THE EFFECT OF FUEL QUALITY ON CARBON DIOXIDE AND NITROGEN OXIDE EMISSIONS, WHILE BURNING BIOMASS AND RDF

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The article analyses the variations in carbon dioxide emission factor depending on parameters characterising biomass and RDF (refuse-derived fuel). The influence of moisture, ash content, heat of combustion, carbon and nitrogen content on the amount of emission factors has been reviewed, by determining their average values. The options for the improvement of the fuel to result in reduced emissions of carbon dioxide and nitrogen oxide have been analysed. Systematic measurements of biomass parameters have been performed, by determining their average values, seasonal limits of variations in these parameters and their mutual relations. Typical average values of RDF parameters and limits of variations have been determined.

Keywords: *ash content, biomass, carbon content, carbon dioxide, emissions, heat of combustion, moisture, nitrogen oxides, refuse-derived fuel*

1. INTRODUCTION

Biomass is a renewable energy source with considerable potential in replacing fossil fuel. As the interest in biomass as a renewable and carbon dioxide (CO_2) neutral energy source is growing, the interest in the influence of biomass combustion on the environmental pollution, climate and climate change is growing as well [1]–[4]. Biomass combustion results in the emissions of gaseous and solid particles in the atmosphere, for instance, carbon dioxide, methane and nitrogen oxides, which create the greenhouse effect and are hazardous for the environment and human health [2], [3]. Most commonly used biomass includes various types of wood of coniferous and deciduous trees – branches, leaves, bark, forestry waste, tree, shrub and wood residues, sawdust and bark from felling sites, which are also referred to as wood waste and wood chips, granules, and briquettes. It has been experimentally proven [5], [6], [7] that the nitrogen contained in the biomass during combustion is the principal source of NOx emissions, namely, as the content of nitrogen increases in fuel, the amount of nitrogen oxide emissions increases proportionately. The other three mechanisms of nitrogen oxide generation that result in nitrogen oxide emissions are not that significant, since they are associated with relatively high temperatures of more than 1,200 °C, while the typical temperature in biomass combustion furnaces

does not exceed 1,100 °C. The content of nitrogen in the wood is pre-determined by several factors: type of wood or the composition of fuel, environment, where the trees have grown – climate, soil, degree of pollution, external pollution during the preparation of fuel, age of the wood, etc. All of these factors determine the content of carbon and nitrogen in the biomass and the resulting CO_2 and NOx emissions, as the biomass is burnt.

One of the most significant alternatives to fossil energy sources and renewable energy sources alike is refuse-derived fuel (RDF). There are two types of RDF – sorted material or refuse-derived fuel from non-hazardous waste and solid recovered fuel (SRF). In accordance with the standard LVS EN 15359:2012 "Solid Recovered Fuel Specifications and Classes", the solid recovered fuel has been divided into five classes, depending on its parameters. Biomass can be, to some extent, classified as RDF, however, the characterising parameters of this type of fuel and, consequently, possible emissions differ, because the lowest heat of combustion, as well as carbon and nitrogen content of these materials are different. RDF that is suitable for certain use (predominantly, the production of concrete) is currently used in relatively low quantities in Latvia.

2. MEASURING EQUIPMENT AND MEANS

When taking measurements for determining the carbon content in fuel and the corresponding GHG emission capacity in flue gases, the following equipment was used:

- Element analyser "*Flash EA1112 Series*", company "*Thermo Fisher Scientific*", Holland.
- Gas analyser "*SWG*-200-1", *MRU GmbH*, Germany.
- Calorimeter "*Berthelot Mahler*", company "*I.S.Co.*", Italy; with additional equipment.
- Calibrated containers for determining the density of the fuel material.
- For calibration, benzoic acid C_6H_5COOH, dodecane $C_{12}H_{26}$, acetanilide C_8H_9NO and atropine $C_{17}H_{23}NO_3$ of the corresponding quality were used.

