Combined Thermal Use of Biomass and Treatment of Wastes

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Content

Abstract

The decentralised usage of biomass in small units is quite propagated. For the thermal treatment of wastes (municipal wastes, hazardous wastes and special fractions of wastes) normally large centralised units are the standard solution in Europe. In this project a modular concept for the complete spectrum of fuels, as indicated above, was developed. The corresponding pilot and demonstration plant is localized at the University of Duisburg-Essen in Essen, is operated by the Institute of Environmental Process Engineering and Plant Design (LUAT) in cooperation with Fhg UMSICHT and consists of a water cooled grate firing system, a steam generator and a complete flue gas cleaning device. Full scale plants based on this concept will have a thermal load 5, 10 and 15 MW. The water cooled grate firing concept allows the combustion of fuels with a large variety of lower calorific values between 6-8 and up to 18-20 MJ/kg. The after combustion chamber is designed for minimum temperatures of 850 °C and a residence time of 2 s. Thus, also very restrictive emission limits for carbon monoxide and hydrocarbons can be achieved by primary measures. The flue gas cleaning in the pilot and demonstration plant is very flexible and consists of a cyclone, bag filter, catalytic/adsorptive mercury removal and a final adsorption stage. In addition an infrared camera is installed to observe and control the fuel combustion on the grate.

In parallel, a test method for characterizing the secondary fuel had been developed. This method uses an oxidizing process in combination with an elementary analysis and a heat conductivity detector to determine the combustion behaviour.

For different fuels (biomass, waste and mixtures of both) detailed experiments have been carried out. Some characteristic results will be presented to demonstrate primary and secondary combustion in dependence of different process parameters like oxygen content, primary to secondary air distribution, furnace temperatures and others. Also the usage of the infrared camera is shown.

Keywords: Use of Biomass; Thermal Treatment of Waste; Grate Firing System; Fuel Characterisation; Infra Red Camera; MARS Plant Concept; Experimental Results

1 Introduction

Biomass usage is very attractive in many EU-countries because of the following reasons:

- guaranteed revenues for power production
- CO_2-neutrality gives advantages concerning emission trading

Thermal treatment of industrial wastes is interesting for production sites, which often have mono-graded wastes from production processes. This condition allows a well specified plant. This leads to the main advantages for decentralised plant concepts in an industrial environment:

- costs for the treatment can be reduced
- power and heat can be used internally

An other aspect for a treatment with power/heat production for municipal wastes is interesting for isolated areas. Here we have a challenge for:

- rural areas
- islands
- developing countries

For these applications a lot of mathematical modelling has been done by the institute [1-11]. For model validation and for a investigation of the grate combustion of different fuels the MARS®-plant was built up.

2 MARS® Plant

The acronym MARS® stands for a Modular Plant concept with an optimisation of the solid residues. Of course, the limits for gaseous species also can be reached by primary or secondary measures.

The plant consists, as mayor components, of a furnace with a water cooled grade firing system, an after combustion chamber, a heat extraction, a dust filter, a catalyst, an adsorber and an exhaust fan (see **Fig. 1**).

