FLUIDIZED BED COMBUSTION WITH THE USE OF GREEK SOLID FUELS

by

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The paper is an overview of the results obtained up to date from the combustion and co-combustion activities with Greek brown coal in different installations, both in semi-industrial and laboratory scale. Combustion tests with Greek lignite were realised in three different circulating fluidized bed combustion facilities. Low rank lignite was burned in a pilot scale facility of approx. 100 kW thermal capacity, located in Athens and a semi-industrial scale of 1.2 MW thermal capacity, located at RWE's power station Niederaussem in Germany. Co-combustion tests with Greek xylitic lignite and waste wood were carried out in the 1 MW_t installation of in Austria. Lab-scale co-combustion tests of Greek pre-dried lignite with biomass were accomplished in a bubbling fluidised bed in order to investigate ash melting problems. The obtained results of all aforementioned activities showed that fluidised bed is the appropriate combustion technology to efficiently exploit the low quality Greek brown coal either alone or in conjunction with biomass species.

Key words: fluidised bed, greek lignite, co-combustion, biomass

Introduction

In Greece, brown coal has the biggest share of primary energy production in 1999, accounting for 8 Mtoe of the country's 9.49 Mtoe total primary production 1 . The increasing demand for electrical power combined with the high cost of desulphurisation facilities which are required when the conventional pulverized fuel combustion technology is applied, implies the necessity to investigate the applicability to the particular coal quality of alternative coal combustion technologies such as fluidized bed combustion. The present work summarizes all efforts targeting to evaluate the possibility of applications of the circulating fluidized bed combustion (CFBC) technology to an extremely poor brown coal, *i. e*. Greek lignite, either alone or in combination with biomass. The main purpose is to prove the applicability of CFBC technology for Greek brown coal and that such installations could offer a serious contribution to cover the increasing demand of electrical power in Greece.

Methodology

Combustion tests with Greek brown coal were carried out in two CFBC facilities, *i. e.* the 1.2 MW_t test facility located in Niederaussem of RWE and the 100 kW_t test rig of National Technical University of Athens. The two facilities are not only different in size but also have a different design concept. The first one (Niederaussem) operates with thermal insulated cyclone whereas the second has a non-insulated cyclone ("cold cyclone") (NTUA). Greek brown coal and its blends with different waste wood species and biomass materials were tested in the 1 MW_t atmospheric CFBC installation of Austrian Energy & Environment (AE&E), and a lab-scale fluidised bed reactor. Detailed description of all facilities is presented in 1-3 . The fuel test matrix elaborated in all experimental series is shown in tab. 1. Typical quality characteristics of Greek lignites from various reserves are given in tab. 2. The sulphur content of Greek lignites varies from 0.5 up to 1% w/w on as received basis, while in some cases it exceeds 1% w/w. Chemical analyses of waste wood and biomass species used during the co-combustion tests are presented in tab. 3. Flue gas desulphurisation was applied during the combustion tests, using various types of limestone as additives, because of the high sulphur content of Greek lignite.

Table 1.Facilities and fuel test matrix applied in the combustion and co-combustion tests

Facility	Fuels	Biomass share % wt
CFBC, 1.2 MW_t	Megalopolis lignite	–
CFBC, 100 kW_t	Megalopolis lignite	–
CFBC, 1 MW_t	Ptolemais lignite (xylitic type) & waste wood	25
BFBC, lab-scale	Megalopolis lignite & olive kernel, straw Ptolemais lignite & waste wood	10, 20, 30, 40, 100 20, 35, 50

Table 2. Typical quality characteristics of various Greek brown coals

Area	Moisture % w/w as received	Ash % w/w dry basis	Net calorific value kcal/kg as received	Sulphur % w/w as received
Ptolemais Kozani	52-58	30-36	1270-1300	0.5
Amynteo	49-54	37-40	1145	0.5
Florina	40	34	1800-2500	>1
Komnina	40-45	32	1500-1850	>1
Megalopolis	56-60	38-45	950-1000	1.2-6
Drama	60	39	1000	0.6
Elasona	42	28	2300	0.65

Combustion of Greek lignite in CFBC

Operation – fuel burnout

Due to the poor fuel quality intensive preheating is required to achieve good ignition conditions. The operation with hot recirculating material (Niederaussem facility) favours the ignition conditions in comparison to the non-insulated cyclone (NTUA facility). In the latter case, the recirculating material is cooled down to approx. 300 °C and this affects negatively the ignition conditions at the lower part of the bed.

