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Characterisation of Refuse Derived Fuels in view of the Fuel Technical Properties

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Abstract

Biomass fuels and refuse derived fuels (RDF) are used in power plants, material industry, mono combustion facilities and co firing plants. It is known from operating experience – concerning the energy conversion density, the ignition and burnout behaviour, the slag formation and corrosion potential - and from comparing the combustion behaviour with fossil fuels, that biomass fuels and RDF can be seen as difficult fuels.

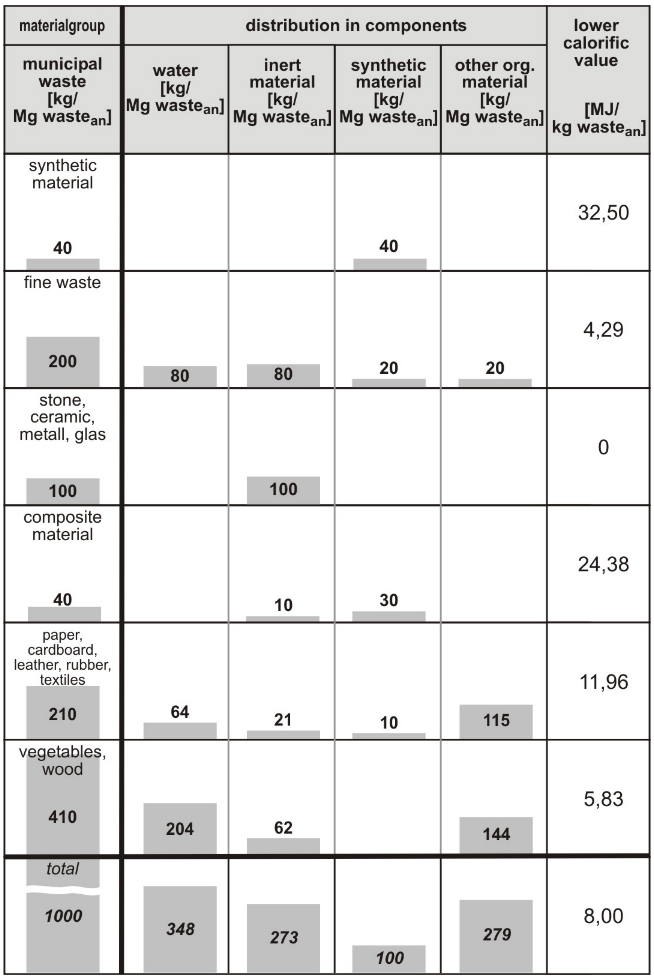
Biomass fuels are of interest concerning the decrease of CO_2 emissions derived from fossil fuels in energy conversion processes. The use of biomass fuels is supported e.g. by the renewable energy law in Germany. In connection with the increasing prices of energy, refuse derived fuels have of late gained great interest especially in industries not only with a high demand of electrical and heat energy but also process steam e.g. material and food industry.

In the design of combustion plants or in the application area e.g. in co-combustion systems, the knowledge about the composition of fuels, calorific value and the ignition behaviour is important. The composition of fuels in relation to the calorific values also plays a vital role in the balancing of plants. Conventional used methods for fuel characterisation of fossil fuels are often not suitable for RDF, due to their heterogeneous composition compared to black coal or lignite.

In the proposed paper methods for RDF characterisation are described and results are discussed. Further, with the C/H and C/O - ratios, correlations concerning calorific value could be developed, which will be discussed in the paper.

