Pre-Drying of Moist Fuels for Power Production

Institute of Process Engineering and Power Plant Technology

Universität Stuttgart
Pfaffenwaldring 23
D-70569 Stuttgart
Tel.: ++49-711-685-3487
Fax: ++49-711-685-3491
j.maier@ivd.uni-stuttgart.de

Contract
JOF3-CT97-0037
and
ERBIC20-CT97-0046

Final Report

01.01.1198 to 31.12.2000

Research funded in part by
The European Commission

Table of Content

Executive Summary

The overall motivation to undertake this research project was to contribute to the reduction of the greenhouse gases' emission – primarily carbon dioxide – from power plants firing solid fossil fuels, in particular, low rank, high moisture fuels such as peat, brown coal and lignite. These fuels are one of the backbones of primary energy supply in various countries of the European Union as well as of Central and Eastern Europe which is mirrored by the fact that one fifth of the world` s production is mined in those regions. In the industrial conversion of these fuels process improvements are expected to substantially alleviate any hazardous impact on the regional and global environment.

Therefore, a consortium comprising of nine partners from industry and universities including three partners from the Newly Associated States (NAS) concentrated on increasing the efficiency of power generation, maintaining boiler availability and reducing emissions from high-moisture fuels by investigating and applying cost effective pre-drying technologies during the project.

The experimental and theoretical investigations focused on different drying techniques and advanced pulverised fuel combustion methods. Fuels of six different countries were extensively analysed and characterised by standard and advanced methods prior to pre-drying by different drying techniques such as a directly and indirectly heated atmospheric fluidised bed dryer (10 kg/h), a pressurised steam dryer (22 bar / 5t/h), an ultra sonic dryer and a newly developed crusher dryer (500 kg/h). As an important result technological and fuel dependent improvements for the industrial implementation were proposed.
Combustion investigations with raw and pre-dried fuels towards ignition, burnout and emission behaviour as well as operational problems such as slagging and fouling and the utilisation of the ash in e.g. cement production were performed in facilities ranging from laboratory scale at 20 kW via 500 kW up to full scale boilers 300 MW. One important result was that NO_x emissions as low as 200 mg/m³ were achieved with pre-dried fuels, thus, omitting any additional flue gas treatment for complying with emission standards.

Furthermore, the process calculation of several concepts showed that the integration of the pre-drying technology into low rank fuel conversion offers a high potential to increase plant efficiencies and thus to substantially reduce the CO_2 emission by such a fuel treatment.

Several fuel and process dependent design and operation parameters were developed. Concluding it can be stated that based on the results the design of a full scale demonstration plant is feasible prior to industrial application of such a pre-treatment for low rank solid fuels.

1 Introduction

During the 3 years of the EU sponsored project industries and universities of Eastern European countries like Bulgaria, Poland and Romania collaborated successfully with partners of Finland, Germany, Greece and the United Kingdom. The generation of power in the participating countries is to a major extent dependent on the utilisation of brown coals and similar low rank fuels (figure 1). Of the participating countries all equal or exceed a share of 10 % of the power production by lignites or peat (excluding the UK). As the greenhouse effect of the utilisation of fossil fuels is one of the generally discussed issues an efficient combustion at high efficiency is required to ensure the further utilisation of these fuels dependent on local availability.

Lignites in Europe

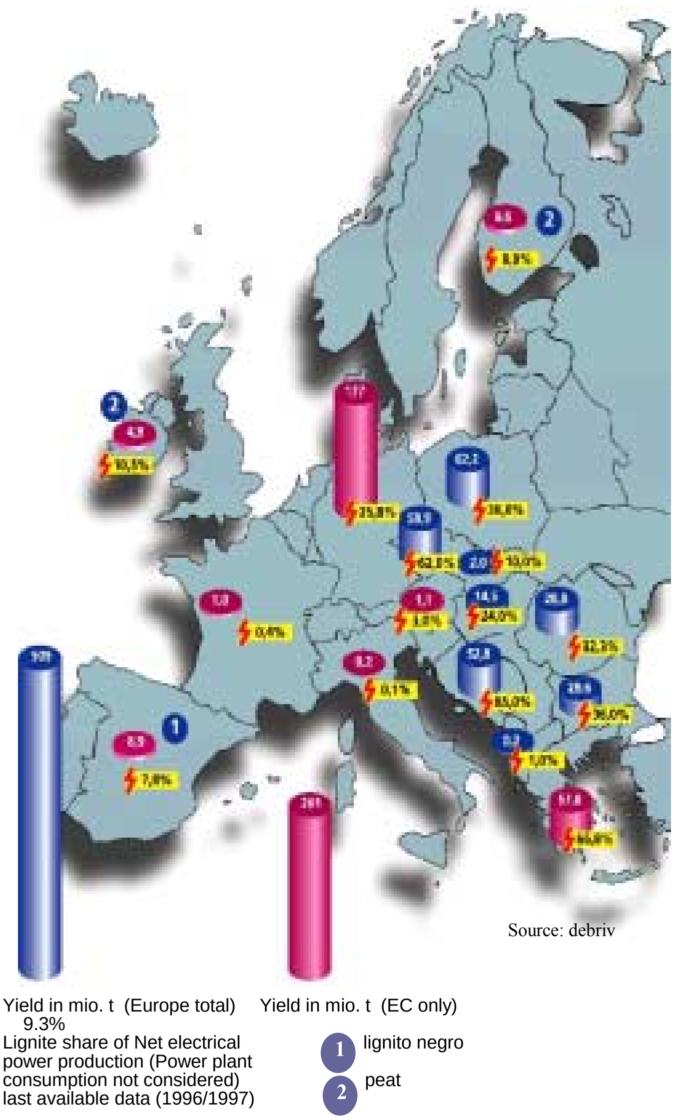


Figure. 1 : Low rank coals in Europe and their share in power generation

Low rank fossil solid fuels such as lignites, brown coal and peat are – among the other coal reserves – expected to be available for energy conversion for at least several hundred years as primary fuel base. This is of particular importance for the Western and Central European regions in which approximately 69 % of the worlds resources (excluding Turkey and Russia) are mined at present.

This is mirrored by statistics showing that e.g. in Germany 167.9 m t of brown coal equivalent to one fifth of the world output was mined in 2000. The next largest producers are Russia (89 m t), USA (80 m t), Poland (64 m t). Further important overseas low rank fuel mining countries are Australia (57 m t), China (55 m t), Canada (36 m t), India and Thailand with a production capacity between 20 and 25 m t.
Low rank fuels are predominantly utilised for electricity generation in the vicinity of the deposits. This is due to the low calorific value and in consequence to the required transportation of fuels compared to black coal, oil and natural gas. Because the moisture content of these fuels is one of the major reasons for the low heating value, any reduction of inherent water will contribute to a higher efficiency of the fuel conversion process and may offer a new market for such an improved primary fuel resource.

Figure 2 shows the percentage of low rank fuels in power generation of major producing countries and emphasises the high potential of any power plant technology integration with improved efficiency. Based on this the final goals of the project are to reduce the CO_2-emissions and the effect on global climate and other negative effects on the local and regional environment by increasing the efficiency of power generation, maintaining the boiler availability by implementing e.g. pre-drying dewatering processes without increasing the investment costs.

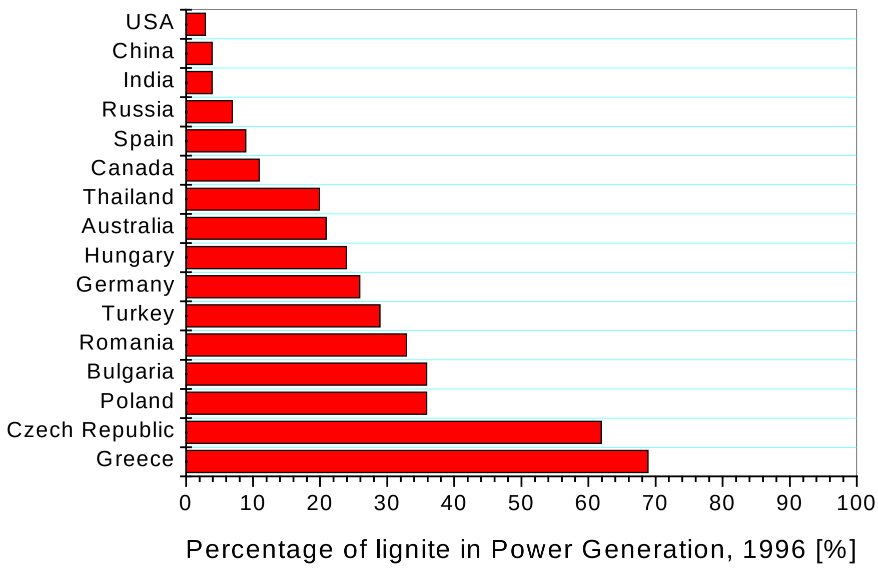


Fig. 2: Percentage of lignite in power generation

The fuels investigated in this project are characterised (see Table 1) by either high moisture contents and, thus carrying high loads of water into the combustion chamber or high contents of unburnable matter ("ash") adding inert material to the combustor as well. At some locations, e.g. Bulgaria and Greece, lignites are characterised by an ash content of up to 55 % and a sulphur level between 2-5.5 %. German, Greek, and Polish lignites contain up to 60 % moisture. The lower calorific heating values are between 4.3 MJ/kg (Megalopolis, Greece) and 19 MJ/kg (Northern Bohemia, Czech Republic).