From the emissions recorded under the optimized operating conditions in CFBC Niederaussem, it is clearly shown that CO content in the flue gas after the cyclone is approx. 658 mg/m_N^3 (at 6% O_2) for the best case. Better burnout was attained for finer fuel particles than the larger ones as indicated by the reduced CO emission. The CO emission during the combustion of Megalopolis lignite is higher than in any previous test performed with Rheinisch or Hungarian coals. The incomplete fuel burnout can be explained from the intensive furnace cooling and the poor fuel quality, which result to low combustion chamber temperatures (≈700 °C). The use of overfire air (OFA) in the upper parts of the combustion chamber of the Niederaussem plant has decreased the combustion chamber temperature and the combustion efficiency.

Table 3. Proximate, ultimate analyses and calorific value of waste wood, olive kernel and straw

Parameter	Railway sleepers	Demolition wood	Olive kernel	Straw
Proximate analysis, % w/w				
Moisture	13.35	15.73	13.5	8.0
Volatiles	73.13	74.83	61.1	71.1
Fixed carbon	12.74	7.92	16.8	15.0
Combustibles	85.87	82.75	77.9	86.7
Ash	0.78	1.52	8.7	5.3
Calorific values kJ/kg , as received basis				
Gross	16815	18620	18080	16473
Net	15463	17188	16782	14846

The high CO emission recorded during the experiments with the finest coal particles in the NTUA facility indicates the incomplete fuel burnout inside the reactor. Several attempts were made to decrease the high excess air, but CO emission was constantly increased, indicating the poor quality burnout when reducing the air flow.

Although the CFBC in Niederaussem was designed as a fast circulating fluidized bed, it was found that during the Megalopolis lignite combustion the operation close to the stationary modus with no air staging to the upper part of the reactor has offered the optimum combustion conditions. For this case a uniform temperature distribution was measured along the reactor height with temperature gradients not higher than 30 K.

The bed temperature achieved during the experiments at was approx. 790 °C. The temperature distribution in the facility at NTUA is dominated by the absence of any secondary air supply and the flue gas cooling by convection surfaces before entering the cyclone. In this way, the operation of the CFBC should be considered rather as stationary fluidized bed with a dense bed height of approx. 50 cm with relative constant temperature. In the dilute phase, which is found in the rest of the reactor – total height equal to 3.4 m – a considerable temperature decrease of 250 K was detected. The temperature distribution along the furnace height as obtained for the three different coal particle sizes is illustrated in fig. 1.

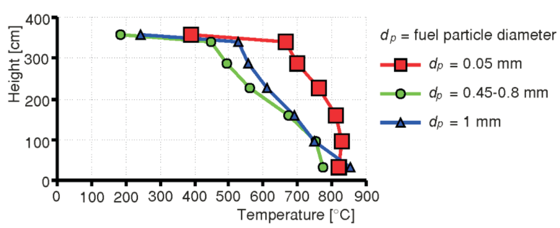

Figure 1. Temperature distribution inside the NTUA experimental CFBC

Emissions

The observed CO emissions from both experimental facilities when burning Megalopolis lignite were generally high (535 – 1070 mg/m_N^3 CO at 6% O_2). These values indicate that the furnace does not have the sufficient height to allow the completion of the combustion reactions.

