Fuel Blends and Alkali Diagnostics

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SUMMARY REPORT

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Sächs. Textilforschungsinstitut e.V	Thyssen Schachtbau Kohletechnik	University of Tampere
IST University of Lisbon	Fechner	University of Göteborg
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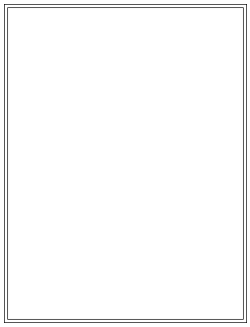
Executive Summary



Thermal utilisation of residues and industrial wastes in combination with fossil fuels and/or biomass will become a very important factor in future energy production in Europe from the viewpoint of environmental aspects, the careful use of resources on fossil fuels as well as developing/increasing new market segments for decentralised energy production. But also in existing markets and technologies like iron and steel or cement production the utilisation of residues or wastes might play a more important role in future. The main goal of the project "Advanced Combustion and Gasification of Fuel Blends and Diagnostics of Alkali and Heavy Metal Release" was the investigation and development of data and technologies for commercial use of wastes in industrial applications.

The basis for our investigation on industrial wastes was the availability of various products suitable for combustion and /or gasification. In the project we have focussed the work mainly on wastes from textile industries as well as waste plastics from different sources.

The necessary facilities for processing the wastes (i.e. sorting, separating, grinding, blending, etc.) were available at the partners. Extensive test series were performed in order to find an optimised preparation process either for single wastes or groups of wastes under consideration of economic and feasibility aspects.

Investigation on fuel blend combustion contained the supply of high quality fuel blends from the partners involved in the preparation and production of these blends. Most necessary combustion facilities were already available at the companies/institutes. Extensive test series in the various facilities ranging from 0.05 MWe up to 39 MWe were performed in order the characterise the combustion processes with special attention to the items given above.

To study the gasification of the prepared fuel blends from industrial wastes and coal a pressurised circulating fluidised bed and an atmospheric entrained flow gasifier were available. For combustion tests of product gases the facilities were equipped with on-line analysers for the flue gas components NH_3, hydrocarbons, NO_x, N_2O, SO_2, CO, CO_2 and O_2. Further analyses were carried out by a FTIR-analyser.

The first aim of the project part "Utilisation of Residues" was development of basic knowledge for characterisation and assessment of these novel residues. On this basis, environmentally compatible valorisation concepts for the various residues were developed for making-up marketable products to be recycled to the economy. Residue samples (fly ashes, bottom ashes, filter material, etc.) were supplied by the partners performing the combustion/gasification tests of the fuel blends in their facilities and were subsequently investigated according to the work programme. After analysis and characterisation of the samples valorisation concepts have been developed or modified in comparison to known concepts. For developing the above mentioned aims and for categorisation of the residues in view of different valorisation lines exact analyses of the matters fed to the process via secondary fuels in the coal have been carried out. Due to the different properties and environmental impact of the residues, specific preparation and valorisation concepts were developed for each case. Above all the fly ashes and filter cakes which may be contaminated by organic noxious matters, in particular dioxins, furanes and halogenated hydrocarbons, as well as by inorganic noxious matters, such as salts, desulfurisation products, or heavy metals have been investigated and the ashes have been classified for potential market

segments, mainly in construction industries.

The conventional method of measuring alkali levels in hot gas consists of extracting a gas sample by means of a condensing probe followed by a number of impingers for the absorption of condensed aerosols. The probe is rinsed after taking the sample and the aqueous liquids are then analysed by flame photometry on alkalis. Sampling takes long time because of the rather low sensitivity of the analysing method and is prone to very many errors of unknown magnitude. There was no continuous monitoring of the alkali levels possible at the beginning of the project and plants had to be run at steady state conditions during the sampling period lasting several hours.

A market study has been performed concerning the availability of gas analysing sensors, especially alkali sensors, and the future marketing possibilities promised after successful development of sensors. The study has shown on the one hand the world-wide novelty and uniqueness of the alkali sensor development to be undertaken in this project and on the other hand has clarified future marketing chances. In a joint effort instrument developers, plant manufacturers and operators have used the world-wide business contacts and screen literature to meet the above mentioned objectives.

It was possible to develop three different on-line alkali measuring devices which have been demonstrated under comparable conditions in a 10 MW plant and the instruments might be ready for commercial use in industry.

The topics investigated in the project as well as the main results can be summarised as follows:

1. Combustion of fuel blends in different types of combustors

The wastes which have been investigated arose from different processing and production processes and varied in chemical composition and physical properties. Depending on their origin or their pre-treatment the wastes were contaminated by heavy metals and organic compounds arising from colours and special coatings, e.g. for flammability reduction and they occurred in form of dust or pieces. One way for efficient energy recovery from those wastes was the co-combustion with coal, which is preferred compared with pure waste incineration, since this was not optimised for energy production and caused some problems with low melting points of the plastic wastes. However, based on the results of our R&D programme it should be considered in later projects.

The specific tasks of the work plan carried out were as follows:

- Development of the handling and the feeding systems required for the combustion of fuel blends
- Testing of various fuel blends to determine factors such as operability and conversion efficiency. This included the analysis of fly ash and other residues.
- Investigation on the influence of particle size.
- Investigation of operating parameters affecting the release of gaseous pollutants, including sulphur, nitrogen and chlorine compounds during the combustion of pure wastes as well as for the co-combustion with coal. In order to develop methods for abatement and control of these pollutants parameters who have been varied are coal, ratio of coal/waste in the blend, fuel/air ratio and air staging. Additionally, the effect of different bed materials were studied in the circulating fluidised bed combustor.
- Investigation of operating parameters (temperature, heat removal from reactor) affecting the release

of gaseous pollutants; measurements included hydrocarbons, NO_x, SO_2, CO, CO_2, N_2O, and O_2 during the co-combustion of fuel blends.

- Evaluation of the results with respect to the impact of co-combustion of plastic waste on the operation of a coal or biomass fired boiler.
- Investigation of operating parameters in a Circulating Fluidised Bed facility (flue gas composition, bed sintering) affecting the release of gaseous pollutants; measurements included hydrocarbons, NO, N_2O, SO_2, CO, CO_2 and O_2 during the combustion of pure coal as well as for the combustion with fuel blends.
- Optimisation of CFB control in order to reduce gaseous emissions and to increase the share of waste-derived fuels in the blends.
- Performance of semi-industrial scale experiments simulating blast furnace conditions, investigation on the influence of fuel type, particle size, blast temperature, fuel blend flow rate and fuel blend injection modes
- Fuel blends in commercial blast furnace operation
- CO_2 reduction potential for utilisation of waste plastics in blast furnaces and in non-iron industries.
- Collection of residue samples for the development of valorisation concepts.
- Potential application from combustion and gasification residues.

2. Gasification of fuel blends in a fluidised bed gasifier

Additionally to the items mentioned in the chapter ”Combustion” the following topics were addressed and had been investigated:

- Primary and secondary High Temperature High Pressure (HTHP) gas clean-up (particulate separation ñ filter performance, tar decomposition ñ cracking efficiency)
- Catalytic treatment and reforming of the dust free fuel gas; investigation on adsorption of alkali and halogen, tar and ammonia cracking reduction of S-content in the product gas

Development of valorisation concepts for residues from combustion and gasification of fuel blends

The main results of the programme contain:

- Conventional valorisation techniques or similar material groups, such as those known in waste incineration
- Physical, chemical and mineralogical characterisation of various residues produced by combustion and gasification
- Environmental compatibility of the matters according to legal regulations e.g. by elution tests
- Possibilities of immobilisation of noxious matters by various methods, e.g. by formation of stabilised products by means of binders or by thermal treatment
- Technological measures for material separation including the possibilities of recovering individual components (crushing, pneumatic separation, magnetic separation, conditioning, leaching, scrubbing, separation of unwanted matters, raw-material recovery)

- Manufacture and testing of construction materials, aggregates, binders; testing for suitability of utilisation, e.g. in road construction, earth works, and landscaping
- Manufacture and testing of mortars for underground use, e.g. material for storage of caved-in goafs

3. Gas analysing sensors, especially alkali sensors

Three techniques for the on-line measurement of alkali species have been developed based on physical detection of alkali atoms.

Simultaneously all three analysers in several individual experimental campaigns of the hot gas duct of two pressurised fluidised bed combustion pilot plants of different design have been demonstrated and optimised. The project aim was getting an overview on alkali concentration levels in hot gas from coal combustion for a variety of fuels and plant operating conditions.

The alkali concentration levels have been correlated to the parameters set or found in the experimental programmes and an attempt has been made to find relations between hot gas conditions and alkali levels and to draw conclusions with respect to generalisation of the results obtained. It has been shown that the risk alkali vapours present to the technology of pressurised fluidised combustion of solid fuels can be assessed on a fairly well defined basis of data at the end of this project. Furthermore, it has been demonstrated that the accuracy and reliability of the three different alkali analysers could be significantly improved and their capability to be used in commercial applications might be possible in future.

