

Section VI.E.

Guidance by source category: Annex C, Part III Source Categories

Firing installations for wood and other biomass fuels

Coordinated by Mr. Hans Peter Fahrni (Switzerland) and Ms. Steffi Richter (Germany)

Draft Guidelines on BAT and BEP for Firing Installations for Wood and Other Biomass Fuels

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1. Introduction

Already now, around 12% of the global energy required is generated by combustion of biomass fuels, which vary from wood to animal by-products and black liquor. A wide variety of appliances is used to convert this biomass into useful energy. In developing countries, around 35% of the energy used originates from biomass, but most of this is for non-commercial use in traditional applications (such as cooking). In a country such as Nepal, over 90% of the primary energy is produced from traditional biomass fuels.

In industrialised countries, the total contribution of biomass to the primary energy mix is only 3%. This mainly involves the combustion of commercial biomass fuels in modern devices – for example, woodchip-fired co-generation plants for heat and power. Other applications are domestic space heating and cooking, industrial heat supply, and large-scale power generation in coal-fired plants [IEA Bio-energy].

In this guideline only large scale applications in industry, power generation, district heating etc. are covered.

2. Biomass Combustion Technologies

For technology selection the total heat input and the wood fuel quantity are of major importance. For large scale plants in particular fluidised bed combustion and grate furnaces are suitable. Technologies for small-scale plants are inter alia underfeed furnaces and cyclone suspension furnaces. Table 1 shows typical thermal capacities and required fuel properties for different types of wood combustion techniques.

Table 1 : Types of biomass furnaces with typical applications and fuels [Nussbaurmer 2003]

Application	Type	Typical size range	Fuels	Ash	Water content
Manual	wood stoves	2kW-10kW	dry wood logs	<2%	5%-20%
	log wood boilers	5 kW-50 kW	log wood, sticky wood residues	<2%	5%—30%
Pellets	pellet stoves and boilers	2 kW-25 kW	wood pellets	<2%	8%-10%
Automatic	understoker furnaces	20 kW-2.5 MW	wood chips, wood residues	<2%	5%—50%
	moving grate furnaces	150kW-15MW	all wood fuels and most biomass	<50%	5%-60%
	pre-oven with grate	20kW-1.5MW	dry wood (residues)	<5%	5%-35%

Application	Type	Typical size range	Fuels	Ash	Water content
	understoker with rotating grate	2 MW-5 MW	wood chips, high water content	<50%	40%-65%
	cigar burner	3 MW-5 MW	straw bales	<5%	20%
	whole bale furnaces	3 MW-5 MW	whole bales	<5%	20%
	straw furnaces	100 kW-5 MW	straw bales with bale cutter	<5%	20%
	stationary fluidized bed	5MW-15MW	various biomass, $d < 10\text{mm}$	<50%	5%-60%
	circulating fluidized bed	15MW-100MW	various biomass, $d < 10\text{mm}$	<50%	5%-60%
	dust combustor, entrained flow	5MW-10MW	various biomass, $d < 5\text{mm}$	<5%	<20%
co-firing ^a	stationary fluidized bed	total 50MW-150MW	various biomass, $d < 10\text{mm}$	<50%	5%-60%
	circulating fluidized bed	total 100-300 MW	various biomass, $d < 10\text{mm}$	<50%	5%-60%
	cigar burner	straw 5 MW-20 MW	straw bales	<5%	20%
	dust combustor in coal boilers	total 100MW-1 GW	various biomass, $d < 2-5\text{mm}$	<5%	<20%

^a Biomass covers typically less than 10% of the total fuel input

2.1. Grate furnaces

Grate furnace systems are today the most common combustion technology used for wood wastes and wood residues. According to the technique the wood fuel is moved through the combustion chamber stationary sloping grates, travelling grates and vibrating or moving grates can be distinguished. Grate firing systems are suitable for all types of wood residues and wood waste with particle sizes between 20 and 300 mm. However, fine particles as pulverised wood may be injected through additional burner lances. A major influence on the combustion efficiency, both for travelling grates and vibrating grates, has the fuel and air guidance. Concerning steam generation the furnace design of grate firing systems offers various options for primary emission reduction, e. g. staged combustion or flue gas re-circulation. The investment for grate firing systems depends considerably on the grate technology and flue gas cleaning technology used. Compared to fluidised bed combustion plants in particular for lower capacities the specific investment relative to the total heat input is considerably lower [CSTB 2000].