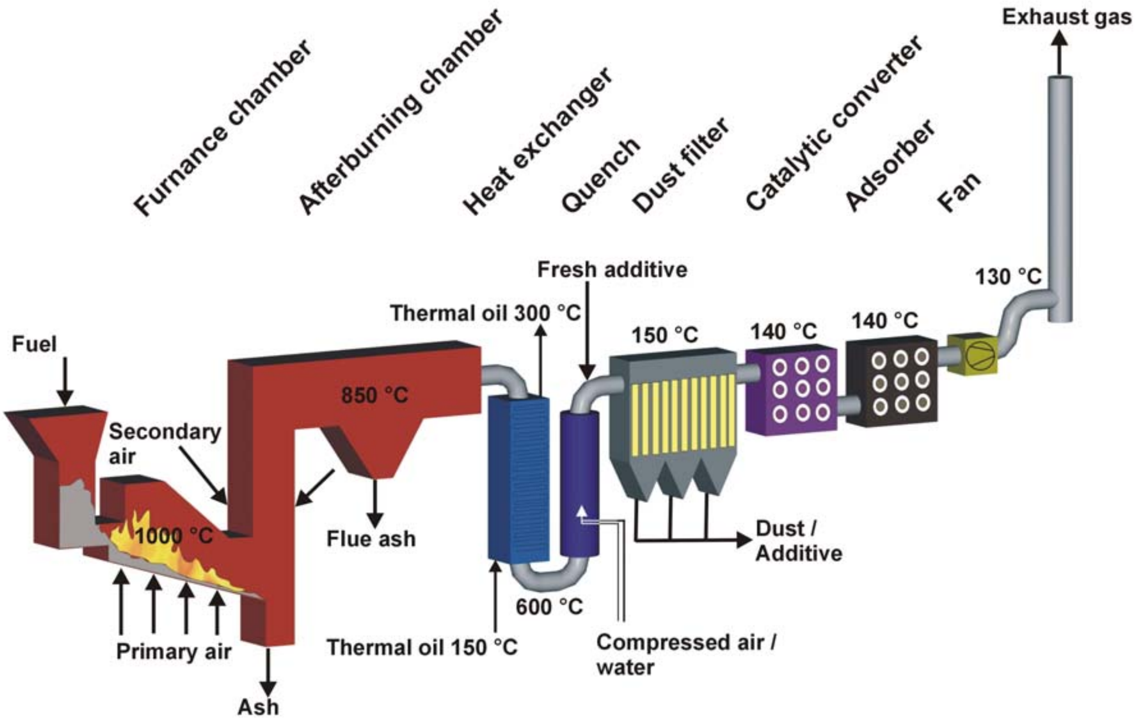

Fig. 1: MARS® Plant – schematic view

The furnace geometry is a parallel flow system, see **Fig. 2**. By the water cooled grate firing concept fuels with a lower calorific value between 8 and 22 MJ/kg can be handled. In this range the gas phase temperatures can be stabilised. Below 8 MJ/kg a oil fired auxiliary burner can be added to reach up with after combustion gas temperatures of 850 °C or higher. For LCVs up to 14 MJ/kg the water cooling for the grade bars can be stopped, because of the very good dry operation behaviour of the system.

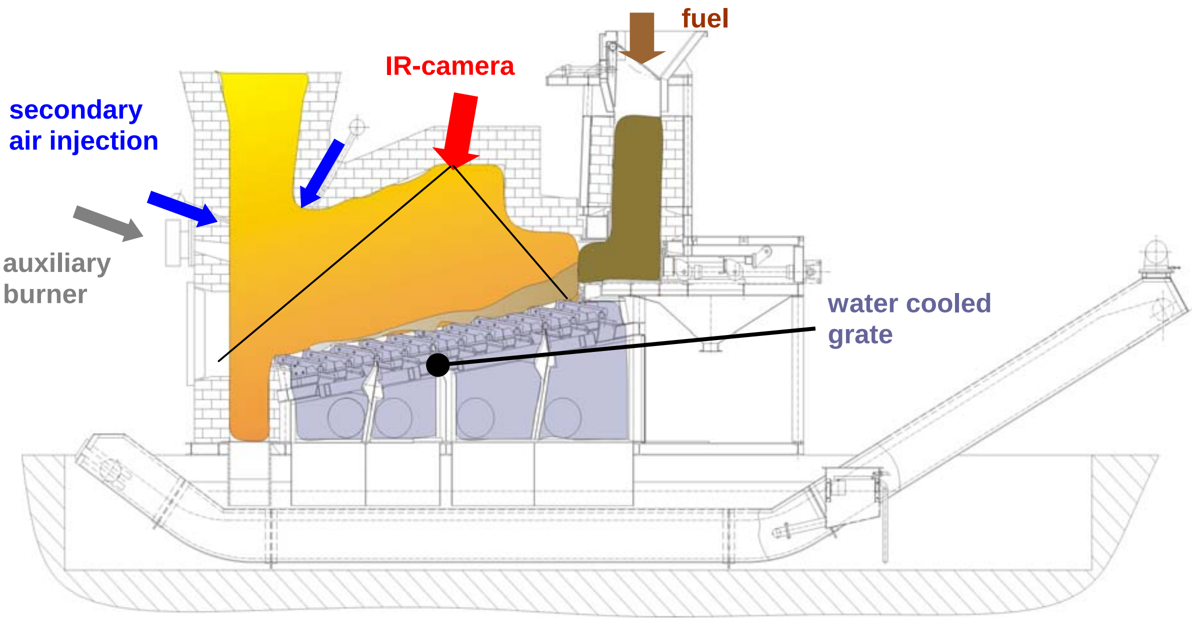

Fig. 2: MARS® Plant – cross section

The main characteristics of the MARS® plant can be seen from **Tab. 1**.

Thermal capacity	1 MW
Main components	water cooled grate
	flexible furnace geometry
	after-combustion chamber
	flexible heat extraction
	flexible flue gas treatment
Fuels	high flexibility in fuel quality (LCV)
	range from biomass to waste
Measurement options	very good measurement access
	good measurement equipment

Tab. 1: MARS® Plant – main characteristics

The plant has been in operation since over 2 years and a lot of different fuels and mixtures of fuels has been tested. The fuels are listed in section 3 of this paper, the used measuring equipment in section 4 and some characteristic results in section 5.

The main aim of this project is to determine and characterise the combustion behaviour of different fuel, specially secondary fuels. The optimisation of the combustion process in terms of primary gaseous emissions and solid residues is also of great importance. Last but not least the evaluation of the raw gas concentrations for the flue gas cleaning devices is of great interest for the industrial partners.

