„SLUDGE FOR HEAT” – EUROPEAN PROJECT PRESENTATION

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ABSTRACT

For small/medium towns there is no standard method for the utilisation of sewage sludge. The problem could be solved by burning the sludge (only mechanically dewatered) together with other locally available combustible wastes, of higher calorific value. Some of the very damp sludge can be partly replaced by the second waste fuel, irrespective of its physical state (solid, liquid or gaseous). Candidate supporting fuels are e.g. the biomass by-products of the maintenance of vegetation within the city (street trees, parks, etc), partly segregated municipal solid waste (MSW), biogas or even animal waste. The technology selected is to burning sewage sludge in a bubbling fluidised bed (very tolerant of low grade or ”difficult” fuels). It has the advantage that the process can be carried out at the site where the sludge originates, at a relatively low temperature but with good efficiently, avoiding the energy consuming drying stage. Designing a system for the thermal utilisation of sewage sludge was preceded by extensive laboratory tests and was backed by many years of research and industrial experience of the members of the group. A pilot installation, 1 MW_t has been designed, with some of the heat produced employed in the gas cleaning system and for heating the premises used by the technical staff and for providing hot water. The combustor is equipped with feed systems for the sewage sludge and for the supporting fuels. On the basis of the experimental results, an automatic process control system has been developed. The effect of bed temperature and air excess on the flue gas composition and the degree of mineralisation of the sewage sludge has been assessed. Burning sewage sludge and supporting fuels on laboratory (5 kW) and pilot (100 kW FBC boiler, type KFD-s14u, own design) scales has shown that, on account of the flue gas concentrations of CO, VOC and NO_x, the optimum operational temperature range should be 880-950 ^oC. In the bed the air excess coefficient should be below 1.6, but it can be increased in the freeboard (the secondary combustion zone). The flue gas concentrations monitored were: O_2, CO, NO, NO_2 and SO_2 (using ECOM®-SG Plus instrument, with electrochemical sensors), VOCs (JUM®, working on the FID principle). The air excess in the freeboard was also continuously recorded. The presence of SO_2 and NO_x was due to the presence of combined sulphur and nitrogen in the fuel, most likely in organic form. It can be assumed that all organic S is converted to SO_2, so that the SO_2 concentration is a measure of the S content in the sewage sludge. If necessary, emissions of SO_2 could easily be reduced by adding crushed limestone to the fluidized bed, even with the S content of the fuel very variable. Fuel nitrogen may be gasified to either HCN or NH_3 or remain in the char. Its subsequent oxidation can lead to the formation of NO, N_2O or N_2, depending on the combustion conditions. The NO_x levels observed with sewage sludge are comparable to those with coal and to reduce them would require a system capable of coping with rapidly changing concentration levels. If the co-combustion fuels are very low in S and N, the flue gas concentrations of SO_2 and NO_x will fall. Wood chips are nearly free of S and their N content is a factor of 2-3 lower than in the sludge. Flue gases from burning segregated MSW (paper, cardboard, polymers, e.g. PE, PP, PET) are similar to those from wood waste and burning biogas is intrinsically clean. Thus the supporting fuels cannot have an adverse effect on the flue gas emissions, which are determined mainly by the elemental composition of the wastes. The use of supporting waste fuels will improve the degree of oxidation of CO and VOCs. There is practically no unburned material in the ash, which is also fully mineralised. The results obtained for selected metallic elements are relevant to the problem of the fate of these elements during the combustion process and particularly their distribution between the flue gases and the ashes – most metals are retained in the ash. Thus the results obtained show that in a bubbling fluidized bed the combustion can be effective and potential pollutant emissions can be kept down.

INTRODUCTION

The present Niepołomice WWTP produces 90 tons, dry weight, of sewage sludge per year. With the planned modified technology the dry weight of the sludge will increase to 143 tons per year and in 2005 the sludge stream is expected to reach 335 tons per year. At present the water content of the partially dewatered sludge will be 80-85%.

The tests and calculations carried out within the project will take into account the limiting parameters of the sludge. The combustor is planned to be larger than required with continuous operation, since the installation may work intermittently, e.g. operating for 8 hours/day, 5 days a week. Increased quantities of sludge can then be dealt with by increasing the time of operation.

To determine heavy metals in the sewage sludge, samples of the sludge, bed material, ash and fine dust were collected, from the feed mechanism, reactor, settling chamber and cyclone respectively. The samples were mixed and used for analysis. The mineralisation of the sludge (feed), ashes and dust and the extraction were carried out using a Perkin-Elmer Microwave Mineraliser and the metals were transferred to an aqueous solution. They were then determined using a Perkin-Elmer mass spectrometer, CP-MS SCIEX ELAN. Table 1 shows the results obtained for the sludge from Niepołomice WWTP.