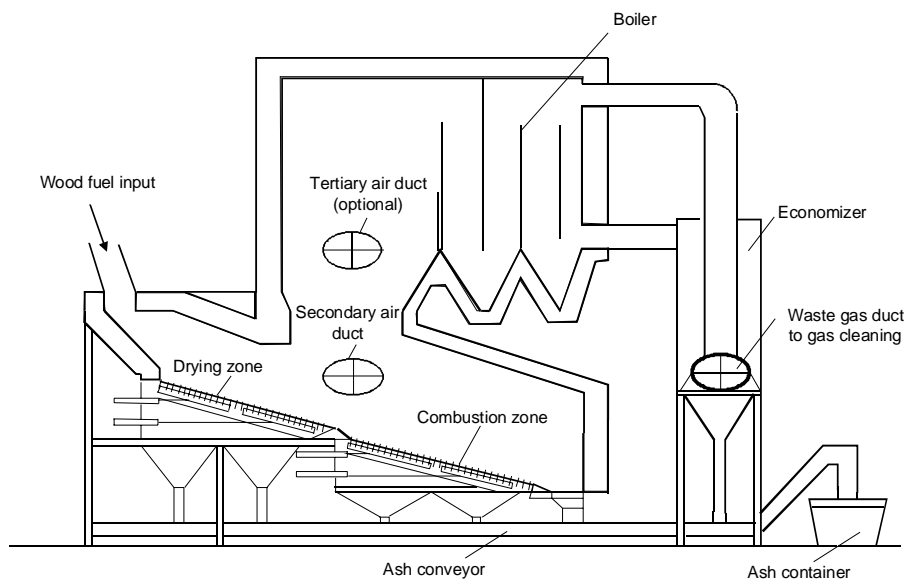


Figure 1: General scheme of a vibrating grate furnace

2.2. Fluidised Bed Combustion

Fluidised bed combustion is utilised for various types of solid fuels. In a typical fluidised bed combustion unit the solid fuel is kept fluidised by injected air together with an inert bed material, in general mainly consisting of limestone or sand and the fuel ash. Nearly exclusively two basic fluidised bed combustion technologies are used for wood combustion. This is atmospheric bubbling fluidised bed combustion (BFBC) and atmospheric circulating fluidised bed combustion (CFBC). Fluidised bed combustion is suitable even for lowest fuel qualities and a great variety of fuels. Regarding wood combustion, nearly all types of wood residues and wood waste can be used. Water contents up to 40 % are possible. Fluidised bed systems are adaptable even to low operation loads. A cycle between low and high loads is in general possible without support fuel and at a rather high speed compared to other combustion technologies. Chlorine induced high temperature corrosion can be suppressed by installing the last superheater unit in the bed. The low combustion temperatures in fluidised bed systems compared to many other combustion technologies offer several operational advantages regarding emission control. The investment for FBC plants is mainly influenced by the FBC technology used and the type of flue gas cleaning installed. CFBC entails a considerably higher specific investment compared to BFBC for plant sizes below 30 MW_{th}. [CSTB 2000]