4. Techno-economic study on industrial utilisation of fuel blends produced from industrial wastes and coal

Accompanying the R&D programme technical, environmental and economic assessment studies of the options available for co-processing of coal with industrial wastes from a variety of sources including textile waste, plastic waste, automobile shredder waste etc. have been carried out.

These studies are based on information supplied by the other partners in the group who were involved in waste collection, upgrading, feed preparation and residue disposal, and on data generated by test work on either co-gasification or co-combustion of these blends in different conversion systems. These data have been scaled up to provide information for the size of plant under consideration bearing in mind the technology and feedstock limitations. The type of information provided by these studies included the feedstock and other raw materials usage, the yields and conversion efficiencies, solid, liquid and gaseous emissions, utilities requirements, capital and operating costs and other financial indicators.

In order to gather the necessary data the project partners have been questioned concerning the processes applied. The data obtained were processed with the software package ECLIPSE which was developed for economic, technical and environmental assessment of energy conversion and allied process plant. This software provides a powerful tool for comparing competing technologies and for making decisions as to optimal technology choices.

The specific work dealt with:

- collection of data on the different wastes which were available including the cost and energy required to convert them into a feedstock suitable for co-processing with coal using the alternative technologies under consideration.
- validation of the results from pilot plant test work and scale-up of results so that they were consistent with the size of plant under consideration.

- using the ECLIPSE process simulation programme performing technical, environmental and economic analyses for the range of proposed feedstocks and the alternative co-processing technologies at a size to suit the technologies and the available waste feedstocks.
- providing of a detailed technical, environmental and economic comparison of the alternative co-processing technologies for each of the waste feedstocks, including sensitivity analyses to determine the conditions required to make these alternatives competitive with existing disposal routes.
- Environmental aspects in thermal utilisation of fuel blends

Objectives of the project

The R&D programme has been set up in three main clusters featuring textile waste co-processing, plastic waste co-processing, and alkali and heavy metal diagnostics.

Ten main items have been investigated covering the following topics and working packages:

- Determination and characterisation of the supplied production wastes with regard to physical and chemical characteristics
- Investigations on special preparation methods for an ecologically and economically effective waste preparation (for instance sorting, separation, shredding, grinding)
- Upgrading and blending with coal or biomass and variation of coal/waste biomass/waste ratios
- Supply of representative fuel blends from wastes and coal to the partners performing the combustion/gasification tests
- Determination of logistic and economic principles of the fuel blend preparation (transport, storage, location for the preparation facilities), environmental aspects
- Combustion & gasification of fuel blends
- Residue valorisation concepts
- Alkali sensor market study
- Alkali diagnostics, measuring campaigns & evaluation
- Techno-economic assessment studies
- Environmental aspects of co-combustion

The R&D programme contained work in lab-scale up to operation in technical plants and special attention was led to contribution of industrial enterprises in the working packages to demonstrate the usability of the results for later technical/commercial operation.

The main working packages were carried out by the following partners:

- Upgrading and preparation of wastes (textiles and plastics) for further utilisation with coal in combustion and gasification: *Sächsisches Textilforschungsinstitut, CITEVE, Fechner, Thyssen Schachtbau, Thyssen Sonnenberg, ICI Films*
- Co-combustion behaviour of wastes (textiles and plastics) and coal in entrained flow and fluidised bed combustion: *IST, University of Bochum, KEMA, ICI Films, IFRF*
- Co-combustion of wastes and coal or biomass in grite firings: *IST and partners under sub-contract*
- Co-gasification behaviour of wastes (textile and plastics) and coal in fluidised bed gasification: *TU Lund*
- Analytics of gaseous emissions, fly ash and residues: *University Bochum, TU Lund, IST, IFRF, DMT-SysTec*

- Utilisation of residues like fly ash and ash in subsequent processes; difference from utilisation and treatment of pure coal ashes: *DMT-SysTec*
- Market study on the world-wide availability of gas analysing sensors, especially alkali sensors, and future marketing chances: *University of Heidelberg, University of Tampere, University of Goeteborg, DMT-FuelTec, RWE, Foster Wheeler, University of Cottbus*
- Refinement and extension of the alkali measurement methods: *University of Heidelberg, University of Tampere, University of Goeteborg, DMT-FuelTec, RWE, Foster Wheeler, University of Cottbus*
- Data base on the rise of textile wastes in industry and their characterisation (amount, composition, contamination, etc.): *University Münster, CITEVE*
- Techno-economic study on industrial utilisation of fuel blends produced from industrial wastes and coal: *University of Ulster*
- Dissemination of co-combustion: *IST and partners under sub-contract*

Each working group consisted of partners from universities, research centres as well as from industry. The main objectives of the project were dealing with the creation of an European data base of textiles and waste plastic materials, suitable for thermal treatment, as well as with preparation of the materials for technical use in combustion and gasification units. A very important part of the work deals with the preparation of fuel blends, transport of the materials as well as with the development of feeding systems. Besides, the combustion and gasification behaviour of the materials special attention was taken to the composition of the fuel and flue gases and the utilisation of the ashes. Especially for the later commercial use of the fuel blends in advanced combustion and gasification technologies it was necessary to develop on-line measurements for alkali and heavy metal diagnostics. Three different systems have been developed and investigated in the project to guarantee an immediate analysis of alkalis and heavy metals in the flue gas stream and to ensure 100 % protection of gas turbines in combined cycle technologies as well as protection of the environment in advanced combustion and incineration technologies. The R&D programme covered basic research work in lab scale as well as large scale tests in commercial units to guarantee a quick transmission of the results for later commercial use.

Working package 1:

Upgrading and preparation of wastes (textiles and plastics) for further utilisation with coal in combustion and gasification

Sächsisches Textilforschungsinstitut (STFI)

The aim of the research work of STFI in the overall project was the transfer of production waste (not suitable for a material recycling) by means of mechanical preparation methods into such a form that it can be combusted after blending with coal in combustion plants.

The following textile wastes regarding their materials composition have been investigated:

- cotton, viscose, viscose-acetate, polyester, polyamide 6

and regarding their textile materials structure

- dust, fluff, fabric selvages, heavy screen fabrics.

The following methods of a mechanical preparation and thermal treatment for selected textile waste have been investigated:

- grinding process with knife mills

- cutting process with cutting machines
- breaking process with tearing machines
- agglomeration process with a plast-agglomerator-system

Compaction/briquetting tests of textile waste from used drying screens of paper industry (PA) and a mixture of fabric selvages consisting of 50 % polyester and 50 % acetate were carried out followed by combustion tests of the briquettes and emission measurements of combustion gases as well as chemical analysis of ashes. The permitted emission values can be kept for a further optimisation of the combustion conditions. The obtained ashes cannot further used and must be landfilled.

Furthermore agglomeration of synthetic textile waste has been investigated. The waste samples contained of used wipes for machines, fabric selvages and reclaimed fibres from used carpets.

The materials were treated by a cutting process and than reprocessed by a plast-agglomerator-system. The wipes, consisting of 100 % cotton, were blended with cut film waste material of polyethylene.

The results in bulk density obtained are between 210 - 350 g/l.

Knife mills have to be tested where very small (dust like) particles can be produced.
Blending and dosage of small particles requires special constructive changes of transport and dosage systems at combustion plants suitable for textile matters.

- The different combustion or gasification technologies are connected to special feeding systems. For these feeding systems a defined degree of treatment of textile waste is necessary
- In principle a higher degree of treatment leads to higher costs. But in this discussion the heat value, depending on the materials composition of the waste and the theoretical costs for landfilling have to be considered.
- Blends of textile waste with coal are very difficult to realise because of the great differences in the materials density and the bulk density.
- Orientating briquetting trials have shown that a very high opening of the textile waste is necessary. The reduction of particle size from 30 mm to 10 mm is connected with a decrease of the throughput of the cutting machine of about 60%.
- The obtained densities for textile briquettes without addition of coal is about 0.7 g/cm^2. A reduction of storage and transport volume of 1/7 can be achieved if there are no high requirements regarding the strength of briquettes. The briquetting with lignite requires a share of coal of about 60%. The densities are > 0,9 g/cm^2 Problems of blendability occurred within the trials. A segregation during the feeding of the compression mould was observed. This led to a reduced briquette quality.
- The investigated industrial waste textiles from paper industry (H1-10 and H1-30) are applicable in combustion plants under practical conditions. The combustion should be a combined process because of the problems arising during a mono-combustion (melting, coke-like sediments). The waste textiles can be used as textile cuttings blended with a second fuel as well as like briquettes with coal. During a combustion trial with blended briquettes (70% coal/30% waste textiles) in a slow-burning stove (nominal capacity 5,6 kW) it was shown that blended briquettes have a stable roasting residue, i.e. the briquettes do not break down and form a coarse embers bed with uniform roasting residues. The problems occurred in mono-combustion of these textiles could not be observed.
- The measured emissions are under control with regard to legal conditions, an after-treatment of the gases and an optimisation of the combustion conditions.

