BIOENERGIESYSTEME GmbH

Research, Development and Design of Plants
for Heat and Power Production from Biomass

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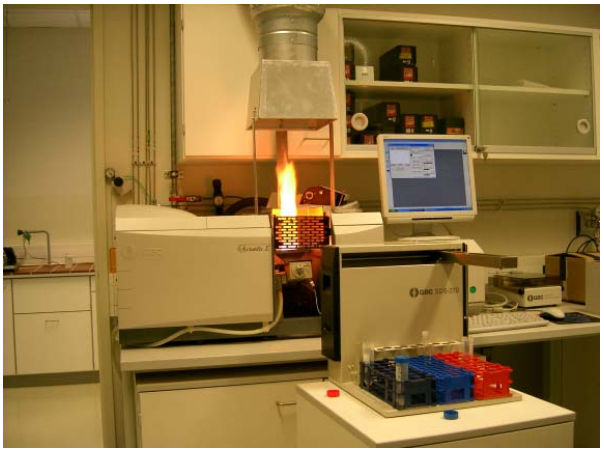
Measurements, Combustion Tests and Analyses

Key Information

BIOS BIOENERGIESYSTEME GmbH



Measurements and Combustion Tests

BIOS BIOENERGIESYSTEME GmbH has an extensive range of equipment for the performance of field tests at combustion units, gasification units and biogas units at its disposal. On the one hand conventional gas analysers and particle measurement techniques and on the other side specially designed innovative methods and devices for fly ash, aerosol and deposit sampling as well as for hot gas measurements (measurement and sampling in the furnace at temperatures up to 1,200°C) are available.

Due to the modular design of the data loggers it is possible to collect measurement data at several distant locations in a plant as well as visualise and store them on a central computer. Therefore, a high flexibility concerning the solution of different measurement problems can be gained. For data evaluation in-house developed software is available.

Measurement	***Processes***
• Conventional flue gas measurements at combustion units: O_2, CO, CO_2, NO_x, NO_2, TOC, dust, HCl, SO_x, NH_3, gaseous heavy metals	• conventional continuous methods • conventional discontinuous methods
• Emission measurements at biogas plants: CH_4, H_2, CO, CO_2, H_2S, NH_3, O_2	• conventional continuous methods
• Product gas measurements at biomass gasification units: CO, CO_2, H_2, CH4, C_xH_y, tars (including tar analyses)	• conventional continuous methods • conventional discontinuous methods
• Measurement of the flue gas temperatures in furnaces and boilers of biomass combustion units using suction pyrometers	• conventional continuous methods
• Measurements to determine mass and energy balances of combustion processes	• conventional continuous and discontinuous methods • conventional discontinuous methods
• Determination of the particle size distribution and concentration of aerosols and fly ashes in the flue gas	• discontinuous methods particle measurement technique • continuous methods electric low-pressure impactor
• Ash, fly ash, and aerosol sampling in biomass combustion processes for subsequent wet chemical analyses and analyses by electron microscopy	• particle sampling and analyses
• Hot gas sampling of particles in the furnace	• high temperature particle sampling
• Deposit sampling and analyses in biomass furnaces and boilers	• deposit sampling

Equipment

Conventional analysers, sensors and methods

Flue gas and product gas analyses and measurements - continuous methods

Parameter	Method	Device
O_2	Paramagnetic	Rosemount NGA 2000
CO/CO_2	NDIR	Rosemount NGA 2000
TOC	Flame Ionisation Detection	Rosemount NGA 2000
TOC	Flame Ionisation Detection	Bernath Atomic 3005
NO_x/NO_2	Chemiluminescence	ECO Physics CLD 700 EL ht
O_2, CO, NO	Electrochemical	Testo 350
H_2	Heat conductivity	Rosemount NGA 2000
CH_4, CO_2	Infra-red technique	GA2000+ Landfill gas analyser
CO, H_2S, NH_3, O_2	Electrochemical	GA2000+ Landfill gas analyser
CO, NO, NO_2, N_2O, HCN, HCl, SO_2, NH_3, CH_4, several hydrocarbons	FT-IR	Ansyco GASMET DX-4000
Pressure	Two wire technique pressure gauge	Contrans P AMD 230
Differential pressure	Two wire technique pressure gauge	Contrans P ASK 800
Temperature	Resistance, thermal stress	
Gas humidity	Thermo-Hygrometer	Jumo B90.7023
Gas velocity	Prandtl-tubes, calorimetric	