Table 1. The concentrations of selected metals in dry sewage sludge from Niepołomice WWTP

Metal	Content, mg/kg	Metal	Content, mg/kg
Mn	337,6	As	8,7
Cu	234,1	Hg	0,8
Pb	61,3	Cd	3,2
Ni	28,3	Cr	51,3

The laboratory tests were carried out using a system consisting of a fluidised bed reactor together with a set of analytical and data recording instruments, as shown in Figure 1. Air, initially mixed with methane, enters the plenum chamber and passes through the distributor into the reactor. Fuel is added from the top, from a disc feeder. The flue gases are sampled from the freeboard and analysed continuously. The results of the analysis and the operational parameters are registered by the computer system at no more than 1 second intervals.

The basic information about the laboratory size fluidised bed reactor is collected in Table 2.

Table 2. The characteristics of the laboratory fluidised bed reactor

Construction material	Quartz tube
Inner diameter of the reactor	96 mm
Cooling system	By radiation
Bed material particle size	0-2.5 mm
Thermal power	2-20 kW
Distributor plate - type	Perforated plate, Φ96 mm
Freeboard	No thermal insulation, Height 300 mm

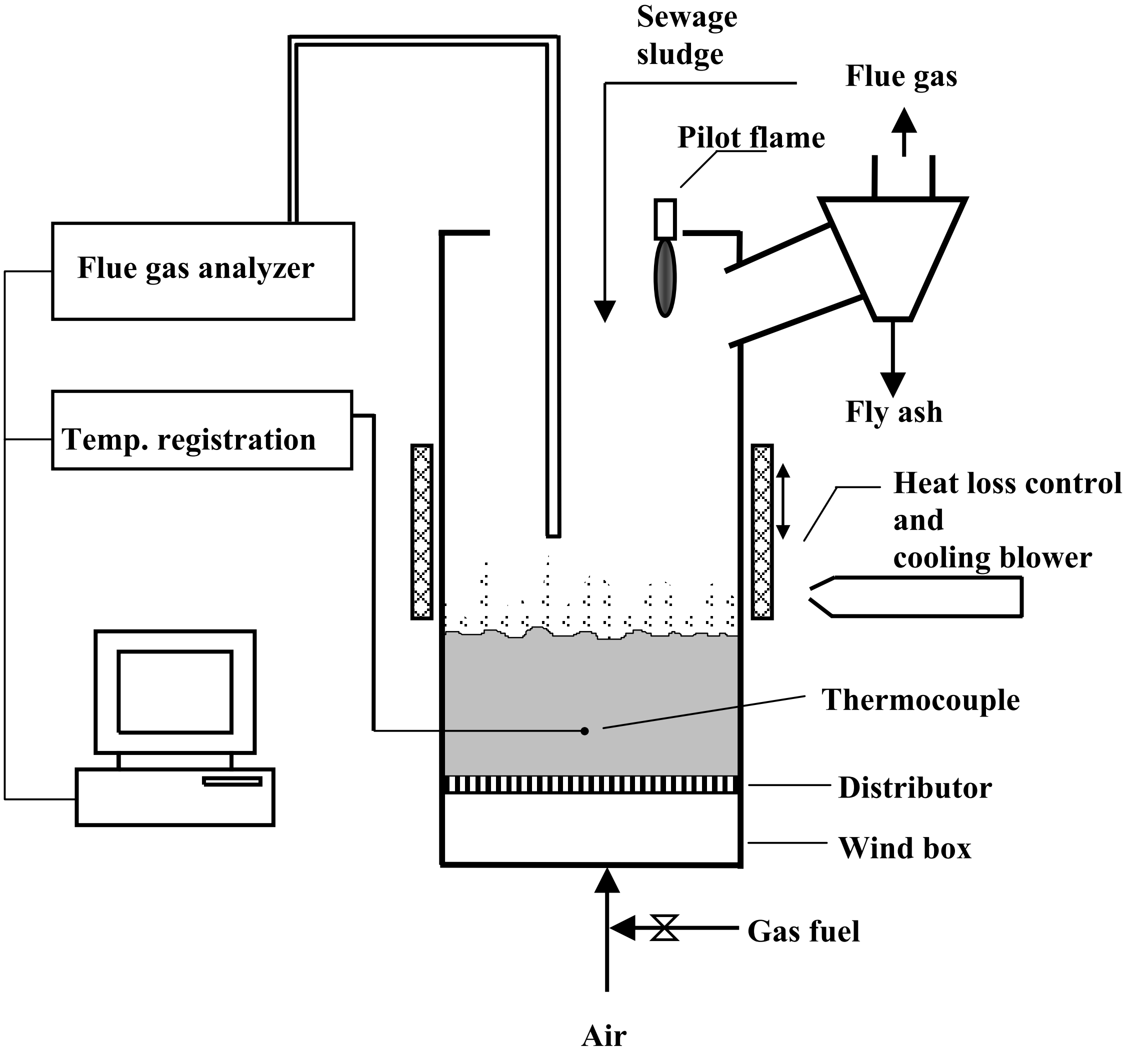

Fig. 1. Schematic of the fluidised bed reactor with the associated control and measuring systems.

Figure 2 gives the results obtained when sewage sludge from Niepołomice was burned. The combined direct plots illustrate the changes bed temperature and the concentrations of the most important constituents of the flue gases during typical runs.

Such experimental data were used to establish the dependence of the flue gas concentrations of CO, CO_2, NO, NO_2, VOC (volatile organic compounds) and SO_2 on bed temperature T and the air excess coefficient λ. If necessary, the emission of SO_2 from the combustion of sewage sludge could be limited by feeding in a calcium based sorbent (e.g. crushed limestone). Changing the velocity of fluidisation by ± 20% is not important from the point of view of the process. However, for a fuel with a very wide range of particle sizes (i.e. under practical conditions) an abrupt change in the fluidisation velocity can cause the elutriation of fine particles, including those of burning sewage sludge.