3 Fuels Used and Fuel Characterisation

The following fuels/wastes have been investigated in the MARS® plant:

- wood pellets
- wood chips
- scrap of paper + plastic scraps in different mixture fractions
- industrial wastes
- wastes similar to municipal wastes
- residual materials
- residual wastes

The main objectives of the trials were the combustion behaviour of the fuels, the raw gas composition and the flue gas cleaning. Investigating the general combustion behaviour means a complete oxidation of CO and hydrocarbons as well as a very low content of unburnt material in the solid combustion residues. Optimising these qualities means to control the following variables (see also **Fig. 3**):

- primary to secondary air ratio,
- primary air distribution to the different zones to control the drying, gasification and combustion processes,
- secondary air distribution between the front and the rear wall to optimise the gas phase oxidation,
- secondary air injection conditions (number and inclination of nozzles),
- water cooling of the grate bars to save final burn-out of the fuel and/or
- specific thermal load in the furnace.

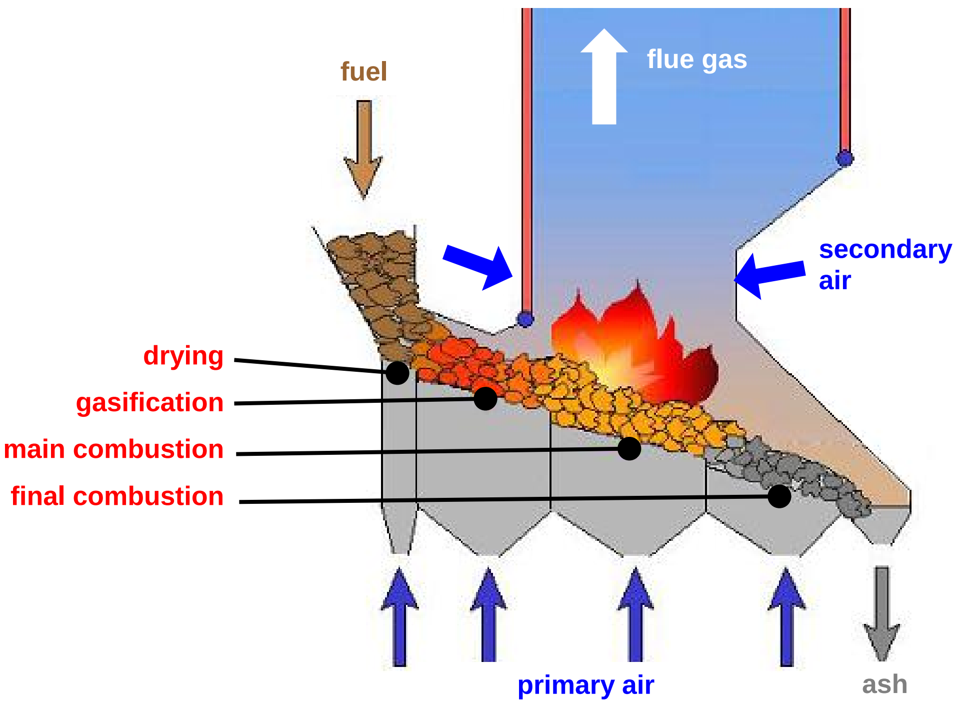

Fig. 3: Main processes in technical plant applications

In **Fig. 3** the different partial processes in the fuel layer are marked schematically. In reality the processes take place simultaneously and are not exactly related to the different primary air supports. For fuels like biomasses and wastes the combustion behaviour is very important for a description and control of the furnace process quantities.
For characterising the different fuel in a more scientific way a special measuring equipment has been developed (**Fig. 4** and **5**) [12].

A small representative portion of the fuel to be characterised and investigated by a modified elementary analysis method [12].
For producing this probe a bigger amount of material was grinded by a cryogenic milling system and homogenised. It is heated up externally by electric heating devices in the probe chamber. The probe generates volatile matter which is released. In a second stage the volatile species are oxidised to CO, CO_2 and H_2O which can be analysed. Doing this procedure in "steps" gives some kinetic information on this process. The basic idea is schematically shown in **Fig. 4**.

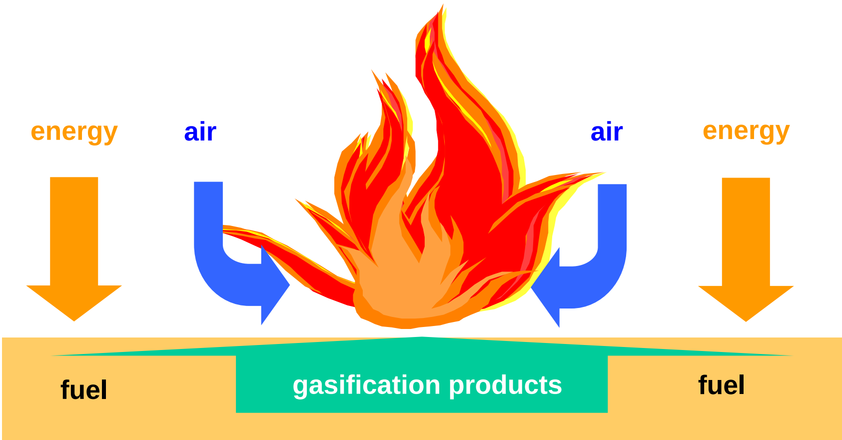

Fig. 4:
Principle processes taking place during the pyrolysis and combustion
[12]

Fig. 5 shows the measuring equipment itself. It consists of an elementary analyser (right hand side) and a heat conductivity measurement (WLD, left hand side).