The ash content as another fuel dependent property is subject to mining and preparation technology - not addressed in this project – conversion efficiency improvements by reducing the water content are most promising.

Table 1 :Overview of the low rank fuels investigated

Coal Sample [wt% raw]	Ptolemais (GR 1) Kardia Field	Ptolemais (GR-2) South Field	Maritza East (BG-1)	Maritza East (BG-2) BF	Pesteana (RO)	Rhenish (DE-1) BF Hambach	Rhenish (DE-2) BF Hambach	Turów (PL)	Jauhoneva (FI)
LHV raw [MJ/kg]	6.69	7.83	5.87	19.5	10.1	11.9	19.94	10.5	6.3
Moisture	48.2	45.5	43.14	13.06	34.4	44.86	9.18	48	61
Ash	16.46	17.02	28.4	15.7	22.09	2.66	4.42	4.4	2.2
C	22.6	24.5	17.2	46.7	29.1	35.64	58.2	30.53	21.71
H (-H2O)	1.56	1.93	1.85	5	2.3	2.77	3.8	3.09	2.15
N	0.68	0.7	0.2	0.52	0.78	0.41	0.66	0.39	0.94
S	0.82	0.62	2.0	4.86	1.33	0.16	0.44	0.25	0.16
O diff	9.65	9.7	7.3	14.1	9.9	13.46	23.3	13.34	11.8

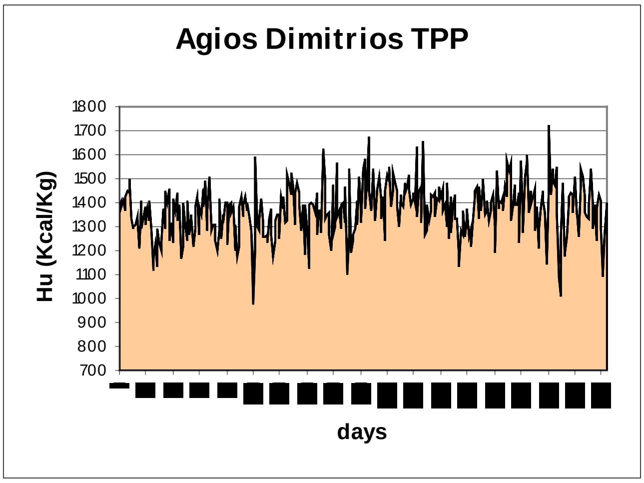
BF: Briquette Factory

Therefore by any pre-drying of such fuels the efficiencies of power plants available in many of the participating countries (see Table 2) can be increased and, thus, the plants competitiveness compared e.g. to black coal power plants can be improved.

Table 2. Brown coal firing units and plant sizes of different countries

	units	MWe, Total	Units < 100 MWe	units 100 - 299 MWe	units ≥ 300 MWe
Hungary	5	800	-	5	-
Poland	43	9058	6	25	12
Bulgaria	17	2690	4	13	-
Romania	51	6895	30	8	13
Czech	55	6864	23	31	1
Greece	18	4490	1	4	13
Germany	107	24288	17	58	32
Total	296	55085	81	144	71
Percentage			38 %	49 %	24 %

By co-combusting low rank coals with pre-dried low rank fuels or higher rank coals such as black coal variations in the heating values over time can be levelled to comply with the design specifications. One parameter to mirror the inhomogeneity of the fuel over time is the lower heating value (see figure 3).



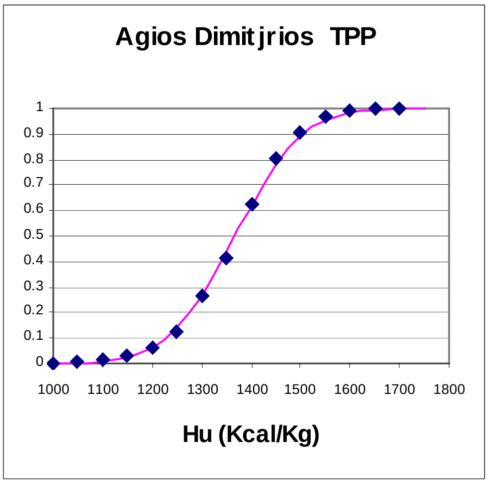


Figure. 3 : Variation in heating value over the course of a year (a),
heating value distribution (b) (PPC)

Based upon the above considerations the following tasks of the project were successfully conducted:

Task A: Provision of fuel characterisation data including propensities for preparation for both raw and pre-dried fuels in comparison

Task B: Optimisation proposals for different drying processes including modelling of available dryer configurations

Task C: Combustion tests concerning the ignition and burn-out characteristics, alleviation of operational problems such as deposit formation on heat transfer surfaces, and the emission of hazardous gaseous components

Task D: Technology implementation studies with special emphasis on overall process efficiency corresponding fuel saving as well as plant response of certain components

2 Objectives and Strategic Aspects

The overall motivation to undertake this research project was to contribute to the reduction of the greenhouse gases' emission – primarily carbon dioxide – from power plants firing solid fossil fuels, in particular, low rank, high moisture fuels such as peat, brown coal and lignite. In the industrial conversion of these fuels process improvements are expected to substantially alleviate any hazardous impact on the regional and global environment by increasing the efficiency of power generation and maintaining the boiler availability by implementing e.g. pre-drying dewatering processes without increasing the investment costs.

2.1 Project Organisation Structure

For the project 6 universities and 3 industrial partners worked jointly together. In the consortium three of the partners were from the Newly Associated States (NAS).

Universities

- Department of Mechanical Engineering,
  National Technical University of Athens (NTUA.DME.THE), (GR)
- Department of Mechanical Engineering,
  Imperial College of Science Technology and Medicine (ICST.DME), UK
- Institute of Power Engineering and Fluid Mechanics,
  Technical University of Wroclaw (TUW.IPF), (PL)
- Research Laboratory Coal Utilisation Technologies,
  Technical University of Sofia (TUS.CUT), (BG)
- Department of Thermodynamics,
  Politehnica University Timisoara (PUT.DT), (RO)
- Institute of Process Engineering and Power Plant Technology (IVD)
  Universität Stuttgart, (DE)

Industry

- RWE Power AG, (DE)
- Fortum Power Oy, (FI)
- Public Power Corporation, (GR)

The project was co-ordinated by the Institute of Process Engineering and Power Plant Technology (IVD). The structure of the project was divided into subgroups, concerned with fuel characterisation, drying tests of high-moisture fuels, combustion of high-moisture and pre-dried fuels, and with process integration and feasibility studies (figure 4).

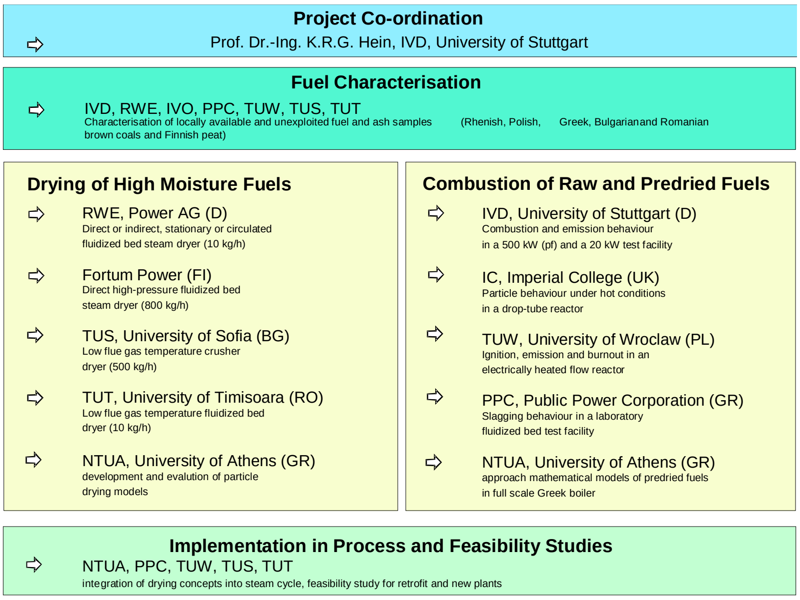


Fig. 4: Scheme of project structure and partners

For each task, investigations with different brown coals (German, Greek, Bulgarian, Polish, and Rumanian) and Finnish peat were conducted.

3 Scientific and Technical Description of the Project

The experimental and theoretical investigations focused on different drying techniques and advanced pulverised fuel combustion methods. Fuels of six different countries were extensively analysed and characterised by standard and advanced methods. Furthermore, process calculation of several concepts were conducted of newly designed and retrofitted plants to show that the integration of the pre-drying technology into low rank fuel conversion offers a high potential to increase plant efficiencies by such fuel treatment.

3.1 Work Program

The work program of the project was divided into four sub-tasks:

Task A:
The feedstock to be used in the experimental facilities will be characterised by conventional (proximate, ultimate, ash fusion) and advanced methods (ash forming components, crystal phases, morphology, element composition, specific inner surface) with regard to drying and combustion behaviour. This provide the basic information for all partners and experimental programme.

