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Characterisation of Refuse Derived Fuels (RDF) in reference to the Fuel Technical Properties

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1 Introduction

Refuse derived fuels (RDF) and Biomass fuels are commonly used in mono-combustion facilities and in co-firing plants as well as in the material industry and power plants. Based on operating experience, the two types of fuels are regarded as difficult fuels when compared to fossil fuels. Specifically that is in regard to the following properties: energy conversion density, ignition and burnout behaviour, slag formation and corrosion potential.

Initially in this paper, the fuel technical properties of RDF and Biomass fuels are discussed. Examples are then used to indicate the effect of these properties on combustion behaviour. Lastly, the various methods that are used to determine the fuel technical properties are explained.

2 Fuel Technical Properties

RDF and biomass fuels can be differentiated from fossil fuels by the following:

- a heterogeneous composition (e.g. size, higher inert material composition, ,volatile matter, chlorine, alkali and heavy metal content)
- lower calorific value,
- lower bulk density,
- lower energy conversion density,

These properties have an influence on the ignition, combustion behaviour, slag formation, corrosion potential and lastly on the energy conversion efficiency.

Due to the application of fossil fuels in high temperature processes, there currently exists extensive information and experience in regards to the optimisation in the running the processes (e.g. combustion of cement clinker). The connection between the single processes can then used to deduce a criterion for the description of fuel technical properties.

These fuel technical properties can be classified as follows [2], [11]:

- Chemical, e.g.
  Elementary analysis – C, H, O etc,
  Immediate analysis – volatile matter, water content etc,
  Trace elements – K, Ca, Mg,

- Mechanical, e.g. particle size, bulk density,
- Calorific, e.g. calorific values, combustion temperature
- Reaction, e.g. gasification, ignition temperature, combustion behaviour, slag formation,

In the assessment of the properties of a fuel, it is also important to consider the technical process boundary conditions. That means a specific criterion is connected to the application area, technical process and the used equipment.

The following examples of Biomass fuels demonstrate the importance of a detailed analysis for comparable fuel technical properties. In the application of the fuels, there are different parameters that can lead to difficulties.

The Table 1 shows the chemical, mechanical and calorific properties of rice husks and sugar pulp. Both have almost similar calorific properties and there is a smaller difference in the chemical properties. Differences are observed more in the mechanical properties (bulk density, pouring and transportation mechanisms). Rice husks are more interesting in terms of the ash utilization. Ash contains a high content of silica and therefore a valuable material (e.g. metallurgical industry). If the ash is subjected to mechanical conditions for instance in a Fluidized bed or a Rotary kiln, a lot of fine dust is formed. A separation process is therefore required and that increases the complexity of the equipment used. Rice husks have small energy conversion efficiency due to the lower bulk density. Hence measures to control the main influential parameters have to be considered in the design of a grate firing system and especially regarding to temperature controls.

Fuel Characteristics	**Units**	**Fuel Type**	
		Rice husks	**Sugar pulp**
Chemical characteristics			
Elementary analysis			
Carbon	Ma. % wf	42,267	44,1
Hydrogen	Ma. % wf	5,122	5,840
Nitrogen	Ma. % wf	1,389	1,5
Oxygen	Ma. % wf	33,222	43,138
Sulphur	Ma. % wf	0,111	0,08
Chlorine $_{total.}$	Ma. % wf	0,111	0,003
S/Cl Ratio	mol/mol	1,106	29,49
Fluorine	Ma. % wf		
Total final ash		100	100
Immeadiate analysis			
Water content	Ma. % roh	10	13,5
Ash	Ma. % wf	17,778	5,34
Volatile matter	Ma. % wf	69,8	79,7
Bonded carbon	Ma. % wf		
Trace analysis			
As	mg/kg		
Pb	mg/kg		
Cd	mg/kg		
Cr_{ges}	mg/kg		
Cu	mg/kg		
Hg	mg/kg		
Ash analysis			
K_2O	Ma. % wf	0,48	6,6
Na_2O	Ma. % wf		0,24
CaO	Ma. % wf	1,37	4,6
MgO	Ma. % wf	0,28	1,8
SiO_2	Ma. % wf	75	0,15
Softening temperature	°C	> 950	1036
Hemispherical shape temperature	°C	1430	1125
Flowing temperature	°C	1467	1170
Mechanical characteristics			
Bulk density	kg/m^3	90 - 110	approx. 300
Calorific characteristics			
Net calorific value	MJ/kg wf	16,4	16,8
Combustion tempeature (*adiabatic*, Lambda = *1,0*)	°C	1961	1905
Combustion temperature (*adiabatic*, Lambda = *1,6*)	°C	1397	1373
Minimum oxygen required	m^3/kg	0,76	0,74
Minimum air required	m^3/kg	3,62	3,5
Minimum waste gas volume	m^3/kg	6,39	6,32