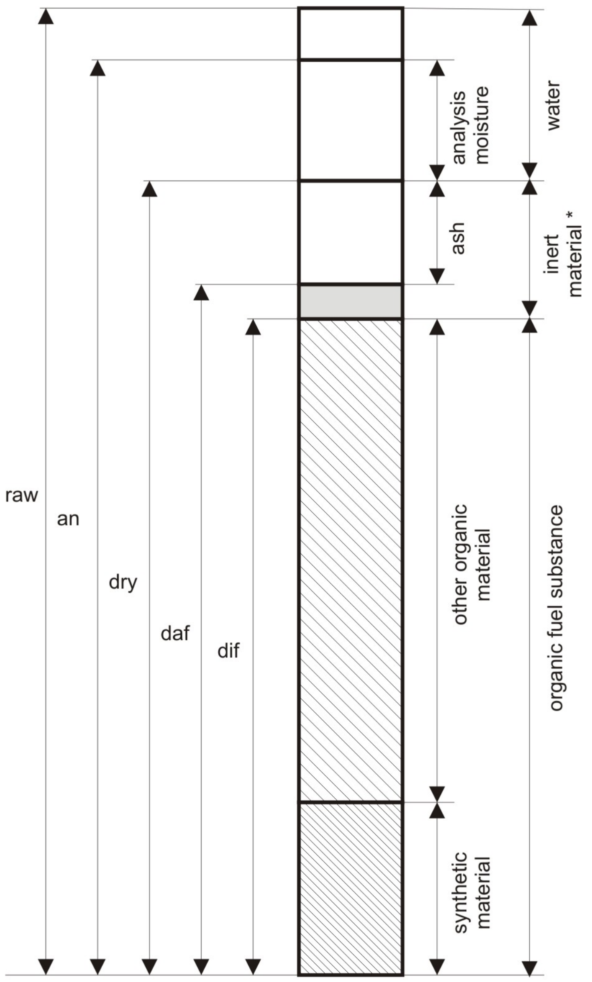
1 Composition of Refuse Derived Fuels

In *Fig. 1* refuse derived fuels that are derived from mechanical and mechanical-biological treatment processes, emanating from local municipal waste and partly industrial waste, are considered.



materialgroup	distribution in components				lower calorific value
municipal waste [kg/ Mg waste$_{an}$]	water [kg/ Mg waste$_{an}$]	inert material [kg/ Mg waste$_{an}$]	synthetic material [kg/ Mg waste$_{an}$]	other org. material [kg/ Mg waste$_{an}$]	[MJ/ kg waste$_{an}$]
synthetic material 40			40		32,50
fine waste 200	80	80	20	20	4,29
stone, ceramic, metall, glas 100		100			0
composite material 40		10	30		24,38
paper, cardboard, leather, rubber, textiles 210	64	21	10	115	11,96
vegetables, wood 410	204	62		144	5,83
total *1000*	*348*	*273*	*100*	*279*	8,00

Fig. 1: Illustration of municipal waste through different material groups and their further subdivision into components water, inert material, synthetic material and other organic components [11].