Task B:
This work package concerned the drying of high-moisture fuels. Different dryer systems will be investigated (fluidised bed dryer (RWE, Fortum Power, TUT), crusher dryer (TUS), ultra sound dryer (TUT)). The fuel throughput of the investigated test dryers vary between 10 kg/h (RWE) and 5 t/h (IVO). Different drying agents (steam, flue gas) and the concept of direct and indirect drying systems will be investigated.

Task C:
A further task will be investigations with regard to changing the combustion and emission behaviour of externally dried high-moisture fuels. Results of investigations with pre-dried fuels will be compared with conventional brown coal combustion tests. The effect of utilising pre-dried fuels as support fuels will be investigated by mathematical 3 D modelling of a full scale boiler (NTUA, PPC). Results of full scale depositions will be compared with the results from the test facilities (PPC, IVD, TUW). For the tests, facilities between 10kW (flow reactor) and 0.5 MW will be utilised. The tests at the IVD will be primarily concerned with in-flame measurements, burnout, emissions, slagging and fouling. Further different fly ash fractions will be characterised regarding utilisation in the cement and concrete industry. TUW will investigate particle, ignition and burnout behaviour depending on the particle size, and the investigations at Imperial College will focus on the particle behaviour under high temperature conditions. A shadow Doppler velocimeter (SDV) and a two-colour pyrometer will be used to locate the particle ignition depending on different heating rates.

Task D:
All investigated data will be utilised in task D to identify the best drying process and to determine the optimum integration configuration of the drying process into a power plant steam cycle. In addition feasibility studies of new (NTUA, TUT, PPC) and existing local plants (TUW, TUS) will be investigated and the market potential of this new technology will be determined.

3.2 Industrial State of the Art

Externally dried brown coal has been used as raw material for briquette production for several years. The drying apparatus generally consisted of indirect tube dryers with a maximum output of 25 t/h. Furthermore different already existing drying concepts have been developed for other industrial products such as animal fodder, foodstuff, wood-based biomass (sawdust, forest residue, bark), as well as public and industrial sludges.
Prior to the start of the project, Fortum Power had performed drying investigations with sawdust, industrial sludge and peat using a pressurised fluidised-bed direct steam dryer with a throughput of more than 5 t/h developed by Fortum Power. In addition NIRO A/S, a Danish subsidiary of the German GEA group, developed an indirect pressurised-fluidised-bed steam dryer which had originally been designed for drying pulp from sugar beets.
In recent years the Finnish company Fortum Power has developed the Bed Mixing Dryer system (BMD). This is a new type of fuel drying technique to be used in combination with fluidised bed combustion. The dryer operates in superheated steam atmosphere at atmospheric pressure. Hot bed material is extracted from the fluidised bed and used directly as heat source for the pre-drying of the fuel. According to new test results the Bed Mixing Dryer technology is a suitable technology to dry moist brown coals. The BMD concept offers the possibility to recover the energy used for the drying. The BMD is already commercialised for peat and bio fuels.
In Loy Yang (Australia), an indirect-steam fluidised-bed dryer with a capacity of 45 t/h (raw fuel) for high-moisture (65 % raw) brown coal was erected in 1995, the results of which have been published. A further pilot-demonstration indirect fluidised-bed dryer system (WTA) has been erected and investigated by Rheinbraun in Frechen (Germany). The throughput of this dryer is about 55 t/h (raw fuel).
A slightly different drying technique is the mechanical/thermal dewatering (MTE). A pilot scale MTE dryer will be installed at RWE in Niederaussem (Germany) with a throughput of about 20 t/h (raw fuel). The value of the remaining moisture content in brown coal when using the MTE system is about 20 %. RWE is currently erecting a WTA pilot dryer in Niederaussem with a capacity of 90 t/h (10 % moisture) of brown coal.

With respect to combustion results concerning pre-dried brown coal, no full scale pulverised brown-coal-fired boiler is currently operating with a thermal input of 100 % pre-dried brown coal. There are some boilers, at RWE (Germany), PPC (Greece), and in Loy Yang (Australia), where pre-dried brown coal is used as supportive fuel. A brown coal boiler of RWE in Niederaussem, is intend to operate with about 40 % of the thermal input covered by pre-dried brown coal.
In Cottbus, Germany, a pressurised fluidised-bed boiler fuelled by externally dried brown coal is installed (60 MW_{el}, 70 MW_{th}).

Lately Germanys’ industry increases the utilisation of pulverised pre-dried brown coal at industrial heating plants (shell boilers) or in cement production, but only few results have been published with regard to emission and operational problems.

4 Results

In the following investigations and major results of the different partners are described and discussed task by task.

4.1 Fuel characterisation (Task A)

The determination of the following fuel and drying effluents characteristics was performed during the duration of the project by all partners to a different extent.

For the drying effluents of the steam dryer pH, TC, TOC, fatty acids, fatty alcohols and resins were analysed.

Next to the proximate (DIN 51719-51720) and ultimate analysis by an elemental analyser the major ash components were determined by XRF thus giving an indication on the composition of the fuels. During the preparation of the fuels e.g. grinding and drying most physical characteristics are likely to change therefore physical particle characteristics were compared for both raw and pre-dried lignites for the lignites of all participating partners. To acquire a first look at particle and fuel properties particle size distributions were collected by sieving and laser diffraction. After this rough classification densities and porosities were gathered (University of Wroclaw, RWE Power AG). Here true (alcohol and gas pycnometer), apparent (Hg and calculated) and bulk densities were considered and the porosity was calculated on basis of true and apparent density total pore volume (incl. macro-, meso-, micropores). Micro- and mesopore volumes were determined by sorption of CO_2 and C_6H_6. Mean pore diameters (Hg intrusion porosimetry), total sample pore volume and the total specific pore volume were analysed and compared . Specific surface areas were analysed by BET adsorption and desorption of C_6H_6 and N_2 (University of Wroclaw, RWE Power AG). Of the samples evaluated by the techniques described above were further evaluated by means of SEM-EDX (University of Wroclaw) as well as XRD concentrating on both the elements and minerals by those advanced analysis techniques (PPC Greece, IVD).

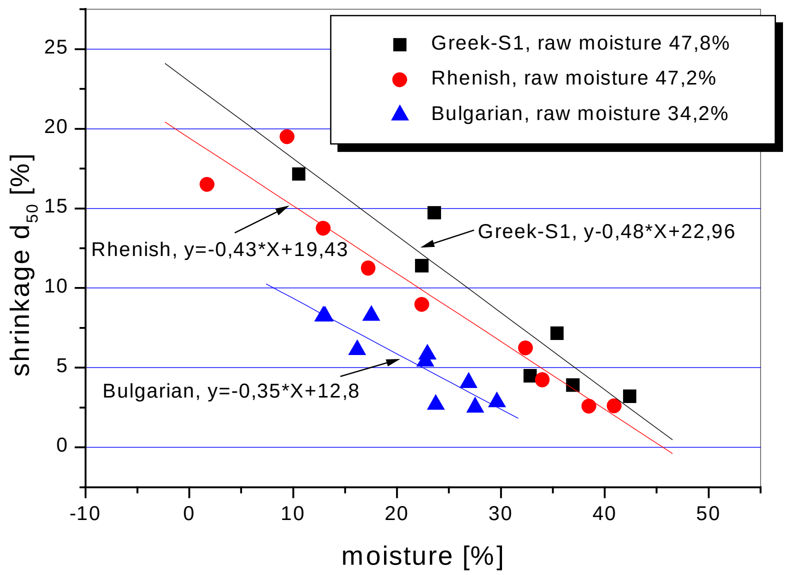


Figure. 4 Particle shrinkage depending on remaining moisture of 1-2 mm fraction

The fuel samples were analysed petrographically regarding mean reflection and maceral composition (IVD).
The remaining moisture content after passing the dryer depended on the drying parameters and on the drying systems. For this the shrinking behaviour was investigated depending on the remaining moisture content of 1-2 mm particle fractions. For this purpose, 26 samples were sieved, dried, and analysed.
The shrinkage as one result of the project and depicted in figure 4 was determined by drying utilising different drying techniques and sieving. The calculated mean shrinkage percentages of three different coals is shown in the graph. The percentage of particle shrinkage is an important parameter regarding the preparation expenditure after drying and a design parameter for the storage containment and the dimensions of the transport system.

Samples were further treated and studied regarding the grindability according to Hardgrove (IVD). This method could only used for coal samples with a remaining moisture content below 25 wt % because for higher moisture levels the particles blocked the sieves during the analyses. The grindability index increased significantly for Greek, Bulgarian and Rhenish brown coal by pre-drying below 20 wt% moisture. The grindability behaviour of Bulgarian coal is significantly improved by pre-drying.