3. MEASUREMENT METHODOLOGY

For determining carbon content in fuel, CHN analyser was used in accordance with the Standard LVS EN ISO 16948; for determining calorific values – LVS EN ISO 18125; for determining moisture – LVS EN ISO 18134; for determining the amount of ashes – LVS EN ISO 18122 and for determining bulk density – LVS EN ISO 17828. For recalculating the data of the analysis for various bases, the standard LVS EN 15296 was used. In CHN analysers, a very small amount of the material was used as a sample – by weighing it very precisely, in milligrams, before inserting it into the unit. To avoid the systematic error, analyser was additionally calibrated by using a stable, lightly volatile and strongly defined chemical. For calibration, benzoic acid C_6H_5COOH, dodecane $C_{12}H_{26}$, acetanilide C_8H_9NO and atropine $C_{17}H_{23}NO_3$ of the corresponding quality were used.

3.1. Sampling

Laboratory data of the biomass fuel parameters, during the second half of 2016 and January–May 2017, acquired from Latvian companies, were gathered. This way we could collect an excellent and representative range of wood fuel samples, for which the deviation of parameters could be wide. The samples were prepared for the analysis in accordance with the requirements that were set forth for measuring the specific parameters, according to the aforementioned standards.

3.2. Deviation and Representation of Parameters

The deviation of parameters for biomass is well represented in Fig. 1, where all the data of the wood pellet analysis conducted in the laboratory, during the four months in 2017 and the entire year of 2016, were gathered. Figure 1 shows the dependence of the net calorific value on moisture. It can be split into two groups – pellets with an ash content of up to 0.5 % (blue squares), and pellets with an ash content above 0.5 % (pink circles). In accordance with the standard LVS EN ISO 17225-2, wood pellet is divided into specification classes A1, A2, and B. Two groups (sets) of the pellet are formed to ensure that one of the two sets belongs to the class A1 according to ash content, e.g., ash content does not exceed 0.5 %. In Fig. 1, each of the mentioned sets is approximated with a straight line. In the ideal situation – if the calorific value depended only on humidity, all experimental points would form such a straight line. In fact, it is a set where each measurement is equivalent to others.

Both sets often overlap, which is why, when determining the average Q_{net} value, all the values in the range 16.8–18.4 GJ/t were taken into account. In this case, more than 300 samples were analysed.
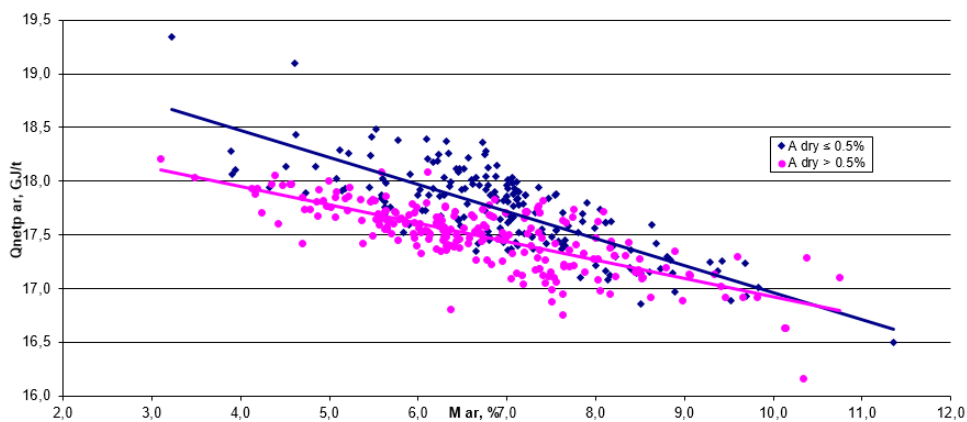

Fig. 1. The dependence of moisture content on the calorific values for different wood pellet samples.

It is obvious that seasonality impact on this scattering is very low. Only in 2.5 % of cases, humidity is out of the interval 4–10 % and does not depend on seasonality. It is understandable because pellet production technology does not depend on the season and weather circumstances.