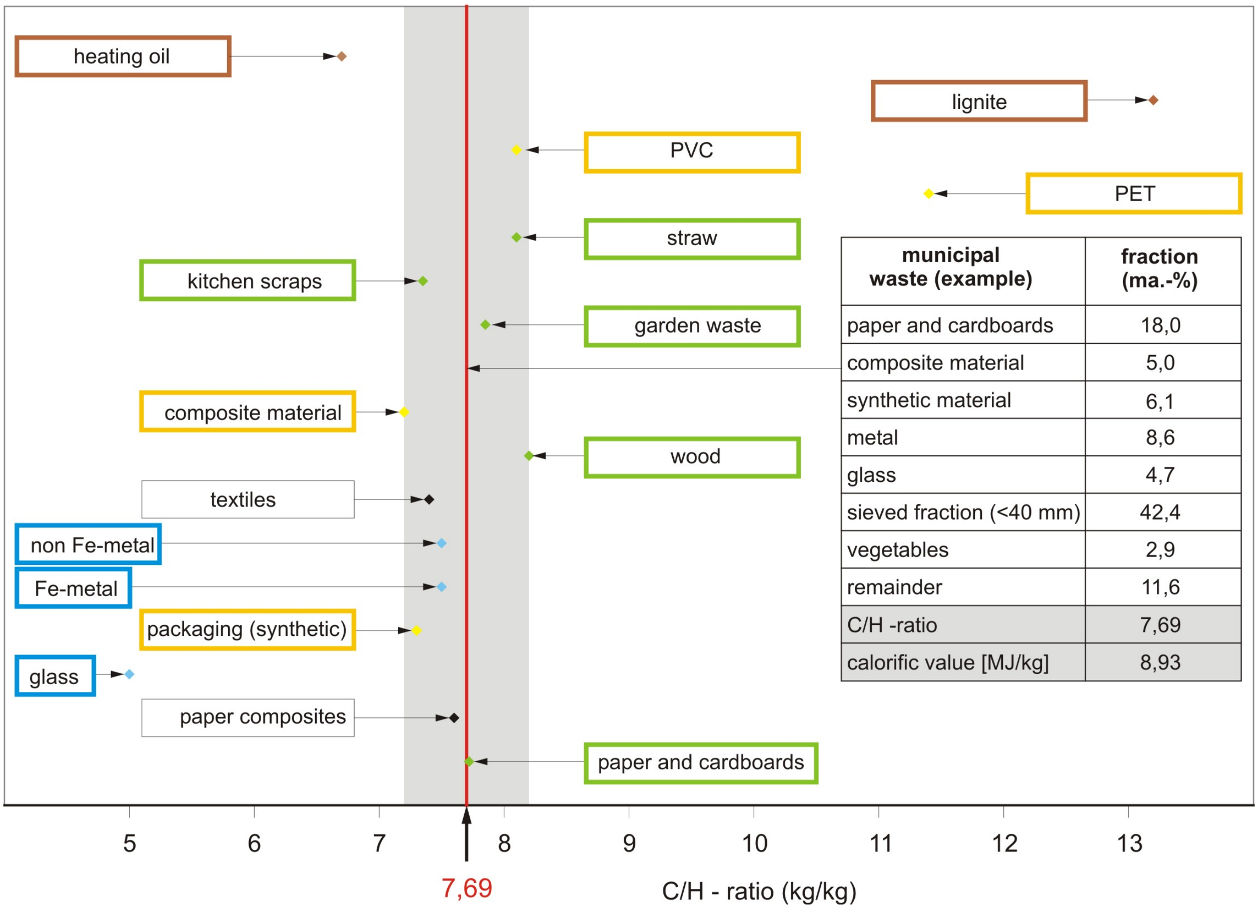


* Depending on the inert material, the content of the inert material can be bigger than the ash content (e.g. separation of CO_2 from carbonates leads to correspondingly greater inert material content in comparison to the ash content).

Fig. 2: Reference state for solid fuels.

The material composition of the waste conditionally varies based on the region and the season. Firstly the local municipal waste can be sub-divided with regard to the material groups (also fractions) into e.g. synthetic materials, fine waste, paper/cardboards, vegetables etc. (left column in

Fig. 1). From the fuel technical point of view, the description of fossil fuels into subdivisions of the components water, inert material and organic fuel substance is purposeful. The component *organic fuel substance* in waste is further differentiated into *synthetic materials* and *other organic components* (central column – distribution of components in *Fig. 1*). The organic fuel substance is free from water and inert material (dif). In a similar way, by which fossil fuels are differentiated between ash and mineral content, waste material is also distinguished between ash and inert material content (see Footnote in *Fig. 2*). From the information of the elementary composition, the reference state in *Fig. 2* must be specified as dry and ash free (daf), water free (dry) or as only ash free (af).



municipal waste (example)	**fraction (ma.-%)**
paper and cardboards	18,0
composite material	5,0
synthetic material	6,1
metal	8,6
glass	4,7
sieved fraction (<40 mm)	42,4
vegetables	2,9
remainder	11,6
C/H -ratio	7,69
calorific value [MJ/kg]	8,93

Fig. 3: Illustration of the C/H - ratio of different material groups in comparison to municipal waste set as an example.