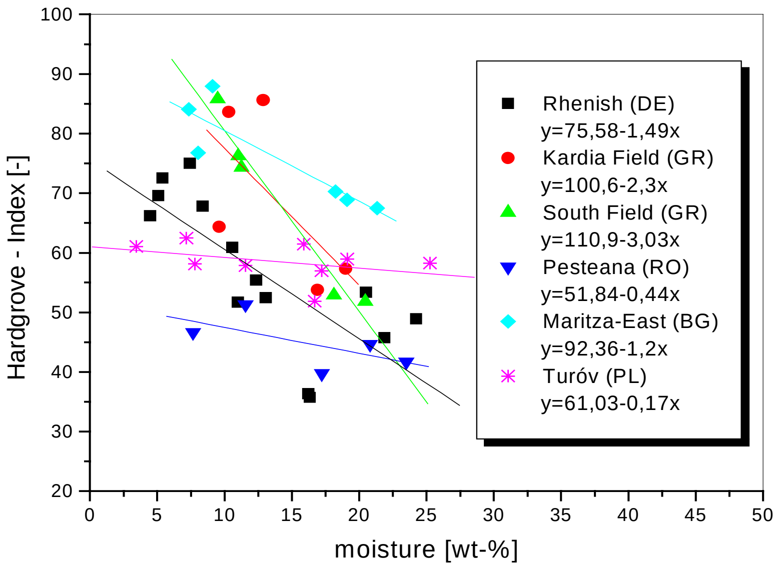


Figure. 5 Hardgrove grindability index depending on left moisture content of different brown coals

The fractionation of ash and sulphur was investigated for the fractions prepared by grinding and sieving (IVD, RWE Power AG). Of the combustion ashes generated by combustion experiments described below ash analyses were performed including the determination of the major ash elements as well as ash fusion temperatures (University of Wroclaw, IVD). Mineralogical analyses were performed for deposits from combustion of a co-combustion flame of dried and natural lignite (PPC Greece).
The resulting compilation of fuel data describes the lignites and the peat thoroughly.

4.2 Drying of lignites (Task B)

The drying of lignite in different dryers was performed by the partners of RWE Power AG, Fortum Power and Heat Oy and the Universities of Sofia as well as Timisoara. NTUA subdivision LSB modelled the drying of fuels by developing a sub-model and integrating the sub-model of single particle fuel heating during the drying process into an existing code to predict the drying behaviour of brown coal.

In the pre-drying project five lignites and one peat were dried. The work performed by the single partners involved with the experimental pre-drying of lignites and peat resulted in both the proven feasibility of all newly designed dryers at the University of Sofia and Timisoara and provided results on the existing dryer concepts regarding heat exchange coefficients for the drying of lignites in pressurised and atmospheric conditions in a fluidised bed dryer with internal heat recovery (RWE Power AG) and drying effluent analysis for a pressurised steam dryer with the related drying experiments (Fortum Power and Heat Oy). The pressurised steam dryer as well as the other dryers were optimised regarding their operating parameters, evaluating pressures, temperatures, air, flue gas and steam supply as well as rotating velocities of the crusher dryer (University of Sofia). As the low grade fuels differ in composition and age, drying techniques applicable for one type of feedstock are not necessarily useful for another. The lignites differed in ash and moisture content from low in ash and high in moisture to high in ash and moisture. Depending on the characteristic the fuels showed different drying behaviours.

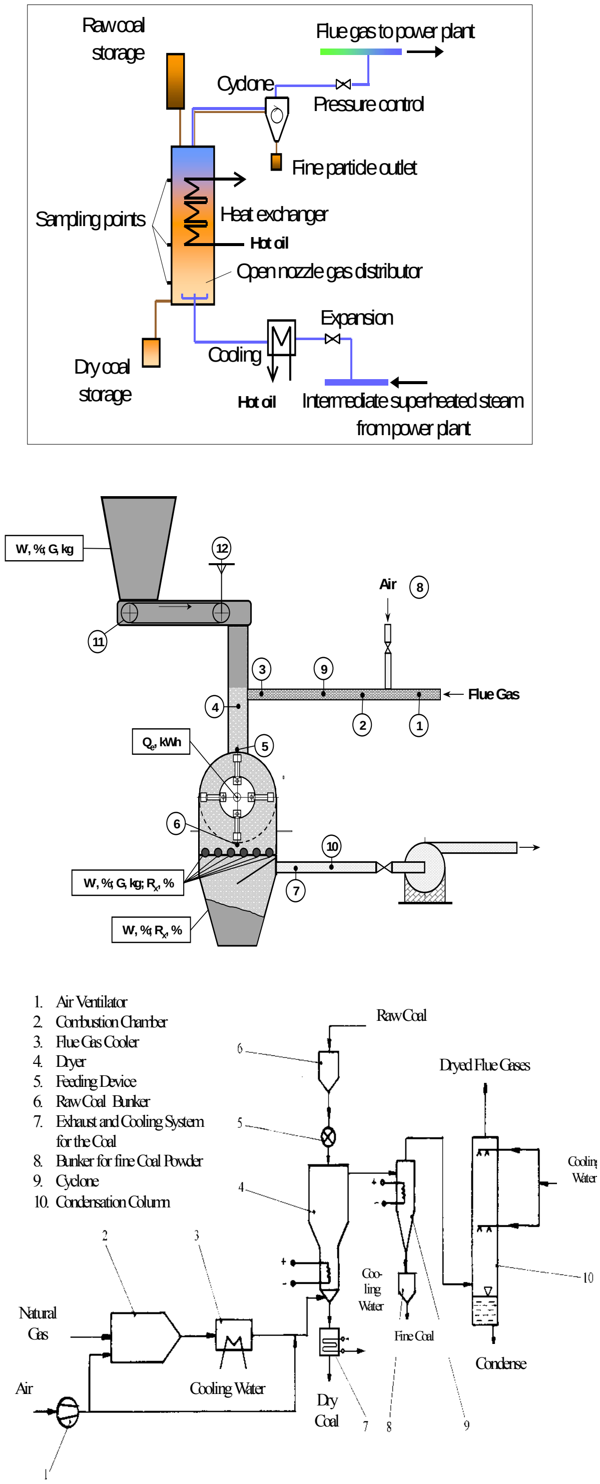


Figure. 5: Dryer of RWE Power AG (a), University of Sofia (b) and University of Timisoara (c)

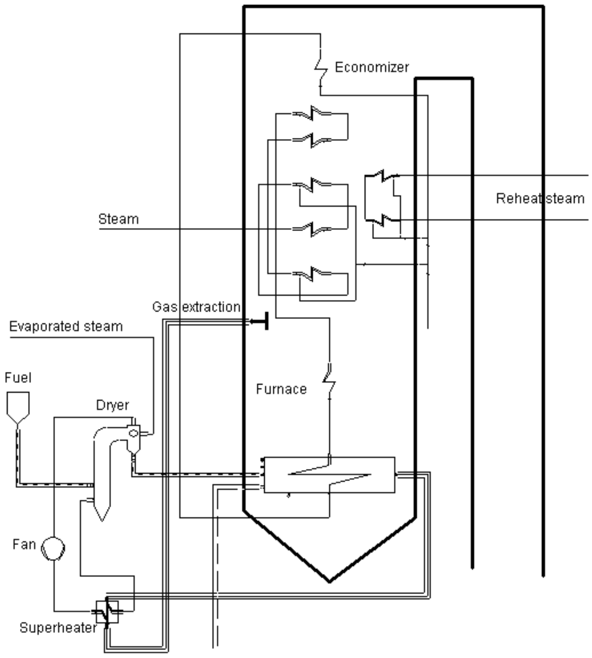


Figure. 6 : HP Flash Dryer (Fortum Power and Heat Oy)

It was found that the drying of peat was difficult in a fluidised bed dryer with internal heat recovery but the remaining fuels were dried to different moistures as described in the following. German lignite was dried from values as high as 54 % moisture to values around 25 % by a pressurised flash dryer, the same dryer dried peat from approx. 60 % moisture to approx. 15 % and Greek brown coal from 50 % to approx. 18 %. When drying in the flash dryer the mean diameter (d_{50}) decreased from approx. 5 to 1 mm (DE), 3 to 0.3 mm (GR) and 1.5 to 0.2 mm (FI). The size after drying was approx. 1/5 for the German sample and 1/10 for the remaining compared to prior drying.

When drying in a fluidised bed the moisture was decreased from approx. 50 % to values as low as 3 % for bed temperatures of 160 °C. At 120 °C (temperature of most tests) the final moisture ranged between 14 % (GR) and 5 % (PL) (RWE Power AG).

The dryer designed and set-up by the University of Sofia was tested and it turned out to be a crusher which dried the lignite to be reduced in particle size to moistures easily to be used in fluidised bed dryers. The crusher dryer decreased the moisture content of the feedstock from values of 50 % to (depending on the dryer load) approx. 40 % at lowest load and 49 % at highest load. For the crusher dryer the size reduction is the main parameter. The fuel is reduced in the d_{50} from approx. 5 to less than 1mm.

For the WTA dryer heat exchange coefficients were determined for all fuels giving an indication for future problems of drying of the fuels investigated.