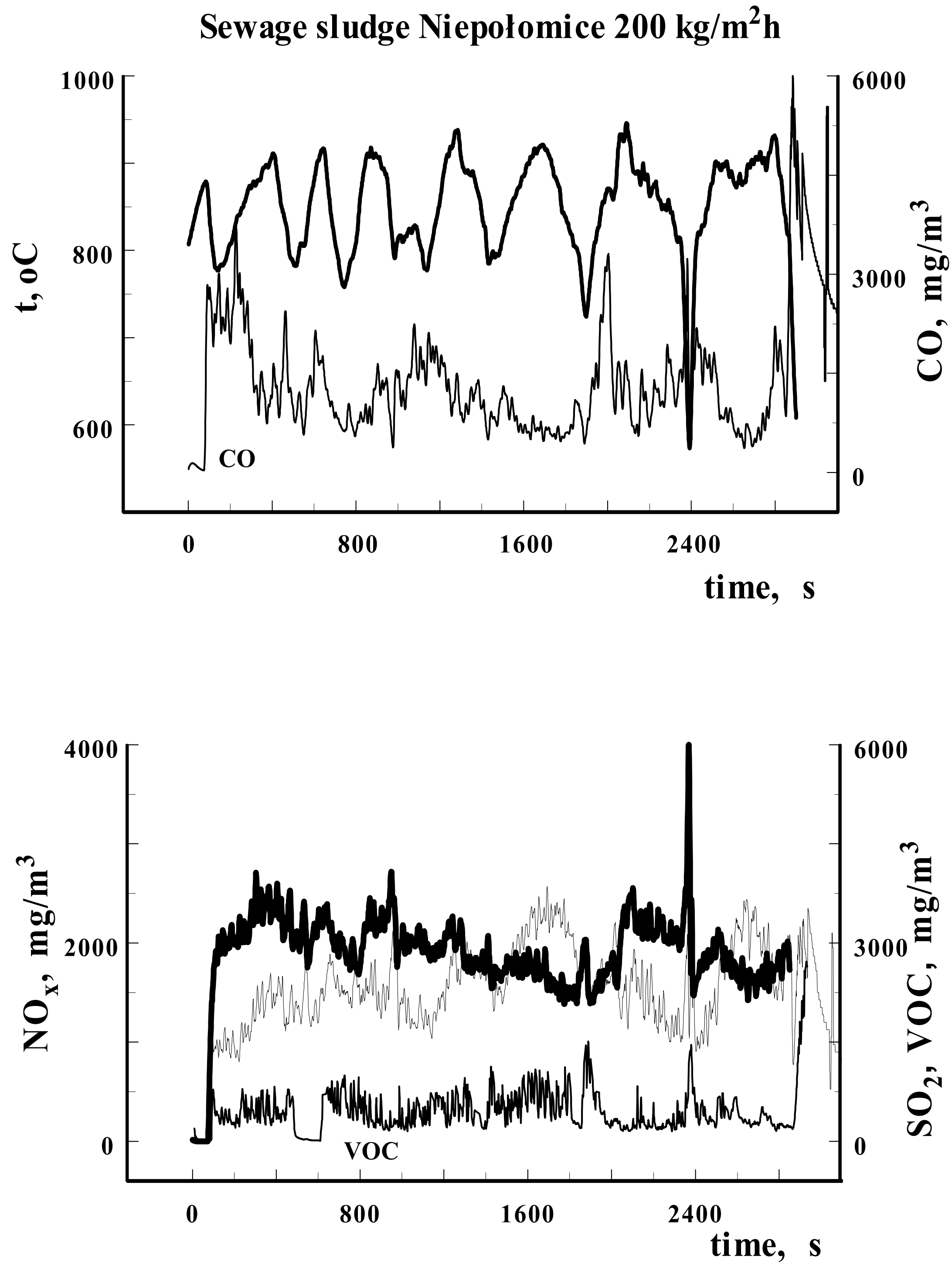

Fig. 2. Changes in selected process parameters during the combustion of sewage sludge from Niepołomice WWTP in a laboratory scale fluidised bed combustor.

This will in turn lead to increased emissions of CO and VOCs. In contrast, falling fluidisation velocity can lead to the largest particles settling on the distributor, perturbation of the fluidisation process and eventually even the melting of the bed material at the bottom of the bed (this was actually observed during one of the tests). Any changes in the fluidisation velocity must be gradual, over times appreciably longer than the mean burn out time of average fuel particles (several minutes) and should not be by more than ± 30% away from the optimum. The optimum fluidisation velocity to use will be determined during test on the planned installations. The procedures required have already been prepared.
During the combustion of sewage sludge the non-volatile metals present in them tend to concentrate in the solid wastes, the degree of enrichment depending on the degree of burn - out and the ash content of the sludge. Metals of medium volatility tend to concentrate on dust particles, captured outside the combustor. Highly volatile metals are often largely lost from the solid phase and are emitted with the flue gases. Table 3 shows some analysis results obtained for a number of metals, which were determined in the sludge burned, in the bed material, particles from the settling chamber and dust captured in the cyclone. With