

THE FIRING PROPERTIES OF THE BIOFRACTION AND RDF PELLETS

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Many cities in developing countries are facing serious problems in dealing with huge municipal solid waste (MSW) generated. The energy recovery of accumulated municipal waste can provide an alternative to replacing a small part of fossil fuels. Refuse Derived Fuel (RDF) is a secondary fuel that contains higher-calorific components of communal waste. The quality of pellets made from RDF and their combustion properties can be influenced by a number of factors. The combustion properties must be known in the interest of forecast the behavior of the fuel during the combustion.

Keywords: combustion parameters of RDF, physical composition of RDF

INTRODUCTION

Increased demand for renewable energy sources, high organic matter content of municipal solid waste, and a limited number of landfill sites make the use of municipal solid waste as a source of energy, biochemical and thermochemical more and more popular [1], [2], [3]. Municipal solid waste (MSW) is a poor-quality fuel and its pre-processing is necessary to prepare fuel pellets to improve its consistency, storage and handling characteristics, combustion behavior and calorific value [4].

Generally speaking, sewage sludge, waste wood, high calorific fractions from mechanical-physical (MPT) and/or mechanical–biological treatment (MBT) plants, calorific fractions of household and commercial waste, shredder lightweight fractions (e.g., electrical and electronic equipment), scrap tyres, food by-products (fats, animal meal, etc.) waste oil, used solvents and viscose plant off gas, etc. may be considered as “Refuse Derived Fuel” (RDF). In the narrow sense of the definition, solid fuels which are prepared from sorted or mixed solid wastes (municipal waste fractions, commercial wastes, production wastes, lightweight fractions from MBT/MPT-plants, etc.) are described as “Solid Recovered Fuel” (SRF) [5]. This fuel

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is a special type of solid municipal waste that contains only a small percentage of non-combustible materials such as metal and glass [6].

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 behavior, the slag formation and corrosion potential – and from comparing the combustion behavior with fossil fuels, that biomass fuels and RDF can be seen as difficult fuels [7].

The production of RDF (or SRF) pellets, which is the subject of our investigation, consists of several single operations to separate unwanted as well as combustible components to achieve optimal combustion parameters. The main operations are filtering; crushing; size reduction; classification: separation of metal, glass or wet organic matter; drying; compression [4].

For higher qualities of RDF and/or SRF, a multi-stage separation process is necessary for manufacturing, including the unit operations of classifying and sorting of waste material fractions, as well as the separation of ferrous and non-ferrous metals and also unwanted heavyweight inert materials (e.g. stones, glass, ceramics, etc.) followed by confectioning of the fuel according to specifications given. The final quality of RDF (or SRF) will ultimately depend on the composition of the input (feeding) materials, as well as on the extent and the intensity of the applied recovery process (*Figure 1*) [5].