In almost all combustion tests, the measured NO_x values were kept at satisfactory emission level. This is due to reduced furnace temperatures and low nitrogen content of lignite, which is considered the major source for NO_x formation in fluidized bed 4 . An increased N_2O emission was detected during the measurements with Megalopolis lignite in comparison to other types of brown coal 5 . The N_2O emissions clearly decreased with increasing bed temperature. A bed temperature increase of 80 °C led to a reduction of 40% in the emitted N_2O.

Greek lignite features a high sulphur content (approx. 1.5%) and therefore particular interest during the combustion tests was given to the flue gas desulphurisation. Two different types of dry additives were used, *i. e*. limestone and chalk. The larger additive particles coming from chalk presented better behaviour as desulphurization agents in comparison to the finer ones of limestone. At the beginning of the lignite combustion test, SO2 concentration was approx. 5000 mg/ m_N^3 SO_2 at 6% O_2, while a final SO_2 retention of 89.9% or 68.8% was achieved at the Niederaussem plant using the two types of limestone under the same *Ca*/*S* ratio (*Ca*/*S* ≈ 3). The corresponding values of SO_2 emissions were approx. 600 mg/ m_N^3 when using chalk as an additive and 1500 mg/ m_N^3 in the limestone test case (*Ca*/*S* = 4.2).

CO-combustion of Greek lignite with biomass in CFBC

Operation during the co-combustion tests

The combustion of Greek xylitic lignite with waste wood was investigated in the 1 MW_t CFBC of AE&E. First tests, focused on differentiations of emitted pollutants and ash melting behaviour when burning lignite/waste wood mixtures, were accomplished in a lab-scale facility and the results are presented elsewhere. Afterwards, an extensive test matrix was elaborated for the evaluation of lignite's co-combustion behaviour in the 1 MW_t CFBC, tab. 4. Solid residue samples from the bottom of the combustion chamber, the fluidised bed, the cyclones and the filter were collected and analysed in an ICP-AES spectrophotometer for heavy metals.

Table 4. Fuel test matrix of the co-combustion tests at the CFB boiler

No.	Fuel blend	% wt	Duration h:min.	Remarks
1	Lignite	100	05:00	
2	Lignite	100	08:10	
3	Lignite/Railway sleepers	75/25	Interrupted	Fuel feeding problems
4	Lignite/Demolition wood	75/25	09:25	
5	Lignite	100	08:13	Limestone addition
6	Lignite/Railway sleepers	75/25	08:04	Limestone addition
7	Lignite/Demolition wood	75/25	08:04	Limestone addition
8	Lignite/Railway sleepers	75/25	08:21	Limestone addition
9	Lignite	100	24:00	Limestone addition in specific time intervals
10	Lignite/Demolition wood	75/25	48:14	Limestone addition in specific time intervals

Significant problems occurred during waste wood handling. Due to the coarse particle size and the increased tar content of railway sleepers, agglomerates were shaped, leading to the formation of "bridges" in the silo. The difficulties during the storage of demolition wood were confronted by adding a vibrator and half filling of the silo. Partial removal of the bed material was necessary to avoid unstable operation of the fluidised and, subsequently, incomplete fuel combustion.

Under steady-state conditions, temperature and pressure at different points in the combustion chamber were continuously monitored. No significant differences were detected in temperature distribution for the various test cases indicating complete fluidisation, well mixing conditions and stable combustion within the bed, fig. 2. Addition of limestone and waste wood enhanced bed pressure drop, due to the increased quantity of bed inert material and the different aerodynamic behaviour of waste wood chips, compared to lignite. However, no significant alterations to the operational characteristics of the boiler were observed.