Flue gas analyses in operation at the pilot-scale combustion plant

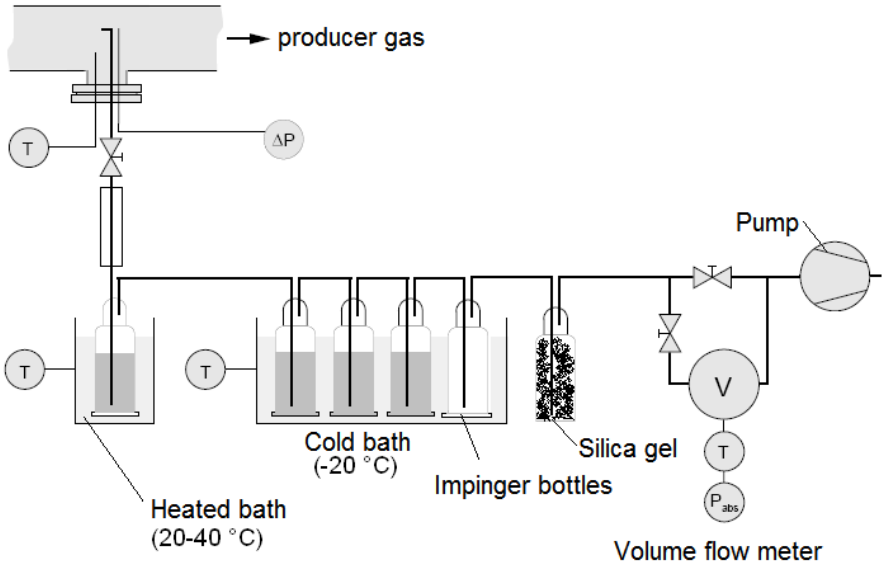
Flue gas analyses in combustion plants - discontinuous methods

Parameter	Method
SO_x- and HCl-concentration in the flue gas	Method according to VDI 3480; gas sampling with heated probe, dust removal and collection of acid compounds in distilled water with H_2O_2, NaOH. Detection by HPLC.
NH_3-concentration in the flue gas	Gas sampling with heated probe, dust removal and collection in H_2SO_4. Detection according to Kjeldahl.
Hg-concentration in the flue gas	Gas sampling with heated probe, dust removal and collection of Hg in cooled H_2SO_4 and diluted nitric acid. Detection by HGAAS or ICP-MS.
Heavy metal vapours in the flue gas	Gas sampling with heated probe, dust removal and collection of heavy metals in cooled diluted nitric acid. Detection by absorption spectrometry (FAAS, ICP-OES or GFAAS) or mass spectrometry (ICP-MS).

Flue gas sampling and gas scrubbing for the determination of SO_x, HCl, NH_3, Hg und gaseous heavy metals in the flue gas

Product gas analyses in gasification plants - discontinuous methods

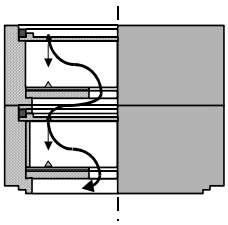
Parameter	Method
Tar sampling and tar analyses	Gravimetric method according to the „Tar Protocol“. Adsorption of tars in propanol at -20°C; evaporation of the solvent in a vacuum dryer and subsequent gravimetric determination of the tar content as well as tar analyses regarding C, H and N.
Gas sampling tube	Discontinuous product gas sampling in a sampling tube and subsequent analyses by means of gas chromatography and mass spectrometry (GC-MS) regarding CO, CO_2, H_2, CH_4, O_2 and N_2.



