0.76	0.97	0.70

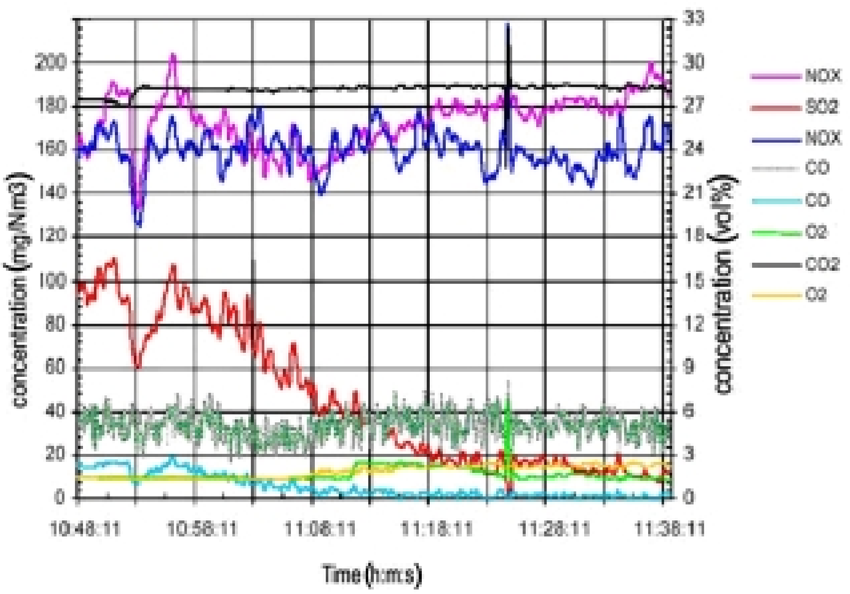

Fig. 5 Concentration of gaseous emissions during combined combustion of coal and wood pellets in pilot fluidized bed boiler 300 kW TU Dresden. The CO, O_2, and NOx concentrations were each measured with two different instrument.

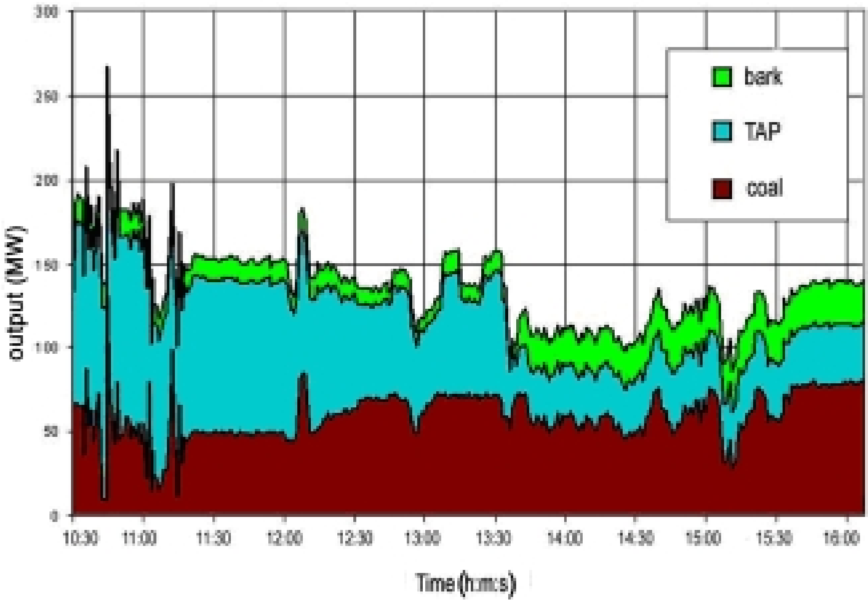

Fig. 6 Output of the circulating fluidized bed boiler Foster Wheeler and distribution of coal, solid alternative fuel (TAP) and bark during combustion experiment.

