"Synergies of Biomass and Solid Recovered Fuel in grate type Energy from Waste Plants"

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Abstract

Solid Recovered Fuels made from commercial/industrial and MSW type waste streams containing high heat value plastics do offer a number of synergies for biomass combustors [1]. The paper covers technical and operational synergies to increase biomass combustion efficiency in a grate fired system typical for waste to energy technology. Results from small laboratory scale tests have proven a more stable and homogeneous bed combustion behaviour. Due to the sometimes poor biomass fuel quality in biomass combustion facilities the following unfavourable operating conditions occur: boiler incrustation, fouling and slaging on the furnace /boiler walls. These effects lead to lower operating hours due to more frequent cleaning cycles [2]. The low and medium priced biomass available from the market has very low heat values (5 GJ/t) and high alkali metal content. Biomass availability in most EU countries lead to an increased amount of low grade biomass fed into grate type combustors. The efforts of the American Chemistry Council, the Institute of Technical Chemistry and PlasticsEurope have assessed the synergies through laboratory scale experiments and have continued to demonstrate the biomass and SRF synergies on a large scale pilot grate type incinerator. The results from the pilot scale confirm that SRF addition of 20 - 40 wt.-% lead to more homogeneous combustion behaviour and an increase of energy efficiency.
## Contents

1 SUMMARY..........................................................................................................................3

2 GRATE SYSTEMS – THE KLEAA FIXED-BED REACTOR AND TAMARA CONTINUOUS GRATE..........................................................................................4

3 TEST PROGRAM AND TEST PROCEDURE.................................................................8

4 BALANCING AND SCALE-UP OF FIXED BED RESULTS ........................................8

4.1 Mass, material, and energy balances of the plant..................................................9

4.2 Theoretical efficiency of the boiler .........................................................................9

4.3 Modelling....................................................................................................................9

5 RESULTS ......................................................................................................................12

5.1 Fuel characterisation ..............................................................................................12

5.2 KLEAA fixed bed results........................................................................................12

5.3 Pilot Plant Results ..................................................................................................14
  5.3.1 Balances ..............................................................................................................14
  5.3.2 Fuel bed temperature courses and Modelling....................................................14
  5.3.3 Emissions and Corrosion potential ..................................................................16

5.4 Energy efficiency.....................................................................................................17

6 REFERENCES AND PUBLICATIONS .......................................................................18
1 Summary

In Europe, solid recovered fuels (SRF) and wood based biomass are often used in power plants with grate firing systems for electrical power and heat generation. Due to the heterogeneity of these technical fuels with often high alkali and halogen contents, slaging on the combustion chamber walls and high-temperature corrosion of the boiler system occur especially in biomass power plants. These operational problems result in a reduced availability and high maintenance costs and influence considerably economic efficiencies of the power plant.

Due to the increasing operational costs for biomass plants a need for additional fuels exists. At present a deficit of SRF production capacity seems to occur [2].

As part of a joint project between PlasticsEurope Deutschland e.V. and the Institute for Technical Chemistry, Thermal Waste Treatment Division, ITC-TAB, of Forschungszentrum Karlsruhe, the potentials of optimising the combustion behaviour of mixtures of biomass with SRF were investigated.

For this purpose, several combustion experiments were performed in the KLEAA fixed-bed batch reactor of ITC-TAB to characterise the combustion behaviour of wood chips with SRF for realistic mixing ratios and other technical parameters such as primary air pre-heat temperature. The time-dependent batch combustion data were transferred from the fixed bed to the length-dependent TAMARA grate system using characteristic numbers developed by ITC-TAB.

According to the results the addition of SRF positively influences the ignition and combustion behaviour of the biomass. Combustion and energy efficiency is increased. By adjusting the operation parameters, the above-mentioned typical biomass operational problems can be minimised. Effects on corrosion are not expected. Full scale demonstration of these synergies is in the planning stage.
2 Grate systems – the KLEAA fixed-bed reactor and TAMARA continuous grate

The phases of a continuous grate furnace process, which comprise the
- ignition phase (heating up, drying, pyrolysis of the first solid fuel layer),
- combustion phase (gas and solid-phase burning, including heating up, drying, pyrolysis of the fuel), and the
- char burn-out phase,

over the length of the grate may be reproduced by an intermittent process in a fixed bed as a function of time. Hence, the findings obtained from a fixed-bed process, e.g. data on combustion, composition of the exhaust gas, heat release, etc., may be transferred to the combustion of the feedstock studied in a continuous grate furnace process. If the combustion behaviour of a standard fuel on the grate and in the fixed bed is known (in this case, wood chips), an experiment with another feedstock (SRF and mixtures with wood chips) in the fixed bed will allow for a qualitative and quantitative evaluation of the combustion behaviour in comparison to the standard fuel. Qualitative evaluation of the combustion behaviour is accomplished e.g. with the help of a video camera. Quantitative evaluation is based on characteristics. Using this approach, the results obtained in the fixed-bed reactor may be transferred to industrial processes.