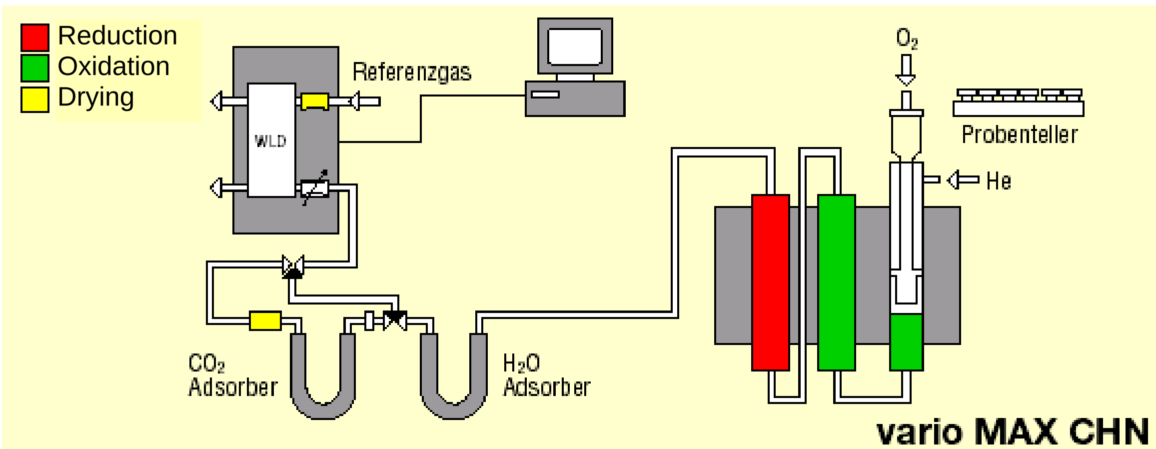

Fig. 5: Measuring equipment [12]

In contrary to normal elementary analyser the first oven is operated without any oxygen to produce the volatile species. These can be analysed. In the arrangement of **Fig. 5** these components are oxidised to CO_2, H_2O and nitrogen components in the second oven. CO_2 and H_2O are absorbed and the N-components are reduced to N_2, which is analysed in the WLD. Consecutively also CO_2 and H_2O are desorbed and also analysed by the WLD. In this way the volatile species concentrations can be determined. By an empirical formula the lower calorific value (LCV) of the volatiles can be calculated. Doing this procedure at different temperatures gives the volatile release as a function of the temperature (**Fig. 6**). The remaining fuel is then oxidised to determine the fixed carbon contend (C_{fix}). On the grate the position of the fuel is a function of the time. The position is also correlated to the fuel temperature. In this way these measuring results give interesting information on the heat and species release from the fuel layer on the grate.

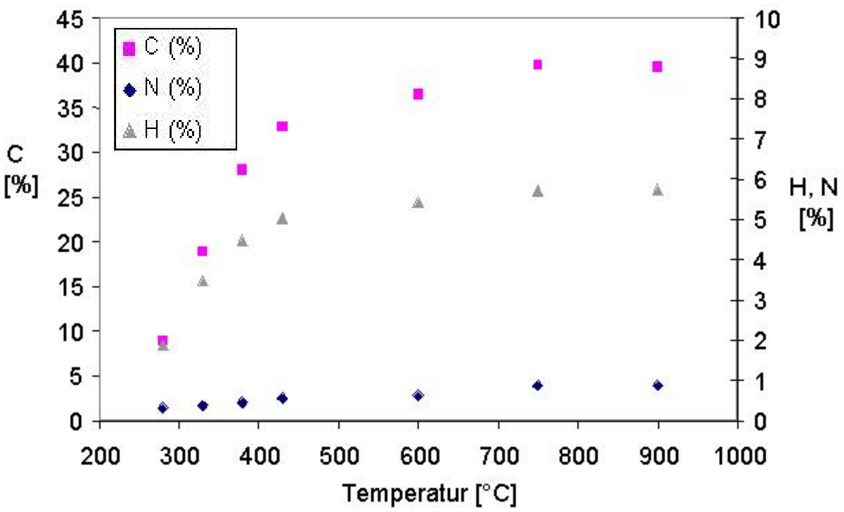

Fig. 6: Composition of the »volatiles« - specific fuel [12]

Fig. 7 shows the heat release of the fuel as a function of the grate position for a special fuel throughput. The first peak the released heat from the volatiles, the second one that from the fixed carbon. The sum of both curves give the chemically released heat from the fuel layer on the grate. This value is very important for the control of the combustion process (e.g. the primary air distribution to the different zones) and is a needed boundary condition for the mathematical modelling of the gas phase combustion.