The research of combustion products as regards the mix of coal and biomass cannot be performed in the labolatory conditons, which would simulate fast burning processes in the fluidized bed. Pilot fluidized bed plant 300 kW (Stonawski, 2002) in TU Dresden can provide basic parameters concerning the feasibility of mix fuels employment, and the chemical characteristics of solid as well as gaseous products Fig. 5. from the point of view of major components.

An option to study these phenomena in the real FCB plant and several long-term experiment condition with reproducible raw materials and controlled mode of operation may enable an energy, economy and ecology parameters evaluation, as well as their sensitivity to process conditions. Labolatory studies are focused on detailed identification of input raw materials (brown coal, biomass, lime stone), so that the measurements could be designated as reproducible.

The aim of research is also combustion tests in the fluidized-bed boiler Foster Wheeler 220 t/h located at Štětí. The experiments are carried out for Czech brown coal, wood, sewage sludge and wastes including analyses and recommendations for optimal thermal utilization and minimizing harmful emissions. Content of the fuel during experiments: coal 80, 90, 70% biofuel 20, 10, 30%.

In the first step was necessary to verify the influence of the bio fuel feeding as regards the combustion and related emission formation and operation of the boiler at 220 t/h. Fig. 6. Concerning these tests the following data were collected:

- Temperature and concentration fields inside combustor.
- Combustor comparative data (efficiency, output, mass balances).
- Fouling of heat exchanging surfaces.
- Balance of choice of elements of combustion.

Evaluation of non-burnt fuels composition as regards the combustion condition.

The second step of the research is thermal analyses of coal, alternative fuel- wood pellets and sewage sludge from treatment plant.

BASIC DESCRIPTION OF THE BOILER

The boiler unit is a refurbished granular combustor with circulating fluidized bed boiler Foster Wheeler. Fig. 7. The boiler parameters are: steam max. output flow 62 kg/s, steam max. output flow for combined fuel 36 kg/s, steam pressure/ temperature 9,3 MPa/ 535 ^{o}C. The boiler unit combustor is made from membrane wall tubes. Combustor flue gases enter the couple of hot cyclones, in which separation of solid phase occurs. This is returned to the combustor chamber. Fine flue ash along with flue gases passes the boiler horizontal draft, and section of common over heaters. In the second boiler draft a three section water heater is located. Flue gases are fed into the refurbished four-section electrostatic separators and follow into the stack. Adding limestone into the combustion process performs the SO_2 emission minimizing.

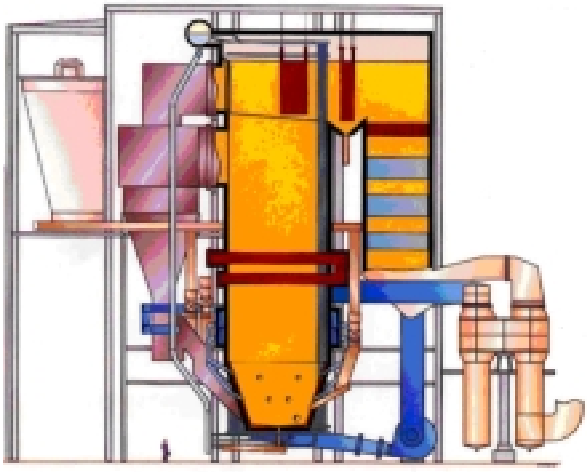

Fig. 7 The fluidized-bed boiler Foster Wheeler 220 t/h.

value are 5 times lower than those prescribed EC limits.

4. Combustion of biofuel and coal has no influence to leaching and the pH factor.
5. Emissions of Cl were lower than 250 mg/m_N^3 at 6% O_2. (because of higher content of plastics and rubber in waste). Recommendation for content of plastics in solid alternative fuel-TAP is therefore max. 5%.
6. Caustic-A, B and saturation - C sludge can replace czech natural limestone VFK 55, VFK 80 and secure desulphurization process has high efficiency. Figs. 11, 12.
7. Figs. 5, 9 shows some of the pollutants expected during the combustion of coal and biomass. The pollutant emissions can be classified in two groups. The first group consists of the unburnt pollutants, which are mainly influenced by the combustion equipment and process. The other group consists of pollutants, which are mainly influenced by the fuel properties. The unburnt pollutants include CO, HC, tar, PAH, C_xH_y and char particles. These pollutants are usually due to poor combustion which is a result of low combustion temperature, insufficient mixing of fuel with combustion air and too short residence time of the combustible gases in the combustion zone. Apart from the unburnt pollutants, ash is also potential pollutant. The quantity of ash, carried with the flue gas from the furnace is governed largely by the feed rate of the fuel, its ash content, the excess air ratio and the distribution of the combustion air. The particulate emissions have different physical characteristics with the size ranging from sub-micron to 2 mm. The solids loading of the flue gas may range from 30 to 100 mg/m^3.