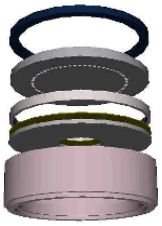
Schematic drawing of the tar sampling train

Particle measurement techniques

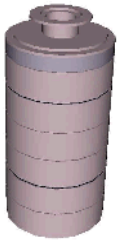
Parameter	Method
Total dust concentration in flue gases	*Method:* Gravimetric method according to VDI 2066. *Device:* Ströhlein ST E 4 *Principle*: For a certain period a slipstream of the flue gas is sucked through a quartz wool filter, where the dust particles are precipitated. The dust concentration in the flue gas is calculated by the mass change of the filter divided by the flue gas volume sucked through the filter. To achieve representative sampling, the slip stream must be taken with the same velocity as the flue gas has at the sampling point (isokinetic sampling).
Particle size distribution and concentration of aerosols in the flue gas (discontinuous method)	*Method*: Low-pressure cascade impactor *Devices*: Hauke LPI30, cut diameters: 8/4/2/1/0.5/0.25/ 0.125/0.0625 µm Dekati DGI, cut diameters: 2.5/1/0.5/0.2 µm *Principle*: A slip stream is isokinetically sampled from the flue gas channel and sucked through the impactor. The impactor consists of several stages. In each stage the flue gas changes its flow direction and particles which are too big to follow the streamlines of the flue gas, are precipitated.
Particle size distribution and concentration of aerosols in the flue gas (continuous method)	*Method*: Electrical low-pressure cascade impactor *Device*: Dekati, 10 lpm *Principle*: At the ELPI inlet particles are charged and then pass several impactor stages. As soon as a particle is separated from the flue gas, it looses its electrical charge. The resulting current is measured for each impactor stage and from these data, the particle size distribution is determined (as a number size distribution). Therefore, the ELPI provides the possibility of quasi-continuously detecting the particle size distribution and concentration of aerosols and fly ashes in the flue gas within a size range between 0.03 and 8.97 µm in intervals down to 1 second. The ELPI is especially applicable for basic research concerning influencing parameters on aerosol (fine particle) formation in combustion plants as well as for the determination of separation efficiencies of fine particle precipitation devices.



particle separation in the impactor



scheme of one impactor stage

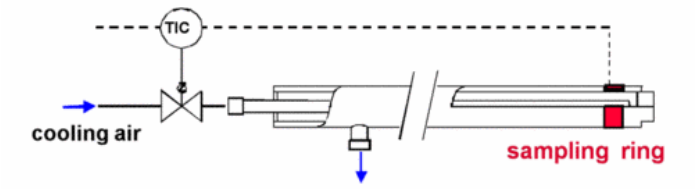


assembled cascade impactor

Deposit sampling

Parameter	Method
Deposit sampling and analyses	*Method:* Sampling with an air cooled deposit probe and subsequent analyses by SEM/EDX *Device*: in-house development *Principle*: • A deposit probe consists of an air cooled tube at which a sampling ring is mounted. • The deposit probe is introduced into the furnace for a certain period. • The surface temperature of the sampling ring is controlled by the cooling air. Thereby it is possible to simulate the surface of a boiler tube. • The sampling ring is weighed before and after exposure to the flue gas and the ash deposit build-up on the ring is determined in g/m^3/h. • Fly ash and aerosol deposits, which have been formed on the sampling ring, are afterwards analysed concerning their structure and chemical composition by using electron microscopy (SEM/EDX). These results represent a basis for the definition of guidelines concerning the melting behaviour of deposits and corrosion risks. • By these measures an evaluation of the risk for deposit build up during the combustion of a certain fuel at certain boiler tube surface temperatures is possible.