With the knowledge of those coefficients new dryers are laid out more easily. For the pressurised flash dryer several drying effluent characteristics were determined resulting in an easier evaluation of possible risk related with the drying of the fuels investigated. Risks could include possible influences on the material of the dryer as well as effluents

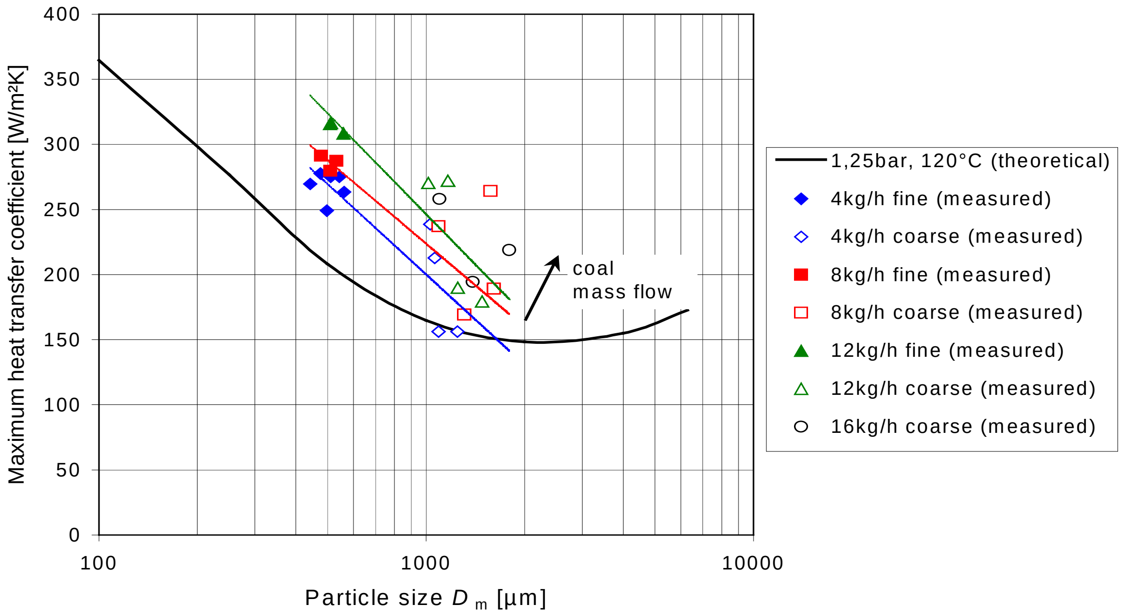


Figure. 7: Heat transfer coefficient over particle size and raw coal mass flow for Greek lignite (RWE Power AG)

chemical composition and related to a necessary conditioning of the effluent (pH value). Thirdly, as mentioned above, the influence of raw coal mass flow is investigated. One interesting result of the investigations is depicted in figure 7 standing for the vast amount of others found in the appendix. Although the Martin theory does not consider kinetic effects, the drying is assumed to be an effect of particle residence time in the fluidised bed. This was not proven conclusively due to secondary effects of raw coal mass flow on bed voidage, pressure drop, and particle size. These effects were not significant and repeatable at all, but did occur for some measurements. Deviations between the different measurements occur due to the different coals used in the Greek sub-programme as well. To prove that the effect is caused solely by particle residence time, it was decided to reconstruct the test dryer in the frame of the next sub-program using Polish brown coal. This was done and the results (see appendix) proved to be meaningful.

The required power input for the drying processes which differ for the techniques was taken into consideration in work package D. In work package D the implementation of drying techniques into existing power plants was investigated.

4.3 Combustion tests (Task C)

Primarily involved in the combustion of the pre-dried fuels by the other partners mentioned above were the partners of the Universities of Stuttgart (IVD) and Wroclaw as well as the Imperial College and the Public Power Co-operation of Greece. The combustion tests included several different aspects including the ignition behaviour of raw and pre-dried lignites determined at a flat flame burner and monitored by both SDV-TCP and TCCI (Imperial College) which was improved by the addition of a quartz chamber and the supplementary Peltier cooler which improved the results.

Ignition characteristics including intrinsic and real combustion kinetics were determined by the pulse technique recording critical ignition temperatures in a slightly larger combustion facility (lab scale: 20 kW; University of Wroclaw) which was improved during the course of the project by an enlargement and a new construction both lowering the influence of the wall atmosphere on the combustion and increasing residence times in the combustion chamber.

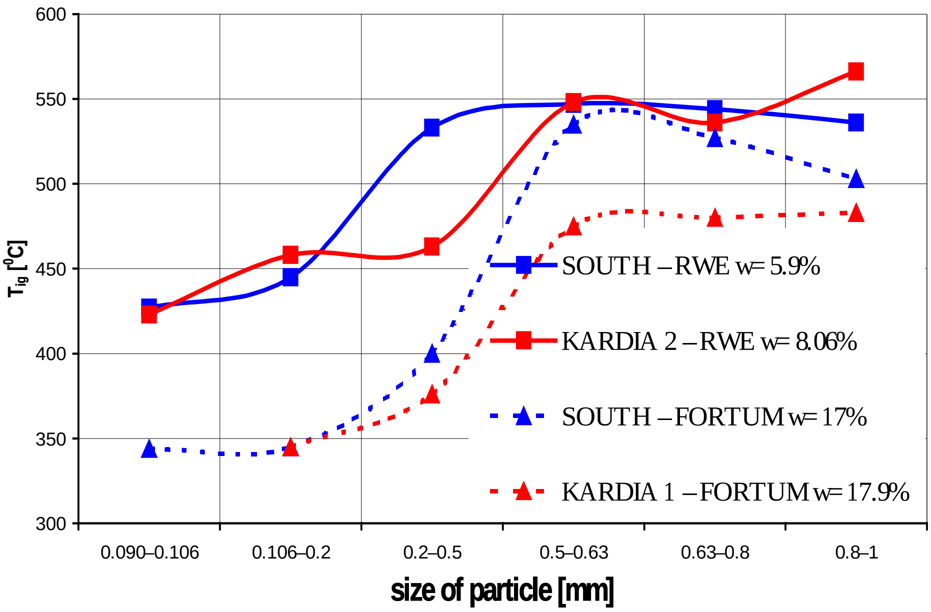


Figure. 8: T_{ig} dependent on size of Greek lignites dried by different methods (University of Wroclaw)

Resulting from the ignition tests similar ignition behaviours were monitored. In general pre-dried samples ignited earlier and at lower temperatures than the raw samples. As is seen from figure 8 the different drying techniques investigated for example for Greek lignites were of an observable influence. The lignite was dried by high pressure steam at Fortum Power and Heat Oy and by low parameters steam in fluidised bed at RWE Power AG. The ignition temperatures for lignites dried by FORTUM under 22bar pressure steam are lower than for these lignites dried by RWE. This effect is significant especially for the small particle below 0.5 mm. As observed from this investigation it was found for other lignites (see Appendix) that depending on the particle size of the investigated fraction the ignition temperature increased by approximately 60 to 100 K, increasing more for larger particles. It was further found that the increase in moisture resulted in an ignition delay for the German lignite with the residence time. The same was noted for the Greek lignite. The combustion behaviour showed similar trends.

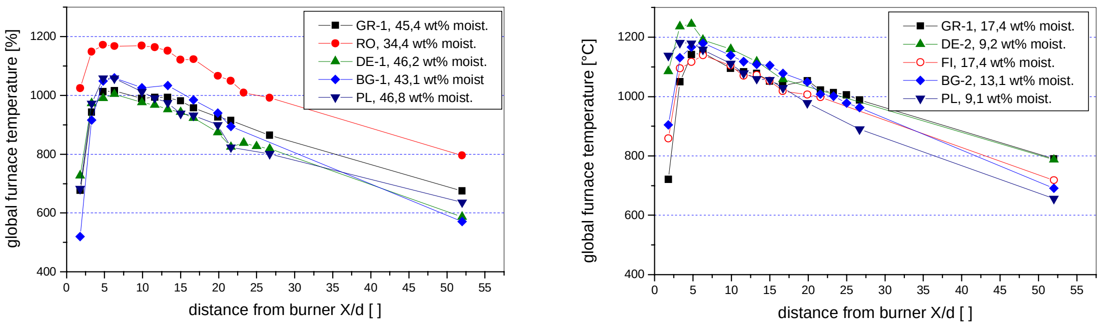


Fig. 9: Temperature profiles of raw and pre-dried combustion test along the furnace (IVD 500kW)

The ignition, combustion, emission and deposition behaviour was characterised by in-flame measurements of temperatures and flue gas concentrations along the combustion chamber (Fig.9). All investigations show a significant improvement of the ignition behaviour when using pre-dried fuels. This was on the one hand indicated by about 250 °C higher temperatures in front of the quarl and by an intensive and stable signal of the flame detector. Further the detected sequence of the ignition temperature between the pre-dried fuels is correlating with their lower heating values. The maximum of the global furnace temperature rises by approximately 130 °C and the flue gas temperature reaches levels of about 1300 °C. The results are relevant when considering the substitution of shares of raw lignite by pre-dried lignite.

In the course of the project combustion experiments were performed concentrating on the emission behaviour of SO_2 and NO_x of the raw and pre-dried fuels in a electrically heated reactor (TUW, IVD).

At a 500 kW pulverised fuel combustion rig (IVD) similar scale up combustion tests were performed for both raw and pre-dried fuels. Ashes of the combustion tests were analysed regarding their burnout and composition (C, H, N, S) to make comparison regarding emissions of SO_2 and NO_x possible. The combustion tests with regard to the SO_2 as well as the NO_x were performed by the University of Wroclaw and the University of Stuttgart concentrating on the parameters of residence time before secondary air addition, moisture content of the fuel sample fired and the particle size of the fuel.