non – volatile metals like Mn, Cu or Ni, 3 – 4 fold enrichment is observed in all solid wastes. For less volatile elements, like Pb or As, the enrichment factor is 2-3 and for very volatile Hg its concentration in the solid products is lower than that in the sludge feed.

Table 3. The heavy metal content (mg/kg) in the sludge, bed material, dust from the settling chamber and cyclone dust

Metal	Sewage sludge	Bed	Settling chamber	Cyclone
Mn	337.6	1112.4	1022.3	972.6
Cu	234.1	722.3	716.4	844.9
Pb	61.26	226.6	164.8	177.6
Ni	28.33	94.44	102.54	111.91
As	8.68	34.31	19.18	22.16
Hg	0.83	0.668	0.586	0.657
Cd	3.19	8.85	6.18	7.70
Cr	51.35	182.4	193.4	197.2

EXAMINATION OF THE EFFECT OF CHANGING THE SIZE OF THE FLUIDISED BED TO SEMI - TECHNICAL

Tests on the semi – technical scale were carried out using the reactor the characteristics of which are summarised in Table 4.

Table 4. The characteristics of the semi – technical scale fluidised bed reactor

Reactor construction	Stainless steel, with ceramic lining
Bed height	300 mm
Main reactor height	600 mm
Thermal power	50 - 150 kW
Distributor type	Overlapping plates, 280x280 mm
Freeboard	Thermally insulated, height 1000 mm

The reactor was used to carry out a series of tests on the combustion of the sewage sludge, with an augmenting fuel (wood chips). Figure 3 shows the inside of the working reactor, fuelled with sewage sludge.

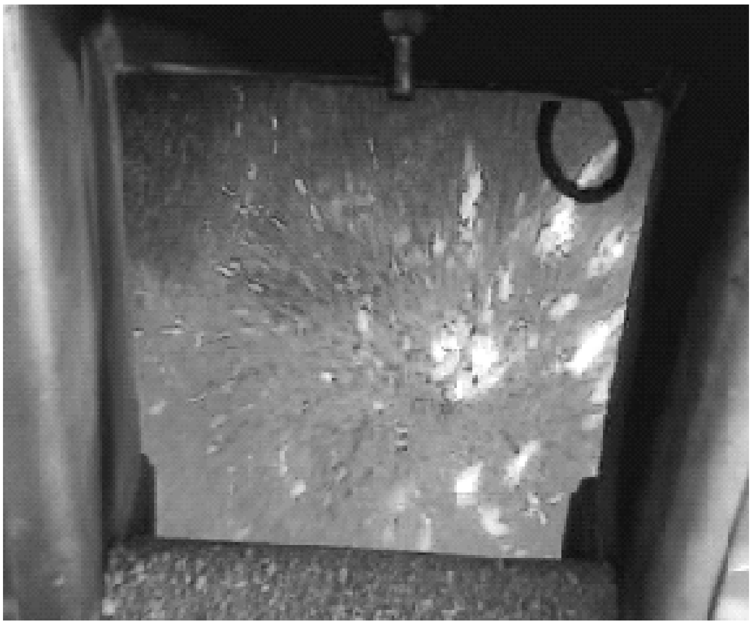

Figure 3. The combustion of solid fuel in the semi - technical scale fluidised bed reactor, 100 kW.