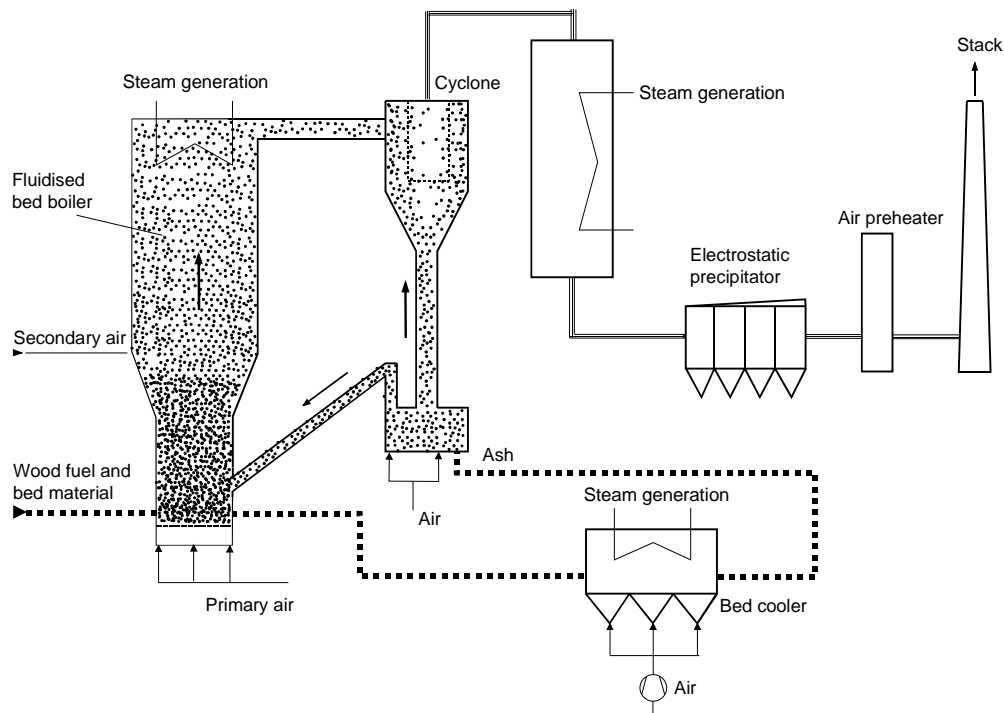


Figure 2: General scheme of a CFBC-furnace

2.3. Further Combustion Technologies for Wood

Further combustion technologies for wood include underfeed stoker furnaces, cyclone suspension furnaces (muffle suspension furnaces), rotary furnaces, turbulent bottom furnaces, fan blower furnaces as well as dust burners. Underfeed furnaces or underfeed stoker furnaces are in particular suitable for the combustion of dry and not too coarse wood particles with a low ash content. This technique is used for total heat inputs up to 5 MW_{th}. Compared to normal grate furnaces the specific investment is mostly lower. As cyclone suspension furnaces require a dust content of at least 50 % their application is limited in particular to the wood processing industry. Dust burners are used for wood dust with a particle size of up to 1 mm. Applications of this burner type are inter alia wood chip driers and the injection of wood dust in cement furnaces. [CSTB 2000]

2.4. Energy Conversion Techniques

For energy conversion downstream wood combustion furnaces heat exchanger systems (boilers) and subsequent systems for combined heat and power production (steam turbines, steam engines etc.) have to be distinguished. Downstream wood combustion furnaces different types of boilers are used according to the heat transfer medium, the plant size, and the energy quality required. Firetube boilers are used for hot water or steam production downstream small-scale and medium-scale wood furnaces. Heat transfer takes only place by convection. Wa-

tertube boilers are used for large-scale and medium-scale wood waste combustion plants. The water to be evaporated flows through tubes surrounded by the hot flue gases. Heat transfer takes place predominantly by radiation. Due to the modified construction compared to firetube boilers considerably higher operating pressures up to 100 bar are possible. Downstream wood furnaces in general only heat or combined heat and power is produced. For this reason condensing power generation can be neglected. Nevertheless, also combined heat and power (CHP) plants may need condensing capacities in case the heat generated is not used. [CSTB 2000]

2.5. Co-Combustion

Co-combustion means the burning of wood wastes and wood residues together with other waste materials or together with fossil fuels. The objective is to realise synergy effects between two combustion processes. These are either operating costs savings by the use of cheaper secondary fuels, an improvement of the combustion efficiency of the combined process compared to the two processes operated separately, or the possible recovery of the materials introduced in the combustion process as for example the input of fuel ash from secondary fuels in the cement clinker produced in a cement burning process. For wood waste and wood residues the co-combustion and co-gasification processes of major importance are co-combustion in cement furnaces, co-combustion in coal fired power plants, co-gasification with fossil fuels or waste and co-incineration in waste incineration plants. [CSTB 2000]

