Flue gas emissions during the combustion of different natural fuel wood qualities

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1 Introduction

Wood is considered to be a regenerative and CO_2 neutral fuel. Thus, thermal use of residual wood from forestry, plantation and wood processing industries can replace considerable amounts of fossil fuels [1]. Extensive emission measurements showed that individual wood furnaces are locally responsible for high emissions of aerosols and hydrocarbons caused by poor furnace technique, fail operation and using wrong fuel wood in the wrong furnace. The different fuel wood qualities are standardized under CEN as Technical Specification with the title “Solid biofuels - Fuel specifications and classes”. Different fuel qualities should have been burned and the properties for their combustion should be investigated in a test furnace at the Universitaet Stuttgart and in furnaces operated in practice [2].

2 Solid Biofuel standardisation and test furnace

The major traded forms of fuel wood are: Briquetts, Pellets, Sawdust, Wood Chips, Hog Fuel and Log Wood. The solid biofuels are just standardized in CEN. The classification is shown in Table 1. Not all classes can be burned in each type of furnace. For pellets, wood chips and hog fuel grate or underfeed firings are mainly used. In Figure 1 the test grate furnace at Universitaet Stuttgart is depicted.

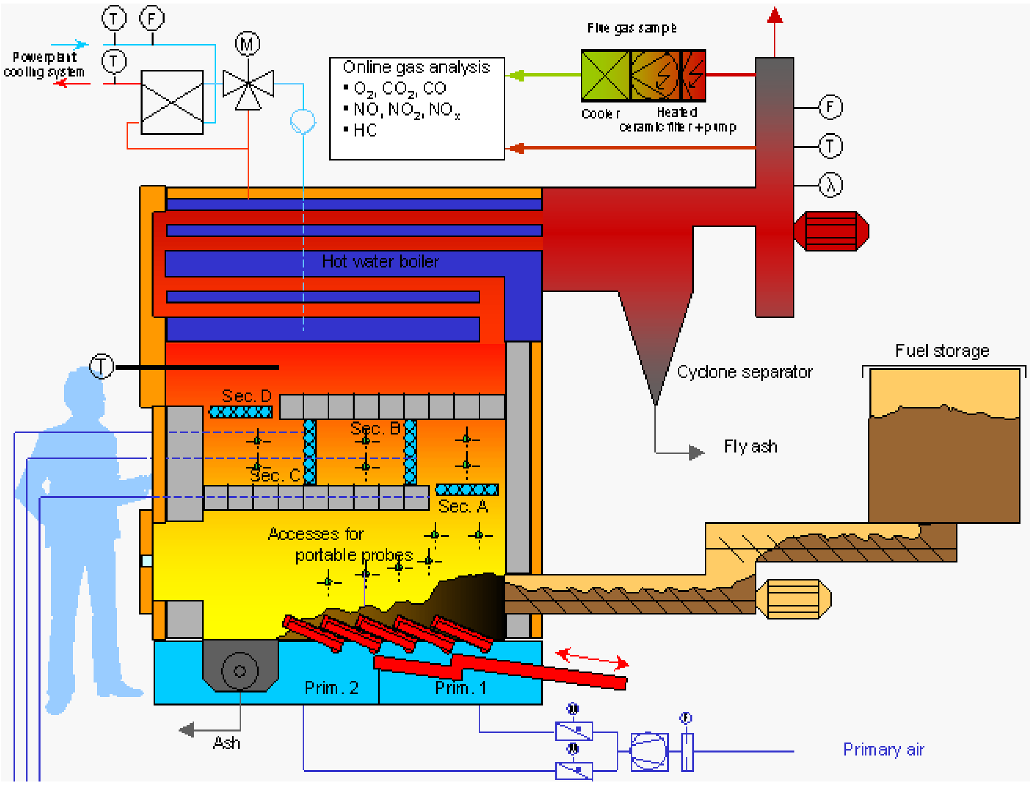

Figure 1. Test grate furnace at Universitaet Stuttgart. 240 kW thermal power, staged air supply, equipped with cyclone as dust separator

Table 1. Fuel wood classification according CEN TC 146, WG 2
"Solid biofuels - Fuel specifications and classes"