The analyses carried out during the tests employed some of the measuring instruments purchased using the funds provided under the present project. The results obtained, after appropriate treatment, are given in Figures 4-6. The results from the laboratory reactor, given in Figure 2 as well as the conclusions from the analysis of tests with the semi – technical size reactor suggest that the change of scale from 5 to 100 kW brings advantages, because with the larger size, longer gas residence times and slower freeboard cooling the oxidation of CO and VOCs is facilitated and their emissions fall. Increasing the dimensions of the freeboard further by increasing its width and increasing the h/d ratio from 1:1 (as in the 100 kW unit) to 3:1 (in the installation now being designed) should bring the concentrations of CO and VOCs down to levels that would satisfy EU regulations. The concentrations of CO_2 and H_2O will not be affected by a change of scale. Lower NO_x concentrations with increasing scale may be associated with the presence of larger sludge particles and the formation of local reducing zones. However, the lowering is unlikely to be by more than 20% with respect to the level observed with the 100 kW combustor (most of the NO_x is derived from fuel nitrogen, i.e. the oxidation of combined N present in the sludge). Further lowering of the NO_x concentration could be achieved by lowering the air excess coefficient, λ.

Changing λ from 2.2 to 1.2 brings about approximately halving of the NO_x concentration. To ensure high degree of oxidation of CO and VOCs with low air excess in the bed, secondary air will be introduced above the bed.

It should be noted that the concentrations of metals are lowest in the "Niepołomice" sludge, which can be attributed to the low degree of industrialisation in that district. The sewage sludge from Niepołomice is thus relatively "clean". In general, the contamination of sewage sludge with heavy metals is strongly linked to both the general degree of industrialisation and to the type of industries that prevail in the given area.