2.6. Wood Gasification

Gasification of wood and wood waste is the conversion of solid and liquid residues derived from the thermochemical decomposition of the organic matter in the wood at high temperatures in a gaseous fuel by adding oxidising reactants. The main objective of wood gasification is to transfer as much as possible of the chemical energy of the wood feedstock into a gaseous fraction (producer gas) consisting mainly of combustible gaseous products with a low molecular weight. The gasification techniques available are in general distinguished related to the reactor type. The two basic gasification techniques available are fixed bed gasification and fluidised bed gasification. For wood gasification the utilisation of fixed bed gasifiers is in general preferred for smaller total heat inputs below 5 MW_{th}. For larger capacities mostly fluidised bed gasifiers are used. The energy content of the producer gas from gasification can be either used thermally for the firing of a boiler or another thermal process (either separately or by co-combustion e. g. in an existing utility boiler or in a cement furnace) or mechanically for power generation in gas engines or gas turbines. Further possibilities are the utilisation of the producer gas for methanol synthesis or in fuels cells. The system needed for producer gas cleaning is determined by the concentration of impurities and by the requirements of the gas utilisation technique used. Depending on the gas utilisation technique gas cleaning is required to avoid erosion, corrosion, unwanted de-

posits, and the fulfillment of emission limits. Basically two different gas cleaning concepts, cold (or wet) gas cleaning and hot gas cleaning can be distinguished. Hot gas cleaning is considered as advantageous for advanced high-efficient systems due to the higher achievable electric and overall efficiencies and due to the non-generation of contaminated wastewater and/or condensate. Even though gasification can be seen as proven and reliable technique, for all plants with electricity generation either in gas turbines or gas motors gas cleaning is still a crucial restriction. Technical problems occur inter alia from gas cleaning process control. Concerning cost effectiveness, negative impacts result from gasification residue disposal and high investment and operating costs of the gas cleaning unit itself. [CSTB 2000]

2.7. Combustion of other biomass

Other biomass includes other solid biofuels such as straw and crops and liquid fuels such as rape oil. Straw combustion requires combustion techniques which are not sensitive to the slagging of ashes. Due to the increases input of mineral matter and chlorine there is an increase of dust, HCl and PCDD/PCDF emissions compared to wood combustion [LfU 2002]. Results of a comparative investigation of emissions from different types of biomass are shown in Table 2. Compared to wood the total mass flow of ashes increased by a factor of 5. The tests have been carried out in a furnace of 50 kW thermal capacity.

Table 2: PCDD/PCDF emissions from different types of biomass [LfU 2002]

Fuel type	PCDD/PCDF ng I-TEQ/m³
Wood (spruce)	0.051
Straw (wheat)	0.656
Hay	0.891
Triticale	0.052
Rape pellets	0.245

PCDD/PCDF emission data for liquid biomass combustion are scarce. Tests at a rape oil motor for combined heat and power production (90 kW thermal power) showed PCDD/PCDF concentrations of 4-7 pg TEQ/m³. PCB concentrations amounted to 40-81 ng/m³ [LfU 2002].

3. Emission control measures

Reduction of PCDD/PCDF emissions includes primary and secondary measures which are summarised in Table 3 [Baumbach 2000], [CSTB 2000], [LfU 2002].