Deposit probe in operation



Scheme of the deposit probe

Sampling ring with deposit

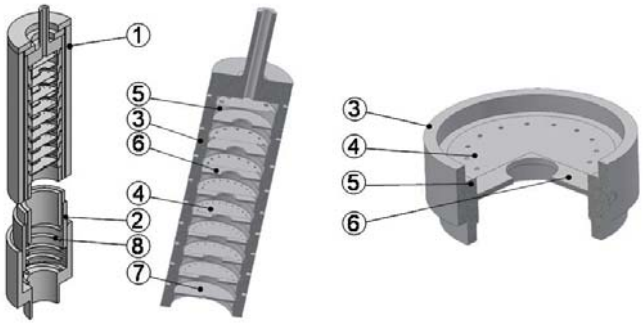
Innovative methods

High-temperature particle sampling

To facilitate particle sampling for subsequent analyses by wet chemical measures and electron microscopy even from a high-temperature environment (e.g.: from the furnace), a special high-temperature low-pressure impactor has been developed in cooperation with the Institute for Process and Particle Engineering, Graz University of Technologies. This device can be applied for in-situ particle sampling at temperatures up to 1,100°C.

High temperature impactor in operation

High temperature impactor immediately after sampling



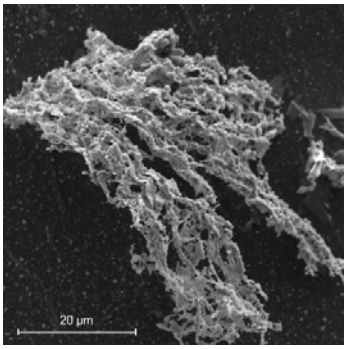
1...outer casing, 2...inner casing, 3...shell, 4...orifice plate,
5...spacer ring, 6...stagnation plate, 7...critical orifice, 8 ... spring

Scheme of the High temperature impactor

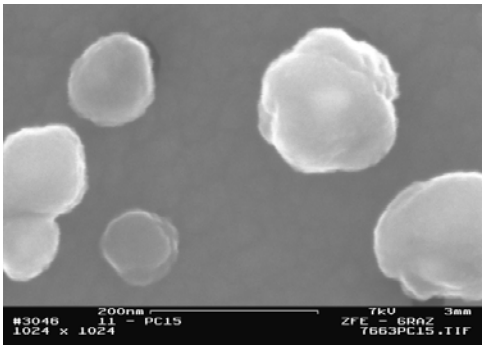
Particle sampling for subsequent analyses by wet chemical measures and electron microscopy

As an additional option the fly ash sampled with the total dust sampling equipment according to VDI 2066 as well as aerosol samples taken with the conventional low-pressure impactor can also be analysed concerning their chemical composition by wet chemical methods.

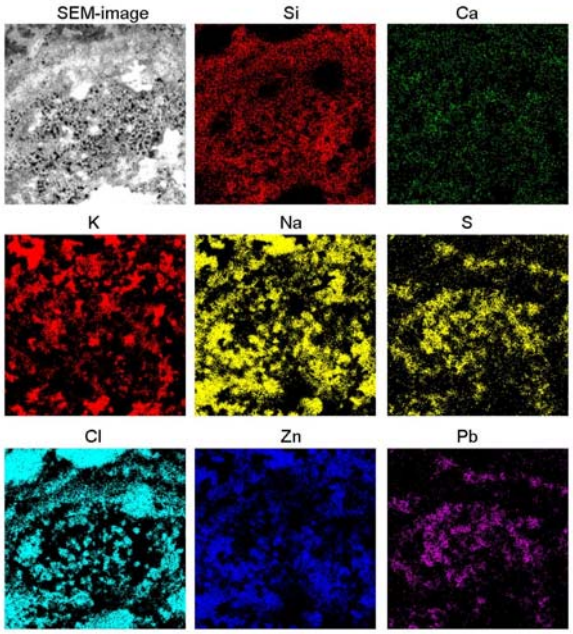
Furthermore, in co-operation with the Institute for Process and Particle Engineering, Graz University of Technology, and the Research Institute for Electron Microscopy, Graz University of Technology, BIOS BIOENERGIESYSTEME GmbH has developed special particle sampling methods, which facilitate analyses of single particles concerning their shape, structure and chemical composition by scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDX).