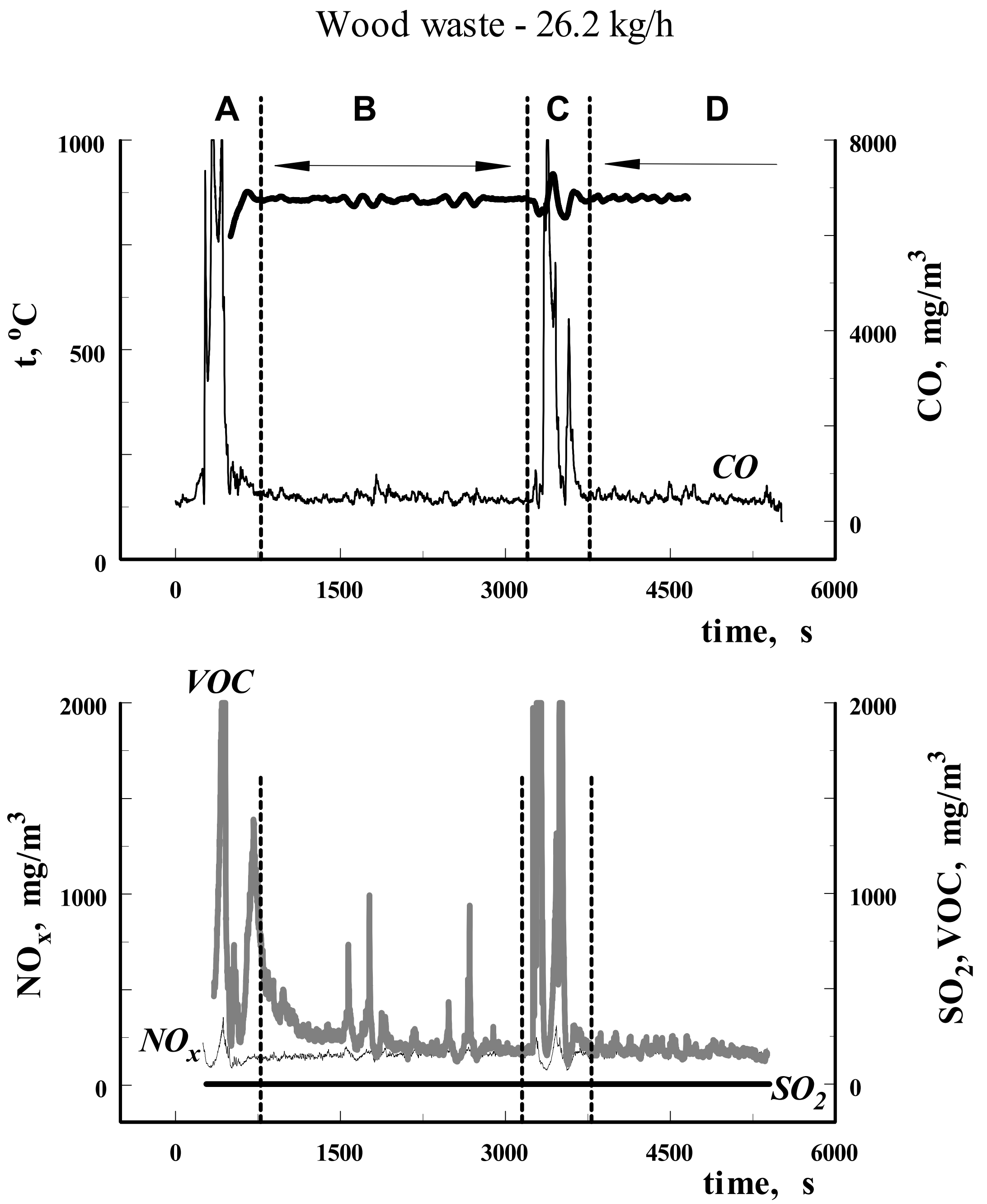

Figure 4. Changes in selected process parameters during the combustion wood chips in the semi – technical scale fluidised bed reactor 100 kW. The fluidized bed temperature and the concentration of CO, NO_x, SO_2, VOCs in the flue gases. A – start up, B and D – operation on wood waste, C – process perturbed.

The 100 kW combustor was run on wood wastes, fed in at a rate of 26.2 kg/h, with air in excess. During the start-up phase, the concentrations of CO, NO_x and VOCs first rose rapidly and then settled at a lower level. This effect is associated with the dynamics of the fluidized bed and the gradual establishment of the required combustion conditions. When the bed temperature reaches about 860 ^oC the process becomes steady. During steady operation, the concentrations of CO, NO_x and VOCs oscillated around mean values of 500, 130 and 200 mg/m^3. It should be noted that SO_2 was undetectable (the detection limit was 0.8 mg/m^3).

In the next experiment, Figure 5 the combustor was supplied with sewage sludge only. The concentration of CO was almost unaffected, but that of NO_x rose from 120 to about 1000 mg/m^3. SO_2 appeared and its concentration fluctuated quite strongly (similarly to the other concentrations). This happened with the bed temperature constant at about 870 ^oC, but before approximately constant sludge feed rate was established. When the sewage sludge alone was burned, the composition of the flue gases also became stabilized. With sewage sludge, increased flue gas concentrations of SO_2 and NO_x were due to the presence of combined sulphur and nitrogen in the fuel, most likely in the form of organic compounds. The temporary peaks appearing in the records for the concentrations of CO, NO_x, SO_2 and VOCs all coincide with fluctuations in the air excess trace (not shown) and are due to variability in the content of combustibles in the fuel feed. During the combustion of sewage sludge, the mean flue gas concentrations of CO and VOCs are 406 and 124 mg/m^3 respectively. The levels are similar to those observed with wood waste, 495 and 175 mg/m^3. In contrast, the concentrations of NO_x and of SO_2 rise, by a factor of about 9 for NO_x – to over 1000 mg/m^3 and for SO_2 to nearly 800 mg/m^3.

The results presented demonstrate that in an atmospheric bubbling fluidized bed the combustion of quite dissimilar materials can be effective, with no unburnt material in the ashes. However, the presence of VOCs in the flue gases showed that under the experimental conditions used a small proportion of the volatiles remained unoxidised. This emphasizes the need for using an installation with higher freeboard, to ensure prolonged residence of the VOCs in an oxidizing atmosphere. Fluctuations in the measured concentrations of flue gas components are linked and due to non-uniformity of the feed material and/or accidental perturbations in the fuel feed rate.

The level of NO_x and SO_2 emissions is associated with the presence of combined nitrogen and sulphur in the fuel. It can be assumed that all the organic S is converted to SO_2, so that the SO_2 concentration is a measure of the S content in the sewage sludge or meat and bone meal. A similar assumption cannot be made about fuel N and the NO_x concentration. Nitrogen in the fuel may be gasified to either HCN or NH_3 or remain in the char. Subsequent oxidation can lead to the formation of NO, N_2O or N_2 depending on the combustion conditions.