In the preparation of waste into refuse derived fuels, the components water and inert material are separated, hence enriching the organic fuel substance and also simultaneously increasing the calorific value. From the separation of water the volatile matter content is firstly not influenced and through the reduction of the inert material a relative enrichment of the organic substance results. The *Fig. 3* shows for the single material groups, that the C/H - ratio lies within a range between 7 and 8. A relative enrichment with synthetic material (exceptional for PET) in comparison to biogenic material groups, for e.g. household waste, paper/cardboard, there is no significant change in the C/H - ratio. However an increase in the C/O - ratio with rising C-content is a resultant noticed (*Fig. 4*).

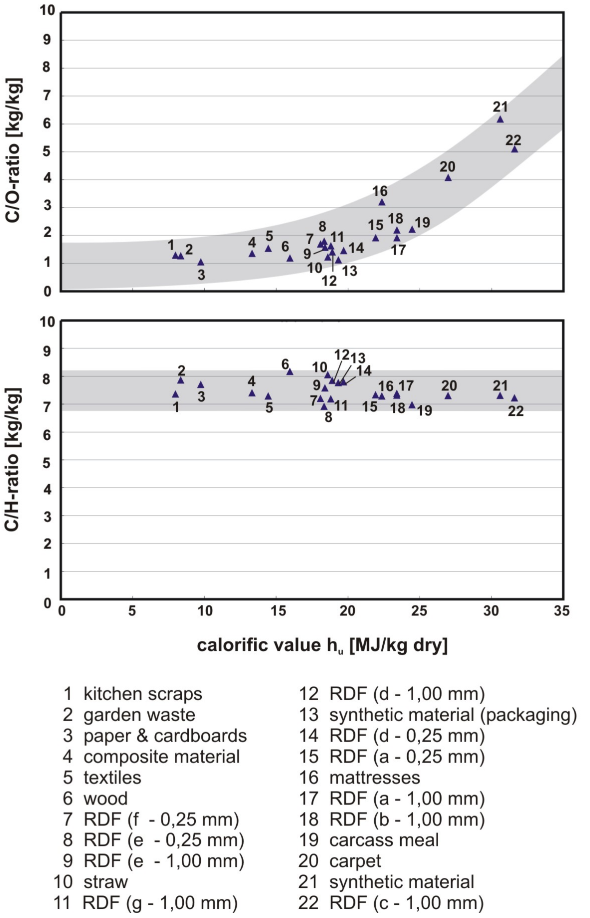


Fig. 4: C/H and C/O - ratios plotted against the carbon content for different waste fractions and different refuse derived fuels.