Table 1: Chemical and calorific properties from Rice husks and sugar pulp.

Sugar pulp poses less difficulty in terms of the energy conversion density since their net calorific value and the bulk density are in the normal range for biomass fuels. In terms of corrosion, it is important to note the lower chlorine and higher sulphur contents and in addition the high sulphur to chlorine (S/Cl) ratio. The further detailed analysis of the trace elements indicates relatively high potassium content in comparison to other Biomass fuels. During the combustion, oxides and salts (e.g. K_2O, KCl, K_2SO_4) are formed. Due to their high melting points e.g. K_2O: 740 °C and K_2SO_4 : 740 °C, they are likely to cause fouling.

In Fig 1 the vapour-pressure curve for potassium chloride (KCl) is shown. At normal fire room temperatures, a substantial amount exists in the gas phase and if in contact with colder surfaces, it can easily solidify. In industry, the fouling can be complex due to the mixing of components as a eutectic. For instance if the combustion of sugar pulp is carried out in a grate firing system, in just a few hours a layer of crust is likely to develop on the heat conduction surfaces.

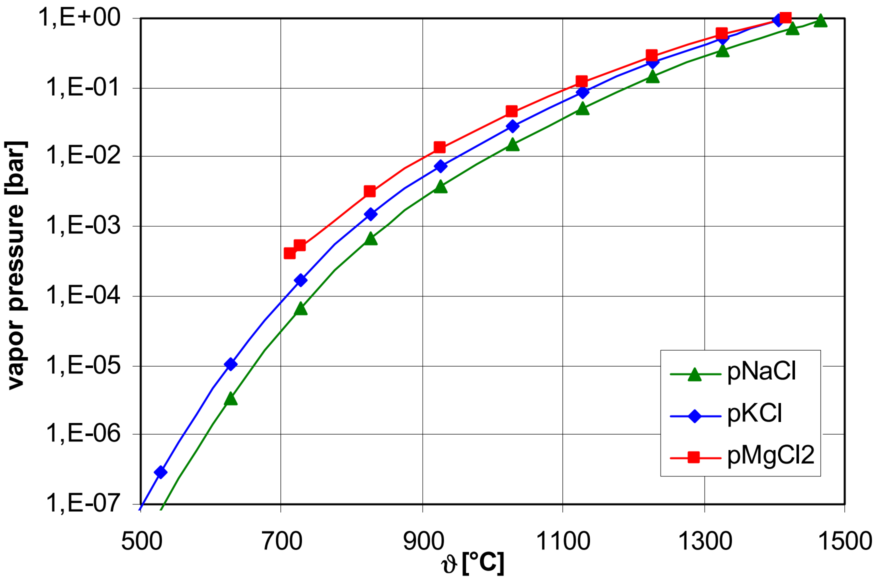

Fig 1: Vapor pressure curve for NaCl, KCl and $MgCl_2$.

In Table 2, the fuel technical properties of Biomass briquettes [5] and wood chips are summarised. In connection with the example for rice husks (Table 1) it shows that lower chlorine content does not necessarily mean a lower corrosion potential.

What is decisive is the way the chlorine is bonded (organic or inorganic) and the complicated interaction with other elements (alkalis, sulphur, heavy metals). Organic bound chlorine is mostly found in fuels with high plastic content (mainly PVC) like in Refuse Derived Fuels.

The maximal value of the inorganic bound chlorine content in such fuels is 2 % [24]. From investigations carried out on the decomposition of PVC (in Helium gas, 20K/min heating rate), it is known that at 300 °C chlorine is separated and forms HCl [13]. In contrast to RDF, approximately 95 % of the total chlorine content in biomass briquettes is inorganic bound (alkali chlorides).