Emissions of SO_2 could easily be limited by adding crushed limestone to the fluidized bed, even if the S content of the fuel was very variable. Lowering the emissions of NO_x would require a system capable of coping with rapidly changing concentration levels.

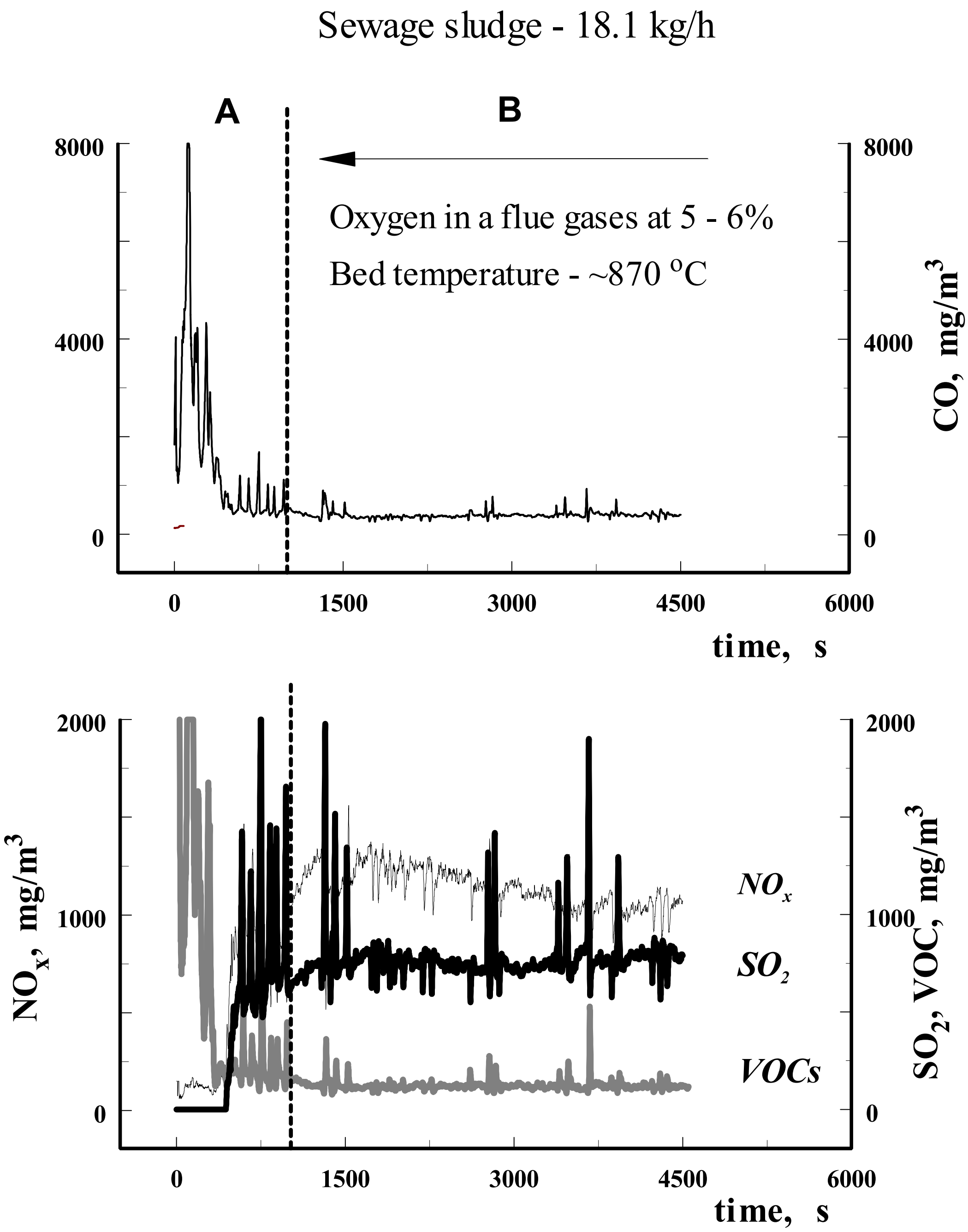

Figure 5. Changes in selected process parameters during the combustion of sewage sludge in the semi – technical scale fluidised bed reactor 100 kW. The concentration of CO, NO_x, SO_2, VOCs in the flue gases. A – start up, B – operation on sewage sludge.