1. Woody biomass	1.1. Forest and plantation wood	1.1.1 Whole trees	1.1.1.1 Deciduous wood
			1.1.1.2 Coniferous wood
			1.1.1.3 Short rotation coppice
			1.1.1.4 Bushes
			1.1.1.5 Blends and mixtures
		1.1.2 Stemwood	1.1.2.1 Deciduous
			1.1.2.2 Coniferous
			1.1.2.3 Blends and mixtures
		1.1.3 Logging residues	1.1.3.1 Fresh/Green (including leaves/needles)
			1.1.3.2 Dry
			1.1.3.3 Blends and mixtures
		1.1.4 Stumps	1.1.4.1 Deciduous wood
			1.1.4.2 Coniferous wood
			1.1.4.3 Short rotation coppice
			1.1.4.4 Bushes
			1.1.4.5 Blends and mixtures
		1.1.5 Bark (from forestry operations)*	
		1.1.6 Landscape management woody biomass	
	1.2. Wood processing industry, by-products and residues	1.2.1 Chemically untreated wood residues	1.2.1.1 Wood without bark
			1.2.1.2 Wood with bark *
			1.2.1.3 Bark (from industry operations)*
			1.2.1.4 Blends and mixtures
		1.2.2 Chemically treated wood residues	1.2.2.1 Wood without bark
			1.2.2.2 Wood with bark *
			1.2.2.3 Bark (from industry operations)*
			1.2.2.4 Blends and mixtures
		1.2.3 Fibrous waste from the pulp and paper industry	1.2.3.1 Chemically untreated fibrous waste
			1.2.3.2 Chemically treated fibrous waste
	1.3. Used wood	1.3.1 Chemically untreated wood	1.3.1.1 Wood without bark
			1.3.1.2 Bark*
			1.3.1.3 Blends and mixtures
		1.3.2 Chemically treated wood	1.3.2.1 Wood without bark
			1.3.2.2 Bark*
			1.3.2.3 Blends and mixtures
	1.4. Blends and mixtures		

3 Investigated fuel qualities

In the state of Baden-Wuerttemberg in Germany fuel wood is originating from different sources as shown in Figure 2.

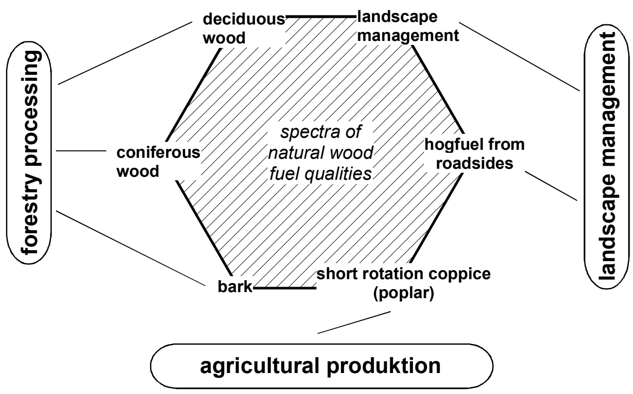

Figure 2. Spectra of natural fuel wood and its origin in Baden-Wuerttemberg

The different fuels used for the investigations and their properties are listed in Table 2. A very important parameter for complete combustion is the moisture content of the fuel.

Table 2. Different natural fuel wood qualities used for the experiments and their determined properties