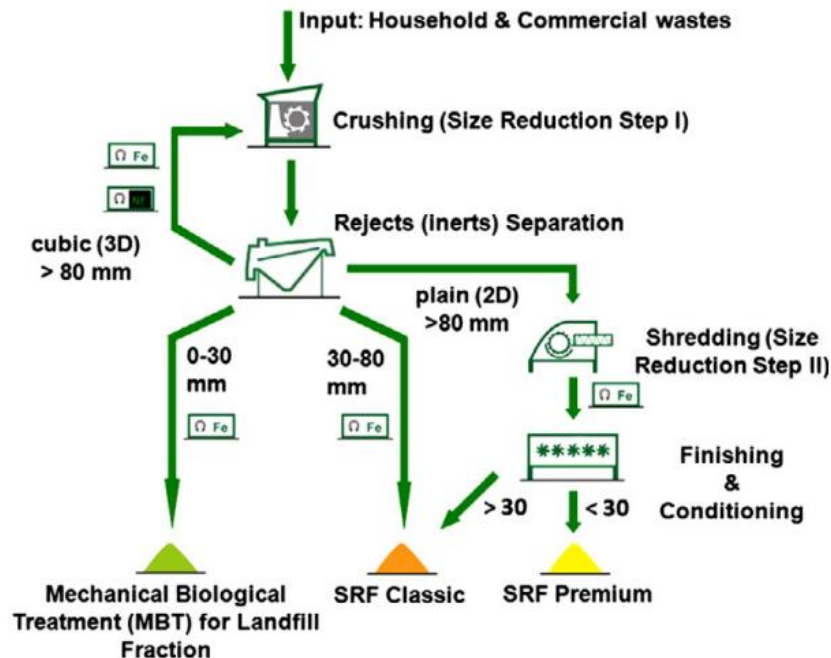


Figure 1

Simplified processing scheme for different RDF/SRF specifications [5]

The physical composition of the RDF pellets found in the literature is shown in *Table 1*, while *Table 2* includes the combustion properties.

Table 1
The physical composition of RDF pellets

Ref.	Plastic	Paper carton	Textile	Biomass	Composite	Food waste	Fine fraction	Other	HHV*
	% m/m								MJ/kg
[1]	17.3	57.1	*	4	—	18.6	—	3.2	19.4 ^{dry}
[5]	16	6	5	6	3	—	55	9	n/a
[7]	4	21	*	41	4	—	20	10	8 ^{wet}
[8]	23	35.1	14	2.1	—	—	20.3	5.5	16.5 ^{dry}
[8]	20	25	0	15	—	—	—	40	17.2 ^{dry}
[8]	9	55	5	0	—	—	—	31	17.4 ^{dry}
[9]	41.5	3.4	21.3	16.7	—	—	10.4	6.8	15.6 ^{wet}
[9]	54.9	3.0	14.2	18.5	—	—	0.8	8.7	16.5 ^{wet}
[9]	64.5	0.6	11.4	9.9	—	—	1.0	12.6	19.3 ^{wet}
[10]	24.5	27.9	8.7	5.9	—	—	23.2	9.3	23.4 ^{dry}
[11]	14.4	14.3	59.4	2.1	4.7	—	—	5.1	21.7 ^{dry}
[12]	42.1	42.1	41.2	7.0	9.6	—	—	—	23.7 ^{wet}
[12]	24.0	24.0	23.5	4.0	48.5	—	—	—	16.1 ^{wet}
[12]	24.0	24.0	23.5	4.0	25	—	—	23.5	17.6 ^{wet}

* HHV – higher heating value

highlighted area – LHV lower heating value

n/a. – no available

The visual inspection of the fine fraction showed that it is a heterogeneous material dominated by soil-like materials and minerals and also contain different quantities of landfilled materials [13]. Fine fractions can be considered as a relevant source of metals and calorific fractions, as well as a fraction suitable for inert and soil-like material recovery [14].

Other types of waste include glass, metal, hazardous household waste, inert waste, health-care waste, various combustible and non-combustible.

In contrast, the carbon content and calorific value were increased by increasing organic waste content up to 40% of the total weight of RDF. The similar trend has been seen for hydrogen content, but it was in lower magnitude. The oxygen content was shown on the opposite response to the carbon content and calorific value, while the nitrogen content tends to increase by putting more organic waste [15].

As shown in *Table 1* the heating value of RDF pellets may differ depending on their composition. The composition of municipal solid waste varies from day to day, so the properties of RDF pellets will also be different [7].

Table 2
Combustion properties of RDF pellets (dry-basis)

Ref.	Moisture	Ash	N	C	H	S	O	HHV
	% m/m							MJ/kg
[9]	17.60	40.00	0.95	35.95	4.50	0.45	n/a	15.60
[9]	19.55	32.30	1.25	44.80	7.15	0.45	n/a	16.50
[9]	19.35	36.05	1.25	43.45	5.90	0.39	n/a	19.25
[16]	1.20	13.34	0.66	51.66	8.82	0.08	25.42	n/a
[17]	22.07	17.11	0.94	45.09	5.78	0.15	30.94	23.44
[18]	n/a	14.70	0.77	43.92	6.36	0.29	33.48	19.54
[18]	n/a	23.75	1.20	47.40	6.15	0.22	19.78	22.55
[15]	6.40	9.20	10.77	49.75	9.04	1.89	28.55	24.96

n/a – no available

According to the literature, the moisture content of RDF pellets can vary ranges from 1.2% m/m to 22.07% m/m, ash content from 9.2% m/m to 40% m/m, and heating value from 15.6 MJ/kg to 24.96 MJ/kg (Table 2).