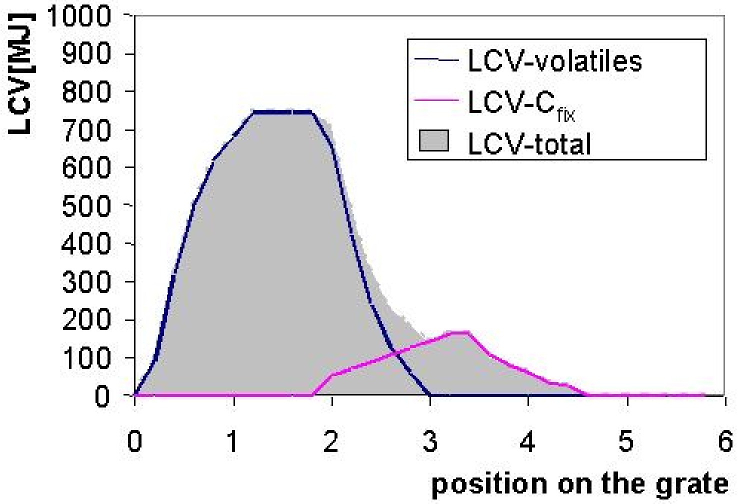

Fig. 7: Lower calorific value for specific fuel [12]

In this way some fuels has been analysed like:

- styrol,
- poly amid,
- wood,
- brown coal,
- wastes from industry
- shredder fractions and
- others.

4 Solid Fuel and Gas Phase Combustion

Infrared cameras are often used in large scaled plants for the continuous temperature measurement of the fuel bed and for the determination of the position of the fire. The principle of the optical temperature measurement is based on the thermal radiation emitted by an object. Thermal radiation is the part of the electromagnetic spectrum which is noticed as radiative heat (**Fig. 8**).

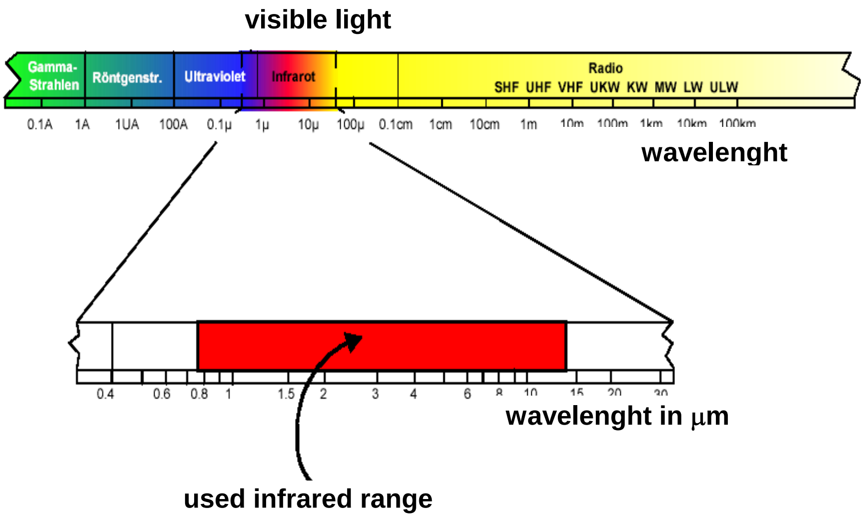

Fig. 8: Electromagnetic spectrum with usable IR-range

Contrary to visible light every object which has a temperature above the absolute origin is emitting thermal radiation. **Fig. 9** shows the typical radiation characteristic of an object at different temperatures. By measuring the radiation of an object it is possible to measure the temperature of it's surface.

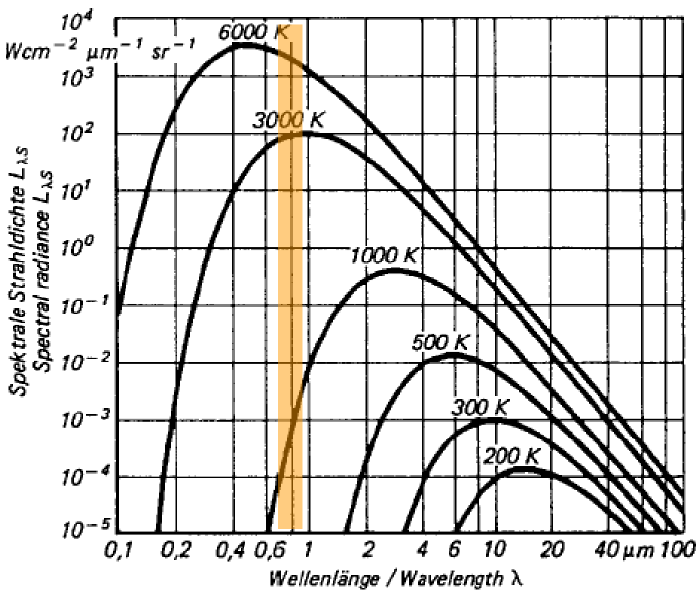

Fig. 9: Radiation characteristic of a black body versus the temperature

Optical temperature measurement of the fuel bed in furnace chambers is subject to radiance absorption by the species which occur in the flue gas. To avoid influences by absorption of infrared radiation it is necessary to choose a range of the infrared spectrum where no gas components like CO_2 and H_2O absorb the infrared radiation.