		wood chips	deciduous wood	coniferous wood	bark	landscape managemen	hogfuel from roadsides	short rotation coppice (poplar)	wood pellets	wood chips	wood chips	wood chips	sawing residues	residues from wood processing
moisture content w	in mass%	49,4	48,1	42,3	60,2	46,6	46,4	34,5	5,9	33,3	30,6	36,4	42,3	58,4
thermogravimetric shortanalysis														
Volatiles	in mass% wf	81,69	82,10	81,13	69,54	74,29	79,50	73,68	81,67	82,3	80,9	82,0	82,2	82,3
Fixed Carbon	in mass% wf	18,04	16,49	18,23	25,94	18,82	17,80	16,42	17,14	17,1	18,5	17,6	17,7	17,1
Ash (550°C)	in mass% wf	0,27	1,41	0,64	4,52	6,89	2,70	6,91	1,19	0,7	0,6	0,3	0,0	0,7
	Σ	100,00	100,00	100,00	100,00	100,00	100,00	97,01	100,00	100,00	100,00	99,99	100,00	100,00
calorimetric analysis														
gross calorific value	in MJ/kg	19,74	19,40	19,58	20,34	19,01	18,52	18,19	19,67	16,57	17,38	18,16	17,98	17,72
net calorific value	in MJ/kg	9,62	9,55	10,74	7,68	9,62	9,65	10,95	17,49	11,10	11,27	11,14	9,90	6,95
elemental analysis														
C	in mass%	48,80	48,40	49,76	51,31	46,79	46,70	45,32	47,11	45,04	46,86	47,94	47,66	47,73
H	in mass%	7,07	5,91	6,27	6,36	6,24	5,90	8,99	6,44	6,50	6,48	6,76	6,72	6,43
N	in mass%	0,02	0,17	0,03	0,29	0,43	0,29	0,46	0,05	0,03	0,07	0,03	0,03	0,05
S	in mass%	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
O (calculated)	in mass%	44,11	45,52	43,95	42,04	46,55	47,11	45,22	46,40	48,43	46,59	45,27	45,60	45,79
	Σ	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
ash analysis														
SiO_2	in mass%	17,50	32,10	13,20	38,30	40,30	37,40	47,30	13,33	33,80	16,84	11,22	30,42	29,74
Al_2O_3	in mass%	2,80	3,70	3,10	6,00	7,40	2,90	8,40	3,13	5,30	1,93	2,21	5,57	2,69
Fe_2O_3	in mass%	1,60	1,40	1,40	2,40	3,50	1,10	3,60	1,41	3,30	0,88	1,08	3,47	2,07
Mn	in mass%	4,61	0,31	2,97	0,88	0,14	0,12	0,13	3,00	0,56	0,75	0,13	0,59	0,13
MgO	in mass%	4,00	4,90	5,20	2,40	4,60	2,50	3,30	5,25	3,70	4,05	4,42	3,89	4,15
CaO	in mass%	35,30	30,50	35,80	28,30	23,40	24,50	18,20	36,16	24,20	34,77	37,50	27,83	27,46
Na_2O	in mass%	0,50	0,80	0,80	0,50	0,80	0,81	0,90	0,81	0,75	0,78	0,69	0,76	0,94
K_2O	in mass%	11,40	8,60	13,00	4,50	9,80	8,20	6,90	13,13	7,92	12,54	13,30	8,25	7,60
TiO_2	in mass%	0,30	0,20	0,30	0,40	0,50	0,15	0,60	0,30	0,41	0,14	0,14	0,38	0,60
P_2O_3	in mass%	3,00	4,40	2,60	1,40	2,20	2,40	2,20	2,63	1,60	4,25	4,47	1,68	1,60
	Σ	81,01	86,91	78,37	85,08	92,64	80,08	91,53	79,15	81,54	76,93	75,15	82,82	76,98

There is a direct correlation between moisture and the heating value. That means, fuel with the extreme moisture content of 100% (pure water) does not burn. But fuels with more than 50% moisture (see the wet bark in the table above) sometimes have to be burned.

4 Results of combustion experiments – test facility

The combustion efficiency and completeness and consequently the flue gas emissions dependencies on the different fuels have been investigated during different combustions experiments at the test grate furnace. The results are presented in the **Figures 3 to 7**.

In **Figure 3** the PM emissions are shown. It can be seen that poplar wood and landscape management wood causes the highest PM emissions, especially during partial load. During partial load wet fuels cannot produce enough heat for a good combustion. Therefore, the products of incomplete combustion like CO can be increased (see **Figure 4**, combustion of bark and partial load with three other fuels).

The VOC emissions, presented in **Figure 5**, are also products of incomplete combustion. Therefore, during partial load when the combustion chamber is not warm enough the wet fuels cause increased VOC emissions which are mostly responsible for odour emissions.