The RDF pellets studied in this article are utilized by pyrolysis. Pyrolysis is nothing more than thermal decomposition in an oxygen-free medium. During the thermal decomposition, gas, liquid and solid end products are formed. The number of end products can vary over a wide range depending on the parameters of the experiment; from pyrolysis temperature, heating rate, pyrolysis time, etc. [19].

It is important to know the combustion parameters of all materials used for energy purposes. In the course of the research, the combustion properties of the RDF pellets and the ash content of the char left behind from pyrolysis were examined.

1. MATERIALS AND METHODS

The investigated RDF pellets were manufactured from solid municipal solid waste, so there is no information on the actual composition of the pellets. The two types of RDF pellets were produced with a difference of about 20 days. Biofraction pellets are manufactured from the bottom product (containing a large amount of organic matter) by selecting municipal solid waste with trommel. The blend pellet contains 34% m/m of RDF pellet and 66% m/m of biofraction.

Organic substances are mostly found in the particle size fraction below 50 mm so that biofraction containing mostly organic matter can be produced from the residual waste with grading and other separation processes. This fraction is very different from the selectively collected green waste, its composition is much more heterogeneous. In addition at the side of biodegradable many other types of waste are presented, such as hazardous waste, because the people cannot be motivated to collect waste responsibly.

The pellets were subjected to the following combustion tests:

- Determination of the moisture content of pellets happens in a drying oven at 105 ± 5 °C by mass content, according to MSZ EN 14774:2010 standard.
- Determination of ash content of pellets and char from pyrolysis by heating to 550 ± 15 °C to constant mass according to MSZ EN 14775: 2010.
- Carlo Erba EA1108 type ultimate analyzer was used for the measurement of the C-, H-, N-, S-, O-content in the pellets according to MSZ EN 15104:2011 standard.
- The calorific test was performed using a Parr 6200 type isoperibol oxygen bomb calorimeter according to MSZ EN 14918:2010 standard. The lower heating value is calculated from the higher heating value, the hydrogen content and the moisture content.
- Determination of the softening and sintering temperature of ash from combustion using a SYLAB IF2000G type heating microscope.
- Thermoanalytical analysis with MOM Q1500D type derivatograph.

The pyrolysis of RDF pellets occurred at 600 °C with a heating rate of 60 °C/h. After the experiments, the solid product (char) was also tested.

2. COMBUSTION PROPERTIES OF PELLETS

Table 3 shows the combustion properties of the samples. The table also contains the parameters of a good quality wood pellet as a reference value.

Table 3
Combustion properties of pellets tested (dry-basis)

Sample	Moisture	Ash	N	C	H	S	O	HHV*
	% m/m							MJ/kg
1. RDF pellet	4.20	17.02	1.33	49.44	6.44	0.42	25.35	22.42
2. RDP pellet	4.74	19.98	1.37	44.22	5.57	0.18	28.67	20.93
Biofraction	4.04	56.68	1.59	24.09	2.84	0.51	14.28	9.07
Blend pellet	4.32	41.16	1.33	38.16	4.88	0.17	14.31	14.83
Wood pellet	7.70	0.79	0.22	44.59	6.11	0.05	48.59	18.24

*HHV– higher calorific value

Although the composition of the pellets tested differs, the hygroscopic moisture content is almost the same. The ash content of RDF pellets is relatively high. This is partly due to the fact that the municipal solid waste, despite the selection, still contains non-combustible materials that go through the system and have not decomposed during keeping the heat at 550 °C. Another possible reason is that during the manufacture of some plastics (like gum), fillers were used that are also non-combustible.