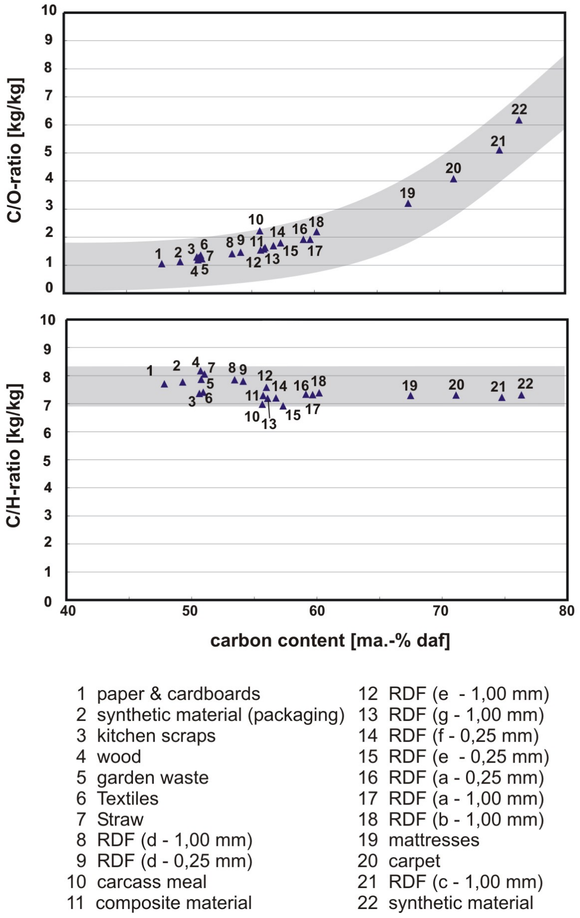
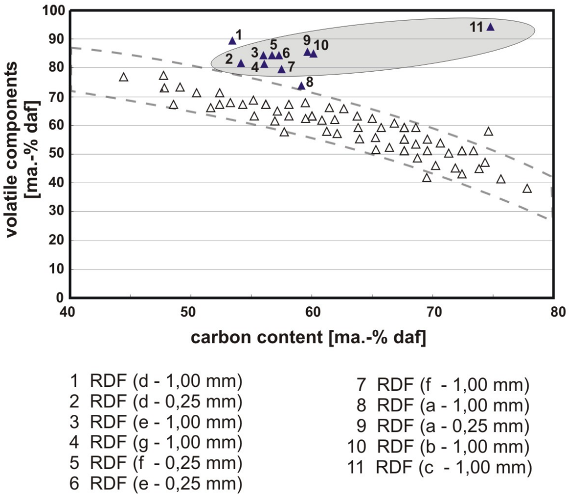


Fig. 5: C/H and C/O - ratios plotted against the calorific value (heating value) for different waste fractions and different refuse derived fuels.

From this consideration it can be derived, that refuse derived fuels with increasing calorific value the C/H - ratio approximately remains constant and the C/O - ratio however increases (*Fig. 5*).

In contrast to fossil fuels, the increase in calorific value is based not on the change in the fuel structure (increase in carbonisation), but on the relative enrichment of the organic fuel substance and particularly the enrichment of the synthetic materials. The content of volatile matter in refuse derived fuels does not like in fossil fuels decrease with an increase in the C - content (equivalent also to increasing calorific value, compare *Fig. 4* and *Fig. 5*) but approximately remains constant or slightly increases (*Fig. 6*).

For the refuse derived fuels (RDF a, b, c, d, e, and f) the minimum required air was calculated as shown in *Fig. 7*. When the minimum required air values are then drawn against the calorific values, these paired values arrange themselves as expected in the indicated relationship (*Fig. 7*).



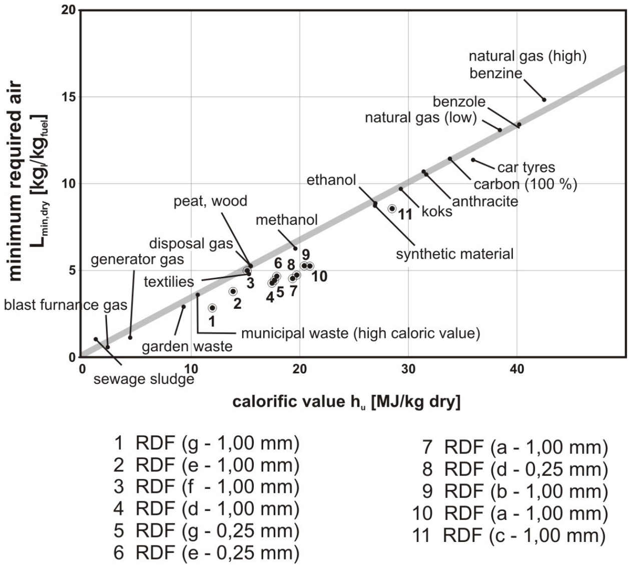


Fig. 6: Percentage of volatile matter dependency to the carbon content of different carbonised coal in comparison to refuse derived fuels.

Fig. 7: Minimum required air (dry) in relation to the calorific value for different fuels and waste.