SEM-image of a coarse fly ash particle sampled during beech combustion



SEM-image of aerosols sampled during bark combustion



SEM-image and element mapping of aerosols sampled with the High-temperature impactor in the hot flue gas at superheater inlet of a waste fired combustion plant
(higher colour intensities indicate higher element concentration levels)

Fuel characterisation and combustion tests

Thermal analyses

Based on a close collaboration with the BIOENERGY 2020+ centre of competence and the Institute for Process and Particle Engineering, Graz University of Technology, a simultaneous TGA-DTG-DSC analyser (STA 409 CD, NETZSCH) coupled with a mass spectrometer is at the disposal of BIOS. With this device samples up to 25 g can be investigated at a TG-resolution of 5 µg in a temperature range between 25 and 1,450°C. Additionally, different gas phase atmospheres (oxidising, reducing, inert, Cl-, S- and/or moisture containing) can be applied.

With this device biomass fuels can be investigated concerning their thermal decomposition behaviour. Furthermore, ashes, deposits and slags can be investigated concerning their behaviour at different temperatures and gas phase conditions. Additionally, due to the coupling with the mass spectrometer, the possibility is given to exactly control the gas phase composition during a test and to identify elements and compounds released from the samples during the thermal treatment. This TGA-MS-coupling offers a broad range of new possibilities in the field of biomass fuel, ash, deposit and slag characterisation.

Simultaneous TGA-DTG-DSC analyser with MS

Lab-scale reactor

In co-operation with the Institute for Process and Particle Engineering, Graz University of Technology, BIOS has developed a laboratory reactor. The reactor is mainly used for test runs to determine relevant basic parameters concerning the combustion of different biomass fuels.

Fields of application

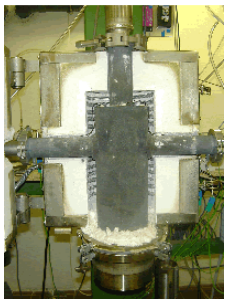
- Determination of the burnout behaviour of biomass fuels.
- Determination of the release of gaseous compounds from the fuel during biomass pyrolysis, gasification and combustion.
- Determination of the release behaviour of ash forming compounds.
- First indications concerning ash melting behaviour.

Layout

The lab-scale reactor consists of a cylindrical retort (height 35 cm, inner diameter 12 cm) which is heated electrically by two separated PID-controllers. The fuel is put in a cylindrical holder of 100 mm height and 95 mm in inner diameter. Both parts are made of fibre-reinforced silica carbide (SiC)-ceramics to avoid reactions of CO, NO and ash with the wall and to avoid oxygen entering the reaction zone. The mounting and vessel for the fuel bed are mounted on a plate which is placed on a mass balance. Air or a O_2/N_2 mixture are introduced through a porous plate at the bottom of the fuel bed. A liquid sealing filled with thermal oil (Therminol 66) is used to separate the mass balance and the reactor mechanically.

With this setup it is possible to measure the mass reduction of the sample during the gasification/combustion process continuously. The sample is introduced into the pre-heated reactor and therefore, a rapid heating, which is well comparable with the one in real thermal conversion processes, can be achieved. The composition of the gases produced can be measured by extraction of gas samples from the retort and application of conventional flue gas analyses (FT-IR, CLD, ND-IR). The initial sample as well as the residues are analysed and therefore, also detailed information about the release of inorganic species from the fuel to the gas phase is obtained.