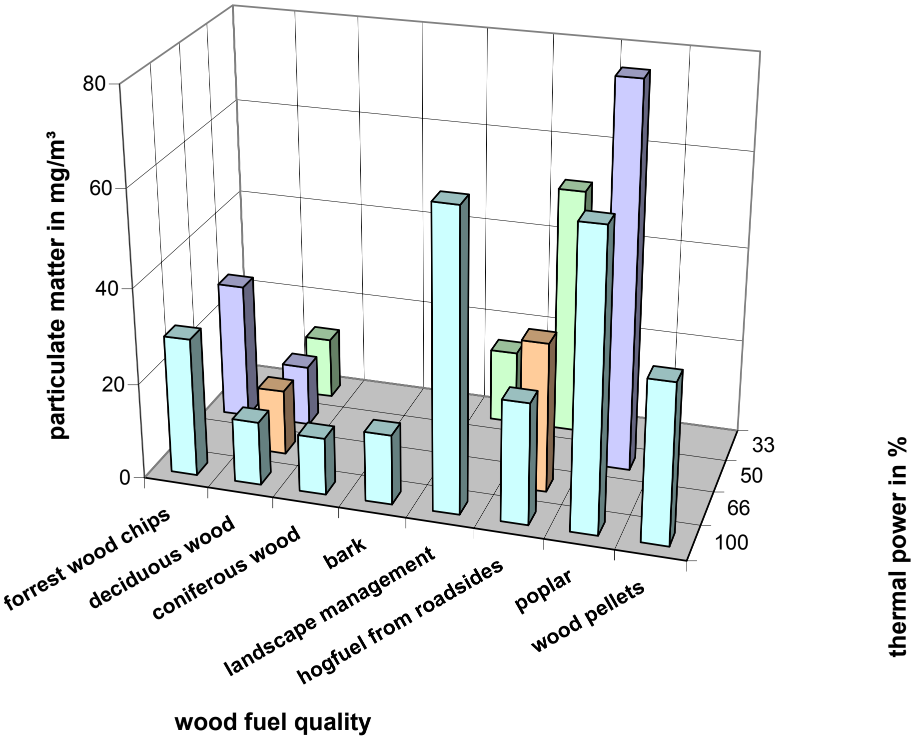

Figure 3. PM emissions during combustion of different natural fuel wood qualities in the test grate furnace with different thermal load

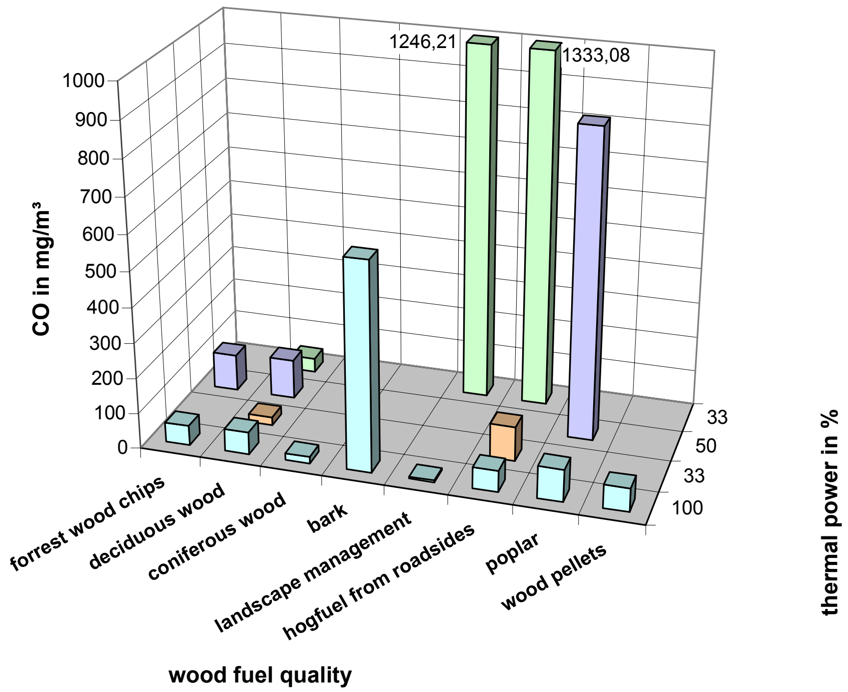

Figure 4. CO emissions during combustion of different natural fuel wood qualities in the test grate furnace with different thermal load