Thyssen Umwelttechnik Beratung GmbH (TUB)

TUB has compared different methods of separation of waste plastics from used cars (SLF). Based on the analysis of the results options have determined for adjustment of a plant configuration to the given

application.

The licensing procedure with the authority “Bezirksregierung Düsseldorf” led to a licence according to ”Bundes-Immissionsschutzgesetz” (Federal Immission Protection Act) for the erection and operation of such a trial plant. In several discussions with the regulatory authority it was possible to reduce excessive demands extraneous to practice to a realisable extent.

As the shredder light-weight fraction contains an important share of plastics and as plastics producers have a joint responsibility for this share the “Verband Kunststofferzeugende Industrie e.V. - VKE” (association of plastic producing industry) carried out a study on thermal and material recovery. This report states the procedure TUB presented to VKE to be the most appropriate system. It is the only system offering well fitting and well defined possibilities for an utilisation of the output material.

Under licensing aspects there is no problem either for using the organic fraction via Thyssen Schachtbau by adding coal and by pelletising since the Thyssen blast furnace operation has a trial licence on the part of the authorities, however, during the running time of the project it was not possible to come to a final approval with Thyssen Steel.

TUB also got into touch with the Belgian and French cement industry to enable an alternative use for the plastic fraction, however, the approach has not led to a final result up to date.

Thyssen Schachtbau Kohletechnik GmbH

TSK has mainly investigated ways for thermal utilisation of waste plastics from cars (SLF = Shredder Light Fraction). Due to its high content of inerts ranging from 20-50 % (dust, metals, glass etc.) a preparation has been carried out to recover the organic components.

The following aspects have been investigated:

- Analytics of SLF and suitable coal components, including besides the immediate analyses of the accompanying components chlorine and metals, such as Cu, Zn, Pb, investigation with regard to identifying the fractions of the SLF where these components are accumulated.
- Methods of blending and conditioning with hard coals, including evaluation of possible industrial methods under technical and commercial aspects in order to blend and condition such divers materials to get a homogenous, pneumatic conveyable fuel. Industrial tests and investigations showed that one possible way to get a homogenous solid fuel is blending the SLF with dried coal in a conveyor screw mixer followed by pelletizing in a pellet press.
- Transport / Pneumatic conveyance of pellets obtained from the tests have been conveyed successfully under industrial conditions.
- Combustion behaviour of the coal enriched shredder fraction (Shredder Carbon Pellets, SCP) have been tested in a small combustion test rig at DMT (fluidised bed furnace).

In general due to its composition the industrial kilns favorized for the thermal utilisation of SCP are

- Blast furnaces
- Cement rotary kilns
- Fluidised bed combustors

The work programmes absolved by Thyssen Sonnenberg Umweltberatung and Thyssen Schachtbau Kohletechnik have delivered the basis for the design of a SLF preparation plant.

It is obvious that this inhomogeneous shredder composition “run of plant” results in an undefined calorific value which can range from 10-22 GJ/t accompanied by undesired components for industrial kilns such as metals, glass etc. Therefore, a serial investigation was carried out regarding the immediate

analysis of SLF at different sizes (< 10 mm, < 5 mm, > 10 mm).

Due to the high inert content in the fraction < 10 mm a future preparation plant will operate with a prescreening < 10 mm followed by a further preparation of the materials > 10 mm.

The second step to recover an acceptable material for the thermal conditioning is to separate metals and other anorganic compounds. The programme work done on this matter was carried out successfully in more detail by project partner Thyssen Umwelttechnik Beratung GmbH.

The materials obtained from the preparation tests showed calorific values ranging from 16-22.000 kJ/kg, however with a typical consistence unuseable for pneumatic transport.

In order to stabilise the calorific value and to decrease the metal and chlorine contents, coal has to be added to the SLF and therefore, technical operations such as combined grinding, briquetting etc. have been evaluated under technical and commercial aspects.

Tests to pelletise SLF showed that a significant improve in pellets strength can be achieved by adding 20 % of pulverised coal. Photographs taken in mm-scale proved the effect that the plastic compounds starts softening and thus binding the pulverised coal.

A semi-industrial test run on a 300 kg/h pellet press confirmed these results and approximately 1 t of pellets were obtained for the Thyssen Stahl AG to investigate the mechanical properties as well as pneumatic conveyance.

The pellets showed a good performance on both criteria so that plant design could be completed to a 5 t/h pellet output capacity.

The combustion tests showed no particular differences when firing pure SLF-pellets or Shredder Carbon Pellets. In both cases emissions were kept on the same level which at least proved a homogenous fuel suitable for fluidised bed combustion.

A suitable way to recover a fuel from raw shredder light fraction for industrial kilns such as rotary kilns or blast furnaces is to separate the inerts e.g. metals and to pelletise the residual organic material in a pellet press after blending with pulverised coal.

The Shredder Carbon Pellets (SCP) are pneumatic conveyable and have a calorific value of at least 22.000 kJ/kg with ash contents below 20 %. The chlorine content will rank below 1 % which allows the combustion in cement kilns. The metal content regarding the critical parameter for steel works Pb, Cu, Zn will rank below 1 % which allows blast furnace operations.

Firing in industrial fluidised bed furnaces seems to work without problems regarding emissions as well as feeding and dosing behaviour.

Fechner GmbH & Co.KG

Fechner in cooperation with Krupp Hoesch Stahl (now Thyssen Krupp Stahl) jointly investigated a concept for blast furnace co-injection of pulverised mixed plastics from post-consumer packaging materials and pulverise coal as a ready-to-inject fuel blend.

The idea behind this fuel blends project was to assess the technical and commercial viability of a low investment and low development risk concept for mixed plastics injection by utilising the existing PCI installations and operational experience at Krupp Hoesch steelworks.

A final evaluation of the operational and commercial viability of this fuel blends concept in comparison to the alternate concept of separate injection of granular plastics or mixed plastics pellets which is also

under investigation by Thyssen Krupp Stahl was one of the major outcomes of the project part.

The technical programme investigated in the project dealt basically with the pulverisation of thermally agglomerated mixed plastics with a sizing between 0 and 10 mm to be milled down to a particle size of less than 2 mm.

Following a critical assessment of candidate impact pulveriser systems an air flow rotor impact mill (turbo-rotor mill) was finally selected for pulverising of mixed plastics agglomerates. The mill design throughput was 5 tons per hour of thermally agglomerated plastics from packaging waste, however, the output capacity varied within the limits of 3 to 4 tons pulverised product per hour.

The subsequent manufacturing of fuel blends with variable mixture ratios of pulverised plastics and coal dust in the range between 10 and 30 wt.-% of plastics was performed in the production, handling and storage facilities at Fechner's Lünen works; and the ready-to-inject fuel blends were finally shipped by silo trucks to the blast furnace site at Dortmund.

The major technical objectives achieved were:

- Pulverisation of thermally agglomerated mixed plastics, including evaluation of different impact pulveriser systems, semi-technical scale grinding trials with potential equipment suppliers, selection and installation of a specific impact pulverising mill for large-scale production of pulverised plastics. Lab-scale investigations of the pneumatic conveying properties of coal dust and pulverised plastics mixtures with respect to the maximum/optimum plastics ratio in the fuel blends were carried out.
- Pulverised fuel blends manufacture, including evaluation of conceivable problems regarding the large-scale manufacturing of almost homogenous fuel blends; assessment of the dosing, mixing and storage equipment requirements. Development of a low-cost approach using Fechner's available handling and mixing installations.

Sufficient fuel blending production trials with sieve analysing and shearing resistance measurements in order to optimise the mixture ratios and the highest possible uniformity of the fuel blends were performed.

Blast furnace injection trials jointly with Krupp Hoesch; production of fuel blends for long term blast furnace injection runs (until end 1996 a total amount of 2,500 tons of mixed plastics has been injected) were carried out.

Based on the above technical assessments and operational experience gained from the mixed plastics grinding, fuel blends manufacturing and blast furnace injection runs the technical viability of the fuel blends concept has been demonstrated.

However, a straight forward evaluation of the commercial viability of this concept for a normal routine blast furnace operation in comparison to the separate and direct injection of plastics agglomerates or pellets (mono-injection concept) needs still more large-scale experience with the two different mixed plastics injection modes which have been investigated.

Working package 2:

Co-combustion behaviour of wastes (textiles and plastics) and coal in entrained flow and fluidised bed combustion

Instituto Superior Tecnico (IST)

The work undertaken at IST dealt with the investigation of co-combustion of natural gas and textile wastes, entrained in a combustion air stream. According to the work, IST contribution can be divided into three main fields of research and action:

- Design and construction of textile wastes feeding system and gas/textile wastes burner;
- Simple gas combustion experiments;
- Mixed gas and textile wastes combustion experiments.