KLEAA fixed bed reactor

Experimental studies for characterising the combustion properties of solid fuels were carried out in the KLEAA fixed-bed reactor. The three main components of the unit (see Figure 2-1) are the combustion chamber with the fixed bed and electrically heated furnace, the secondary combustion chamber, and the flue gas cleaning system, consisting of a heat exchanger, a filter chamber, and a carbon adsorber. The fuel bed has a volume of 10 l, which allows for the use of solid fuel fractions with a maximum particle size of about 80 mm. The furnace and secondary combustion chamber can be heated up electrically to a maximum temperature of 1100 °C. Primary air is supplied from below through a sintered metal plate and can be pre-heated up to a maximum temperature of 300 °C ([3] - [8]).
Figure 2-1: Schematic representation of the KLEAA fixed-bed reactor

The major advantage of this test facility consists in the fact that the fuels usually do not have to be crushed to determine the influence of major properties, such as particle diameter and particle shape, on the combustion behaviour. Thus, it is accounted for the heterogeneity of technically relevant fuels. By quantifying the results obtained in KLEAA using the respective characteristic numbers, transfer to a continuous process is possible. Experiments in the TAMARA pilot plant were aimed at validating the results obtained in KLEAA and at studying the emissions and formation of a coating due to the addition of SRF. For these experiments, three different settings were chosen (100% wet biomass, admixture of 20% and 40% SRF). Moreover, the increase in energy efficiency as a result of the addition of SRF was studied theoretically.

The sections below will first highlight the experiments and measurements conducted in TAMARA. Then, the experiment program, plant balances, and the results obtained will be presented.

**TAMARA pilot plant**

In the following section, detailed information on the experiment and measurement technology will be provided. Since relevant research in the field of waste combustion cannot be performed on the laboratory scale only, the TAMARA test facility was built and taken into operation in 1987. TAMARA is a German acronym and stands for “test facility for waste combustion, flue gas cleaning, residue treatment, and water purification”. It models a grate combustion plant equipped with a flue gas cleaning line.
The fuel load of the TAMARA advancing grate ranges between 150 kg/h and 300 kg/h, maximum flue gas flow is 1500 Nm³/h. The maximum thermal load is limited to 0.5 MW and steam is produced at a pressure between 5 and 30 bar. The combustion temperature is controlled by the temperature at the inlet of the post-combustion chamber and shall not exceed 1200°C.

Feeding of the fuel is controlled by the central control system. Additional feeders for shredded, granular or fine-grained matter allow for the co-feeding of various fuels and waste fractions, such as wood chips, straw pellets, limestone and post-consumer mixed plastic waste.

The advancing grate with a length of 3200 mm and a width of 800 mm is divided into 4 primary air zones, in which the grate kinematics and the residence time of the fuel are
controlled independently. The fuel residence time can be adjusted between 10 and 20 min per zone. Secondary air is supplied optionally on 3 different levels above the combustion chamber via nozzles at each secondary air inlet. Raw and cleaned flue gas recycling to all air ports is possible. A counterflow, centre flow, and parallel flow configuration of the combustion chamber is obtained by installing variable roof elements. The walls are made of SiC.

The pilot plant is equipped with sensors to monitor online parameters of the process like temperature, pressure, gas flow rate, pH values or the concentration of major constituents of the raw gas and in the stack. Furthermore, openings in the combustion chamber and in the first post-combustion chamber allow to measure concentrations and temperatures at specific points by the use of appropriate lances.

The gas cleaning line is composed of a pre-quencher to adjust the gas temperature to approximately 180°C and prevent low-temperature formation of PCDD/F in the fabric filter. For the abatement of acid gases and Hg, a separate ceramic and two Venturi scrubbers are implemented. For improved Hg removal, the pH value of the scrubbing solution is kept below 1, whereas the second scrubber is operated at pH = 7 for SO₂ removal. At the end of the flue gas cleaning line, an SCR reactor removes NOₓ from the exhaust gas.
3 Test program and test procedure

The following table gives a survey of the tests performed.