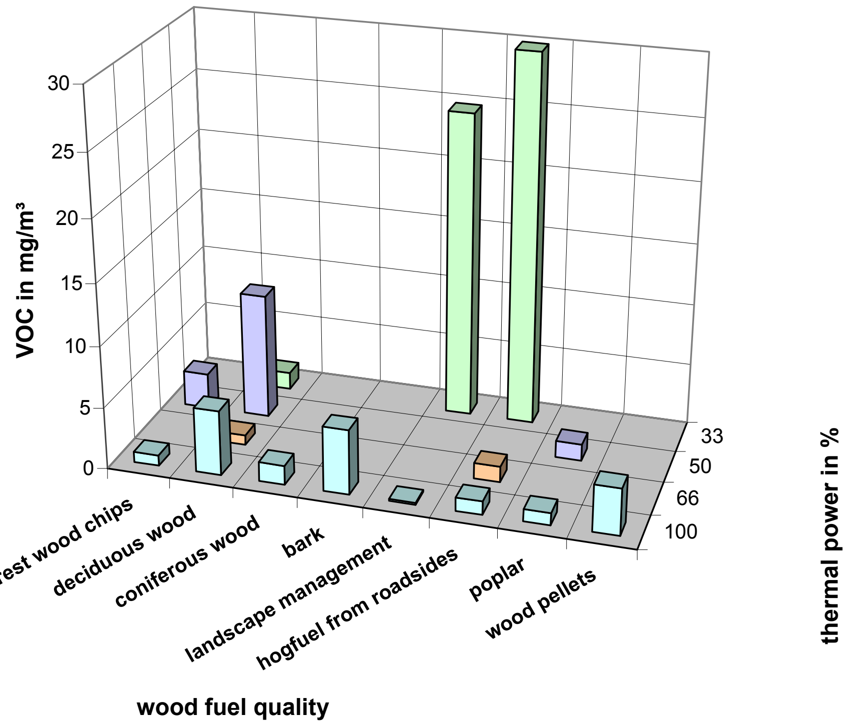

Figure 5. VOC (Volatile Organic Compounds) emissions during combustion of different natural fuel wood qualities in the test grate furnace with different thermal load

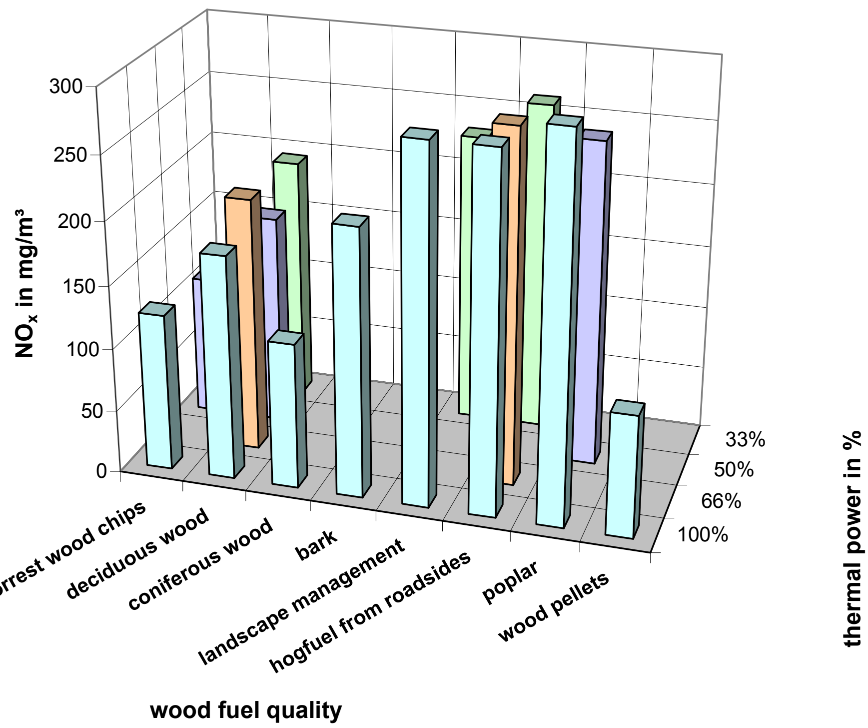

Figure 6. NO_x (Nitrogen Oxides) emissions during combustion of different natural fuel wood qualities in the test grate furnace with different thermal load

Finally the NO_x emissions during combustion of the different fuels is shown in **Figure 6.** These emissions are not products of incomplete combustion. But, these NO_x emissions are dependent on the nitrogen content of the fuel as can be seen in **Figure 7** (results of all experiments).