Design and construction of a feeding system to continuously feed textile residues in a gas stream, for co-combustion with gas was developed and tested.

The textile wastes feeding system consists of a feed hopper that delivers pulverised textile wastes into a vibrating chute and then to a balanced injector system in the primary air line, from where it is pneumatically delivered to the burner through a high-quality metal shielded weighbridge, so that the solids in the feed hopper can be weighted. The loss-in-weight is measured every few micro-seconds, this information being averaged and stored as a weight loss rate in a computer.

The design and construction of a burner for co-combustion of textile wastes with gas was successful.

IST has undertaken several flue gas measurements for co-firing two kinds of agriculture wastes (pine shell and peach stone) and two types of textile wastes with propane. The influence of thermal ratio (waste/propane) in the flue gas composition was sought. Detailed in-flame measurements for major local mean gas species (O_2, CO, CO_2, unburned hydrocarbons and NO_x) and local mean gas temperatures for combined flames of gas + textile wastes and gas + biomass were collected. Detailed flue gas measurements for different air staging configurations were also conducted.

Overall, the complete set of results have allowed to draw the following conclusions:

1 NO_x emissions increase with the waste/propane thermal ratio regardless the type of waste. The increase is remarkable in the case of one type of textile waste owing to its high nitrogen content (fuel-NO) and in the case of peach stone, probably because of its smaller particle size distribution (thermal-NO).
2 In general, as the waste/propane thermal ratio increases the CO and UHC emissions increase, particularly for the propane + biomass flames.
3 Attempts to co-fire pulverised-coal with textiles were impossible due to their different physical proprieties between those solids.
4 NO_x emissions from propane + textiles and propane + biomass flames can be effectively controlled with recourse to air staging.

University of Bochum (LEAT)

LEAT investigated the combustion behaviour of coal/textile blends in a CFBC.

The first step was the construction of a new heat exchanger for the CFBC test facility as replacement of the old one which had a low efficiency. For the collection of fly ash samples needed for the development of valorisation concepts at DMT-SysTec an additional filter was built. The new devices were tested successfully.

First combustion trials using blends from coal and shear dust failed due to the fact that the existing metering system was not able to feed the textile fibres continuously. The mixtures separated in the hopper and additionally it occurred bridging. So the most important task became the development of a reliable feeding system for the different kinds of textile wastes, all of them having very specific physical properties. LEAT planned to integrate a separate metering system for textile wastes into the test facility. In co-operation with the company Emde a metering system employing an unique stirring device was

developed. This system can feed most of the textile wastes considered. The greatest advantage of two separate metering systems is that fluctuations of the textile massflow have only a small effect on the operation of the facility. The reason is that the ratio of energy-input of the textile waste is low in comparison to the coal. The dosing of coal with an independent metering system is very precise. In addition fuel preparation is not necessary. Problems with the metering of textile wastes do not lead to a shut down of the facility, since the energy input of the textiles can be easily compensated by additional coal. In view of the later planned industrial implementation of co-combustion of wastes this is relevant.

Different kinds of textile wastes have been investigated and the operating parameters of the CFBC in order to optimise the co-combustion of textile wastes have been improved.

The optimisation of the burning process inside the CFBC is influenced by primary measures. Possible parameters like air staging through different injection ports and variation of average combustion temperature were examined. In these series of investigations shear dust I consisting of 50 % polyacrylics next to 50 % cotton, shear dust II consisting of 100 % polyacrylic, agglomerated textile waste TA which is production waste of the car industry and TD consisting of 100 % polypropylene were applied. The major difference between those textile wastes was the nitrogen content (shear dust I: N = 14 %, shear dust II: N = 24,34 % TA: N = 1 % and TD: N = 0 %). This content establishes the formation of N_2O and NO_x.

The pollutant formation of fuel blends from coal and textile waste in a CFBC is mainly influenced by two significant factors. On one hand the physical properties of the textiles lead to difficulties running the combustion process itself. The high CO- and C_xH_y-emissions are caused by the physical properties especially the low bulk density of the textiles because they lead to fast transportation through the combustion chamber without giving enough residence time for burning. On the other hand the high nitrogen content of the synthetic fibres results in increased nitric pollution. The reduction of NO_x and N_2O is possible due to primary measures like air staging, variation of the air ratio and the combustion temperature. The dosability of textile blends and scraps are disadvantageous but excellent for agglomerates. The major disadvantage of burning the agglomerates is that the emissions lead to high CO- and C_xH_y-emissions due to their physical properties.

Summarizing, the co-combustion of textile waste inside a CFBC is a possible but not favourable solution. If it is intended to employ this type of co-combustion, the textile fraction of the fuel ought to be minimal. For the future more experiments applying cotton are needed. As soon as the CO-problems has been overcome, the combustion of fuel blends from coal and cotton in a CFBC will be a good solution.

In a second field LEAT investigated the use of textiles with a high nitrogen content as a substitute for NH_3 in the SNCR-process. This textile waste consist of a milled agglomerated shear dust with a particle size smaller than 100 µm. These investigations were performed in a drop tube furnace with an electrical capacity of 50 kW. For the simulation of the flue gas in coal fired power plant dried flue gas of a natural gas burner with a fixed fraction NO was used. The addition of the textiles were intended to reduce the NO_x-emission.

The prepared textile dust with a high nitrogen content is an excellent substitute of NH_3 for the SNCR-process. With the addition of NH_3 the NO_x-emissions may be reduced to about 33 %. The experimental results using textile waste as a substitute for NH_3 showed a reduction of NO_x up to 85 %. The main conclusions are that the molar fraction of the fuel bound nitrogen from the additive, the gas temperature and the residence within the furnace are the majorly significant parameters for NO_x-reduction in the SNCR-process. Further investigations are necessary in the drop tube furnace for exact predictions of the

SNCR-process. A variation of the operating parameters like gas temperature, molar ratio of the additive and residence time within the furnace are required, accompanied with further experiments in technical scale plants.

KEMA

KEMA has worked on reactivity measurements as selection criteria for combustion of mixed plastic waste. The activity consisted of several research steps, like sampling, analysis, prediction of quality of waste products, prediction of emissions and drop tube furnace experiments.

The topics on sampling/analysis were evaluated successfully and tests dealing with quality of waste products, emission measurements and drop tube furnace experiments have been carried out.

International Flame Research Foundation (IFRF)

The primary objective of the IFRF work has been the investigation in a semi-technical scale for firing solid fuels through the tuyeres of a blast furnace, as a means of reducing the coke content whilst maintaining and/or improving the reduction of iron oxide.

The programme examined the possibilities of firing a blend of European coal with plastics in simulated blast air. The following parameters have been investigated:

- blending ratio
- fuel heat input
- fuel velocity
- flame length and flame boundary conditions
- flame penetration based on the kinetic energy of the blast
- burnout

The emphasis has been toward the testing of systems for the feeding of granulated and powder plastics. The results from these tests have defined the particle size that can be fed with the coal to make specific blends.

It is desirable for the blast furnace simulation, that the particles are as small as possible, in order to expose a large surface area which should ensure complete burnout.

Plastics have been identified as possible fuels that can be used with coal of various rank to form a blended fuel that is suitable for injection into the blast furnace

A detailed evaluation of the combustion behaviour of plastic blended with coal with different injection methods has been carried out. Furthermore, ash samples have been taken for ash valorisation with other project partners.

Finally, the potential for plastic fuel as a blend fuel with coal for replacement of coke in the blast furnace has been ascertained.

ICI Films

ICI as one of the industrial project partners has taken over the large scale combustion of fuel blends consisting of coal and plastics film wastes in a 40 MW circulating fluidised bed boiler (CFB).

Due to serious damages in the boiler ICI decided to leave the project.

However, first trials in 1996 have shown that the system after further optimisation will work sufficiently. ICI has plastic waste samples available in a 100 t scale and was able to deliver the material for further combustion tests to the other project partners.

IST together with industrial partners in Portugal has taken over the project part and has carried out combustion tests in large scale boilers.

In addition, IST have conducted detailed flue gas measurements of O_2, CO, CO_2, unburned hydrocarbons and NO_x at the PORTUCEL full-scale biomass boiler. During the tests around 40 tonnes of plastics of four different types were burned. The plastics have been burned in combination with biomass at different thermal ratios. From the data collected, it was possible to draw the following conclusions.

1 There is a value of plastics/biomass ratio that corresponds to a maximum value of NO_x emissions; above and below this value NO_x emissions decrease. Consistently, this is the value to which corresponds a higher value of the mean boiler temperature.
2 SOx emissions from the combined combustion of biomass + plastics are always insignificant. However, they increase marginally as the plastics thermal input increases because of the sulphur present in one type of plastic.
3 CO and UHC emissions were not detected in the flue gases for any of the tested conditions.
4 During extended and continuous boiler operation, firing small quantities of biomass plus high amounts of plastics, there was a propensity for the latter to melt on the grate with the combustion efficiency suffering accordingly.