The test program simulates a technical challenge for an operator, who would like to add SRF to his biomass power plant to increase the energy efficiency and avoid slagging of the combustion chamber walls and the boiler system. The thermal load has to be kept constant, here to 0.4 MW. When increasing the NCV by adding SRF to the wet biomass, the total mass flow has to be reduced according Table 3-1.

Table 3-1: Test program

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TA 1</td>
<td>Wood chips</td>
<td>50</td>
<td>0.4</td>
<td>7.2</td>
<td>100</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Slate particles</td>
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<td>0</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>TA 3</td>
<td>Wood chips</td>
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<td>0.4</td>
<td>7.2</td>
<td>80</td>
<td>120</td>
<td>20</td>
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<tr>
<td></td>
<td>SBS2 Remondis</td>
<td>25</td>
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<td>15</td>
<td>20</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slate particles</td>
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<td></td>
<td>0</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>TA 4</td>
<td>Wood chips</td>
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<td>0.4</td>
<td>7.2</td>
<td>60</td>
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<tr>
<td></td>
<td>SBS2 Remondis</td>
<td>25</td>
<td></td>
<td>15</td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slate particles</td>
<td>0</td>
<td></td>
<td>0</td>
<td></td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

In total, three different test settings were chosen: TA1 is the reference states with combustion of wet biomass with primary air pre-heating. In TA3 and TA4, 20% and 40% SRF were added, respectively. To protect the grate bars from the radiation of the surrounding combustion chamber walls, expanded slate was used together with the low-ash basic wooden fuel. For comparison of the test results, expanded slate was also added when using the higher-ash containing SRF.

4 Balancing and Scale-up of Fixed bed results

All balances serve to check the plausibility of the measured values. In addition, the air leakage flow can be determined from the mass and material balances. The heat losses and plant efficiency can be calculated from the energy balance. The scope of balancing comprises the grate system with the combustion chamber, boiler and quench.

To predict the combustion behaviour of a new fuel in an industrial grate furnace, the experimental results from the fixed bed reactor KLEAA are transferred with help of characteristic numbers to the technical scale.
4.1 Mass, material, and energy balances of the plant

The mass, material, and energy balances are calculated according VDI regulation 3460, page 2. The individual balancing equations will not be given.

4.2 Theoretical efficiency of the boiler

To assess the effects of the addition of SRF to biomass and the influence of a decreasing primary air temperature on plant efficiency, the theoretical efficiency of the boiler is introduced by

$$\eta_f \approx 1 - \frac{\vartheta_{\text{Fluegas}}}{\vartheta_{\text{adiabatic}}}$$

where $\vartheta_{\text{Fluegas}}$ is the balancing or outlet temperature of the boiler and $\vartheta_{\text{adiabatic}}$ the adiabatic combustion temperature

$$\vartheta_{\text{adiabatic}} = f (\lambda, l_{\text{min}}, \vartheta_{\text{air}}, \vartheta_{\text{fuel}})$$

that depends on the fuel parameter $l_{\text{min}}$ as minimum air demand as well as on the air ratio $\lambda$ and on air- and fuel inlet temperatures.

Electric efficiency can be increased, among other measures, when increasing the temperature and pressure of the boiler. This largely depends on the corrosion resistance and stability of materials against the substances contained in the coatings. Composition of the coatings, however, may be influenced by primary measures, such as the addition of sulphur-containing components at a high chlorine content of the fuel or SO$_2$ recycling [9]. The S/Cl ratio should be $> 2$ mol/mol in order to reduce susceptibility to corrosion. Other parameters influencing the stability of the boiler are a homogeneous temperature and flow distribution and a good gas burn-out. These parameters largely depend on the solid combustion process and the furnace geometry, and, hence, can be influenced (within certain limits concerning the geometry).

4.3 Modelling

The total combustion process in a fixed bed reactor can be subdivided into 3 phases generally as it was described in chapter 2.

The ignition phase characterized by the drying process of the fuel ends with the ignition of the fuel bed by radiative heat from the furnace. The time up to the first ignition is defined as Ignition Time IT.

With a steep incline of CO$_2$ and a decline of O$_2$ the combustion process transfers into the quasi-stationary combustion phase. During this phase the gas species O$_2$, CO$_2$, CO$_2$, H$_2$, C$_{\text{org}}$ and H$_2$O are released on a nearly constant level and could be characterized
quantitatively by the stoichiometric ratio $\lambda$. The experiment ends with the final char burn-out phase. The ignition- or reaction front propagates with a nearly constant velocity in opposite direction to the primary air flow. From the temperature distribution in the fixed bed as function of time, the Reaction Front Velocity, RFV is derived.