Based on the information in the literature, RDF pellet samples may contain high carbon content material due to the heating value around 20 MJ/kg.

As regards the comparison of RDF pellet 1 and wood pellet, the much higher heat value of the RDF pellet is due to the higher carbon content and lower moisture content. At the same time, the ash content and nitrogen content are higher, which can be considered unfavorable in the case of combustion.

Table 4 shows the proximate analysis of the pellets. As we can see, there is a strong relationship between the fix carbon content of the samples and the heating value. The RDF pellet 1 sample has the highest fix carbon content and the highest calorific value.

Table 4
Proximate analysis of pellets tested

Sample	Moisture	Volatile	Fix carbon	Ash
	% m/m			
1. RDF pellet	11.02	41.07	30.40	17.51
2. RDF pellet	8.51	45.09	24.25	22.15
Biofraction	22.08	23.73	12.19	42.00
Blend pellet	13.94	39.41	28.12	18.50

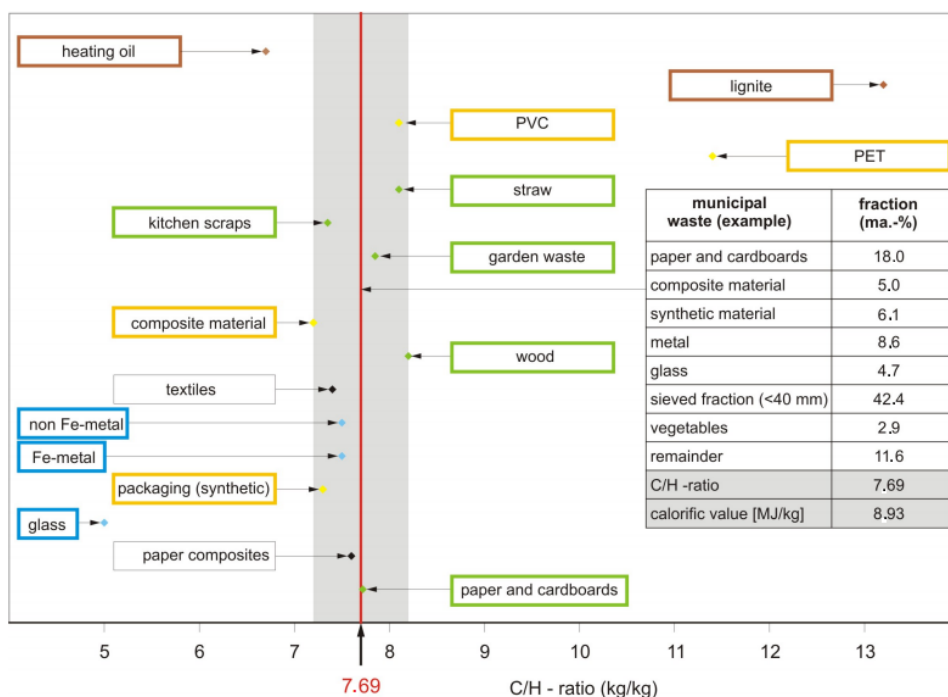


Figure 2

Illustration of the C/H ratio of different material groups in comparison to municipal waste set as an example [7]

Figure 2 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 (Figure 3) [7].