Working package 3:

Co-gasification behaviour of wastes (textile and plastics) and coal in fluidised bed gasification

University of Lund

TU Lund has carried out work on gasification experiments of the fuel blends of coal and textile and plastic wastes. The experiences showed a need of development in mixing procedure of fuel blends and also a necessity of modifications in the existing feeding system.

Several successful and stable gasification experiments were done with coal and textile waste blends. The main goals in these experiments were

- to study the effect of the various mixing methods on feeding process
- to see whether different mixtures behave differently in the gasifier
- to study reliability of the gasifier and reproducibility of the gasification results

The experiments conducted showed a great improvement both in the gasifier operation and in the gasification quality, however, the intensive gasification of the coal blends in the gasifier resulted in high temperature induced material exhaustion of the reactor tube followed by melting of it and breaking down of two reactor furnaces.

Therefore further tests after reparation were carried out exclusively with biomass/textile waste blends.

Gas analyses showed a fluctuation in the product gas composition which is a new phenomenon in the gas analyses for the Lund gasifier. It is believed that sometimes a separation of fuel blends results in an uneven oxygen distribution in the bed. The input oxygen reacts in the first hand with textile which is more reactive than coal or biomass and results in total combustion of the textile fraction. In this case the amount of CO_2 in the gas increases at the expense of the combustible gases.

According to the preliminary calculations the Volumetric Heating Value of the product gas varies

between 3.5 and 4.5 MJ/Nm^3, depending on the operational conditions.

Study of the concentrations of trace gases shows that during coal/textile experiments more sulphur compounds are produced. The concentration of H_2S within these experiments exceeds 700 ppmv in the gas. The amounts of the SO_2 and COS in the gas are also higher than those in the biomass/textile gasification. The content of the sulphur compounds is not considerably affected by the textile-mixing ratio.

Adding textile to biomass does not effect the composition of the product gas. However at high mixing ratios the amount of the unburned carbon in the fly ash increases.

There is a clear relationship between the biomass/textile mixing ratio and the concentrations of the trace gases such as NH_3, HCl and H_2S. While the S, Cl and N contents of the textile are higher than those of the biomass, increased textile addition increases the amount of these traces in the gas.

The ammonia formation in the gasifier is regulated by three important factors: the fuel-nitrogen, the gasification temperature and the ER value. The relationship between the fuel-nitrogen and the ammonia concentration in the gas is linear. Higher temperature results in decrease of the ammonia. The effect of the higher ER in ammonia decreasing is due to both gas dilution and also the improved oxygen availability in the gasifier.

The amount of the lighter PAHs in the tar is larger in the case of mixture gasification. The compounds with the molecular weight larger than 168 (dibenzofurane) make about 84 to 95 % of the total PAHs for the pure biomass while the corresponding value for the mixture is below 55% at its highest value.

Textile addition contributes to increase the formation of the light hydrocarbons such as benzene, toluene, ethane and butane.

The heating value of the gas affected mostly by the ER value. Including the combustion heats of the light hydrocarbons improves the gas heating value by 15 to 28%.

Working package 4:
Analytics of gaseous emissions, fly ash and residues and

Working package 5:

Utilisation of residues like fly ash and ash in subsequent processes; difference from utilisation and treatment of pure coal ashes

One partner has carried out valorisation concepts for residues. Residues of combustion and gasification of fuel blends were delivered by the other project partners working on co-combustion and co-gasification.

DMT-SysTec

In existing literature only few reports are found in this context. One of these reports deals with thermal utilisation of textile floor matting materials in a stationary fluidised-bed firing (single-fuel firing system). The composition of the resulting ashes with high calcium oxide concentrations should allow manifold applications in cement industries. Utilisation possibilities quoted in the project are proportioning to concrete mixes as well as an additive for cement production feedstock. Supposedly, there are further utilisation possibilities, such as production of sand-lime bricks and lightweight

concrete. The ashes should contain only small concentrations of heavy metal and the elution rates of these heavy metals should be low as well, thus allowing environmentally benign and cost-effective disposal on mineral-matter dumps.

Further examples are the use of textile carpet wastes as fuel or feedstock in blast furnaces or in a modified refuse incineration plant. Initial field trials have shown that the resulting blast furnace slags are particularly suited for producing cement qualities intended for under-water use, and the refuse incineration slags are suited for use as sand for various purposes in civil engineering and road construction. Dusts from dust separation systems as well as residual ashes need to be dumped.

Bochum University has carried out combustion tests in the fluidised bed combustion furnace with fuel blends of coal and textiles (blends of propylene and flax, TA and TD). The investigations into the utilisation possibilities obtained with these residues have shown that the levels of, for example, heavy metals are low enough and that they remain under the limit values for construction materials for restricted installation. Furthermore it would be possible to use the residues as underground mortar, e.g. for backfilling or roadside packs. At the same time the criteria to be fulfilled by the fluidised bed ash include the following: homogenous chemical composition and constituents,constant particle size distribution, sufficient strength, controlled carbon and CaO and availability of adequate quantities

Special construction material tests to establish the suitability of the residues in certain construction materials, e.g. in mortars or mining mortars, or preparation tests, e.g. to separate interfering components must be investigated with larger quantities of ashes.

Lund University has also conducted gasification tests (with different ER values and used bed material) with biomass and textiles. The loss on ignition, some heavy metal levels and the PAH values exceed the limiting values for utilisation as construction material and for dumping on a mineral dump. Reducing the textile portion down to, for example, 5 % does not produce any basic advantage. In addition the chemical composition, with more than 75 % MgO, also renders them unsuitable for such a use.

If the high MgO level is maintained with an optimisation of the gasification process, however, it would be possible to recover the MgO at very high cost. Since the MgO exhibits a higher density than the other ash portions, consideration can be given to the procedures of wash table grading or grading in autogenous heavy media (upstream classification). It has not been possible to conduct examinations in this respect because the quantities of the samples were too small. The drawback of this procedure is the necessary drying of the separated material. The remaining residue with high carbon levels could then be returned to the reactor. In view of the small ash portions both in the biomass and in the textiles, only a small residue would have to be dumped in total. The advantages of this procedure would be a saving in fuel and bed material.

Further investigations were carried out with residues from the combustion of biomass and the co-combustion of biomass and high ash-containing plastics (IST) and from the combustion of fuel blends from coal and plastics in a 1 MW plant (a pulverised dry firing system, KEMA).

Without additional treatment the residues from the combustion of biomass/plastic and coal/plastic cannot be used in the construction materials domain due to e.g. high Cl-, sulphate-, heavy metal content and partly due to very high electrical conductivity.

It is very laborious and costly to wash out the interfering constituents, e.g. to reduce the chlorine content, because the material washed out would then have to be dried and the contaminated solvent would have to undergo further treatment. In addition it is not possible to say anything about the requisite plant concept and possible investment costs without more detailed knowledge of the quantities arising and the actual residue qualities.

One possible form of recycling would be use in a cement works as a supplier of fuel and minerals. For this purpose, however, the cement works would have to be equipped with the requisite gas cleaning facilities and the mineral composition of the residue would have to fit the raw materials concept.

A further possibility for recycling is integration of the ashes or polluting constituents in cement. In this case the total material would be evaluated in terms of its properties. On top of the installation costs, the integration would involve a high additional expenditure. Beyond this there is only the possibility of dumping on a household waste dump.

Working package 6:

Market study on the world-wide availability of gas analysing sensors, especially alkali sensors, and future marketing chances

All partners of the alkali measuring project group have contributed in the preparation of a market study for on-line measurement of alkali and heavy metal species. The study has been published under the title ”Diagnostics of Alkali and Heavy Metal Release” (EUR 18291 EN; ISBN 3-00-002948-6).

BTU Cottbus

In order to gain an overview about the current state-of-the-art of the techniques and about the existing opportunities for the use of on-line alkali and heavy metal sensors, information was requested from more than 50 selected companies and institutions. The majority of written questions was answered. The results of this survey, of phone calls and literature searches were contributed to the market study. It could be shown that on-line detectors are not yet available world-wide although both in Japan and in the USA there is ongoing research to develop corresponding measuring devices till commercial availability.

According to the survey, a potential market for on-line alkali measuring devices exists in the following areas: Combined cycle plants using pressurised fluidised bed combustion (PFBC, CPFBC), combined cycle plants using integrated gasification cycles and hot gas cleaning (IGCC), combined cycle plants using pressurised pulverised coal combustion (PPCC), plants for the thermal exploitation of waste, especially plastic waste (combustion, pyrolysis, gasification) and municipal solid waste (conversion), plants for the thermal conversion of biomass. Correspondingly potential buyers and users of on-line systems would be: Gas turbine producers, boiler producers, engineering companies, energy providers and municipal waste combustion companies.