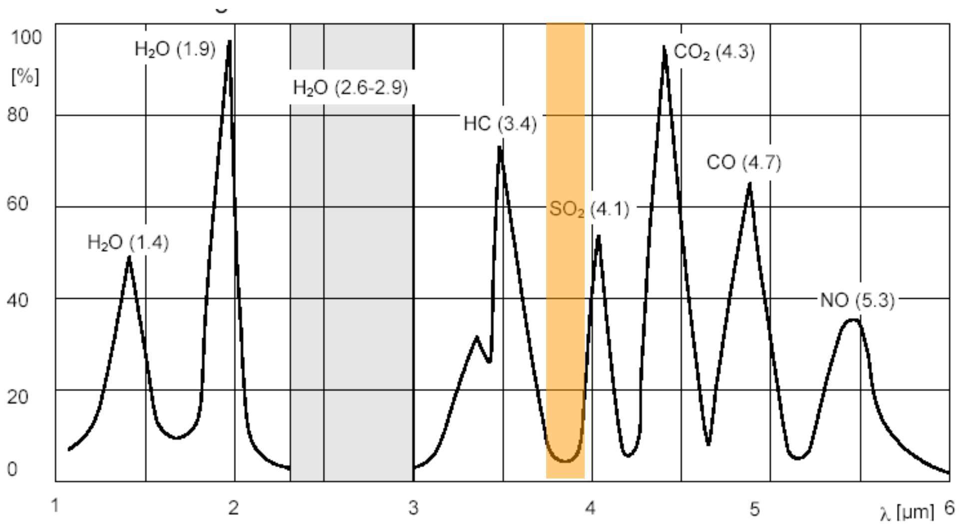

Fig. 10: Absorption/ radiation range of the flue gas

The camera which was used for the investigations comprises a flame filter which lets pass radiance with a wavelength of 3.9 µm. The camera is installed on an emergency pull out appliance at the slab of the combustion chamber (**Fig 11**). For operation it is moved into the combustion chamber through a protected opening. The important specifications are shown in **Tab. 2**.

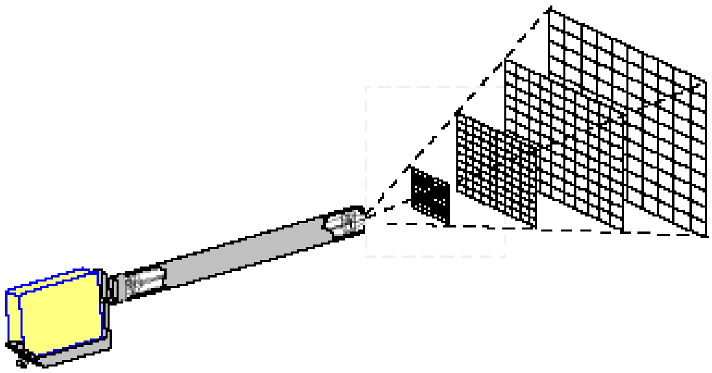

Fig. 11: MARS® Plant – IR-camera at the furnace roof

Specifications	water cooled probe	
	operation temperature	up to 2000 °C (probe)
	measuring range	600 - 1250 °C
	measuring frequency	up to 50 Hz
	resolution	100 x 100 pixels
	aperture angle	58 °
	flame filter	3,9 µm

Tab. 2: IR-camera measuring equipment - characteristic qualities

With this measuring equipment some very useful information on the combustion behaviour can be achieved. The surface temperature distribution of the burning fuel layer is shown in **Fig. 12**.