Relevant primary measures are similar to the waste incineration sector. Additional flue gas cleaning can be carried out with absorption or adsorption processes. Downstream wood waste combustion in general only adsorption processes are used due to their lower costs. Dry sorbent injection (entrained flow reactor) gained major importance downstream wood combustion due to its technical simplicity and its low costs. As adsorption agent in general a mixture of calciferous substance and activated carbon or lignite activated carbon (activated carbon produced from lignite) is used. Possible calciferous agents are limestone (CaCO_3), lime (CaO), and hydrated lime ($\text{Ca}(\text{OH})_2$). While the calciferous agents remove SO_2 , HCl , and HF , the various types of activated carbon minimise heavy metal emissions (Hg, Cd, As), PCDD/PCDF emissions, and emissions of polycyclic aromatic hydrocarbons. A typical mixture used in an entrained flow reactor consists of 85 to 95 % calciferous agent and 5 to 15 % activated carbon. As secondary NO_x -emission reduction measure in particular downstream large-scale wood waste combustion installations the SNCR (selective non-catalytic reduction) technique is used. This technique also reduces PCDD/PCDF emissions.

Table 3: PCDD/PCDF emission control measures for biomass firing installations

Management options	Emission level (%)	Estimated costs	Management risks
Primary measures: - Control of fuel quality - Optimised burn-out (e.g. reduction of excess air) - Increased residence time of flue gases upstream the boiler	Resulting emission level not quantified	higher fuel price No additional cost for new installations	High water content increases PCDD/PCDF formation
Secondary measures: - Efficient dust abatement - Dry sorbent injection - Selective non-catalytic reduction (SNCR) - Selective catalytic reduction (SCR)	Medium efficiency High efficiency Medium efficiency High efficiency	Additional investment ¹⁾ : SNCR 50-60 % SCR 110-180 %	Filter temperature < 200 °C Disposal of used sorbents not common in small plants not common in biomass combustion plants
¹⁾ Percentage related to the investment for furnace, boiler and dust collector of wood combustion plants with 1-10 MW thermal capacity			

4. Fuel characteristics

Fuel quality plays a major role in PCDD/PCDF formation during biomass combustion (see chapter 5.1). Independent of the furnace type, the combustion of natural wood causes in general low levels of PCDD/PCDF emissions. High levels are expected from burning treated wood (wood waste) in particular in the case of coatings. Combustion of contaminated biomass such as urban wood waste and demolition wood should be strictly limited to installations with efficient flue gas cleaning [Nussbaumer 2003].

The moisture content of biomass can be high. Therefore, dryers may be used prior to combustion. Steam dryers are considered to be safe with low environmental impact. Another method is based on drying with flue gas which is subsequently fed to the stack. In this case emissions of organic compounds such as waxes or aromatic compounds are possible [IPPC 2003].

5. Process Outputs

5.1. Formation of PCDD and PCDF in combustion processes

The dominant reaction for the formation of dioxins and furans in combustion processes is the de novo synthesis. Summarised, the following parameters are responsible for PCDD/PCDF formation [Nussbaumer 1998]:

- Temperature for the de novo synthesis: It occurs in the temperature range from approx. 180°C to 500°C and reaches a maximum rate at approx. 300°C.
- Chlorine (HCl content; Cl content): Dioxins can also be formed in absence of organic chlorinated compounds. The presence of particulate carbon and a chlorine source is sufficient.

Investigations at a stationary grate combustor have shown that the total amount of PCDD PCDF and coplanar PCB formed was proportional to the chlorine content of the combustion samples when the temperature of the combustion chamber was lower than 700°C. On the other hand, when the grate temperature of the combustion chamber was higher than 800°C, there was only a slight formation of PCDD PCDF and coplanar PCB regardless of the chlorine content of the fuel [Yasuhara 2003].

- Unburnt carbon: The amount of PCDD and PCDF on fly ash from municipal solid waste incineration exhibits an almost linear correlation with its carbon content. A tenfold reduction of the residual carbon content in fly ash leads to a similar reduction of the PCDD/PCDF content.
- Oxygen content: The dioxin emissions are also influenced by the residual oxygen content in the flue gas. Possible explanations for this effect can be a lower carbon burn out due to a lower temperature in the combustion

zone or the influence of oxygen on the oxidation of the dioxin formation catalyst.

- Heavy metals (Cu) which act as a catalyst.

5.2. Emissions of PCDD/PCDF

Table 4 gives an overview of emission values observed for different types of wood fuel burned in industrial boilers.