The volatile chlorine is transported with flue gas to the heating exchanger surfaces. With different salt species (alkaline chlorides) and at different saturation temperature, fractions of the deposited salts accumulate on the heating exchanger surfaces [14].

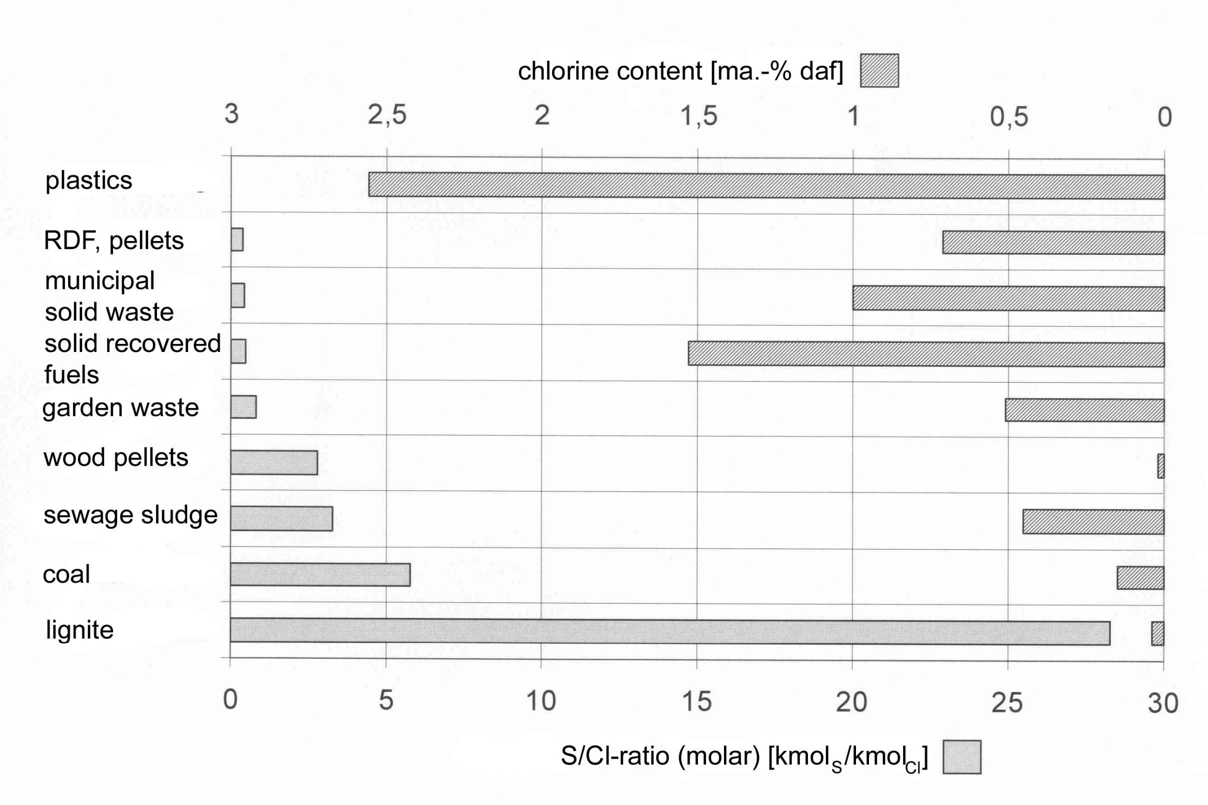

Fig *2:* Chlorine content and molarity ratios of sulphur to chlorine for chosen fossil fuels, biomass fuels and RDF [15].

Source: plastic, sewage sludge, lignite, coal: [16]; RDF, pellets, garden waste: [17]; municipal solid waste: [18], solid recovered fuels: [19]; wood pellets: [20].

In terms of the risks from corrosion, it can be further pointed out that the sulphur to chlorine (S/Cl) ratio for Biomass fuels (e.g. wood pellets, or garden waste) is distinctively smaller in comparison to lignite and anthracite coal (*Fig* 2).