Reactor including process control and in-situ FT-IR spectrometer



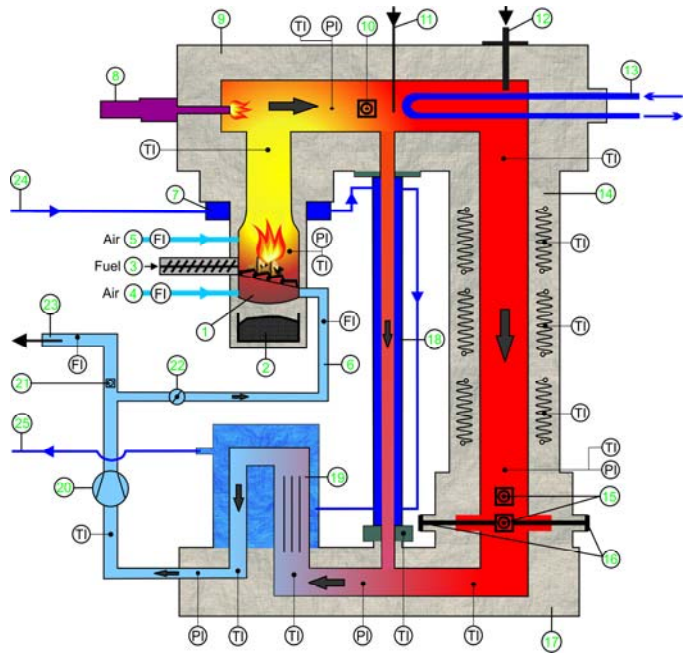
Retort and electrically heated furnace

Fuel and residues (ashes) from a test run with beech wood chips

Fuel and residues (ashes) from a test run with straw pellets

Biomass furnace coupled with a drop-tube

Based on co-operations with the BIOENERGY 2020+ centre of competence, a special and unique device for the investigation of the combustion behaviour of biomass fuels as well as of deposit formation, erosion and corrosion in heat exchangers is available for BIOS. The testing facility consist of a continuously fed grate-fired furnace (55 kW_{NCV}), which can be operated with chipped and pelletised biomass fuels. The flue gases are led over a well isolated secondary combustion zone and an upper connection duct to an electrically heated drop-tube. The drop-tube is made of a 2 m long SiC pipe and can be externally electrically heated in order to adjust the temperature and flow conditions at its outlet. There, a measurement port for gas, particle and deposit sampling and measurements is installed.



1 continuously fed grate-fired furnace (12-50 kWNCV)
2 ash tray
3 fuel supply
4 primary air
5 secondary air
6 flue gas recirculation
7 water cooled section around secondary combustion chamber
8 gas burner (8 – 90 kW)
9 upper connection duct
10 measurement port for high temperature impactor and high temperature gas sampling
11 injection port for additives
12 injection port for ash particles
13 radiatively cooled section
14 electrically heated drop-tube
15 measurement ports for gas, particle and deposit sampling
16 optical ports
17 lower connection duct
18 water cooled bypass
19 water cooled heat exchanger
20 flue gas fan
21 measurement port in flue gas channel (O_2, CO, CO_2, NO_x OGC, PM_1, dust)
22 valve for flue gas recirculation control
23 flue gas duct to chimney
24 water inlet
25 water outlet
TI…temperature measurement, PI…pressure measurement
FI…flow measurement

Schematic drawing of the biomass furnace coupled with a drop-tube

Within dedicated test runs it is therefore possible to determine the combustion and release behaviour of various biomass fuels in a fixed-bed system as well as to evaluate particle and deposit formation behaviour under continuous operation conditions. Thereby, the temperature profile of the flue gas can be adjusted by a cooling device in the upper connection duct as well as by the heating of the drop tube. By these measures it is possible to simulate the temperature conditions at the inlet of for instance hot water boilers or superheaters of steam boilers.