Table 4: PCDD/PCDF concentrations for different types of wood fuels

Type of wood	Reference	PCDD/PCDF ng I-TEQ/m ³ (at 13% O ₂)
Natural wood	Field tests [Baumbach 2000] [Wilken 1993] [Strecker 1994] [Hasler 1993]	0.02–2.73 0.01–0.70 0.01–0.15 0.02–0.21
Lump wood (natural)	[FNR 2000]	0.02–0.1
Wood chips (natural)	[FNR 2000]	0–0.7
Natural wood and particle board	Field tests [Baumbach 2000] [Wilken 1993] [Strecker 1994] [Hasler 1993]	0.09–0.81 0.02–3.30 0.05–0.19 0.02–0.08
Mixed wood (natural, treated, coated)	Field tests [Baumbach 2000] [Wilken 1993] [Strecker 1994] [Nussbaumer 1994]	0.37–16.0 0.01–1.39 0.03–4.11 2.70–14.4
Wood waste	[FNR 2000]	0.02–14.4
Particle board	[FNR 2000]	0.02–0.08
Particle board with PVC or NH ₄ Cl	[FNR 2000]	0.04–9.8
Particle board with PCP	[FNR 2000]	0.2–12.1

For biomass-fired plants, in particular wood-fired installations, an emission level of 0.1 ng I-TEQ/m³ is generally regarded as achievable [IPPC 2003].

5.3. Other releases of PCDD/PCDF

PCDD/PCDF are discharged with solid combustion residues such as bottom ashes and fly ash. In general, PCDD/PCDF concentrations increase with decreasing particle size [LfU 2002]. Therefore, captured fly ash has to be disposed of in an environmentally sound manner in particular in the case of wood waste combustion.

The fly ash from straw combustion units is disposed of, primarily due to its high content of cadmium. The bottom ash is normally bought back to the fields or used as a road construction material [IPPC 2003].

6. Best Available Techniques (BAT) and Best Environmental Practices (BEP) for firing installations for wood and other biomass

Firing installations shall achieve PCDD/PCDF emission levels below 0.1 ng I-TEQ/m³ (at 11 % O₂).

6.1. Primary measures and process optimization to reduce PCDD/PCDF

[Nussbaumer 1998]

- Prevention of illegal incineration:
Incineration of household waste in wood stoves or open fires can lead to extremely high PCDD/PCDF and has to be strictly avoided.
Open burning of urban waste wood and utilization of urban waste wood in conventional combustion systems also has to be strictly avoided.
- Optimized combustion technology: Improved burn out of gases and fly ash and reduction of dust content:
 - Reduction of excess air ratio to $\lambda < 1.5 - 2$;
 - Good mixing quality of gas and air (high turbulence);
 - Sufficient residence time in the hot zone;
 - Minimal disturbance of the glow bed and homogenous distribution of the primary air;
 - Optional integration of SNCR for NO_x reduction.
- Measures in the boiler:
 - Minimal residence time in the temperature range between 180°C and 500°C and minimal dust deposition ability.
- Optimized plant operation:
 - Application of advanced combustion control technologies to ensure optimal burn out in practice.
 - Stationary operation, no on/off operation and prevention of rapid changes of heat the demand.

6.2. Secondary measures

- Optimized gas cleaning:
 - Prevention of the temperature window of the de novo synthesis in filters (filter temperature < 120°C);
 - PCDD/PCDF separation in dust separators (electrostatic precipitators, fabric filters) in combination with sorbent injection (if necessary);
- Optional destruction of PCDD/PCDF by catalytic oxidation, i.e. in combination with SCR for NO_x reduction.

7. Performance Monitoring and Reporting

PCDD/PCDF emissions shall be monitored in accordance with international standard methods.

In order to ensure complete combustion furnaces shall be equipped with measuring instruments which continuously determine carbon monoxide emission mass concentrations.

In order to ensure the performance of emission control equipment, furnaces shall be equipped with measuring instruments which continuously determine dust emission mass concentrations qualitatively or quantitatively (depending on plant size).

In addition, quality control procedures shall be implemented with regard to fuel composition.

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