Fuel Characteristics	**Units**	**Fuel Type**		
		Biomass briquetts	**Wood chips [5]**	**Wood chips [6]**
Chemical characteristics				
Elementary analysis				
Carbon	Ma. % wf			45
Hydrogen	Ma. % wf			5,63
Nitrogen	Ma. % wf			0,376
Oxygen	Ma. % wf			36,37
Sulphur	Ma. % wf	0,51	0,06	0
Chlorine $_{\text{total.}}$	Ma. % wf	0,574	0,0453	0,1225
Chlorine $_{\text{anorganic.}}$	Ma. % wf	0,534	0,0329	
S/Cl Ratio	mol/mol	0,89	1,32	0,00
Fluorine	Ma. % wf	0,0086	<0,001	
Total final ash	Ma. % wf			100
Immeadiate analysis				
Water content	Ma. % roh	17,6	45,5	20
Ash	Ma. % wf	32,4	1	12,5
Volatile matter	Ma. % wf			
Bonded carbon	Ma. % wf			
Trace analysis				
As	mg/kg	<2	<2	
Pb	mg/kg	68	52	
Cd	mg/kg	1,5	<0,6	
Cr_{ges}	mg/kg	200	<5	
Cu	mg/kg	116	5	
Hg	mg/kg	0,08	<0,07	
Ash analysis				
K_2O	Ma. % wf	3,9	2,8	
Na_2O	Ma. % wf	1,4	2,7	
CaO	Ma. % wf			
MgO	Ma. % wf	1,8	3,9	
SiO_2	Ma. % wf			
Softening temperature	°C	1170	1160	
Hemispherical shape temperature	°C	1190	1180	
Flowing temperature	°C	1370	1190	
Mechanical characteristics				
Bulk density	kg/m^3			150
Calorific characteristics				
Net calorific value	MJ/kg wf	13,24	18,28	18,98
Combustion temp (*adiabatic*, Lambda = *1,0*)	°C			2549
Combustion temperature (*adiabatic*, Lambda = *1,6*)	°C			1839
Minimum oxygen required	m^3/kg			0,72
Minimum air required	m^3/kg			3,46
Minimum waste gas volume	m^3/kg			4,16

Table 2: Chemical and calorific properties from Biomass briquettes and wood chips.

The examples are supposed to show that it is not possible to characterise a fuel with only a few parameters. It is therefore important to undertake technical laboratory and pilot scale investigations. From such investigations, the operations in large plants can be simulated and the results can be correlated with information obtained existing plants.

For Refuse Derived Fuels, there exists definitively little information in terms of fuel characteristics in comparison to Biomass. Initial information has been derived from the practical experience demands in the application of RDF in different power plants and cements production plants [21], [22], [23].

For RDF there has been documented initial progress in the analysis of the chemical, mechanical and calorific properties [3]. On the other hand, it has been difficult to find a comparable method for the evaluation of the technical reaction parameters. In the following section of the paper, the possible methods to practically characterise the fuel technical properties will be discussed.

3 Methods to Characterise Fuel Technical Properties

3.1 Determination of Ignition and Combustion Behaviour

To accurately determine the ignition and combustion behaviour of behaviour of fuels is to investigate a number of parameters. In detail these are the ignition temperature, thermal absorption rate, combustion air mass flow rate and temperature, flow rate in fuel bed and particle size. For these investigations, the following set of equipment can be used.

- Ignition reactor
- Laboratory Thermo balance
- Technical Thermo balance
- Batch reactor

Ignition reactor

The ignition reactor is used to determine the ignition behaviour of fuels. In this equipment a powdered sample mass of approx. 300 mg is burnt in a pre-heated reactor up to a temperature of 1100 °C. Through an optical sensor and an installed thermal element, the temperature distribution over the current flow can be ascertained.

Laboratory Thermo Balance

With a laboratory thermo balance (Fig 1) the ignition and combustion behaviour under different Temperature-Time conditions, varied gas atmosphere, kinetic reaction constants etc, for samples (max is 1 g) can be determined. Since the samples amount is small, homogenisation is hence necessary and a major that is major difficulty for RDF. The running of industrial processes (e.g. rotary kiln, combustion chamber) can be simulated [7].