DESIGN, CONSTRUCTION AND TESTING OF THE 1 MW FBC

To arrive at the quantities needed for developing the design of the full scale installation mathematical modelling of the thermal balance for the combustor has been used. Based on literature data, measurements and estimates of the properties of the sewage sludge and the wood chips a series of calculations has been carried out to determine the maximum possible moisture content of the fuel feed as a function of the preheat temperature of the fluidising air. It indicates that with maximum air preheat (to 400 ^oC) the highest possible water content of the fuel is expected to be 47%.

Mixtures of sewage sludge and meat and bone meal can be burned in a fluidized bed without using a supporting highly calorific fuel. The factor limiting the possibility of burning such wastes may be their water content, but drying in a fluidized bed prior to combustion is more effective and consumes less energy than in other reactors.

In the course of combustion tests, with up to 50% of the projected load, emissions were measured and analysed (the results should be better for full load), with different materials fed in. Analysis results for the flue gases obtained before and after the scrubber led to an assessment of the efficiency of the scrubbing system. The results have been tabulated.

During the combustion of wood chips, the emission levels of SO_2 and NO_x are low. During the planned co-combustion, in 1:1 proportions, of wet sludge (80% water) and fresh wood chips (30 % moisture) the expected emissions can be assessed: CO - 90 mg/m^3, NO_x – 530 mg/m^3, SO_2 – 234 mg/m^3.

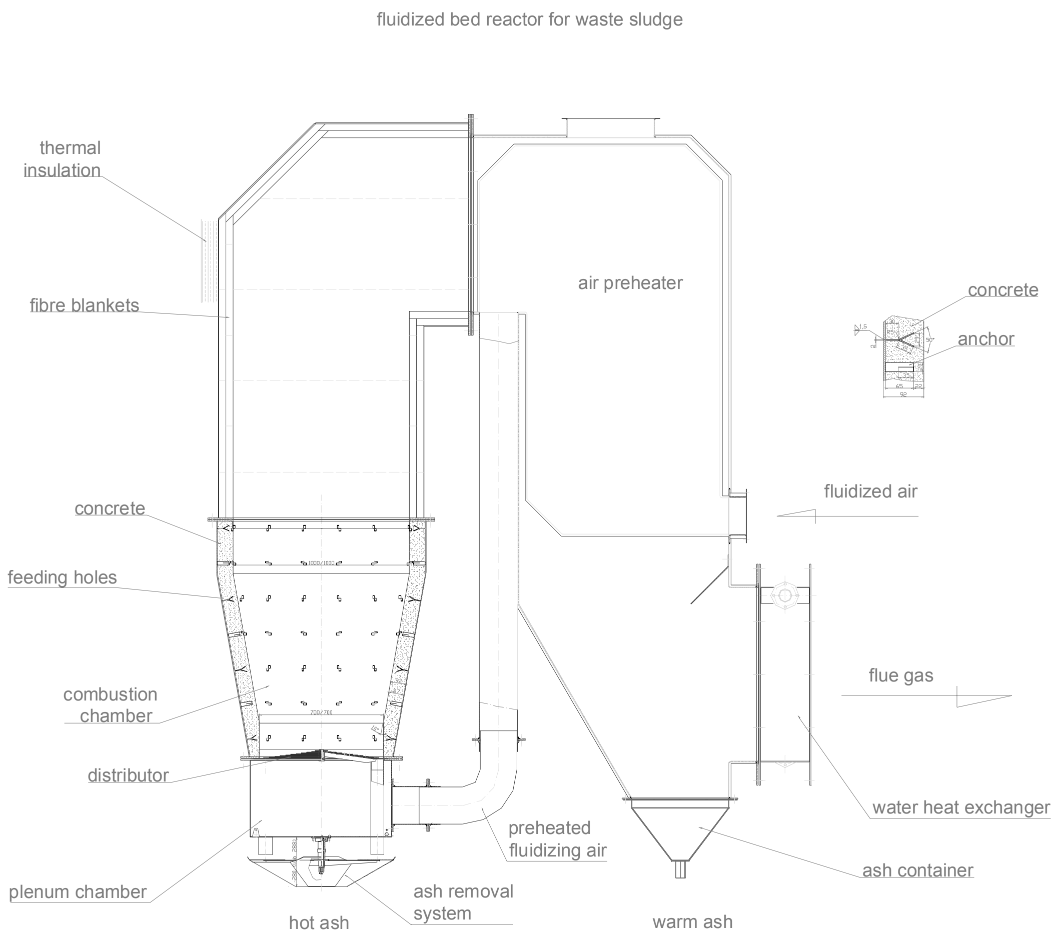

Figure 6. 1 MW_{th} FBC - Technical documentation of "Sludge for Heat" installation.