The Ignition Rate IR is defined as the product of the reaction front velocity RFV and the bulk density of the feedstock. It describes the fuel mass ignited per grate area and time.

The Mass Conversion Rate MCR describes the fuel mass loss per area and time. It is determined from the mass loss signal of the fuel bed scales. In order to allow an easy comparison between the ignition rate and the mass conversion rate the latter is corrected by the ash content of the fuel. MCR is defined as

$$MCR = \frac{dm_F}{A_{\text{GRATE}} \cdot (1 - \xi_{\text{ASH,F}})} \cdot dt \quad \text{[kg/m}^2\text{s]}, \quad \text{Eq. (5-3)}$$

where:

$dm_F/dt$ [kg/s] - fuel mass release, determined by the balance signal

$A_{\text{GRATE}}$ [m$^2$] - grate area, here: fuelbed area

$\xi_{\text{ASH,F}}$ [%] - ash content of the fuel, mass

Figure 4-1 shows a schematic of a fuel bed on a continuous combustion grate. The local fuel mass is plotted versus the length of the grate. The characteristic parameters IT, IR and MCR as derived from the fixed grate reactor KLEAA determine the typical combustion regimes - ignition, main combustion and char burn-out - on the grate. IT with the transport velocity of the fuel $u_{\text{trans}}$ on the grate determines the ignition length $x_{\text{grate}}$ (1).
With this model assumption, the combustion behaviour of the fuel mixtures on the grate can be estimated from fixed bed experiments. Knowing the fuel transport velocity on the grate (grate velocity + slip), the time dependent fixed bed data are transferred to length scale on the grate by the equation.

\[ x_{\text{grate}} = u_{\text{trans}} \cdot IT. \]  

Eq. (5-4)

IR determines the location where the flame front reaches the grate, i.e. all the fuel is ignited (2). The plane defined by IR shows the position of the plane front, it separates the drying and degassing zone from the combustion and gasification zone.

\[ L_{\text{MCZ,IR}} = \frac{m_{\text{Fuel,0}} - m_{\text{Ash}}}{IR_{\text{KLEAA}} \cdot (1 - \zeta_{\text{Ash}}) \cdot b_{\text{Grate}}}. \]  

Eq. (5-5)

with IR\text{KLEAA}: Ignition Rate determined from fixed bed experiments

\( b_{\text{Grate}} \): Width of the grate.

The fuel mass flow entering the Main Combustion Zone MCZ \( m_{\text{Fuel,0}} \) is the charged mass flow minus the water which is evaporated during the ignition time.

\[ m_{\text{Fuel,0}} = m_{0,\text{Fuel}} - m_{\text{Water,IT}}. \]  

Eq. (5-6)

With \( m_{0,\text{Fuel}} \) mass flow charging the grate

\( m_{\text{Water,IT}} \) is determined by:

\[ m_{\text{Water,IT}} = \left( m_{0,\text{Fuel}} - m_{\text{Fuel,IT}} \right) \cdot \frac{x_{\text{Grate}} \cdot b_{\text{Grate}}}{t_{\text{KLEAA}} \cdot A_{\text{KLEAA}}}. \]  

Eq. (5-7)

The mass flow of ashes \( m_{\text{Ash}} \) is calculated from the ash content of the fuel \( \zeta_{\text{Ash}} \):

\[ m_{\text{Ash}} = m_{\text{Fuel,0}} \cdot \zeta_{\text{Ash}}. \]  

Eq. (5-8)

\( m_{\text{Fuel,IT}} \) is determined from KLEAA experiments

From the signal of the balance of KLEAA the mass loss into the gas phase is calculated according Eq. 5-3. With Eq. 5-9 the required length of the grate \( L_{\text{MCR}} \) is estimated. With the boundary condition of \( \text{MCR}_{\text{KLEAA}} = \text{MCR}_{\text{TAMARA}} \):

\[ L_{\text{MCR}} = \frac{m_{\text{Fuel,0}} - m_{\text{Ash}}}{\text{MCR}_{\text{KLEAA}} \cdot (1 - \zeta_{\text{Ash}}) \cdot b_{\text{Grate}}}. \]  

Eq. (5-9)

Mass conversion Rate MCR I and II determine the integrated fuel consumption rate over the grate length and thus determine the required grate length for complete burn-out of solid fuel.
5 Results

The results will cover fuel specifications as well as the individual tests and their balances, the emission behaviour and transfer of the KLEAA characteristics to TAMARA. As the combustion behaviour of the SRF, named SBS2® from Remondis, is similar to that of the Finnish SRF, SBS2® was used for this campaign for logistics reasons.