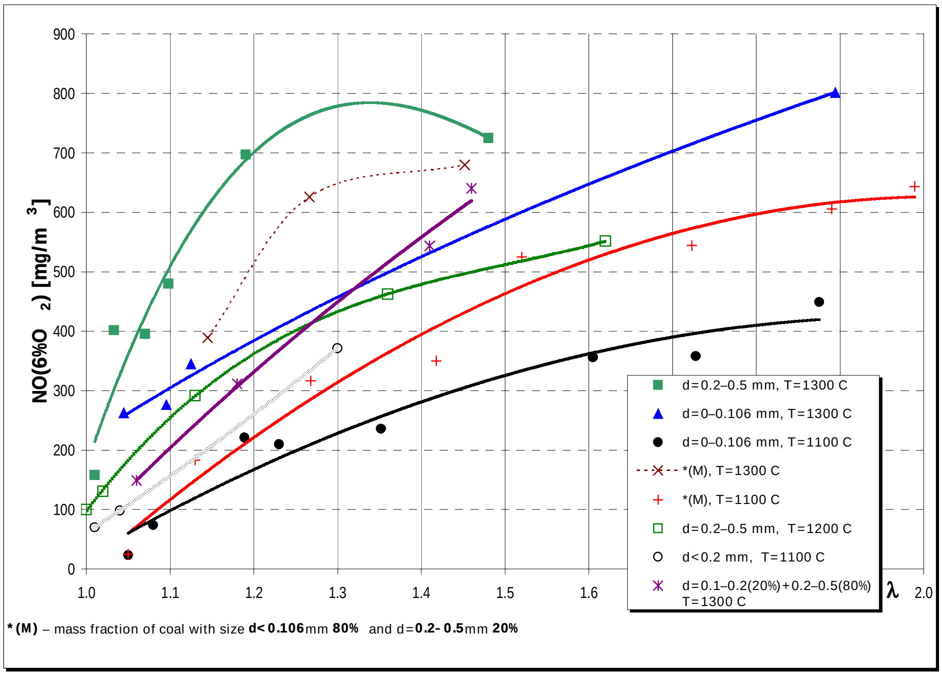


Figure. 10:Effect of particle size on NO emission for Rhenish lignite (University of Wroclaw)

As one of the several results gathered related to the emission behaviour of pre-dried lignites and the comparison between pre-dried and raw lignites the results of a Rhenish lignite are presented in figure 10. Further depicted in the figure is the relation between NO emission and particle size. Combustion test were performed at temperatures of 1373 K, 1473 K, 1573 K and for particle sizes d = 0–0,106, d<0,2 and d = 0,2–0,5 mm. To explain the effect of particle size on NO emission, investigations of coal–nitrogen release in the first stage of combustion i.e. pyrolysis were made for Rhenish and Greek coal.

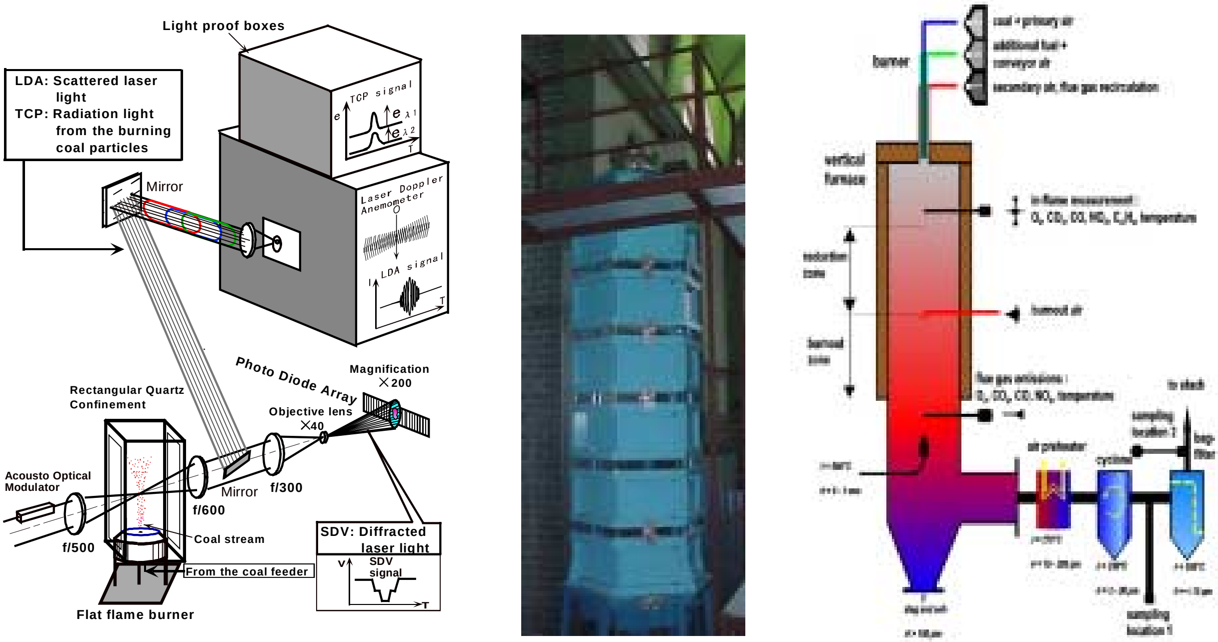


Figure. 11: Measurement facility of IC (a), University of Wroclaw (b) and IVD, Universität Stuttgart (c)

The particle size of the fuel had an influence as well. Increasing NO_x emission were found with larger particle sizes whereas SO_2 showed a contrary behaviour (U Wroclaw). Excess air ratios slightly larger than one minimised those effects.
The emission behaviour of NO_x and SO_2 was investigated by unstaged and air-staged conditions (IVD) of raw and pre-dried fuels. The highest NO_x emissions were detected for Peat and Pesteana brown coal and the lowest for the Maritza-East lignites.

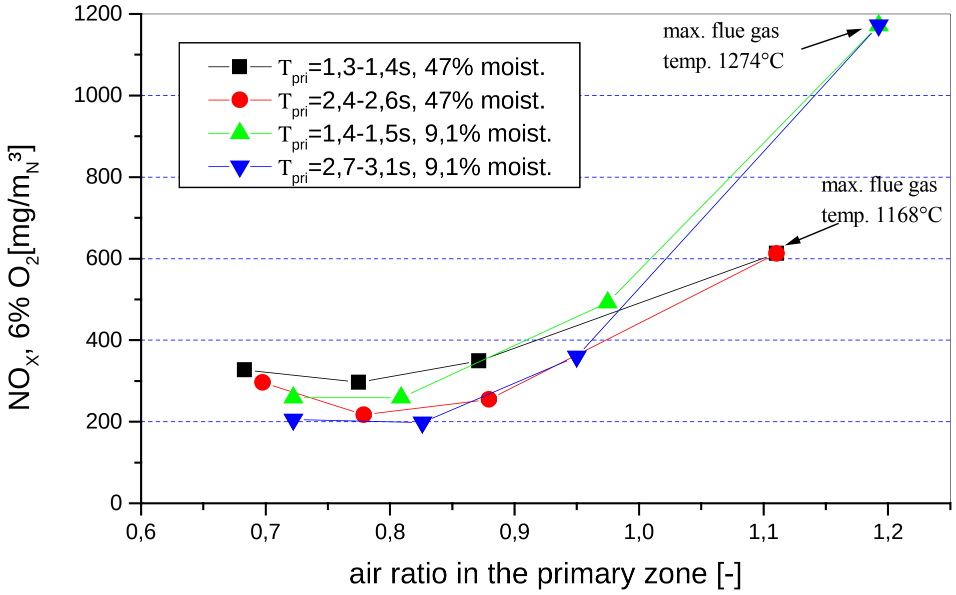


Fig. 12: Comparison of NO_x emissions of raw and pre-dried fuels (IVD)

Those results correlate with the amount of detected fuel nitrogen and with the combustion temperature in unstaged conditions. A general result of all test was that lower NO_x emission were achieved by using pre-dried fuels in air-staged conditions (Fig.12). This result correlates with higher combustion temperatures in the sub-stoichiometric zone by using pre-dried fuels. The investigated results of unstaged conditions correlated well with the literature that higher NO_x emission correlate with higher combustion temperatures by using pre-dried fuels. The burnout and loss on ignition was only slightly improved by using pre-dried fuels.

Depending on the high sulphur content and the low desulphurisation potential correlated with a low Calcium and Magnesium content of the Maritza East and Pesteana brown coals, SO_2 emissions between 6000 and 13,000 mg/Nm³ at 6 % O_2 were detected. The desulphurisation potential of Rhenish and Ptolemais brown coals is very high which results in SO_2 emissions below 400 mg/Nm³ at 6 % O_2 (IVD).

The burnout of particles was investigated with regard to the particle size of the fuel fired and with regard to the fuel moisture (IVD). Considering the burnout of the different fuels and fuel qualities it was found that the pre-drying and thus the lower moisture input to the plant was not the main influencing parameter it was rather found that the main influence was deduced from the particle size fired. Particle sizes larger than about 500 µm in the feed resulted in a lower burnout than smaller feed particle sizes.

Regarding operational problems such as slagging and fouling deposits along the height of the furnace were characterised and fly ashes of different cleaning devices (hopper, air-preheater, cyclone, bag-filter) were investigated.
The overall ash distribution of the recovered ash by the different devices varied significantly between the fuels. This indicates differences in the occurrence of ash in the organic matter of the coal.
The overall ash composition of the different fuels varied in a wide range. The fuels and their ashes were characterised by base / acid ratio and alkali-index. An overview about the ash composition of the fuels is shown in figure 13.