Together with DMT and the University of Heidelberg a comparative test programme with off-line measurements carried out by BTU Cottbus and the ELIF method of the University of Heidelberg was outlined. The measurements were carried out at DMTís atmospheric fluidising reactor ALFRED at a temperature of about 850°C. Sampling was made with 3 gas washing bottles and for the analysis of alkali species ion selective measurements were chosen. The tests were carried out with two different coals (Westerholt bituminous coal and Rheinbraun lignite) both with and without additives (CH_3COONa, CH_3COOK), and measurements were made between cyclone and hot gas filter and behind filter.

Potassium off-line measurements are 2 to 200 times higher than on-line measurements, Sodium off-line measurements are 1,25 to 40 times higher than corresponding on-line measurements. It could not be found a reason for that bad results.

Alkali concentrations measured behind cyclone were much higher than those measured behind filter. An

explanation was supposed in the high amount of ash particles in the flue gas before filtration. There could have been alkali deposition on the surface of ash particles or there could have remained a water soluble alkali fraction in the ash. In order to see if this assumption was right, BTU Cottbus tested several samples of ash for their content of water soluble alkali compounds. At cyclone there is only a very little amount of alkali compounds in the ash. It could be shown that the ash particles donít have a significant influence on alkali concentration before filter. The alkali content at filter was much higher than that at cyclone. One explanation could be that alkali deposition took place at the filter within previous experiments and these deposits have been removed now.

Thermochemical equilibrium calculations

These calculations were carried out with the program ChemSage produced by GTT Technologies. GTT Technologies also delivered a data file, which was originally created for the investigation of gas species and condensed phases formed during coal combustion processes and which was extended for the calculation of alkali release processes. This data file uses for the slag phase the Quasi-chemical excess model. For the other phases it uses the ideal mixing model.

BTU Cottbus carried out calculations comparable to the on-line measuring results of the measurement campaigns at Foster Wheeler Energia Oy in Karhula/Finland carried out within this programme. Furthermore calculations have been carried out for the influence of temperature, limestone addition and addition of various alkali getter materials.

Results of the calculations are 4 to 10 times higher than on-line measurements. At 800 K - 1500 K, which is the temperature region of the Karhula tests, mainly NaCl and KCl are present, whereas at more than 1500 K also NaOH and KOH show high concentrations. Na_2SO_4 becomes unstable at T > 800 K and K_2SO_4 reaches its maximum at 1500 K.

To summarise the results it can be said that SiO_2 is the only getter material of importance. Other materials probably only act via their content of SiO_2 (e.g. bauxite, $CaO.MgO.2SiO_2$) and their use is only convenient if those materials are less expensive. But attention should be given to the fact that for the materials tested more than the amount corresponding to pure SiO_2 is necessary.

Working package 7:

Alkali measurements applying three different analysers in flue gas streams of combustion facilities and

Working package 8:

Refinement and extension of the alkali measurement methods

University of Heidelberg (PCI)

The ELIF measurement method of PCI covered the following activities:

- Design, construction and test of an in-situ optical access for use in industrial-scale systems under realistic PFBC conditions. The new design allows incoupling of the laser beam and collection of fluorescence at just one window. The durability of this optical access was demonstrated for conditions of 10 bar total pressure and ca. 800°C during continuous plant operation over periods of about two weeks.

- Integration of a new detection set-up in the ELIF measuring system using fibre optics to connect to the optical access. Simultaneous two-channel detection is also still feasible. The fibre optic cable allows the detection system to be placed together with the remaining electronics in a compact way and also much reduces adjustment effort. The components of the detection unit are in a fixed arrangement, requiring no adjustment except the simple rotation of a wheel to change neutral density filters for different fluorescence intensities.
- Redesign of evaluation software, allowing more efficient, user-friendly operation of the ELIF-system and a fast overview of results.
- In-situ acquisition of on-line data on alkali release from the 10 MW PFBC plant of Foster Wheeler Energia/Karhula, Finland, including observation of short-term (e.g. pulsing of hot-gas filter during cleaning, addition of limestone) and longer term effects (e.g. variations in load and oxygen excess). Measurements were made during two periods of plant operation of 10-14 days each and were interrupted only briefly for refilling the laser (ca. 15 min) and securing the data. The ELIF-system could be operated non-stop for at least 24 hours. In addition, simultaneous measurements were made with the Tampere and Göteborg groups, using the PEARLS and SI techniques respectively, so that direct comparisons can be made. Measured concentrations are of the same order of magnitude for all three measuring techniques.
- Calibration of the ELIF signals was performed on a facility designed and constructed by the group from Tampere.
- Survey of possibilities for detection of heavy metals using the ELIF-method, including assessment of collisional effects. Some detection schemes for Cd, Ni and Zn compounds were selected, whereby single-photon excitation is to be preferred in the first instance, since lower laser energies will be required and interpretation of signals should be more straightforward.

University of Tampere (TUT)

The PEARLS alkali measuring instrument of the TUT group has been tested in the 10 MW PCFB of Foster Wheeler Energia Oy. The instrument has been used for simultaneous alkali measurements together with the ELIF and surface ionisation instruments during different operations of the PCFB.

The PEARLS alkali measuring instrument has been developed by utilising a new photodetector which substantially improves performance.

- Improved detection limit below 1 ppb (previously 5 ppb)
- Improved data acquisition rate 2 values/s (previously 10 values/minute)

The improved data acquisition rate makes it possible to analyse fast phenomena, like alkali behaviour during the hot gas filter cleaning pulse.

A pressurised and transportable test/calibration unit was designed and manufactured. The operation of the unit is based on the known vapour pressure of alkali salts at a determined temperature. The unit will help to improve the accuracy and develop the components of the measuring instrument.

TUT provided background information for other partners by establishing the format for preparative actions and sending a full copy of the technical drawings of the PEARLS instrument to the partners. The following features were utilised in the design of the ELIF and surface ionisation instruments:

- Identical DN 150 / DN50 reducer flange design for all instruments

- Architecture of the instrument body (surface ionisation)
- Division of the sampling line to heating zones (surface ionisation)
- Protective arrangements of the sampling line (surface ionisation)
- Ball valve for window protection (ELIF)

The PEARLS instrument has been improved significantly in the test runs, comparison with the two other on-line instruments showed comparable alkali levels.

University of Göteborg (GU)

The main objective of the project has been to develop an on-line alkali measurement instrument for power plant applications based on surface ionisation (SI). Alkali metal atoms are well known to easily ionise in contact with hot metal surfaces, and the instrument developed in this project is based on this principle. This is an almost unique property of alkali compounds, which implies that a sensitive and selective detector can be developed. The primary parts of the detector are a filament, generally made of platinum, and an ion collector. The platinum filament is supported between two electrodes and is resistively heated for alkali vaporisation in ionic form. The filament is based at a positive voltage of 500 V to repel the formed positive alkali ions. The ion collector is situated close to the filament and is grounded through a sensitive electrometer. The measured current is proportional to the arrival rate of alkali atoms onto the filament.

In this project an instrument consisting of a SI alkali detector, a hot gas sampling line, and a control system has been constructed according to prevailing high pressure and high temperature standards. The instrument has been tested during two extended measurement campaigns in a PCFB combustion pilot plant at Foster Wheeler's R&D Center in Karhula, Finland. During the campaigns, the instrument was under operation for more than 500 hours during pressurised combustion of coal. Simultaneous alkali measurements with the groups from PCI and TUT were performed on several occasions during the campaigns. The measurement campaigns have been evaluated in cooperation with PCI, TUT, and FW, and this work also included the calibration of the SI instrument. It can be concluded that the developed instrument has performed well and the experimental runs confirmed that the instrument can operate during extended times in the hostile environment present at a power plant.

After the campaigns the SI instrument has been further developed. The SI instrument operation has been simplified by increased computer control, and the reliability of the measurement procedure has been further improved. The SI detector has also been tested in a laboratory scale pressurised gasification unit, in order to analyse the requirements for instrument use in gasification. A description of the SI instrument, together with descriptions of the other detectors developed in the program, has been published in a market study on "Diagnostics of Alkali and Heavy Metal Release".

The developed instrument monitors the total alkali concentration (Na+K) in the hot flue gas of a pressurised system. In an extension of the technique, the instrument is also intended to differentiate between Na and K as well as discriminate between alkali species in molecular and particulate form. It was found that platinum might be a suitable material for the ionising hot filament, both considering ionisation efficiency and filament life time. A large number of other filament materials where also tested with respect to thermal stability and their surface ionisation efficiency for Na and K. A few of the tested materials can be considered as alternatives to Pt in future SI applications, including platinum alloys, high temperature steels, and Kanthal. Based on the investigations, it can be concluded that all tested materials (except Pt) are oxidised at the high temperatures used in the instrument and are therefore not suitable for differential measurements of Na and K. It is suggested that the combination of SI detection

and ion mobility spectroscopy or mass spectroscopy is investigated in future work on Na and K separation.