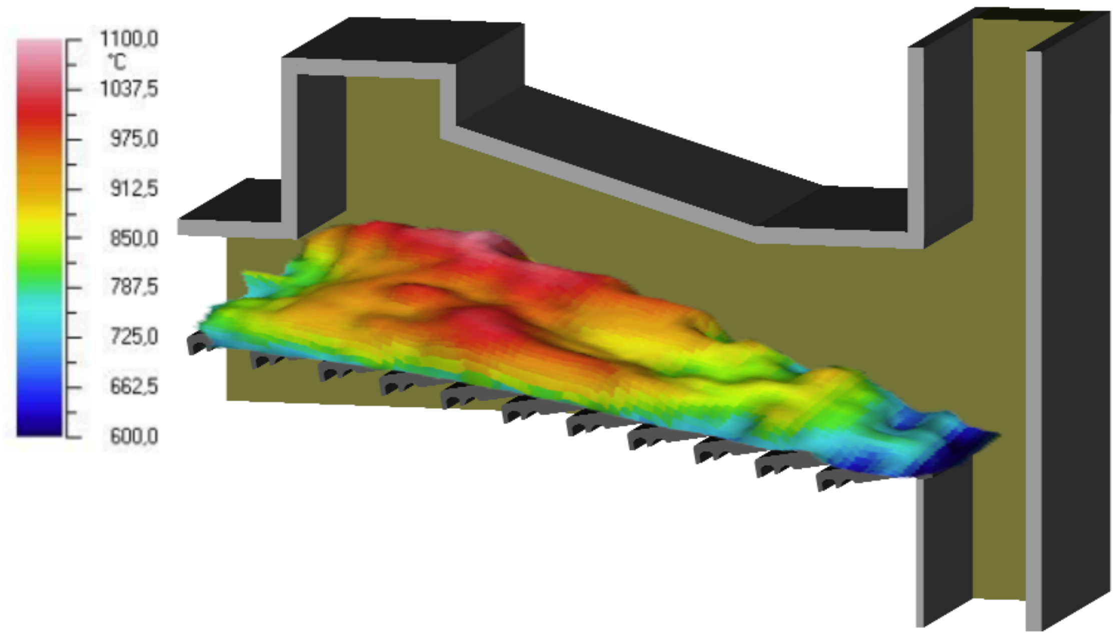

Fig. 12: MARS® Plant – Surface temperature of the combustion bed

By a digital image processing this surface can be subdivided in the primary air zones. For each zone the mean, minimum and maximum temperature can be determined. This gives the possibility for a primary air control adopted to the fuel respectively to the combustion behaviour of the fuel.

5 Experimental Results

For the different fuels, described in section 3, detailed measurement have been carried out. In **Fig. 13** a typical result of the measured species concentrations is shown for a situation, where the fuel was changed from a “biomass 1” to a “biomass 2”.

The concentration of CO is very low (below 10 mg/m^3). NO is on a level of roughly 100 mg/m^3 which can be explained by the cooling of the grate bars and therefore by the lower combustion temperatures. CO_2 and O_2 are on the expected level. The raw gas values for HCl concentration for biomass 1 are near 400 mg/m^3 , for biomass 2 near 450 mg/m^3.

The raw and clean gas concentrations can be seen from **Fig. 14**. Raw gas is in the range of 230 mg/m^3. After the bag filter values below 1 mg/m^3 can be achieved. A realistic clean gas value will be reached by adopting a much lower pressure loss over the dust filter.