5.1 Fuel characterisation

Table 5-1 lists the fuel specifications.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Approximate analysis (as del.) [wt-%]</th>
<th>Elemental analysis (daf) [wt-%]</th>
<th>mg/kg</th>
<th>NCV as del. [MJ/kg]</th>
<th>NCV dry [MJ/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>moisture</td>
<td>ash</td>
<td>volatiles</td>
<td>Cfix</td>
<td>C</td>
</tr>
<tr>
<td>SBS2 -PCW Remondis</td>
<td>25.0</td>
<td>9.2</td>
<td>53.3</td>
<td>12.5</td>
<td>58.8</td>
</tr>
<tr>
<td>A 1 wood chips</td>
<td>50.0</td>
<td>1.5</td>
<td>35.5</td>
<td>13.0</td>
<td>51.1</td>
</tr>
</tbody>
</table>

SBS2® from Remondis has high levels of N, S and Cl compared to the wood chips. HCl-, SO₂ and NOₓ- emissions are expected to increase when co-firing SRF with wood chips. As known from literature higher amounts of species in wood chips up to 0.5 are known [16], for SRF the N- content is normally about 1 to 1.3, so the here presented value for SRF is not representative.

5.2 KLEAA fixed bed results

The experiments to characterise the combustion behaviour of mixtures of biomass with SRF were carried out using fresh forest wood chips with a moisture of 50 wt.% and a Finnish plastic-enriched fraction with primary air pre-heating. Primary air pre-heating is often used to increase energetic efficiency. The results are summarised in Figure 5-2 where the mass loss is plotted as a function of time.
Operational parameters:
Specific primary air supply: 310 kg/(h m²)
Primary air temperature: 200 °C
Wall temperature: 900 °C
Main fuel:
Wood chips with 50 wt-% moisture
SRF: SRF from Finland with 10 wt-% moisture, NCV 18 MJ/kg

Combustion phase I
Increase SRF - ratio
Phase I
80 % SRF

Combustion phase II

$\vartheta_{\text{max,0\%}}$: 1235 °C
$\vartheta_{\text{max,40\%}}$: 1130 °C
$\vartheta_{\text{max,20\%}}$: 1230 °C
$\vartheta_{\text{max,80\%}}$: 1100 °C

Figure 5-2: Loss of mass in tests with varying mixtures of biomass and SRF

It is obvious from the basic experiment with 100% wood chips (top figure: black line on the right) that the combustion process is divided into two phases: In combustion phase I, about 50% of the mass are converted within 85% of the experiment duration. In combustion phase II, the remaining 50% are converted within 15% of the experiment time. This high conversion rate in the second phase results in a considerable increase in temperature from 800°C in phase I to more than 1200°C in phase II in which alkali compounds may released. Condensation of these compounds on “colder walls” of e.g. 1000°C causes slaging in the furnace. The high conversion rate in phase II is due to the drying of the biomass from below and the decomposition of wood that starts at 130°C already. If the ignition front from above hits this dried and partly degassed layer, the activated fuel reacts rather quickly. With an increasing SRF fraction, the weighed-in mass is reduced, which results in a decreasing bulk density of the mixture and a decrease in total moisture. At the same time, reactivity of the mixture increases.

The aim is to approach the inclines of the curves of combustion phase I and II to homogenize the combustion behaviour.

The two-phase combustion process can be homogenised considerably when adding 40% SRF to the wet biomass already. The combustion temperature peaks are reduced to about 1100°C.
5.3 Pilot Plant Results

The results from the pilot plant tests were divided into the balancing, courses of fuel bed temperatures and into the emission behaviour.

5.3.1 Balances

The deviations in the mass balance are between 1.8% and 7.6% compared to the volume flow measurements of the flue gas after the gas cleaning system.

From the difference of the mass flows in and out enthalpy flows, the loss heat flow and boiler efficiency can be calculated. The values lie in between 81% and 90% and are in the order typical of test facilities.

5.3.2 Fuel bed temperature courses and Modelling

The fuel bed temperature distribution is an indicator for the reactivity of the fuel and its conversion behaviour. The orange area characterises the grate zone upstream of the charging area. Fuel is fed onto the grate at 0.4 m.