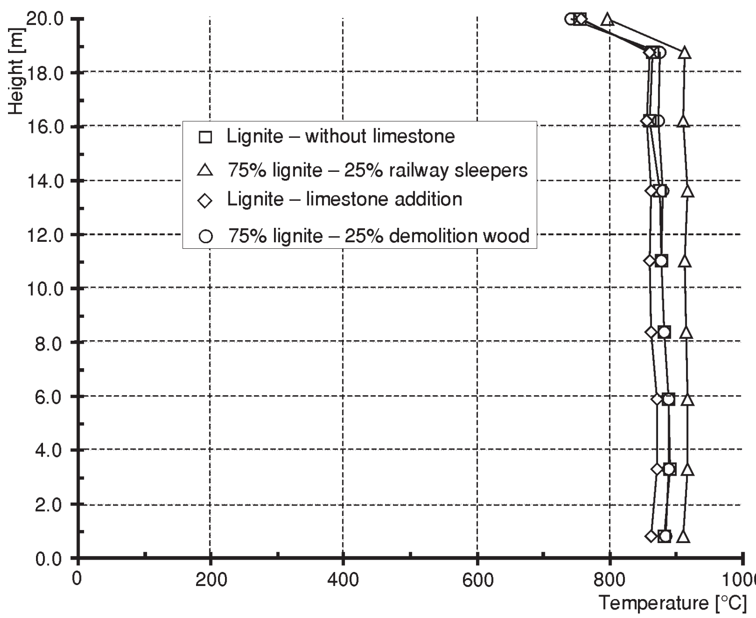

Figure 2. Temperature profile in the combustion chamber of the 1 MW_t CFBC

Emissions

Despite the variations in fuel's moisture content, steady state conditions were achieved during the lignite combustion. For all excess air ratios, CO emissions were maintained at low levels, below 100 mg/Nm^3, and the fluctuations observed could be considered insignificant. Similar results were achieved when bed temperature was increased above 850 °C, fig. 2. During lignite combustion, CO emissions were minimised (~20 mg/Nm3) when oxygen concentration was 3% (dry basis) and bed temperature increased to 910 °C. The addition of waste wood samples resulted in significant fluctuations in CO emissions, due to the inhomogeneous supply of both demolition wood and railway sleepers. Thus, higher excess air ratios were applied to avoid CO peaks.

Generally, the effect of temperature was stronger than the one of excess air ratio, and this is particularly true for the lignite – railway sleepers blend. During waste wood co-combustion with lignite, NO_x emissions were dependent upon the operating conditions and were not affected by the variations of the nitrogen content in raw fuels, which were limited. Increased excess air ratios and bed temperatures during the co-combustion tests, aiming to achieve higher combustion efficiency values, led to enhanced NO_x emissions.

In the lignite combustion tests, SO_2 values exceeded 5000 mg/Nm^3, when no desulphurisation was applied, due to its high sulphur content. The addition of limestone resulted in reduced SO_2 emissions, between 225 and 400 mg/Nm^3. SO_2 emissions were further decreased approximately to 180 mg/Nm^3 during the co-combustion tests, due to the low sulphur content of waste wood species. As anticipated, desulphurisation efficiency increased with higher *Ca*/*S* ratios, fig. 3, and more than 90% was achieved for *Ca*/*S* above 5.5. However, *Ca*/*S* ratio about 2–3 is generally considered sufficient to achieve the same desulphurisation efficiency. This discrepancy could be attributed to the variations of lignite moisture content and the inaccurate sulphur balance. Data for emitted pollutants coming from the lab-scale tests are in accordance with the results of the 1 MW_t CFBC facility. NO_x emissions dependence on operating conditions and reduction of SO_2 emission when biomass percentage in the fuel blend is increased, were also proved in the lab-scale tests.