The combustion reactor coupled with a drop-tube therefore represents an efficient application oriented possibility to investigate different biomass fuels concerning their combustion and release behaviour as well as to investigate the deposition, erosion and corrosion behaviour of fly ash particles and condensable ash forming vapours on heat exchanger surfaces under continuous operation conditions. The data achieved form a valuable basis for advanced fuel characterisation and especially for the development of appropriate deposit formation and corrosion models.

Combustion tests at pilot-scale combustion plants

Based on co-operations with the BIOENERGY 2020+ centre of competence and an Austrian furnace and boiler manufacturer pilot-scale combustion plants for combustion tests with various types of biomass fuels are available for BIOS. These combustion plants, which have especially been designed for the performance of such test runs, are based on moving grate combustion technologies and hot water boilers (180 and 350 kW_{th}). Especially for the development of combustion technologies for "new" and regarding their combustion behaviour not well known biomass fuels, tests runs at these plants are of outstanding relevance with respect to fuel characterisation and the subsequent conception and design of real-scale plants.

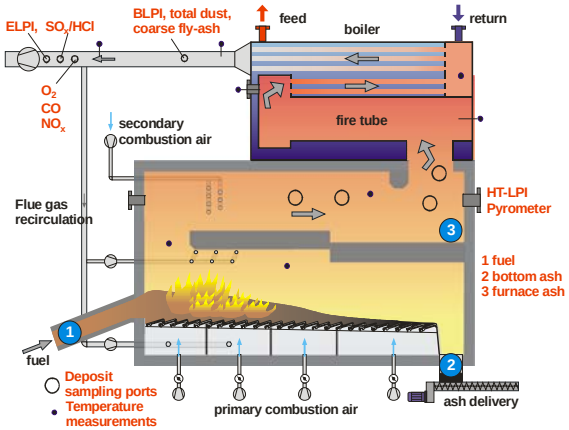
Within dedicated test runs with the respective biomass fuel, which usually last for several days, plant operation data are collected by the process control system and additionally, samples from all relevant in-going and out-going streams are taken. Usually the following parameters are determined and samples are taken:

- flue gas composition,
- temperatures and volume flows of the flue gas in different plant sections,
- furnace and boiler temperatures,
- deposit formation in furnaces and boilers (applying deposit probes),
- particle size distributions, concentrations and chemical compositions of fly ashes and aerosols (fine particulates) in different sections of the plant,
- fuel and ash sampling and subsequent chemical analyses of the samples taken.

As a first step during the evaluation of the test runs, mass, energy and element balances over the respective plant are calculated. Based on these balances on the one hand a plausibility check of the measurement results is performed, and on the other hand, the behaviour of certain elements of interest is studied. In the following the results of the test runs are evaluated with special respect to the:

- combustion behaviour of the fuel investigated,
- formation of hazardous gaseous emissions (NO_x, HCl, SO_x, heavy metals),
- aerosol and fly ash formation,
- formation and chemical characterisation of ash deposits as well as evaluation of their potential for corrosion
- slagging behaviour of the ashes formed.

The data gained from these evaluations form an important basis for the characterisation of a new biomass fuel and also represent a starting point for the subsequent development, conception and design of an appropriate combustion plant including flue gas cleaning system which is tailored to the demands of the respective fuel.



Typical set up for a combustion test run with a new biomass fuel

1 fuel sampling
2 bottom ash sampling
3 furnace ash sampling

BLPI … Berner-type low-pressure impactor
ELPI … electrical low-pressure impactor
HT-LPI … high-temperature low-pressure impactor

Analyses

BIOS BIOENERGIESYSTEME GmbH offers a wide range of chemical and electron microscopic analyses. Due to a co-operation agreement with the BIOENERGY 2020+ centre of competence, not only own equipment but also external laboratories and equipment can be used. Additionally, a close co-operation with the Research Institute for Electron Microscopy and Fine Structure Research at the Graz University of Technology guarantees an unmatched quality of data even from the smallest sample available. Therefore, a high flexibility concerning the solution of different analytic problems in the field of thermochemical biomass conversion is guaranteed.