![Figure 5-3: Comparison of Fuel bed temperature courses as a function of SRF- ratio](image)

The reason for the increase of the fuel bed temperature in TAMARA pilot plant is the lower water content of the mixture, which shorten the drying process and increase the mass conversion rate MCR (incline of the curves in Figure 5-2) with increasing SRF-content.
With increase of the MCR and decreasing of the total mass flow onto the grate with increase of SRF ratio in the fuel mixture (due to the boundary condition of constant thermal power of the boiler) the required length for the burnout is shortened (according to Eq. 5-9) as it is supported by the modelled curves in Figure 5-4.

![Figure 5-4: Required burnout length on the grate calculated by the MCRs derived from fixed bed reactor experiments for specific primary flow of 465 kg/(h m²) compared with visual viewing points in TAMARA pilot plant](image)

Figure 5-4: Required burnout length on the grate calculated by the MCRs derived from fixed bed reactor experiments for specific primary flow of 465 kg/(h m²) compared with visual viewing points in TAMARA pilot plant

With the support of visual viewing from the discharge of the grate the burnout length could be validated in a sufficient manner.

Usually, operators prefer to run plants on the safe side, i.e. with a short fire, such that grate length is sufficient for combustion when using moisture and ash-richer fuel. However, shortening of the fire also means a higher load of the front wall, as strands of the pyrolysis and gasification gases reach the secondary air level at the front wall of the plant and cause accordingly high temperatures and NOₓ formation there. This may be reduced by a corresponding redistribution of the primary air towards the centre of the grate. As a result, the fire is extended. This was confirmed by an additional experiment in the grate furnace.
5.3.3 Emissions and Corrosion potential

In the section below, major results of the measurements of emissions and ash compositions will be outlined.

**Figure 5-5** shows the raw gas concentrations of HCl, SO$_2$, NO$_x$, CO, C$_{org}$, and dust. Unfortunately, the dust concentration for wood combustion is incorrect due to boiler depositions. Estimation of the dust concentrations was based on the assumption that about 50% of the dust is deposited in the boiler. It is obvious that the addition of SRF causes all emissions, except for CO and C$_{org}$, to increase. Emissions of HCl increase from 40 mg/m$^3$ for wood to about 300 mg/m$^3$ for 40% SRF. Similar increases occur for NO$_x$ from about 80 mg/m$^3$ to 250 mg/m$^3$. However, gas and solid burn-out remain on the same good level. The gas burn-out is very good below 3 mg/m$^3$ organic carbon and 1 mg/m$^3$ CO.

![Comparison of raw gas concentrations and other parameters](image)

**Figure 5-5**: Comparison of the raw gas concentrations and other parameters

(*: estimated)

The Total Carbon TC value of all samples (boiler and grate ashes) is below 0.5 wt-%. In case of co-combustion, adequate exhaust gas cleaning will be required. In spite of the decreasing S/Cl ratio, however, the corrosion hazard is not expected to increase, as the ratio itself still is > 50 at 40% SRF.
5.4 Energy efficiency

Co-combustion of SRF with wet biomass is also assessed using the energy efficiency based on the theoretical boiler efficiency. The theoretical boiler efficiency is shown in Figure 5-6 as a function of the air ratio.

![Theoretical boiler efficiency for combustion processes without and with primary air pre-heating](image)

The parameter shown in the curves is the mixing ratio of wood and SRF. The left figure shows the results obtained without primary air pre-heating. The right figure refers to primary air pre-heating to 200°C. The balancing temperature is defined to be the gas...
temperature downstream of the boiler or air pre-heater of 180°C. The ash discharge temperature is assumed to be 100°C.

When assuming an air ratio of 1.4 which is a conventional value for biomass combustion, a theoretical boiler efficiency of 84% is reached without primary air pre-heating. Pre-heating of the air to 200°C increases the efficiency by 1.2% to 85.2%. If 40% SRF are added to homogenise the combustion process, efficiency (in the right figure) increases further to 87.6%.

Alternatively, the combustion behaviour may be influenced positively by reducing the primary air temperature [8]. To maintain the same boiler efficiency, either addition of 20% of SRF would be necessary or if no corresponding licence and exhaust gas treatment exists the reduction of the air ratio from 1.4 to 1.2 is possible.

These calculations reveal the basic relationships. In reality, however, impurities of the boiler walls also play a role and cause the balancing temperature (boiler discharge temperature) to increase.

6 References and publications