In Fig. 2, scattering of the chips and wood residue parameters is given. Explanation of the scattering is the same as for Fig. 1 (see above); only in this case

scattering is much larger. This can be explained with physical and chemical as well as humidity differences in examples.
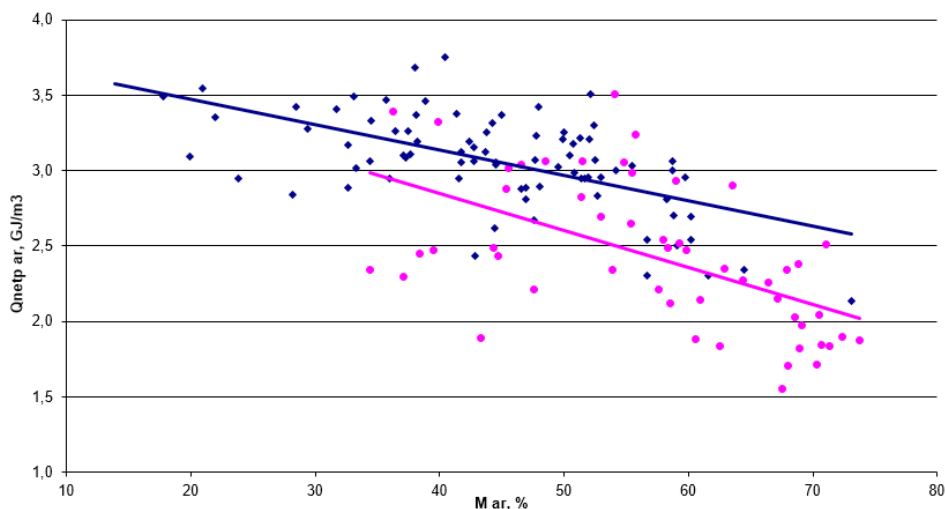

Fig. 2. The dependence of net calorific value of the wood chips and timber offcuts and residues on moisture. Note: "pink circles" – residues; "blue squares" – chips.

3.3. Seasonality

The seasonal changes in the wood fuel material parameters may be mainly related to the change in the moisture content. However, the analysis revealed that wood pellet and briquette seasonality was almost unnoticeable. It is understood that at a greater extent the moisture content depends on the technological production process of the fuel. Dependence on seasonality of the humidity of wood chips and wood residues is noticeable but not significant.

3.4 Calculation of Emission Factors

The CO_2 emission factor was calculated by taking into account the physico-chemical characteristics experimentally determined during the research, by using the emission factor calculation formula (1). Oxidation factor p according to the IPCC Guidelines is determined p = 1.

$$E'_{CO2} = \frac{C^d \times M_{CO_2} \times 1000}{Q_z^d \times M_C \times 100},\tag{1}$$

where E'_{CO2} – CO_2 emission factor (t CO_2/TJ);

C_d – coal content in fuel operating weight (%);

M_{CO2} – CO_2 molecular weight (44.0098 g/mcl);

M_C – C molecular weight (12.011 g/mcl);

Q_z^d – net calorific value of fuel operating weight (GJ/t);

1000 – transition from GJ to TJ;

100 – determining % value.

4. RESULTS

The average values of parameters in CO_2 and NOx emissions by fuel combustion are collected in Table 1.

The Average Values of Parameters in CO_2 and NOx Emissions by Fuel Combustion

Fuel	Moisture, %	Q_{net} value	Carbon content, %	Nitrogen content, %
Firewood	Average 51	7.73 GJ/bulk.m³	22.88	0.06
	10	16.24	42.03	0.11
	20	14.16	37.36	0.10
	30	12.09	32.69	0.08
	40	10.01	28.02	0.07
	55	6.9	21.02	0.05
Wood residue [1]	Average 57.2	2.69 GJ/bulk.m³	20.3	0.43
Wood chips [2]	Average 44.7	3.26 GJ/bulk.m³	23.92	0.25
Wood briquettes	Average 9.65	16.78 GJ/t	48.1	0.11
Wood pellets	Average 7.38	17.54 GJ/t	49.83	0.11
RDF; SRF	Average 10.3	20.8 GJ/t	51.42	0.93

Note: [1] Bulk density for residue 0.424 kg/m³

[2] Bulk density for chips 0.367 kg/m³

4.1. SRF and RDF Characterisation

According to the stipulations of the EN 15359 [8], solid recovered fuel is defined as quality assured fuel, and it should not be confused with the RDF. RDF is a non-standardised low quality fuel that contains mixed unprocessed combustible components of municipal solid waste and uses only energy from waste plants [9]. According to Wilén *et.al.* [10], the high quality recovered fuels (class SRF I) can be produced from commercial, construction, demolition and industrial waste, but quality class SRF II-III from household and commercial waste after source separation. According to [11], the coarse fraction after mechanical pre-treatment of municipal solid waste is suitable for the production of refuse derived fuel in Latvia.