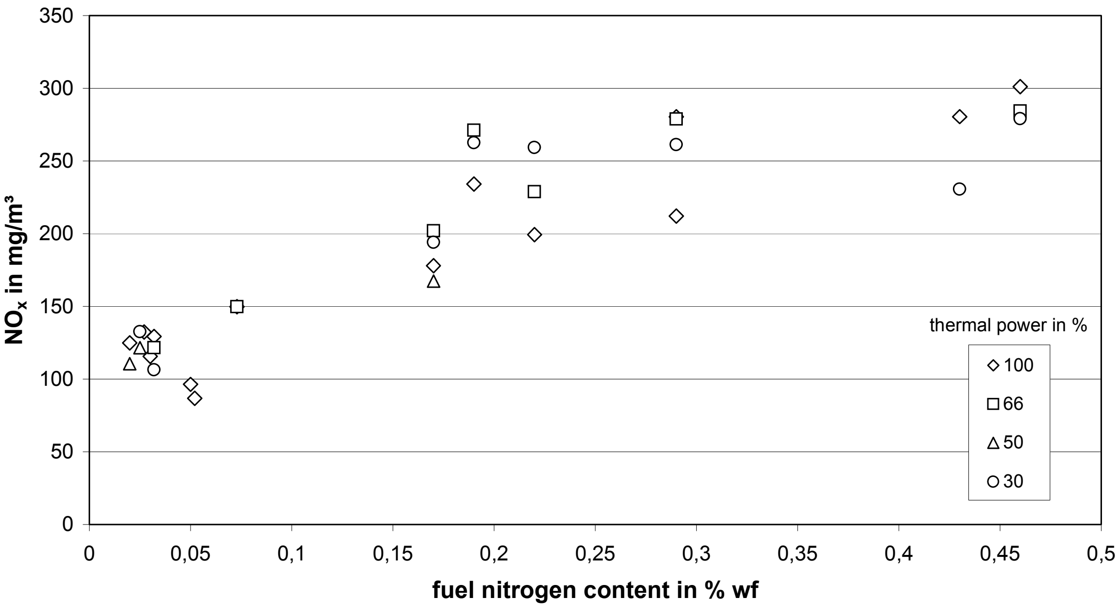

Figure 7. NO_x (Nitrogen Oxides) emissions during combustion of different natural fuel wood qualities in the test grate furnace; dependency on the nitrogen content of the different fuels

5 Results of combustion experiments at real world furnaces in practice

Since in test facilities almost ideal conditions are existing supplementing experiments were carried out at real practical furnaces. The target was to identify problems in practice and to investigate the transferability of the results won at the test facility. In **Figure 8** the PM emissions at different furnaces using different natural kinds of fuel wood are presented.

It can be recognised that the PM emission level is general higher than at the test facility (different scale compared to Figure 3!). Again, the highest emission are observed during partial load and with one obviously problematic wood residue fuel.

In **Figure 9** the CO emissions measured at the different furnaces in practice are depicted.
It can be seen that also the same fuel with the high PM emissions causes high CO emissions. Obviously the combination of this fuel burned in this plant is not harmonizing. Under partial load the CO emissions are high again which is the same result as at the test facility.

There is the question whether the PM emissions depend on the ash content of the fuel. But, this could not be confirmed, see Figure 10 which shows the PM emissions over the ash content. A correlation does not exist. The combustion technology has more influence on the PM emissions than the ash content of the wood fuel.