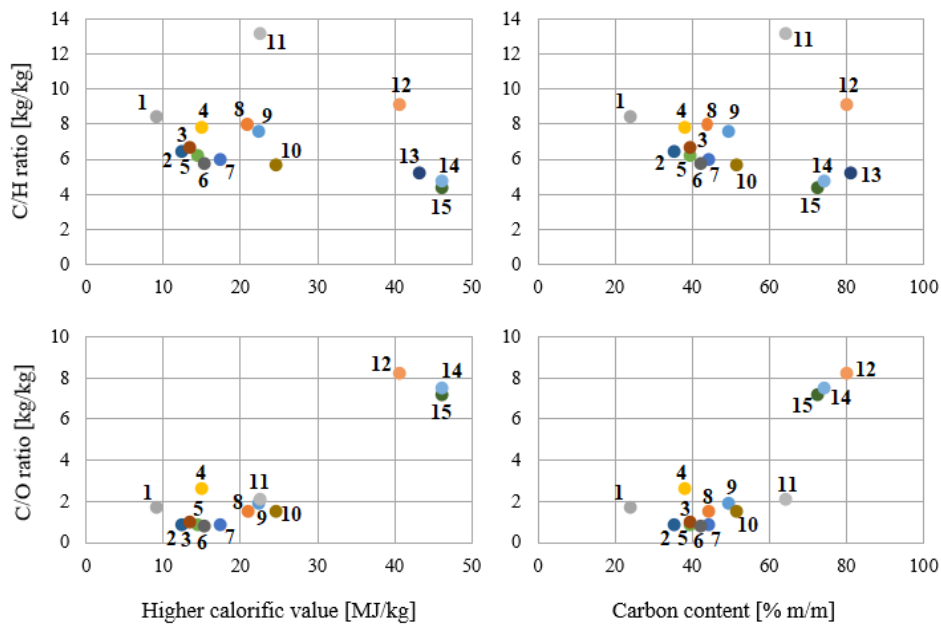


Figure 3

C/H and C/O ratios plotted against the higher calorific value and the carbon content for different waste fractions and different refuse-derived fuels

- | | | |
|-----------------------|-------------------------------|----------------------------------|
| 1. Biofraction | 7. Textil | 12. PS (e.g., sourcream box) |
| 2. Glossy paper | 8. 2. RDF | 13. 90 C/PP (e.g., bag of chips) |
| 3. Recycled newsprint | 9. 1. RDF | 14. HDPE 1. |
| 4. RDF/Bio mix | 10. 84C/PAP (e.g., juice box) | 15. HDPE 2. |
| 5. Carton | | |
| 6. Paper napkin | 11. PET | |

According to Figure 3, the RDF/Bio mixture is located near the group of paper and textiles, while the group of plastics is severely separated. 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 (Figure 3) [7]. If the physical composition of the RDF sample is not known, we can get a good approximation from the investigation of the C/O ratio, the C/H ratio, the calorific value, and the carbon content. Figure 3 illustrates well that which materials can be in the RDF.

3. INVESTIGATION OF SOLID BY-PRODUCTS AFTER COMBUSTION AND PYROLYSIS OF RDF PELLETS

RDF pellets can be utilized on a large scale in many ways. One possibility is to operate a heat generating device with RDF fuel and the other to use it as a pyrolysis feedstock. In the latter case, the ultimate goal is to maximize the amount of gaseous product. In either case, there are solid by-products of RDF pellets remaining after combustion and pyrolysis, called ash and char. The investigation results of these solid residues are shown below.

3.1. Determination of softening parameters of RDF ash

Attention should be paid to solving the problem of slag formation and corrosion caused by it when the RDF pellets are used in high-temperature operation. The degree of damage to the combustion plant is influenced by the chemical and mineral composition of the ash resulting from the combustion, the sintering, softening and melting properties [20]. In-laboratory softening studies indicate with acceptable accuracy the behavior of ash in industrial boilers (amount of ash deposited in the combustion chamber and heat exchanger surfaces, ash aggregation, and corrosion caused by it) [21].