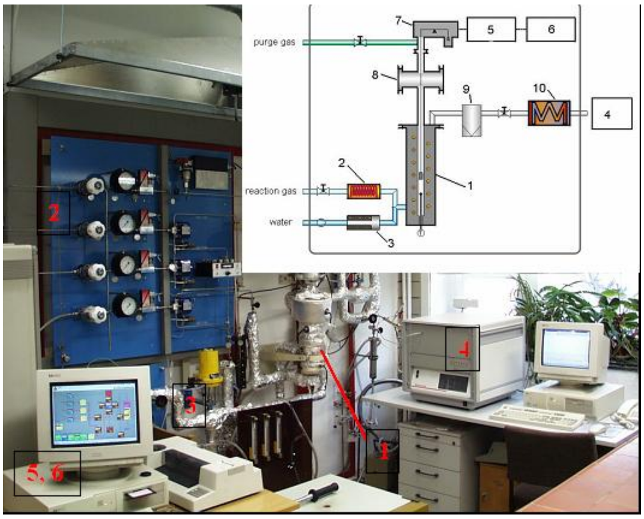

Fig 3: Laboratory thermo balance.

Technical Thermo Balance

The technical thermo balance can weigh samples up to a size of 3 kg, and hence can suitable for investigating heterogeneous lumpy samples. It is therefore used to supplement the laboratory thermal balance.

Batch Reactor

The batch reactor is utilised for the determination of kinetic data for the solid material conversion on the packed bed or in a fluidized bed (ignition and burnt out behaviour) [4], [8], [9], [12]. The specifications of the Batch reactor are summarised in Table 3.

Fig 4 and Fig 5 show a schematic diagram and a photo of the batch reactor. With parameter variation, grate firing and fluidised bed reactor systems can be simulated.

PARAMETER	DATA
Combustion chamber	
Thermal efficiency	40 kW
Combustion room temperature	850 - 950 °C
Maximum fuel volume	32 l
Grate-firing surface area	11 dm^2
Primary air flowrate	5 - 250 m^3/h
Secondary air flowrate	3 -30 m^3/h

Table 3: Specifications of the Batch reactor.

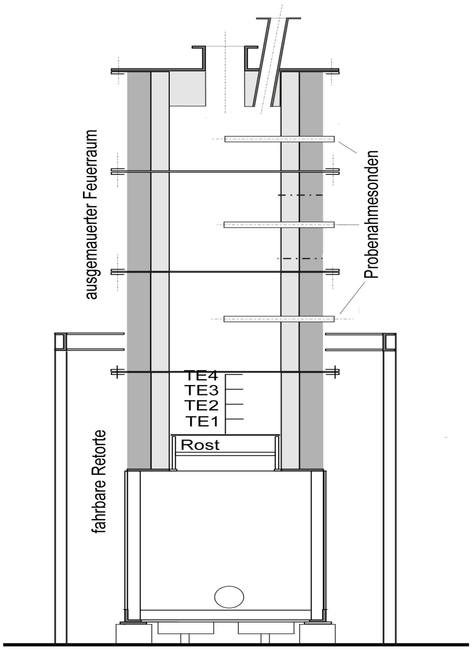

Fig 4: Schematic diagram of Batch reactor.

Fig 5 : Photo of the Batch reactor.

The next section elaborates more on the results obtained during an experiment in the batch reactor with use of the Biomass briquettes and wood chips. Table 2 contains the chemical, mechanical, calorific properties of the two materials. Fig 6 indicates the temperature change with time on the fuel bed of the batch reactor. Both materials have nearly the same calorific value of 12 MJ/kg but different amount of water and ash (Biomass briquettes: Water: 18 Ma. -%, Ash: 35 Ma. -%; Wood chips: Water: 45 Ma. -%, Ash: 1 Ma.- %).

It can be noted that the ignition of biomass is faster than for wood chips due to lower water content. Furthermore, the temperature decrease in Biomass briquettes is slower due to the high ash content (heat storage effect). It has be mentioned that in the current research project [1], three batch reactors are being used and initial ring tests are carried out to fix the parameter variation and evaluation of results.