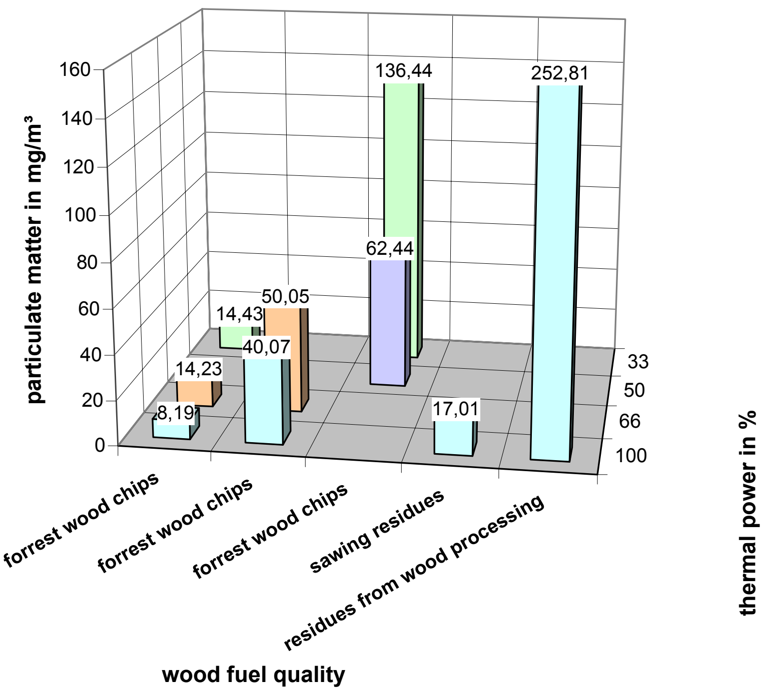

Figure 8. PM emissions during combustion of different natural fuel wood qualities in different furnaces on real practical use under different thermal load

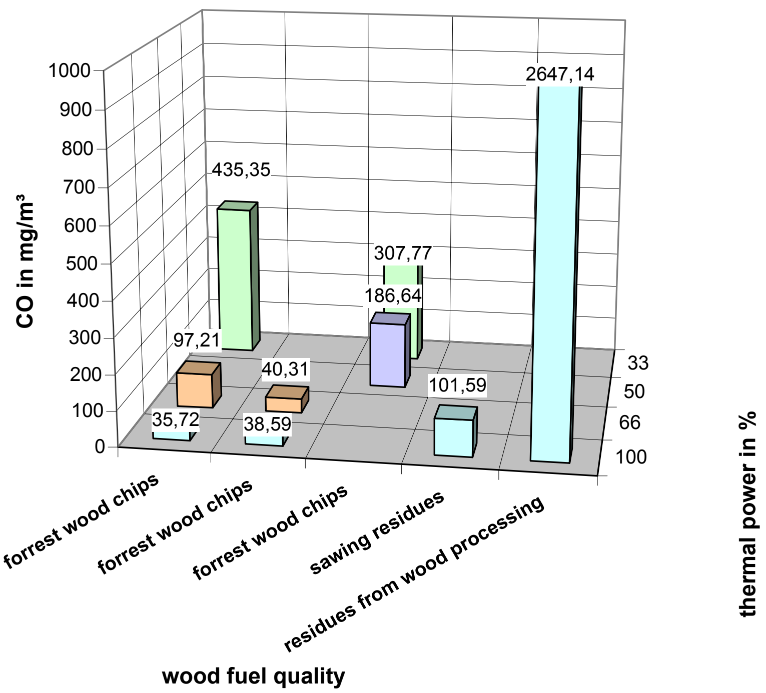

Figure 9. CO emissions during combustion of different natural fuel wood qualities in different furnaces on real practical use under different thermal load