A lower heating value of RDF is 12–16 MJ/kg, moisture 15–25 % and ash 10–22 % [12]. According to Nithikul [13], a lower heating value (LHV) of RDF is 19.4 MJ/kg and percent of C is approximately 57 % in Thailand.

The average theoretical LHV of RDF is calculated as 15.7 MJ/kg, but the experimentally determined LHV of RDF samples was 15.1 MJ/kg, ash content was 16 % and moisture content was 6 % in Latvia [14]. The elemental analysis for solid recovered fuels is C – 47.1 % (dry basis), H – 7.1 %, O – 29.4 %, N – 0.7 %, S – 0.24 %, Cl – 0.6 % [15]. According to Conesa *et al*. [16], the elemental and proximate analyses of SRF are C – 40.85 % (wt. %), H – 5.33 %, O – 42.39 %, N – 1.07 %, S – 0.15 %, and humidity – 16.7 %. According to Kim *et al.* [17], the elemental analysis of SRF showed that 66.8–70.39 % of the samples comprised carbon, 16.81–18.81 % comprised hydrogen, 11.19–15.47 % accounted for oxygen, and only 1% was

nitrogen and sulphur. The present results for RDF and SRF parameter measurements in Latvia are collected in Table 2.

Parameters of RDF and SRF in Latvia

No.	W_{ar}	A_{dry}	Q_{gr}	Q_{gr}, dry	Q_{netp}, AR	S, dry	Cl, dry	N, dry	C, dry	H, dry	DT	FT
	%	%	MJ/kg	MJ/kg	GJ/t	%	%	%	%	%	°C	°C
1	2.8	51.5	12.72	13.08	11.34	0.57	0.85	1.45	33.15	3.77	-	-
2	1.6	29.4	26.05	26.47	24.68	0.29	1.18	0.69	53.75	6.02	-	-
3	2.3	31.5	26.33	26.96	24.95	0.29	1.77	0.81	55.22	5.89	1120	1190
4	2.0	29.5	24.06	24.54	22.69	0.30	1.72	1.25	43.31	3.84	-	-
5	2.2	18.6	24.67	25.21	23.30	0.30	1.78	1.29	50.52	5.39	-	-
6	2.9	13.7	23.69	24.40	22.31	0.26	1.12	0.89	58.65	7.11	1160	1210
7	2.2	17.0	22.78	23.30	21.41	0.28	1.58	0.59	55.74	7.34	1120	1200
8	1.8	41.7	22.85	23.26	21.48	0.52	1.84	0.67	43.55	6.31	-	-
9	2.5	19.5	22.49	23.07	21.12	0.41	1.09	0.80	49.04	7.04	-	-
10	2.1	16.6	26.47	27.04	25.10	0.33	1.16	0.66	61.03	9.22	1130	1220
11	3.7	15.5	20.95	21.75	19.56	0.24	1.28	1.28	49.29	6.87	-	-
12	26.5	12.8	24.69	33.61	23.05	0.23	2.22	0.34	59.00	7.80	1150	1200
13	22.4	9.5	26.94	34.72	25.34	0.19	2.18	0.35	61.00	8.20	1150	1200
14	31.1	19.1	16.36	23.74	14.67	0.30	1.28	1.56	52.97	6.28	1150	1240
15	40.4	16.2	11.29	18.94	9.50	1.02	2.88	1.32	45.03	6.21	1130	1210
16	24.6	15.1	19.28	25.58	17.66	-	-	-	-	-	1140	1230
17	7.5	-	28.91	31.26	27.47	-	0.81	-	-	-	-	-
18	14.0	-	19.74	22.96	18.24	-	1.13	-	-	-	-	-
19	3.6	-	22.79	23.63	21.40	-	0.42	-	-	-	-	-
Average	10.3	22.3	22.27	24.92	20.80	0.37	1.46	0.93	51.4	6.49	1139	1208
St. dev.	12.3	11.5	4.69	4.86	4.76	0.21	0.59	0.40	7.78	1.46	-	-
Min	1.6	9.5	11.29	13.08	9.50	0.19	0.42	0.34	33.2	3.77	-	-
Max	40.4	51.5	28.91	34.72	27.47	1.02	2.88	1.56	61	9.22	-	-

We can see that the value of the parameters vary in the very broad range and all depends on collection and separation technology. Minimising moisture content in raw materials is of significance for production of good quality SRF.