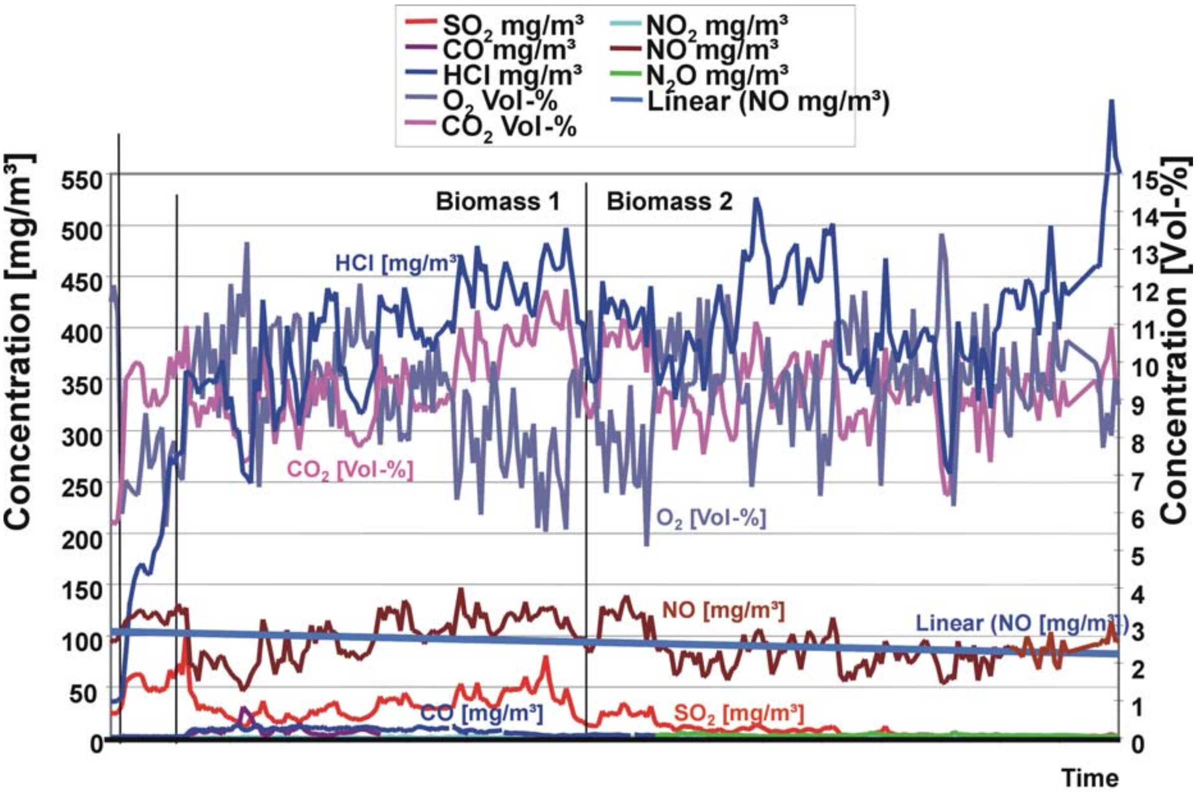

Fig. 13: MARS® Plant – Species concentration as a function of time

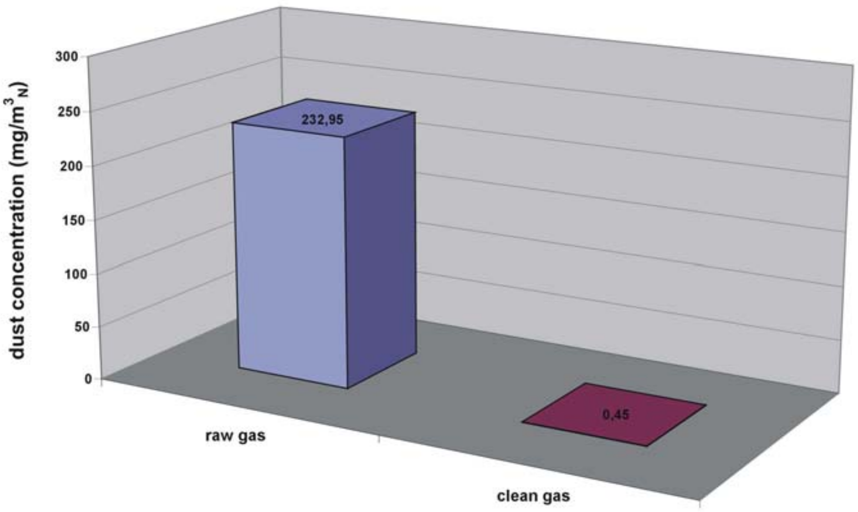

Fig. 14: MARS® Plant – Raw and clean gas dust concentrations

6 Plant Concept

All results and findings from the MARS® plant will be used for the conceptual planning for a modular plant with the thermal power of 5, 10,15 or 20 MW. The principle view can be seen from **Fig. 15**.

This concept will be proposed to the market by our industrial partners. It consists of a very compact and modularised concept which can be used for different decentralised applications for islands, hospitals and developing countries.

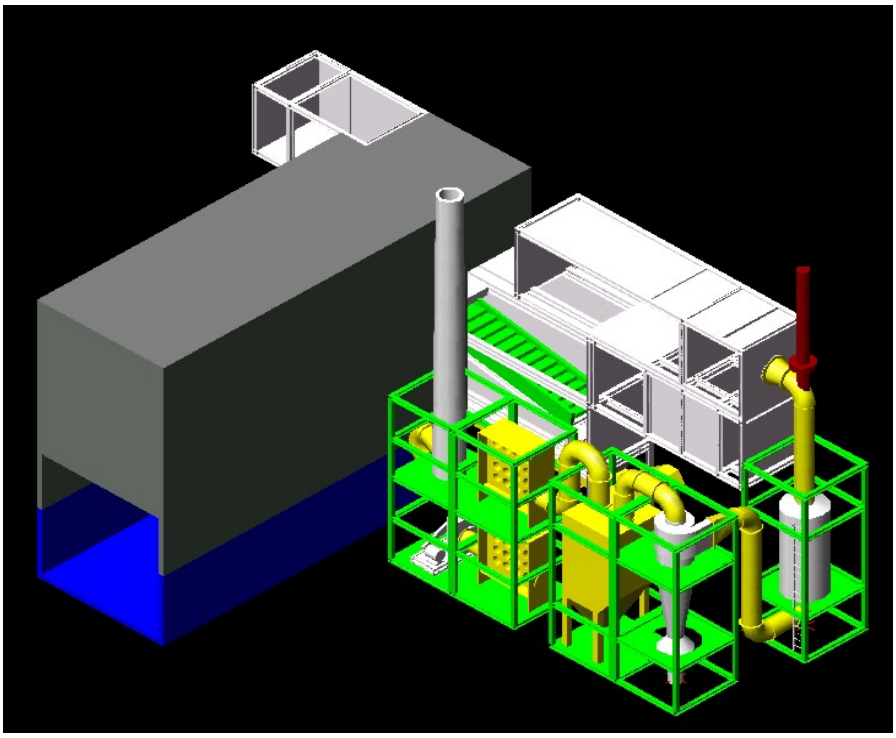

Fig. 15: MARS® Plant – Concept for a modular plant with a thermal power of 5, 10, 15 or 20 MW

7 Conclusion

The MARS® plant is used since over 2 years successfully. It has been used for fuel testing and combustion trials. In the project a fuel characterising measuring equipment has been developed and tested for different fuels. It will be further developed for a more realistic description of heterogeneous fuels. An IR-camera system was also applied for determining the combustion behaviour of the fuel by the fuel surface temperature.
The system is now on a technology level to be used in real applications.

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