2 Calculation of the Calorific Value from the Fuel Composition

In the balancing of combustion plants, the calorific value of the used fuel represents an important requirement. In literature there are various so called *calorific value formulas* mentioned. The relationship between the fuel composition and the calorific value is formed through the following:

- the calorific value of the individual fuel components or
- through coefficients, with which the respective fuel components are involved in the total calorific value.

An exact relationship between the fuel composition and the calorific value exists only for gaseous fuels. For the *Verbandsformel* or the *Dulong Formula* [15] known calorific value formula (*Heizformel*), for solid fuels the total calorific value is evaluated from respective fuel components and the related individual heating values. Therefore the fuel structure (especially different bonding heats) remains unconsidered. The accuracy of this calculation is hence for practical applications insufficient. Correspondingly there is a series of modifications that have been developed and which are similar in configuration to the *Verbandsfomel*

$$h_u = k_1 \cdot c + k_2 \cdot h - k_3 \cdot o + k_4 \cdot s + k_5 \cdot n - k_6 \cdot w \qquad (1).$$

Thereby *c,h,o,n,s,w* are the mass components of carbon, hydrogen, oxygen, sulphur, nitrogen and water which in combination with ash component *a* depict the elementary analysis of the fuel

$$c + h + o + s + n + w + a = 1 \qquad (2).$$

The coefficients k_1 to k_5 in equation (1) in comparison to the *Verbandsformel* do not indicate individual values, but consider how components of the respective fuel are involved in the calorific value. The coefficient k_6 is the condensation enthalpy of the water *w*. The derivation of the factors at this point can be referred to [5]. The accuracy of the *calorific value formula* is particularly very good, when the evaluation of the coefficients is for a defined fuel (e.g. lignite, anthracite) that is taken from a specific referred deposit.

The above discussed relationship between C/H and C/O - ratios with volatile matter content and the calorific value indicate, that for refuse derived fuels it is therefore possible to derive a calorific value formula based on the fuel composition.

Firstly if the influence of sulphur and nitrogen on the fuel is disregarded, then according to equation (1) ($k_4 = k_5 = 0$) the following results:

$$h_u = k_1 \cdot c + k_2 \cdot h - k_3 \cdot o - k_6 \cdot w \qquad (3).$$

equation (3) containing k_1, k_2, k_3 as three unknowns. With a fixed C/H - ratio – here simplified

$$C / H = 7 \qquad (4)$$

and equation (2) , results in total three equations, such that k_1, k_2, k_3 can be evaluated.

The comparison of the equation (3) evaluated calorific value to the experimentally evaluated calorific value is shown in *Fig. 8*. The good correlations show that it is therefore worthwhile the above considerations to be further pursued. At this point the specifications of the coefficients k_1, k_2, k_3 are intentionally disregarded, since a large sample range is required for accurate evaluation.