Fig. 8 Storage of biofuel

The fuel (brown coal 11 MJ/kg) is fed into the combustor by four screw feeders. The biofuel is fed by one feeder, as is the operational need. Fig. 8. Concerning biofuel, predominantly properties of wood waste, sludge and biosludge is investigated.

CONCLUSION

1. Operation of the boiler Foster Wheeler 220 t/h Štětí is stable as far as the ratio 50 % coal and 50 % biofuel and waste. Fig. 10. Maximum flue gas emissions CO were 40 mg/m_N^3 and NO_x 200 mg/m_N^3. SO_2 emissions were always under limit 500 mg/m_N^3 in narrow range ratio fuel/biofuel.
2. Concentration of heavy metals is in compliance with environmental directive of European Union EU 2000/76/EG.
3. Content of PCDD/F after recalculation is evaluated by the equivalent of toxicity and this

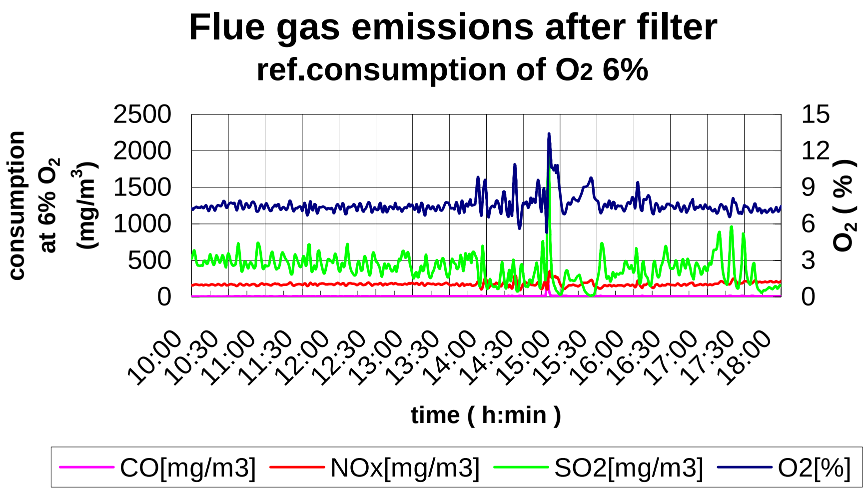

Fig. 9 Flue gas concentration during combined combustion tests -coal 80% and 20% biofuel.