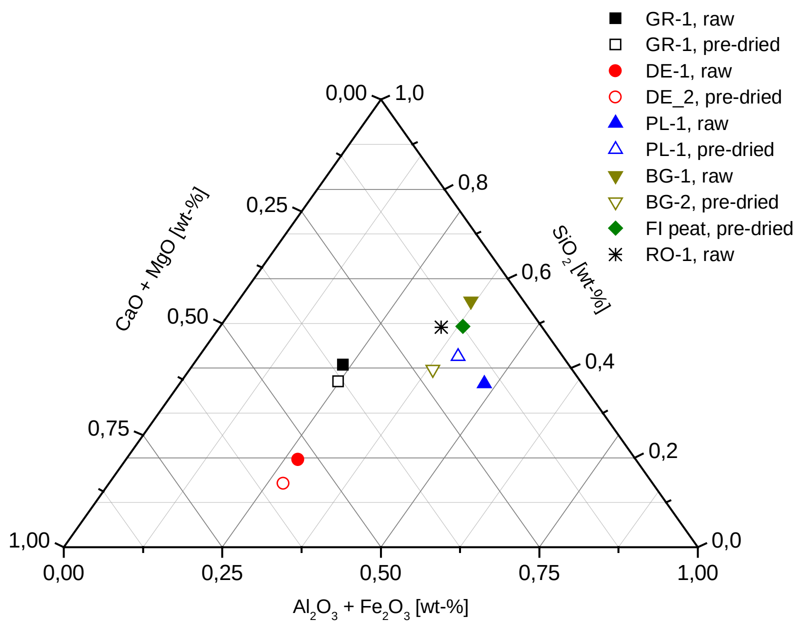


Fig. 13: Oxide composition of fly ash samples of the investigated fuels

All fuels show an enrichment of alkali in the small fly ash particle fraction collected by the bag-filter and an enrichment of acid components such as Silica in the larger particles collected by the ash hopper.
The deposit and fly ash composition of the Ptolemais brown coal correlated well with results of full scale experiments investigated and described by the project partner PPC (see Appendix). The critical temperature at which a significant increase of the fusion starts was about 1200 °C.
The fly ash particles of Polish brown coal and Finnish peat showed a high porosity correlated with cenos- and plerospheres.
The deposits and fly ashes of the Finnish peat were characterised by high amounts of Phosphor (2.5 and 4 wt-%).

4.4 Implementation of drying concepts (Task D)

The partners engaged in the evaluation of efficiency improvements for different power plants when integrating different pre-drying concepts for the preparation of lignites and peat are the Universities of Athens, Romania, Poland, and Bulgaria. Fortum Power and Heat Oy from Finland was involved as well and calculated the influence of the pressure for a flash dryer operated with steam of different pressures.

The drying techniques of WTA, Flash Drying, Drying by Flue gas recirculation were compared based on the possible improvement which is achieved by implementing those drying concepts in the power generation process of a Greek power plant and the power plants of the partners of Poland, Finland, Bulgaria and Romania. Included in the comparison is the MTE technique, a mechanical/thermal drying technique with slightly higher final moistures (approx. 20 %) than the other techniques (as low as 10 %). The MTE process was not investigated experimentally in the frame of this programme but is included in the investigation of the efficiency improvements regarding the implementation of the different drying techniques in existing and non-existing power plants to complete the investigation on available drying techniques. Therefore tube dryers were investigated as well although not explicitly content of the work programme drawn up at the start of the project.

For a test case of a Greek power plant (37.09 % efficiency) an improvement of 6.9 % was determined for WTA. Flue gas recirculation resulted in an increase ranging between 0.24 to 4.71 %. With the flash dryer efficiency increases of approx. 2 % were calculated.

Dryers integrated as in figure 6 and 14 show a typical result of a calculated dryer. Here the same dryer as in figure 6 presented.

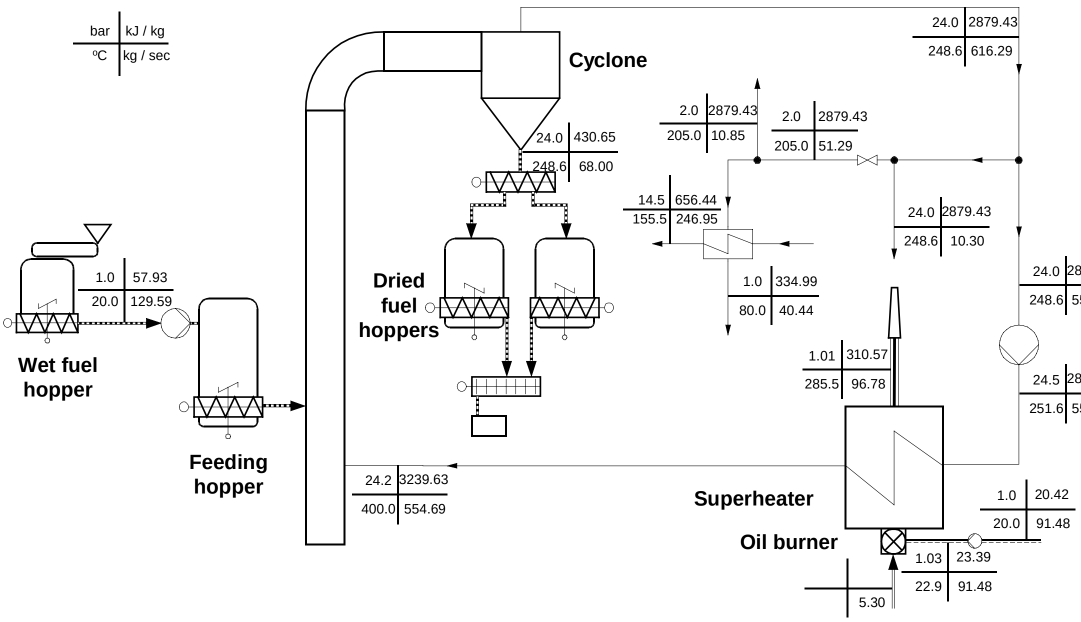


Figure. 14: Example of a HP Flash dryer calculated by the University of Athens

Next to the comparison of the different drying techniques and the calculation of the implementation in the Greek power plant, possible implementations were calculated for the sites of Poland, Romania and Bulgaria.

Table 3: Efficiency increases and produced power outputs (NTUA)

Test Case (Drying Method)	Raw Fuel Consumption (kg/s)	Drying Medium Characteristics	Drying Medium Consumption (kg/s) (% total)	P_{gross} (MW)	P_{net} (MW)	η (%)	Δη (%)-Points
Flue Gas Recirculation	162.30	Flue Gas, 921.8°C Preh. Air, 270°C	190.0 (24.16 %) 100.0 (21.81 %)	362.8	335.9	37.09	**-**
Tubular Dryer	130.15	Bled Steam, 2.23 bar / 203.1°C	74.87	327.3	303.5	41.80	**4.71**
Tubular Dryer	132.10	Bled Steam, 5.18 bar / 294.5°C	73.62	321.7	297.9	40.42	**3.33**
Tubular Dryer	131.56	Bled Steam, 20 bar / 470.1°C	72.39	296.7	274.0	37.33	**0.24**
WTA	130.10	Fuel Moist. 3.20 bar / 140°C	68.08	362.8	319.3	43.99	**6.90**
WTA	134.95	Fuel Moist. 5.00 bar / 162.8°C	74.24	367.2	314.0	41.70	**4.61**
NIRO	129.80	Bled Steam, 20 bar / 470.1°C	63.52	305.3	280.5	38.72	**1.63**
NIRO	129.80	Bled Steam, 20 bar / 470.1°C	63.52	309.8	284.8	39.32	**2.23**
High P Flash	129.59 (coal) 5.30 (oil)	Steam , 24.2 bar / 400°C	554.69	391.3	364.6	38.47	**1.38**
High P Flash	129.90 (coal) 5.31 (oil)	Steam, 24.2 bar / 400°C	555.98	397.8	370.9	39.05	**1.96**
MTE	132.50	Bled Steam, 10.5 bar / 382.1°C	10.53	354.0	328.9	44.48	**7.39**

At all sites the best alternative when retro-fitting the specific power plant was determined not necessarily the same for all sites depending primarily on both the economic and the fuel situation but also on the fuel characteristics. For all sites an improvement was found to the status quo.

5 Comparison between planned activities and work accomplished

The involved partners succeeded in the tasks they were assigned to with some minor exceptions when either the task has proven difficult or improvements to the anticipated programme e.g. to test facilities was approved by the Commission. These adaptations usually enhance the whole project with further knowledge gathered. In the following these adjustments are specified compared to the proposed and contracted programme.
Compared to the planned fuel characterisation tests project partners like TUW, Fortum Power, IVD, RWE Power enlarged significantly this task by further analysis like reactivity, hardgrove-index, coalification, density, pore distribution, ph, organically soluble components etc..
Overall Fortum Power, NTUA, TUW, TUT, RWE Power and IVD performed their programmes only with minor deviations.
PPC did not perform test runs with laboratory fluidised bed reactor. In adjustment with the project partners and the commission results of several boiler depositions analyses of different locations from a full scale boiler combusting pre-dried brown coal as a supplementary fuel to even out the changing lower heating value of the low rank fuel fired as main fuel.
Imperial College did not utilise the anticipated facilities for the tests planned but used a flat flame burner. The tests performed at this facility were the same as anticipated with necessary adjustments made to compensate for the different facility. The selected facility had the advantage of an improved heating behaviour in the initial stages of heating up the fuel.
The University of Sofia performed their tests as anticipated but had to relocate the test facility due to the unavailability of the rig at the power station.