Activities

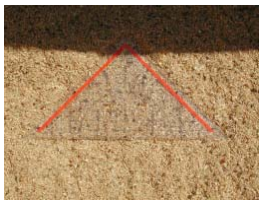
Wet chemical analyses of

- fuels
- substrates
- digestates
- ashes and aerosols (fine particulates)
- deposits
- condensate and condensate sludge
- boiler water

regarding

- major elements (C, H, N, S, Cl)
- minor elements (e.g. Si, Ca, Mg, K, Na, Fe, P)
- trace elements (heavy metals)
- sample specific parameters such as ph-value, electric conductivity, calorific value, moisture content, ash content, organic and inorganic carbon, organic dry substance (ODS), chemical oxygen demand (COD), SO_3, SO_4, NH_3, NH_4, NO_3, NO_2, etc.


wood chips (spruce)


sawdust


wood pellets


bark


waste wood


straw


Switchgrass


Cynara


Miscanthus


reject from the paper industry

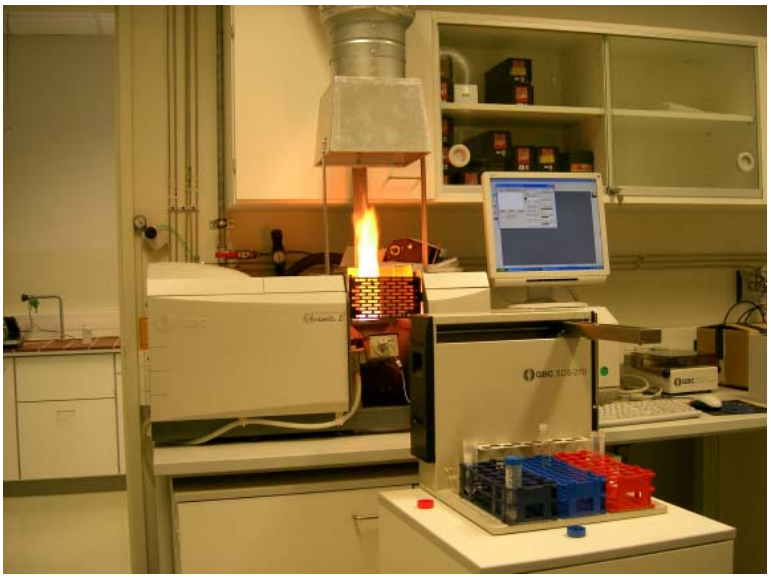

olive residues

cotton residues

Analytical Equipment

Besides the measurement equipment already mentioned a huge pool of additional sample preparation equipment, measurement equipment and analysers is available covering a broad field of applications.

- Inductive coupled Argon-plasma atomic emission spectrometer SPECTRO ARCOS
- Atomic absorption spectrometers (FAAS)
  - Flame atomic absorption spectrometer GBC Avanta Sigma
  - Graphite furnace atomic absorption spectrometer GBC
- UV/VIS Spectrometer
  - GBC Cintra 20 with thermostatted 6 x 1 cell holder
- Elemental analyser
  - C-, H-analyser LECO RC-612-C
- Calorimetry
  - IKA C200
- Digestion devices
  - Micro wave digestion device Paar Multiwave 3000
  - AOD 1 Decomposition System IKA
- Liquid chromatograph
  - ICS 90 Dionex
  - AGILENT 1200
- Milling and mechanical sample preparation devices
  - Power Cutting Mill pulverisette 25 Fritsch
  - Variable Speed Rotor Mill pulverisette 14 Fritsch
  - Planetary Mono Mill pulverisette 6 Fritsch
- Ultra Pure Water Systems
  - TKA GenPure
  - TKA Pacific UP/UPW



Atomic absorption spectrometers (FAAS)