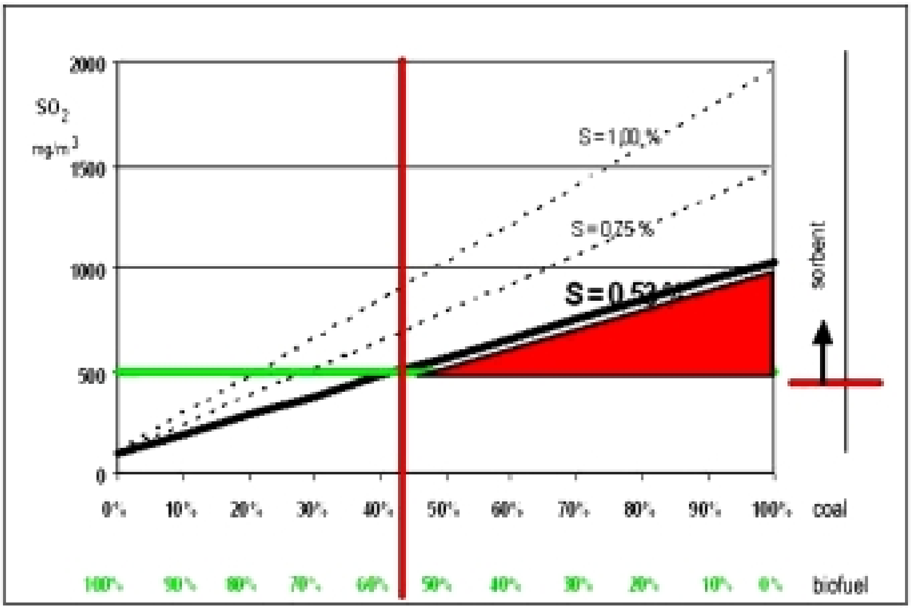

Fig. 10 Influence of the ratio coal/biofuel on the concentration of the SO_2 and environmental limit.

8. Here are three routes of formation of NO during coal combustion, namely: thermal, prompt and fuel-NO. Another point of consideration during combustion of biomass with respect to NO_x and N_2O emissions is catalytic effect of the char and ash on the formation and reduction of NO_x and N_2O. The net concentration of NO and N_2O in the flue gases of the furnace are a function of the homogenous gas phase reactions, the heterogeneously catalyzed reactions and gas/solid phase reactions. Char for example provides a catalytic surface for the gas phase NO reduction by CO, which is estimated to account for about 50% of the NO reduction. Further char is also very effective for catalytic reduction of N_2O as well as for direct reduction of N_2O. In the case of fluidized bed combustion, the presence of CaO, MgO and Fe_2O_3 in the fuel can lead the formation of an active bed which catalyze the reduction of NO and N_2O, especially under fuel-rich

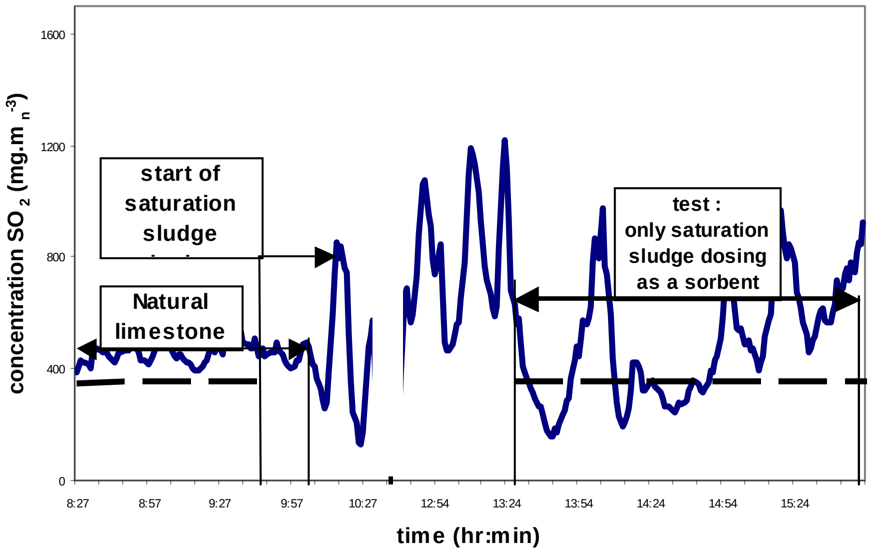

Fig. 11 Saturation of sludge dosing as a sorbent in the large FCB boiler.