Laboratory investigations have been performed with alkali-containing particles in the size range 0.05-1 mm. The SI technique can be used to detect single particles in this important size range, and that a selection between alkali in molecular form and alkali-containing particles can be based on this principle. The results also suggest that a new type of particle analyser can be constructed based on SI technique. This simple and very sensitive device may prove ideal as an ”early warning” system for measurements of increased particle concentrations in a gas turbine inlet.

DMT-FuelTec

DMT pursued different tasks in the project, including the adaptation and modification of the analysers to application in industrial plant. In particular, a rugged but versatile hot gas extraction probe system permitting reliable sampling for accurate online measurements was designed and constructed. The retractable probe system was to include a pressure lock and to incorporate a measuring chamber for the ELIF analyser providing a number of windows in order to let the exciting laser irradiation in and to detect the fluorescence signal, and providing an opportunity in its pressurised fluidised bed combustion facility FRED to test developments in analyser improvements and to carry out combustion experiments at conditions most suited to the instrument development needs. These runs complemented the field measurement campaigns of the instrument developing teams.

Based on observations at measurements with the ELIF method, drawing on experience with an extractive sampling line forming part of one of the three analysers and including DMT expertise from other instrument developments, a new retractable hot gas extraction probe system was conceived, designed and constructed that incorporated the following features:

- The system is strictly modular in design. The various functions of the system are allotted to individual components.
- Components needing servicing or exchange/replacement are readily accessible.
- The extracting gas tube is indirectly heated and can be replaced with tubes made from other materials if required.
- The probe system is fitted to the plant via pressure lock. It can be withdrawn under pressure, isolated and independently de-pressurised.
- The measuring cell provides four rectangularly arranged access ports for observation. The measuring cell has its own individual heating system.
- The sampling gas is passed, downstream the measuring chamber, to a cooler, followed by a strainer, to the pressure let down valve that controls also the total gas flow through the system. The gas can then be vented or used for other purposes, e.g. conventional gas analysis.

Foster Wheeler Energia Oy (FW)

The Foster Wheeler Pressurised Circulating Fluidised Bed Test Facility in Karhula, Finland, provided over 1000 h of operation on coal to be utilised for alkali measurements under industrial conditions during the two test segments in 1997. The measuring teas, from the University of Göteborg, Heidelberg University and Tampere University of Technology, were able to take advantage of a large part of the operation. Technically, instruments of all three measuring teams showed remarkable potential for industrial use.

During summer 1998, the final results of the measurements of all teams were submitted to Foster Wheeler. The alkali emission results were reviewed together with steady state process data, and possible correlations with process parameters like temperature and pressure were investigated. Clear connections between the alkali emission and the amount of particulate in the flue gas as well as the flue gas temperature could be observed.

In general, with dust-free flue gas, the sodium and potassium emissions were in the range of 25 ppb (6% O_2) at temperatures of 800-850°C, and the range of 10 ppb is reachable at temperatures of 700-750°C already without special getters or process modifications with the coal used during the test campaign.

The main results of the project were published during the presentation of the alkali group and in the poster session of the final project meeting in Brussels on November 11-12, 1998.

A joint publication on alkali measurements was submitted together with the measurement teams to the organisers of the 6th International CFB Conference to be held in Würzburg in 1999.

RWE Energie AG

The objective of RWE's participation in the project was to get actual and detailed information on possibilities of online measuring techniques of alkali in pressurised combustion or gasification processes.

To get results with the alkali online measuring systems at the pressurised fluidised bed combustion test facilities of Foster Wheeler it was necessary to work out a main test programme, in which the basic requirements (types of coal and additives to be used, constant and variable process parameters during the test runs) are described. This main test programme has been discussed with all partners involved. The programme has been taken into account all important parameters and operating conditions of the plant and the needs of the three different measuring systems.

Concerning this main test programme RWE has participated in the following items:

1 Participation in planning the experimental programme for runs in different PFBC-test units in cooperation with Technische Universität Cottbus and plant manufacturers.

2 Adaptation and study on the requirements of the analysing system in gasification plants.

The requirements of the analysing system for gasification plants have been discussed together with the University of Heidelberg furthermore. The considered aspects for feasibility of the ELIF measurements are as follows:

- Fluorescence quenching
- Absorption of laser beam
- Background emission
- Dimensions and geometry of the system.

The result was, that measurements under the stated conditions (HTW-gasification) will be feasible.

The potential application relating to gasification of the measurement system are future power plant concepts with combined cycle like "IGCC" or "PFBC second generation".

The PFBC-process with extremely staged combustion could be one possible option for a high efficiency power plant concept. The process will be investigated in a laboratory scale at different places and is in the very beginning of the development.

To get an impression what alkaline values are to be expected in a future combined cycle process like the staged combustion, the university of Cottbus did some calculations with their program chemsage for the use of lignite.

After finishing the investigation of the potential applications of the measurement system in gasification plants it was discussed to use the systems in atmospheric combustion in conventional boilers.

This had the following background:

The alkali-content of the rhenish lignite of some mining areas will increase during the next years. Important for RWE Energie is to get knowledge of the influence of higher ranges of alkali content. Suitable measuring systems need to be tested. Therefore theoretical investigations have been carried out concerning the possible application of the Elif-system.

Especially it is important to get a better understanding of alkali deposition and the incipience of fouling and corrosion.

The test employment of one or more measurement systems in conventional firing systems at RWE Energie is under consideration.

Working package 9:

Data base on the rise of textile wastes in industry and their characterisation (amount, composition, contamination etc.)

Two project partners were involved in this topic.

University of Münster (FATM)

FATM carried out a data base study on the rise of textile wastes from different textile branches in Germany.

The main aim of this study was the calculation of the textile production waste that arises in the Federal Republic of Germany, according to production phases, in order to gain a basic idea about the amount of production waste that would be available for the combustion and gasification as an addition to coal. Typical waste quotas are determined for the individual production processes of the textile industry. In connection with the amounts and types of raw materials used, these quotas will make it possible to give a differentiated estimate of the arising amount of waste according to its type and the raw material structure. These are basics for a following market study on the real and potential markets.

The calculation of the arising amount of textile production waste is mainly based on two sources. The first is the official statistic on production in the German industry in 1995, which provides production data for the different branches of the textile industry. The other is a questionnaire sent to companies by the FATM in 1996, which was used to get and calculate waste quotas for different production processes.

In addition to waste quotas and waste volumes a breakdown by types of fibre for the raw materials is given.

There is a significant concentration of textile mills on three German states. When taking the number of employees as a measure for the regional distribution of production, about 76% of the textile production waste in 1995, i.e. 83,000 t (83 kt), is concentrated in: Nordrhein-Westfalen (NRW): 32 kt, Baden-Württemberg (BW) 16 kt and Bayern (BY) 14 kt. At the county level, about 60% of the rise of all textile waste is concentrated on only 6 regions: Münster (NRW): 12 kt, Düsseldorf (NRW). 12 kt; Oberfranken (BY) 8 kt, Freiburg (BW) 7kt; Stuttgart (BW) 5 kt and Kassel (Hessen) 5 kt. We find a similar result

for the regional rise of textile dusts, which are of special interest due to problems in recycling and current prices of disposal on one hand, and opportunities in preparing the dusts for co-combustion with coal on the other hand. About 12kt, i.e. 65% of all textile dusts from production arise in only 7 counties: Münster (NRW), Düsseldorf (NRW) and Köln (NRW) with a combined amount of dusts of 5.2 kt, Freiburg (BW) and Stuttgart (BW) with a combined amount of 4.4kt, Oberfranken (BY) 1.4 kt and Kassel (Hessen) 900 t.

Disposal Costs of and Profits from Textile Production Waste

Textile waste is handled as a commercial good. A positive price for a type of waste indicates a path for recycling the waste inside or outside the textile chain. If there is a negative price for textile waste, the textile companies have to pay for disposal and only in this case textile waste will be offered for co-combustion in stead of landfilling.

The operational result is that mainly textile dusts will be offered for co-combustion with coal because fibre waste from the non-wovens-production can be classified as textile dusts due to the very short length of residual fibers.

Collecting Systems and Remarks on the Logistics for Textile Waste, esp. Dusts

Corresponding to the regional rise of textile waste there are a few companies in these regions which have specialised in buying and selling textile waste. It is therefore possible to refer to an existing logistics system for collecting textile dust from a great number of mills.

In spite of the very low density of textile dust we have a cost-intensive ratio of volume and weight in the transporting system. Since the three major waste-producing regions are located in three corners of Germany, a central point for preparing textile dust for co-combustion in a power plant nearby may not necessarily be the optimal solution with respect to transportation cost. Thus co-combustion plants in the main three regions might be the optimum solution with respect to logistics.