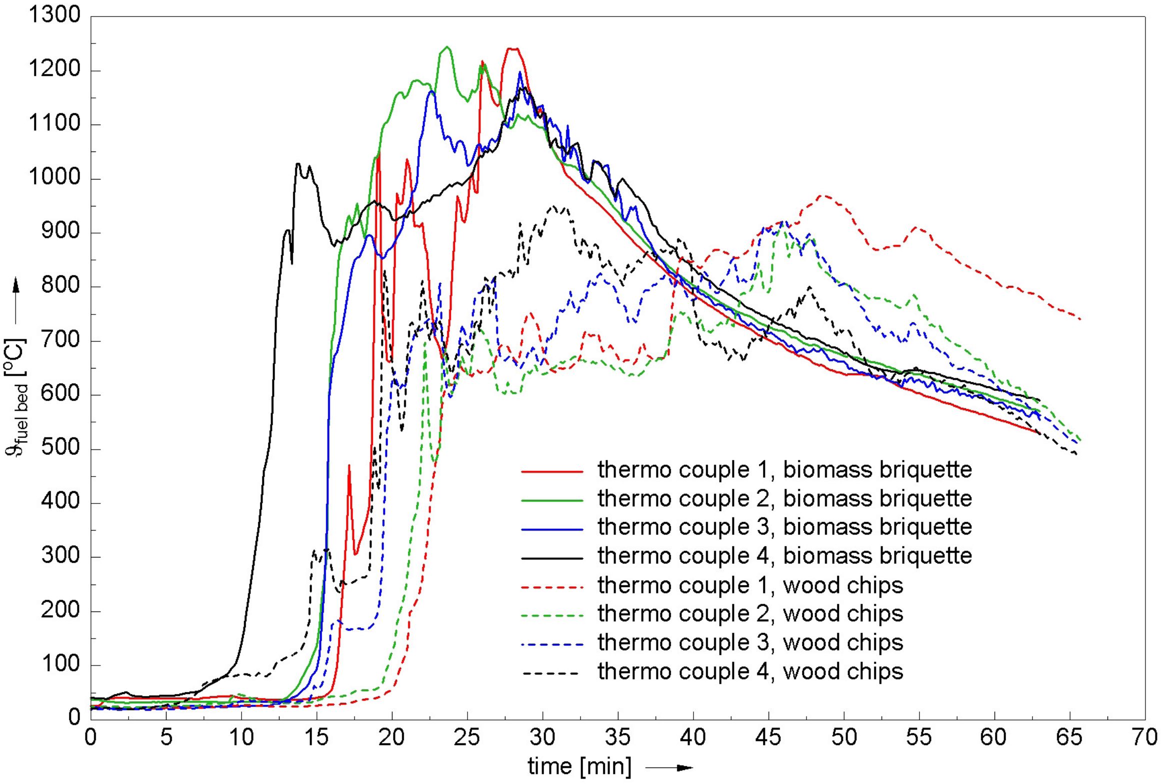

Fig 6: Bed temperature (Thermo elements from 1 till 4 across the bed height) with time for two experimental settings.

3.2 Degasification and Slag Formation

Slag formation increases the total resistance against heat transference and leads to lower overall efficiency. The reduced heat transference increases the gas temperature in the fire room. Eventually the rate of fouling increases and can result in unplanned down time. The fouling is the main cause for corrosion in boiler equipment. By the application of RDF and Biomass (e.g. power plants) it is important to determine the slag formation process. Initial tests are done to determine the melting of the ash (ash melting microscope) and then the degasification and fouling in a slag formation reactor (field tube). In addition to investigations in the slag formation reactor, the ash to salt ratio (ASP) is a method used to determine the amount of fouling in technical processes [10], [14].

The information obtained from the above mentioned experimental equipment should be coupled with results and experience from industrial plants in order to derive a suitable criteria for determining the fuel technical properties. The current research project stands to address these demanding technical issues [1].

4 Summary

Refuse derived materials and biomass fuels have special properties which make them to be classified as difficult fuels. When applied in technical processes, measures have to be taken in order to fully utilise their potential as fuels.

The lack of substantial information concerning their properties is the challenging part and hence there is a need for laboratory and pilot plant investigations (e.g. Thermo balance, Batch reactor, Slag formation reactor). In this way, a method can be developed in the characterisation of technical fuel properties and which then can be coupled with results from practical run plants for enhanced effectivity.

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