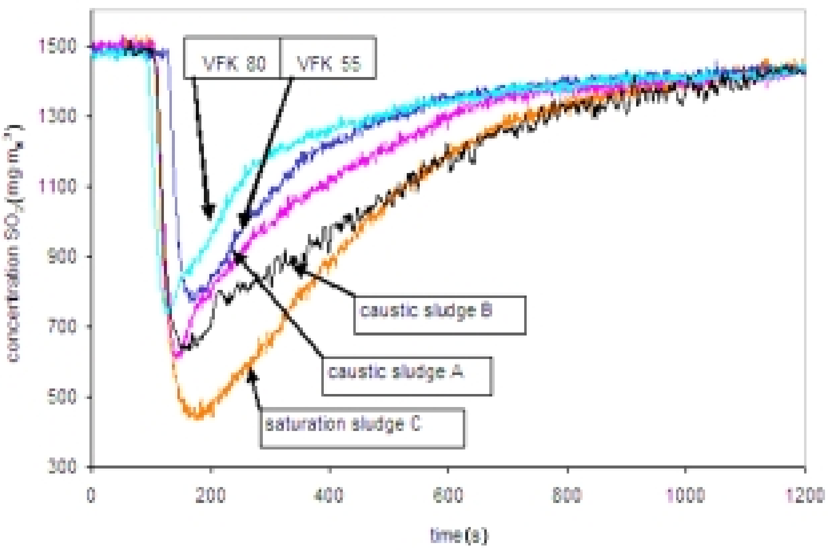

Fig. 12 Time behavior of concentration of SO_2 on the outlet from boiler model with circulating fluidized layer after dosing the sorbent.

combustion conditions. Biomass has high contents of volatile matter and low contents of fixed carbon, so that the effect of char on formation of NO_x and N_2O may be significant. However, the catalytic effect of the ash could be important for residues, which have high CaO contents.

9. The major advantages of fluidized bed combustors are:

- Uniform temperature distribution due intense solid mixing- no exists hot spots even with strongly exothermic reactions.
- Large solid gas exchange area by virtue of small solid grain size.
- High heat transfer coefficients between bed and the heat exchanging surfaces.
- The intense motion of the fluidized bed makes it possible to combust a wide range of fuels having different sizes, shapes, moisture contents and heating values. The fuel supplied can be wet or dry and either a paste or a solid.
- The high heat capacity of fluidized bed permits stable combustion at low temperatures cca

850 ^{o}C, so that the formation of thermal and prompt nitrogen oxides can be suppressed.

10. Following disadvantages of fluidized bed combustors are:

- Solid separation or gas purification equipment required because of solids entrained by fluidizing gas and the high dust load in the flue gas.
- Erosion of internals resulting from high solids velocities.
- Possibility of de-fluidization due to agglomeration of solids.
- Increase in fouling and corrosion due to presence of compounds with low melting point in the ash. Straw increase K_2O on 18 – 20%. High concentration of potassium and chloride in the straw and insufficient control of temperatures caused a severe fouling in the cyclones and in convective path and several unscheduled shut downs in orders to clean the plant.
- Ash deposition from biomass fuels that contain certain chemicals can also create corrosion and erosion of metals. Two most abundant inorganic elements are Si and K, which form silicates with a low melting point. The combustion leads to the condensation of molten silicates, which are likely to cause fouling and corrosion. Metals are exposed to chemical attack when silicates are present because protective layers of oxides can be relatively soluble and/or reactive in silicate slag. In addition, the very high volatilities of alkali metals can lead to unexpected corrosion by reactions such as:

$$\mathrm{K_2O}(silicate) + \mathrm{Fe} \rightarrow \mathrm{FeO}(silicate) + \mathrm{K}(g)$$

From the results of experiments and thermal modeling it is clear that 15% of alternative fuels can be used in the large fluidized-bed boilers located in the Czech Republic. The combined combustion will enable to fulfill the promise of the Czech Republic to the European Commission concerning the development of renewable energy resources by 2010 (Hein and Scheurer, 2000).

AKNOWLEDGMENTS

The paper was prepared within the research of the project MSM 6198910019 “DeCO$_x$ processes”.

REFERENCES

Energy for the future – Renewable Sources of Energy, 1997, European Commission, White Paper for a Community Strategy, COM (97)599.

Hein, K.R.G. and Scheurer, W.: 2000, Combined combustion of biomass, wastes and residues with coal. EU Seminar Cottbus. European Commission.

Stonawski, L.: 2002, VŠB-TU Ostrava. The utilization of alternative fuels in power engineering. Doctor´s degree theses.