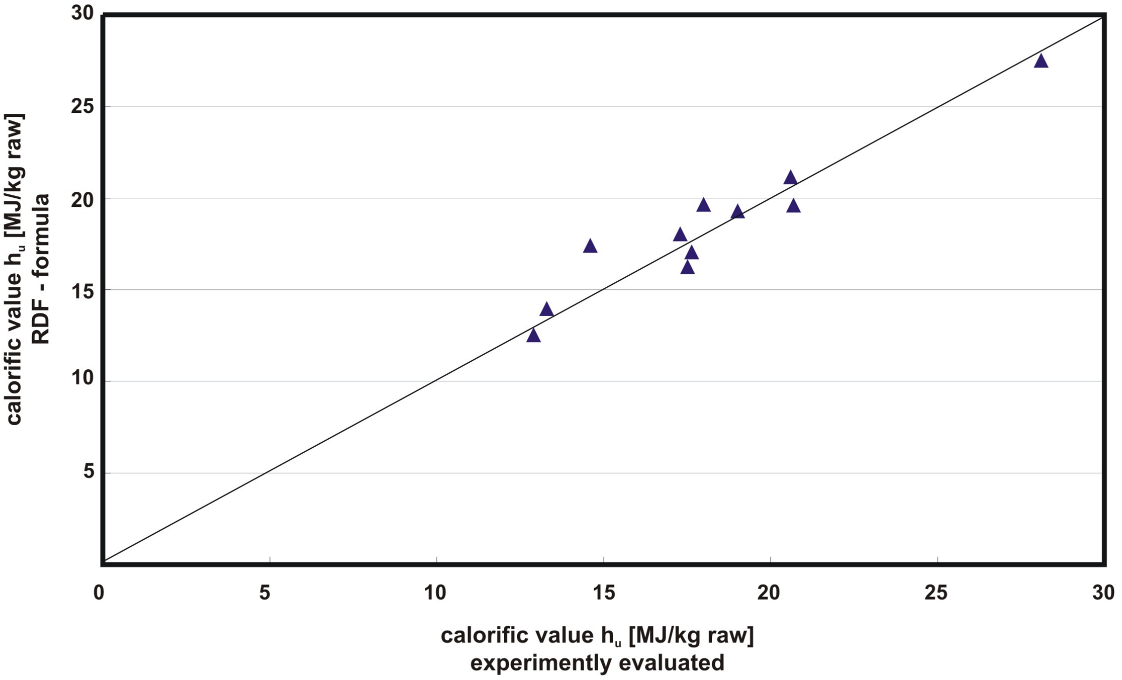


Fig. 8: Comparison of experimentally evaluated calorific value to the one evaluated through the calorific value formula (Heizformel).

3 Summary

Fossil fuels – coal, crude oil, natural gas etc. have been extensively investigated and that is due to their background application in plants for energy conversion and also in material industry. Thereby in combination with the respective processes, criterion on fuel technical properties can be derived. From the fuel technical point of view, the following properties are to be considered for the required assessment (e.g. [5], [8] and [15]):

- chemical
- mechanical
- calorific
- reaction technical.

The paper deals about fuel properties for refuse derived fuels. Papers were already published in [1], [2], [6], [13] and [13].

In relation to refuse derived fuels, up to now mainly the trace element analysis (chemical characteristics) have been investigated and discussed (in [4], [6], [7], [10] and [12]). Specifically the trace element analysis has been carried out in view of the release of harmful substances or the corrosion potential. Furthermore information for refuse derived fuels regarding to energetic evaluations (calorific properties, heat exchange ratio) could be derived [3]. This is especially in view of their application in the material industry. Apparently it is interesting to note the relationship between the elementary compositions (chemical properties) to the calorific value (calorific properties). Furthermore for the design of plants and in other application areas, the behaviour of ignition (reaction technical properties) is important to know.

The composition of fuels in relation to the calorific values also plays a vital role in the balancing of plants. With the presumption of a defined C/H - ratio, when balancing, information about the composition of the fuel can be derived from the flue gas composition. In [9] it is discussed about this calculation method, which was used for the online balancing of biomass and municipal solid waste (MSW) plants.

Interesting to note is how the C/H and C/O - ratios of refuse derived fuels relate in comparison to fossil fuels and *normal* municipal waste. Another aspect to consider is the extent of dependency of these ratios to the calorific value or the minimum required air. This paper is focussed on the above mentioned interesting aspects and these were further elaborated in detail.

4 Symbols and Abbreviations

an	analysis state
C	carbon
RDF	refuse derived fuel
H	hydrogen
h_u	lower heating value
L_{min}	minimimum required air
O	oxygen
raw	delivery state (raw)
daf	dry and ash free
dry	water free
dif	dry and inert material free
c	mass fraction carbon
h	mass fraction hydrogen
o	mass fraction oxygen
n	mass fraction nitrogen
s	mass fraction sulphur
a	mass fraction ash
w	mass fraction water
k_1	coefficient for carbon
k_2	coefficient for hydrogen
k_3	coefficient for oxygen
k_4	coefficient for sulphur
k_5	coefficient for nitrogen
k_6	coefficient for water

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