5. EMISSION FACTORS

CO_2 and NOx emission factors are collected in Table 3.

Table 3

CO$_2$ and NOx Emission Factors

Fuel	Fuel carbon consumption (C), %	Net calorific value (Q$_z$), GJ/t	Emission factors (E'$_{CO2}$), t/TJ	Nitrogen consumption (N) %	Nitrogen oxides emission factors (E'$_{NO2}$),t/TJ
Firewood, W=51% (Latvia average)	22.88	7.73	108.45	0.06	0.2844
Firewood, W=20%	37.36	14.16	96.67	0.10	0.2587
Firewood, W=40%	28.02	10.01	102.57	0.07	0.2562
Wood residue W=57.2%	20.3	2.69	117.32	0.43	2.4851
Wood chips, W=44.7%	23.92	3.26	98.703	0.25	1.0316
Wood briquettes, W=9.65%	48.1	16.78	105.03	0.11	0.2402
Wood pellets, W=7.38%	49.83	17.54	104.09	0.11	0.2298
RDF W= 10.3%	51.42	20.8	90.58	0.93	0.6383

6. MEASUREMENT UNCERTAINTY

Measurement uncertainty, when determining the specific parameter, was performed in accordance with the Theory of Errors. The standard deviation of each parameter was determined 10 times by measuring the same sample and by determining the average deviation, which described the deviation in the acquired result. In CHN measurements, the uncertainty estimation was included in the software of the device. The absolute result was recalculated to the relative error: carbon content uncertainty was ±1.5%; moisture ±2.0%; ash amount ±2.5%; calorific value ±4.5%; density ±5%.

For wood materials, the EF uncertainty estimation was significantly larger, because the parameter variations were much larger and by using the IPCC methodology the uncertainty increased. The estimated EF determination errors for wood materials are reflected in Table 4.

Table 4

The Uncertainty of Determining Emission Factors

Fuel	Uncertainty, ± %
Diesel fuel	2
Coal	3
Firewood	5
Pellets and briquettes	4
Wood chips and timber offcuts	10

7. CONCLUSIONS

1. The research of Latvian wood biomass and RDF parameters has been performed. The variations in carbon dioxide and nitrogen oxide emission factor depending on parameters characterising biomass and RDF have also been analysed.
2. The influence of moisture, ash content, heat of combustion, carbon and nitrogen content on the amount of emission factors has been reviewed by determining potential limits of their variations for each type of fuel.
3. The options for the improvement of fuel have been offered, thus ensuring lower emissions of carbon dioxide and nitrogen oxides; in the event of biomass they include the reduction of moisture and ash content, for RDF – more thorough sorting of raw materials.
4. The average values of RDF parameters and limits of their variations have been determined; the values of CO_2 and NOx emission factors of biomass and RDF have been compared and analysed.

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KURINĀMĀ KVALITĀTES IETEKME UZ OGLEKĻA DIOKSĪDA UN SLĀPEKĻA OKSĪDU EMISIJĀM, SADEDZINOT BIOMASU UN NAIK

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K o p s a v i l k u m s

Rakstā analizētas oglekļa dioksīda un slāpekļa oksīdu emisijas faktora izmaiņas atkarībā no biomasu un NAIK (no atkritumiem iegūtais kurināmais) raksturojošiem parametriem. Apskatīta mitruma, pelnu satura, sadegšanas siltuma oglekļa un slāpekļa satura ietekme uz emisijas faktoru lielumu, nosakot to vidējās vērtības. Analizētas kurināmā materiāla uzlabošanas iespējas, nodrošinot mazākas oglekļa dioksīda un slāpekļa oksīdu emisijas. Veikti sistemātiski biomasas parametru mērījumi, nosakot vidējos lielumus, sezonālas parametru izmaiņu robežas, un savstarpējās attiecības. Noteiktas tipiskas NAIK parametru vidējās vērtības un izmaiņu robežas.
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