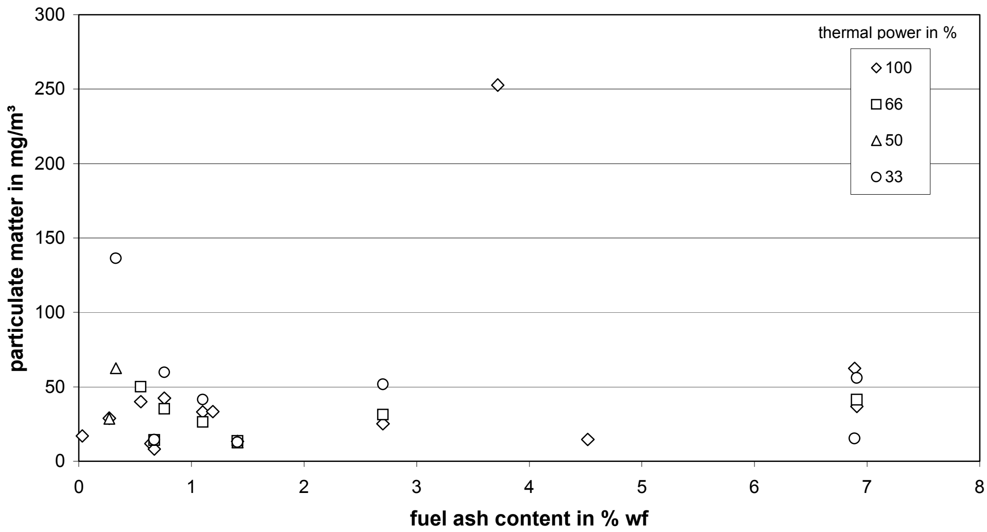

Figure 10. PM emissions over the fuel ash content

6 Size distribution of PM emissions of wood chip combustion plants

The PM size distribution has been measured at different wood combustion plants [5]. These different measurements showed always a similar result: around 90% of PM is smaller than 1µm aerodynamic diameter. So, the wood combustion is a source of fine dust which can penetrate into the deeper alveols and lungs of human beings [4].

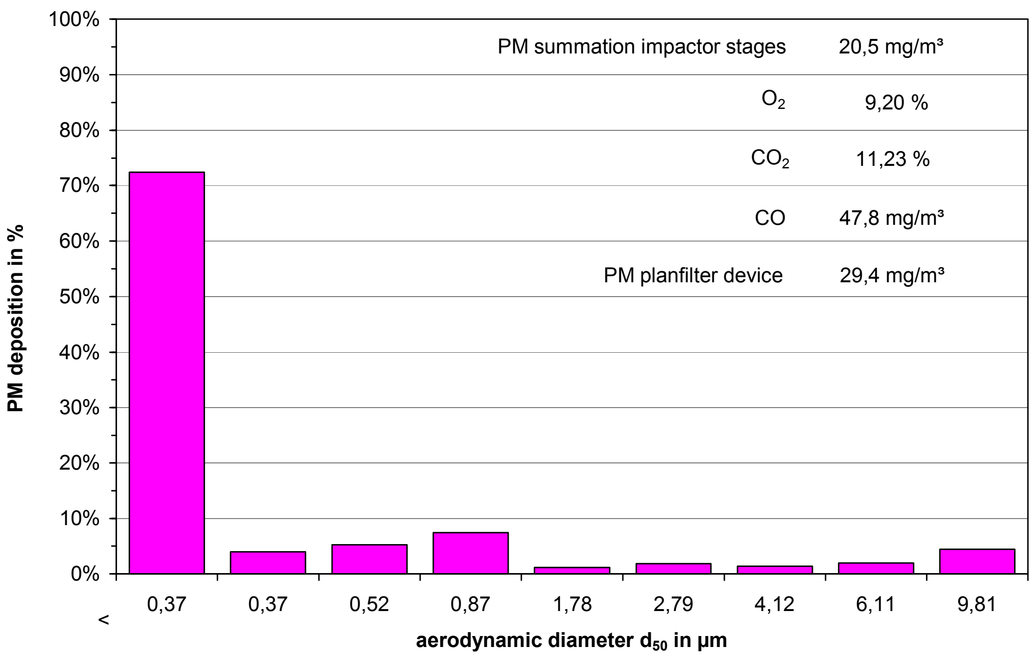

Figure 11. Size distribution of particulate matter emissions (PM) during wood combustion

7 Conclusions

As a result of the emission measurements it could be shown that especially under partial load and using wet wood fuels the emissions of PM, CO and VOC are increased. A pre-drying and a storage under dry conditions (under a roof) is recommended. Considering the PM emissions and the ash content of the fuel no correlation could be observed. In this case the combustion technology and the flue gas cleaning are the important parameters. If certain frame conditions are observed the combustion is good and the emissions are low. But, wood of secondary quality like from Poplar and from bark causes lower combustion quality in general.

9 Literature

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Acknowledgement:
We thank the BWPlus project at Forschungszentrum Karlsruhe, Germany, for the support of this project.