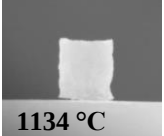
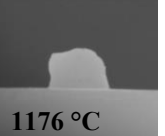
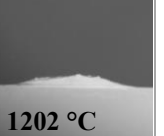
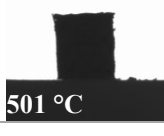
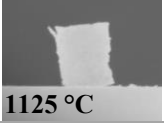
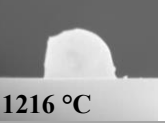
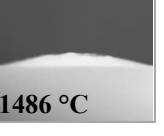
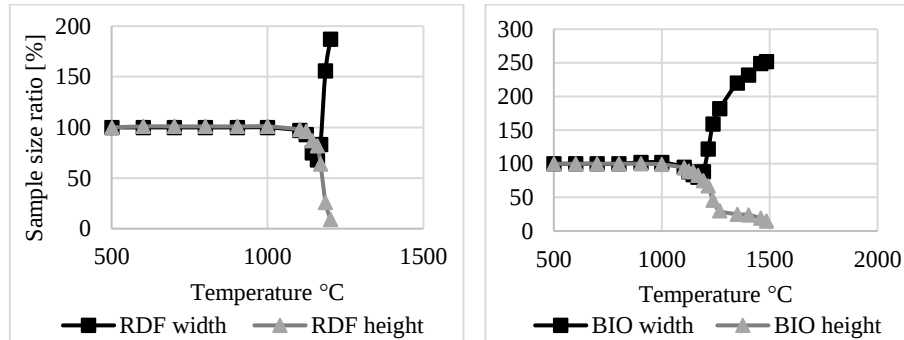
Sample	Temperature °C			
1. RDF pellet	 501 °C	 1134 °C	 1176 °C	 1202 °C
Biofraction pellet	 501 °C	 1125 °C	 1216 °C	 1486 °C

Figure 4

Images of ash from 1. RDF pellets and biofraction made during ash softening testing

Based on previous experiences [22], the biofraction could have contain several substances that increase the melting point temperature (Si, Ca, Mg, Al) of the resulting ash, while the 1. RDF pellet may contain alkali metal (Na, K) and phosphorus oxides because of its lower melting point. In both cases, the sphericalization of the ash samples starts at around 1,160 °C. This temperature is well above the temperature of the pyrolysis, so it cannot cause any problems.

**Figure 5**

Degree of deformation of ash samples from 1. RDF pellets and biofraction

3.2. Determination of ash content of RDF char

The ash content of the char samples remaining after pyrolysis was also analyzed, the results of which are shown in *Table 5* below.

Table 5
Ash content of chars

Sample	Ash content % m/m
Char of RDF pellet pyrolyzed at 700 °C	53.25 ± 1.64
Char of biofraction pellet pyrolyzed at 700 °C	84.14 ± 0.17
Char of blend pellet pyrolyzed at 700 °C	77.24 ± 2.13

The ash content of pyrolyzed pellets under the same conditions may be different due to their composition. The higher the ash content of the pyrolyzed sample the less content of combustible in it. It can be stated that the settings for pyrolysis should be adapted to the composition of the RDF pellet. Thus, the organic composition of the waste not only influences the moisture and ash content of the fuel as well as the heat of combustion but also the setting of the parameters of pyrolysis.

Although, there is no effect on pyrolysis, the softening properties of ash of the char will be tested in the future.

CONCLUSION

The article examines the combustion properties important for the usability of RDF pellets: physical composition, moisture content, ash content, element composition, lower and higher heating value, ash softening and sintering properties. Refuse-derived fuels are used in power plants, material industry, mono combustion facilities and co-firing plants. RDF pellets can be utilized on a large scale in many ways. One

possibility is to operate a heat generating device with RDF fuel and the other to use it as a pyrolysis feedstock.

Several factors influence the combustion parameters of RDF pellets:

1. The great difference in combustion properties is due to the different composition of heterogeneous components of RDF pellets (such as wood, fabric, plastic), which is caused by the ever-changing composition of municipal solid waste due to different consuming habits of people. This is a relatively poor-quality fuel and its pre-processing is necessary to prepare fuel pellets to improve its consistency, storage and handling characteristics, combustion behavior and calorific value. However, recycling of this waste is necessary, and pyrolysis could represent a solution.
2. In manufacturing technology, as there are no standards for the production of RDF (unlike for the production of SRF), there may be significant differences between the quality of RDF from different producers.

The different ash content of chars is also due to the different proportions of the components found in RDF pellets. It can be stated that the settings for pyrolysis should be adapted to the composition of the RDF pellet. Thus, the organic composition of the waste not only influences the moisture and ash content of the fuel as well as the heat of combustion but also the setting of the parameters of pyrolysis.

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