Conclusion

From a total of currently about 83,000 t/p.a. of all types of textile waste from the textile production chain, only 18,000 t/p.a. of textile dusts, including short fibres, are offered for co-combustion with coal. Although this type of textile waste has a high content of energy, it has to be collected from a great number of plants and to be prepared for co-combustion in a power plant with an extra feeding system. Technical and environmental problems with co-combustion, as well as the low rise of textile dusts over time in hundreds of mills located in several regions of Germany, seem to call for small technology concepts for using the energy content of textile dusts at the place of origin.

CITEVE

CITEVE worked on the calculation of the main textile production waste arising in Portugal, according to production phases of the fourth more representative industrial sectors in the country and, on other hand, the determination and characterisation of the supplied production wastes, with regard to its fundamental characteristics. CITEVE also supplied representative wastes to the Portuguese partner (IST) performing the combustion tests (package 1).

The results developed, gathered from different companies, allowed the calculation of percentual medium figures of waste on production phases. It was possible to calculate figures for: secondary raw material, primary waste and secondary waste.

In terms of waste samples and quantities samples were supplied to the University of Lund and to the partner IST, about 1 ton of seeds, dust and very short fibres of cotton, 500 kg from a blowing at a spinning mill and other 500 kg from the gig operation at finishing. This last kind constituted of short

fibres (short woollen) with colour and finishing/dyestuff.

Those two kinds of waste supplied to IST and other four, for a total of six main kinds of waste have been identified as the most representative secondary waste in Portugal.

The kind and quantity of wastes produced depends mainly on the production process. CITEVE collected information about different production processes of the most representative industrial sectors in the country: wool, cotton, knitting and clothing.

This wastes were divided in 3 categories:

A: secondary raw material

B: Primary wastes

C: Secondary wastes

Since A and B wastes have conditions to be recycled only C wastes were admitted to be submitted to combustion.

Besides clothing and knitting industries do not have A and B category of wastes, therefore only wool and cotton industries were considered to be analysed, in what to category C of wastes concerns.

Quantity of wastes produced

The calculation of the arising amount of textile production waste was mainly based on the following sources:

- Gathering of industrial quotes of waste per process by means of diagnostics on site.
- Statistics of ”Interlaine” and “L’Atlas du Textile Mondial” de Françoise Depin. The first given for 1995 and the second for 1994, concerning the Portuguese textile production of the main four industrial sectors in country.

Joining both sources it was possible to approximate calculations of national textile production waste.

Regarding the wastes which can not be raw material of another process (not recyclable), the amount is just about 13600 ton/a.

The regional arise of textile wastes for combustion or gasification has to be determinate under aspects of logistics optimisation between regions.

Regarding this aspect, the distribution of the Portuguese companies in land was found with the support of a study from ”CENESTAP - Centro de Estudos TÍxteis Aplicados”, of 06/08/97, with about 1 800 companies.

With this study, it was possible to establish the distribution of the six more representative Portuguese Districts, considering the number of companies per District (Braga, Porto, Guarda, Castelo Branco, Lisboa e Set˙bal).

Working package 10:

Techno-economic study on industrial utilisation of fuel blends produced from industrial wastes and coal

One partner has worked on this topic using data and test results from all other participants in the project.

University of Ulster (UUE)

The work of the Energy Research Centre of the University of Ulster was to perform technical,

environmental and economic assessment studies of a range of power generation technologies using coal/textile waste/plastic waste blends. Models have been developed for many different technologies including combustion in fixed bed, bubbling bed, circulating fluidised bed and entrained flow reactors, and gasification in a fixed bed gasifier with a gas engine, and a fluidised bed gasifier using a gas turbine in simple cycle, combined cycle, STIG and ISTIG mode. These models have been used to integrate the results from the other partners.

The specific work programme called for :

- the collection of data on the wastes which are available and an assessment of the cost and energy required to convert them to a feedstock suitable for co-processing with coal.
- the validation of the pilot plant results and scale-up to suitable size of operation
- the performance of techno-economic assessment studies for the range of proposed feedstocks and the alternative co-processing technologies at a suitable size of operation
- the performance of sensitivity analyses to determine the conditions required to make these alternatives competitive with existing disposal routes.

Information has been obtained from the other partners on the situation with regard waste textile arising in Germany and Portugal and plastic waste arising in Germany. Further information with regard to the geographic location was required in order to determine the relationship between cost of transportation and size of waste processing plant.

The technologies modelled included :

- small scale combustion in a fixed bed furnace,
- medium scale combustion in a bubbling or circulating fluidised bed,
- large scale entrained flow combustion,
- small scale gasification in a fixed bed gasifier with a gas engine,
- medium scale fluidised bed gasification using either a gas engine or a gas turbine,
- medium to large scale fluidised bed gasification systems using gas turbine topping cycle and steam turbine bottoming cycle,
- medium sized fluidised bed gasifier with STIG and ISTIG configuration.

The overall results from the work using the ECLIPSE process simulator can be concluded as follows:

- The addition of 5% plastic waste to a coal fired PF power station reduces its efficiency by 0.3% due to the high moisture content of the plastics. There is a small increase in capital cost associated with feeding the waste plastic to the boiler. For the overall economics to be the same as the coal only case, the power station could afford to pay up to 20 ECU/dry tonne for the plastic waste, compared with 37 ECU/tonne for the coal. The disposal of plastic waste normally costs approximately 94 ECU/dry tonne. Therefore, provided the cost of transporting, handling and preparing the plastic waste for use in the power station does not exceed 114 ECU/dry tonne then it is economic for the power station to use plastic waste.
- The addition of 20% plastic waste to a Texaco IGCC power station increases the net efficiency by 0.2% due to the improved gasification qualities of plastic over coal. There is an increased capital cost for handling the plastic waste which means that for the overall economics to be the same as the coal only case, the power station could afford to pay up to 38 ECU/dry tonne for the plastic waste, similar to the coal price. Again, the disposal of plastic waste normally costs approximately 94 ECU/dry tonne and therefore provided the cost of transporting, handling and preparing the plastic waste for use in the power station does not exceed 132 ECU/dry tonne then it is economic for the power station to use plastic waste.
- While there is sufficiently large amounts of plastic waste available, the amount of textile waste

suitable for co-combustion in Portugal and Germany is limited. If all the available textile waste in Germany is used in a 450 MWe British Coal Air Blown Gasifier (BCABG), less than 2% of the coal thermal input can be replaced by textiles. This generally has a small positive benefit to the BCABG power station which means that the textiles have a value of 32 ECU/t to this power station.

- With textile waste suitable for co-processing of only 18,400 tonnes/year in Germany this imposes limits on the maximum size of a power station. When using a 5% textile share in a CFBC power station a 122 MWe plant can be sustained with the available textile dust, while with a 20% textile blend this is reduced to 24 MWe. For textile waste arising in Germany the ideal location for a power plant is Gießen for larger scale plants, while Freiburg or Münster are best suitable for smaller plants. Using textiles in a CFBC power station reduced the efficiency and increases the capital cost. However, the textiles have a positive value to the power station if it can be assumed that the textile disposal cost of about 135 ECU/tonne is avoided. Hence, although the textiles have a higher transport cost than coal, the overall fuel cost is improved when textiles are employed. As a result a reduction in BESP can be achieved. The best reduction in electricity price for co-combustion of coal with textiles can be accomplished for a 5 MWe power station with a 20% textile share. For a 5% textile share the most advantageous size is a 20 MWe CFBC plant.
- The co-combustion of a wide range of blends of waste plastic film with biomass was successfully modelled. The value of waste plastic as a feedstock was shown to be between 13 ECU/tonne and 21 ECU/tonne greater than the equivalent ECU/GJ value of the biomass feedstock, due to its improved combustion performance. In the specific case studied there are problems with the availability of suitable plastic waste and the high transport cost. However, it has been shown that this particular technology can successfully recover the energy from blends of waste plastic with biomass. Under more favourable waste plastic supply conditions and waste plastic transport distances it has the potential to be economically viable.

Conclusions

It can be stated at the end of the project that all 20 partners have worked together in a very co-operative way, that all groups have reached the main goals of their planned working packages and that a number of results have been obtained for later technical/industrial use as described above. On the other side some of the work have shown that there is still demand for additional development before using the results commercially.

Due to the large amount of waste plastics in Europe thermal utilisation will be an attractive option in a number of industrial applications, however, as already described, standardisation equalisation of national laws and reduction of preparation costs must be considered and solutions must be developed. In the case of environmental standards for incineration plants an European law is already underway which will be extremely useful for utilisation of the waste plastics.

The textile waste market seems to be very limited and it can be concluded that due to the limited amount of textile wastes for thermal utilisation the material will only be of interest for local application in grite firing in some regions of Europe, however, the material can be used in combination with biomass and can improve the combustion behaviour of boilers.

The developed on-line alkali and heavy metal devices might be ready for technical application in advanced power generation technologies but also in conventional boilers, incineration plants and in boilers where biomass is burnt.

Dissemination of the main results of the project is underway and might help to distribute the developed data and information to further interested partners in research and industry elsewhere in Europe.