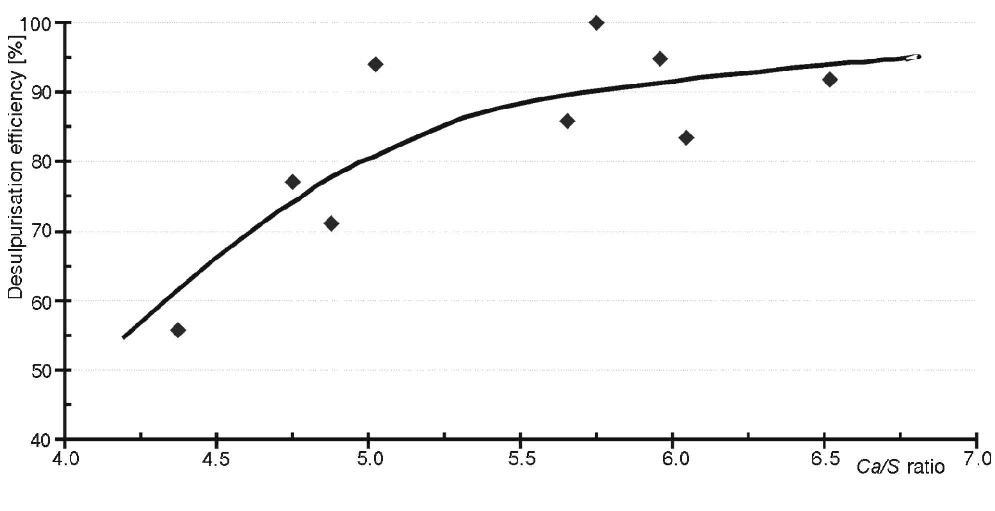

Figure 3. Desulphurisation efficiency as a function of Ca/S ratio

Heavy metals in solid residues

Lignite has, by far, the highest ash content and thus the majority of the metal elements detected in the ash samples came from the lignite ash. Increased heavy metal concentrations are observed in the fly ash samples, due to the addition of limestone in the bed. The latter increases fine particulate emissions and results in higher metal emissions, such as Mn, Co, Ni, Cr, Pb, Cd, Sn, V, and Ti. Low concentrations of the metal elements Co, Ni, Cr, Pb, Cd, Cs, and V were measured in the bottom ash samples. The high concentration of Ti is attributed to its low volatility.

Agglomeration

Apart from the alterations on emitted pollutants, the influence of biomass addition on the ash behaviour and tendency to form agglomerates with fuel or sand particles at high temperatures was investigated in the lab-scale tests. During these combustion tests, the bed temperature was continuously raised and indications when ash agglomeration starts were detected. Among other measurements, the differential pressure below and above the distributor was recorded. During the tests with pure lignite fused agglomerates were created (bed temperature ≈840 °C), caused mainly by its sulphur components of low melting point. Addition of biomass species at relatively low shares, *i. e.* less than 30% wt, diminishes these agglomerates, because of its low sulphur content and the insignificant ash quantity produced during its combustion. However, the temperature when agglomerates start to form during the olive kernel combustion is low, *i. e.* 860 °C, due to its high alkali content – mainly K – that reduces the sintering and melting temperatures of the ash and the bed materials. Defluidisation phenomena when using straw were observed at similar temperature values as seen in other experimental studies and were attributed to the formation of low melting temperature eutectic compounds of alkali-silicates 7, 8 . As a general assessment of the experimental results and theoretical calculations on ash deposition index 3 , it is concluded that biomass addition in the fuel blend up to 30% wt does not effect significant changes to the ash fusibility behaviour.

Conclusions

The most significant conclusion that arises from the experimental series with Greek lignite as base fuel is that CFBC technology offers very attractive possibilities for the utilization of coals of extremely poor quality or similar "difficult" fuels, like biomass residues and waste. In order to avoid the incomplete fuel burnout and the emissions-related problems, special care must be given to the design and the operation of a large scale CFBC plant, which should conform to the Greek lignite specifications. The combustion chamber height is connected with the operation with thermal insulated or not insulated cyclone in order to achieve satisfactory fuel burnout and exclude the post combustion phenomena inside the cyclone. The properties of the sorbent additive should be investigated in relation to the combustion chamber conditions to achieve maximum flue gas desulphurization. It was also found that the stationary operation of the CFBC with the air supply to the lower part of the reactor is more suitable when using these low quality fuels.

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