Overall the project work were performed very successfully. For that the comprehensive work program was worked out close to the time schedule which implemented a fruitful co-operation and manifold exchange among the partners.

6 Conclusions

Overall, the work carried out increased significantly the understanding of a number of important issues. Emphasis was laid on drying and utilisation of low rank fuels by the integration of a pre-drying technique into a power plant process.

- The work indicated that pre-dried fuel combustion and co-combustion can have positive impacts on feasibility, environmental and economic issues.

- The investigated low rank fuel cover a wide range of fuel related properties. This fact implies that an individually engineered pre-drying and combustion technology has to be implemented to gain the maximum environmental and economical benefit of the technology.

- The techno-economic studies examined various pre-drying processes and the implementation of different pre-drying configurations into retro-fitted and new plants. For all sites an increase in efficiency was determined. Most significant efficiency improvements (2-7 %) were detected when implementing the atmospheric and pressurised WTA, HP-Flash, and MTE technologies.

- Issues related to the fuel, design, operability, suitability and residues of different dryers were intensively investigated by several partners. Requirements and operating criteria were defined and recommendation made in aid of selection of the most appropriate configuration.

- Data generated regarding fuel preparation aspects shows a positive impact of pre-drying on the grinding behaviour. The overall preparation benefit related to the fuel properties as well as the pre-drying and combustion technology.

- A range of issues related to the combustion of pre-dried low rank fuels were explored by experimental tests and combustion models. The data generated improved the understanding of pre-dried low rank fuel combustion significantly. Issues considered were:
    - ignition, burnout and emission behaviour
    - operational problems (slagging and fouling)
    - fly ash properties

7 Recommendation

During the course of the project a number of partners have identified various follow-on activities through further R&D initiatives and for demonstration projects.

Besides the atmospheric drying technologies pressurised systems offer a high potential to increase the efficiency and thus substantially reduce the environmental impact of such a fuel treatment.

The thermal dewatering technology can have a significant potential to reduce fuel related operational problems by removing soluble impurities of the fuel with the water. The optimum process and fuel related parameters of this technology have to be further investigated.

The work carried out in this project increased significantly the understanding of a number of important issues. To further promote this technology operational problems like slagging, fouling and corrosion have to be thoroughly investigated and understood to derive a manageable and economic solution.

Overall the developed and available pre-drying technology has a high potential to increase the plant efficiency and thus substantially reduce the CO_2 emission. To increase the attractiveness of this technology further more economic systems have to be developed to keep this main fuel resource competitive on the world energy market.

Different highly efficient solid fossil fuel related energy conversion systems are now available to utilise pre-dried low rank fuels. The maximum advantage of this combined cycle energy conversion systems can only be achieved by implementing an individual pre-drying system related to the conversion process and fuel properties.

The pre-drying technology offers a new market to utilise the improved low rank fuels. A successful establishment of this fuel on the energy market needs the development of efficient and economical conversion systems.

8 Acknowledgements

The R&D programme reported here was supported in part by the European Commission, Directorate General XII, under the Joule III and INCO Programme. The European Commission project manager was Dr. P. Dechamps.

Furthermore the authors would like to thank all partners for their exemplary co-operation in successfully executing this project.

9 ANNEX

List of conference presentations

List of prototypes

Table of project outputs

List of conference presentations

Buschsieweke, F., König, J., (1999), "Experimental Investigations on Drying Behaviour of Bulgarian Brown Coal in a Steam Fluidised Bed", Annual Bulgarian Energy Forum, 15-18th June 1999, Varna, BLG

Buschsieweke, F., König, J., (1999), "Untersuchungen zur Braunkohletrocknung in einer druckaufgeladenen Dampfwirbelschicht", VDI-Tagung „Entwicklungslinien in der Energie- und Kraftwerkstechnik“, 22nd-23rd September 1999, Essen, D

Buschsieweke, F., Hannes, J., (1999), "Investigations on Brown Coal Drying in a Pressurized Steam Fluidised Bed", 16th Annual International Pittsburgh Coal Conference, 11-15th Oct. 1999, Pittsburgh, PA, USA

Buschsieweke, F., Hannes, J., (1999), "Investigations on Brown Coal Drying in a Pressurized Steam Fluidised Bed", Workshop “Power generation units with high efficiency”, 18th-19th Nov. 1999, Wroclaw, PL

Kavouridis, C. and Pavloudakis, F.(1999), “Supportive Fuels and Homogenisation Methods to Improve Lignite Quality Produced from the Ptolemais - Amyndeon Multi-Seam Deposits for Power Generation Purposes” Proceedings of EC Thermie Workshop on Financing Clean Coal Technologies”, Thessaloniki Greece - April 1999.

Kruczek H. et. al. (1999) “Modified 200MW power plant cycle utilizing predrying brown coal combustion”, Workshop Proceedings Power Generation Units with High Efficiency, Wrocław Poland, 13.1–13.10

Kruczek H., Grochowski A. (2000) “Low–ran coal effect, its predrying and Ca, Na additives on NO_x and SO_2 emission”, 28th Inter. Symp. on Combustion, Edinburgh, Scotland (WIP), Report PRE 32/2000, TUW Poland

Maier, J. and Splietthoff, H. (1999), “Particle and Emission Behaviour of Raw and Predried Lignite in a 20 kW and in a 500 kW Test Facility”, 23 rd Int. Conference on Coal Utilization & Fuel Systems. Clearwater USA, 9-13rd March

Splietthoff, H.; Maier, J.; Hocquel, M.; Kluger, F.; Hein, K.R.G.; König, J.; Derichs, W.; Meschgbiz, A. (1999), “Effect of Pre-Drying on Combustion Behaviour and Boiler Design” Workshop Proceedings “Pre-Drying Processes For The Efficient And Clean Utilisation Of Brown Coals In The Enlarged EU Market”, Athens (Greece), April 23rd 81-107.

Tchorbadjisky, I., Todoriev, Hr., Pavlov, I. (2000). “ Niedertemperatur-Grobmahltrocknung von feuchter Kohle”, VGB Konferenz “Forschung für die Kraftwerkstechnik 2000”, TB234A, Posterbeiträge, Schwerpunkt: Feuerungen, Beitrag A7.

Tchorbadjisky, I., Todoriev, Hr., Pavlov, I. (2000a). “Niedertemperatur-Mahltrocknung von feuchter Kohle für Staub- und Wirbelschichtfeuerungen”, XXXII. Kraftwerkstechnisches Kolloquium “Nutzung Schwieriger Brennstoffe in Kraftwerken”, Beitragsmanuskripte (Vorträge V17 bis V38), V27, 99-106.

Tchorbadjisky, I., Todoriev, Hr., Pavlov, I. (1999). “Experience and Trends in Bulgaria in Using Dried Lignite for Power Generation”, Workshop Proceedings “Pre-Drying Processes For The Efficient And Clean Utilisation Of Brown Coals In The Enlarged EU Market”, Athens (Greece), April 23rd 29-36.

Ionel, I., (1999a). “Carbon dioxide reduction by means of suitable pre drying of moisture fuels”**.** Mediterranean Combustion Symposium, Antalya, 498-507.

Ionel, I., (1999b). “Facility for pre-drying of moist fuels and recovery of the vapours enthalpy”, ECOS’99, Tokyo, 415-421.

Ionel, I., (1999c). “ Environmental Strategy in Romania”. Workshop Power Generation Units with high efficiency, Wroklaw, 8.1-8.20.

Ionel, I., (1999e). “Energy saving by pre-drying moist fuels and recovery of the exhausted vapours enthalpy”. Energy Forum, Varna, Vol. II, 105-109.

Ionel, I., (1999f). “Fluidised bed facility for testing the pre-drying of Romanian Lignite”. National Forum for Research: Thermodynamics and Thermal Engines, Romanian Academy, Vol. 2, 95-105.

Ionel, I., (1999g). “Optimisation by means of the FLUENT Code of a pre-drying fluidised system for Romanian Lignite”. EU THERMIE Workshop, Athens, 265-295.

Ionel, I., Ungureanu, C., Oprisa-Stanescu, P. D., Danciu, D. (2000). “Modelarea unui uscator în strat fluidizat”. National Conference on Thermodynamics, Sibiu, Vol. I, 175-180.

Ionel, I., (2000). Dispersarea noxelor. Timisoara:Editura Politehnica.

Patents

No patents

PhD thesis

No PhD thesis published yet

Prototype

Hammer Crusher-Dryer by TUS

Table of project outputs

Project output for the duration of the project (01.01.1998 to 31.12.2001)

1

	Reports issued	Conference Publications	Publications	Doctoral Thesis / Masters Thesis
Type				
Number	0	20	0	0

2

	Demonstrations	Prototypes	Patents
Type		Crusher Dryer	
Number	0	1	0