

NEW TECHNOLOGIES REDUCING EMISSIONS FROM COMBUSTION OF BIOFUELS

ABSTRACT

In reducing CO₂ emissions, bioenergy will be the most important source of renewable energy in the next few decades. Wind and solar energy can also be quite important, but in the longer run. In principle combustion of biomass fuels is environmentally friendly. This is because CO₂ released in the combustion process are recycled back into natural circulation. Normally biofuels contain only small amounts of nitrogen and sulphur. However, depending on combustion technology used, biomass fuels can be also a source of quite high emissions. This means mainly combustion of biomass fuels in small appliances like wood stoves, fireplaces, small boilers etc. When burning fuels having high volatile matter content, combustion in appliance using batch type combustion is a quite unsteady-state process. Emissions of carbon monoxide (CO), other combustible gases and particulates are quite difficult to avoid. In the case of continuous combustion processes this is not normally a problem. In the following presentation some means of reducing emissions from combustion of biofuels are presented.

I DOMESTIC FIREWOOD USE

Firewood use is still quite important also in industrialised countries like Finland. Use of wood fuels in Finland is totally 57 TWh of which firewood use in small houses is 11 TWh. It has been estimated that in Finland 2/3 of carbon monoxide emissions and even more than 90% of hydrocarbon and PAH emissions in stationary combustion processes (transportation excluded) are due to small scale wood combustion. This is why small scale wood fuel combustion has a net effect on green house gas effect /1/. For example total carbon monoxide emissions from small scale wood combustion are two fold compared to that of energy production in large power plants. Methane emission is of the same order as emission from transportation and seven fold compared with energy production.

An idea of the carbon monoxide and methane emissions from small heating appliances can be have from figures 1 and 2 where they are compared with emissions from other sources. CO emissions of transport are clearly greatest. Next one is domestic wood heating. Emissions are two fold compared with those of other energy production. Methane emissions from space heating are almost equal with emissions of transportation and seven fold compared with energy production /2/.

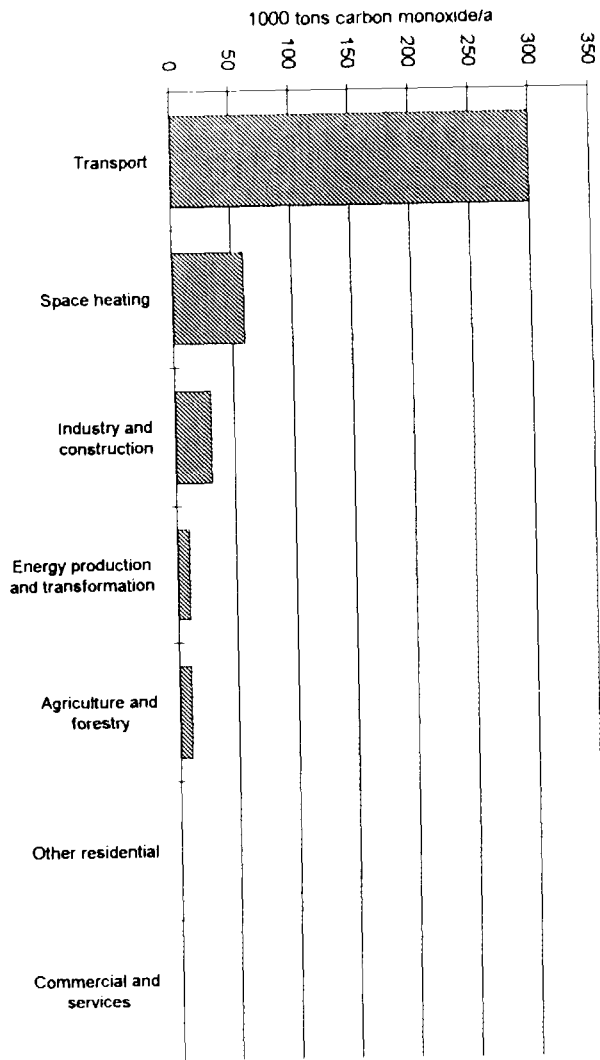


Fig 1. Carbon monoxide emissions in Finland by source.

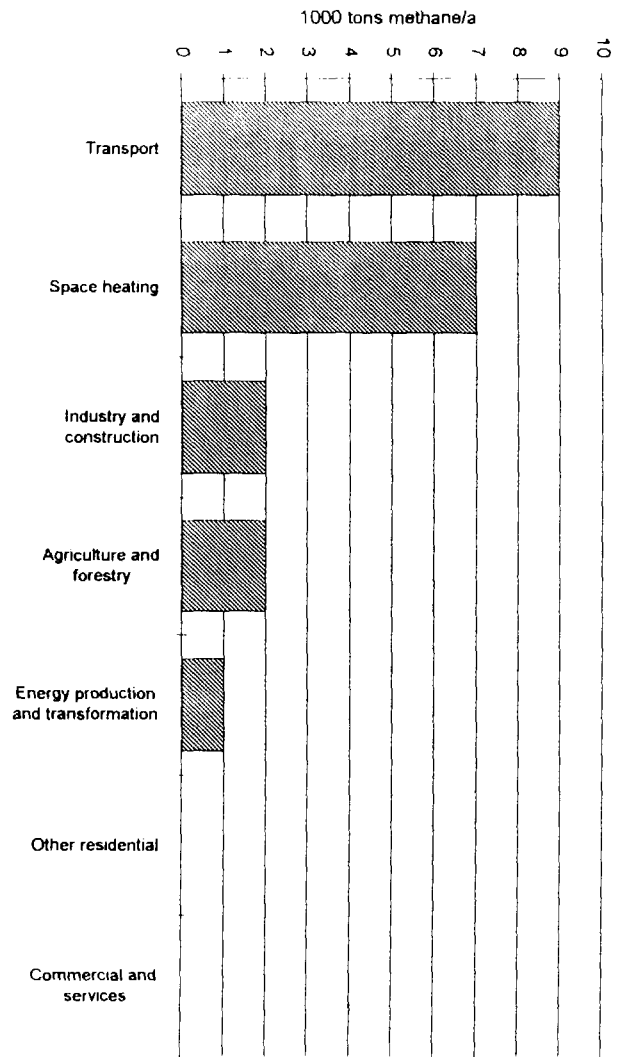


Fig 2. Methane emissions in Finland by source.

Emissions from small heating appliances can be reduced by developing the combustion techniques, but also using other measures, for example catalytic converters. In certain stages of the batch combustion, temperature is not high enough, gas mixing is not good enough and residence time is too short for complete combustion. When placed to a suitable place inside a heating appliance, a catalytic converter can oxidise unburned gases in the flue gas into compounds that are not harmful to the environment.

A catalyst augments the rate of chemical reactions without itself being consumed. It helps chemical reactions to go through other path where the activation energy of the reactions is lower. If the frequency factor (A) that describes the rate of reaction in the Arrhenius equation can be assumed to be constant, the activation energy determines essentially the reaction rate. With the aid of a catalyst, reactions go through an other way where the activation energy is lower. Catalytic converters can be used when burning clean wood. Commercial catalytic converters have long life-time and there are quite cheap. An example of the effect of a catalytic converted on carbon monoxide emission from a wood stove is shown in figure 3. 90% CO-conversion can be easily reached.

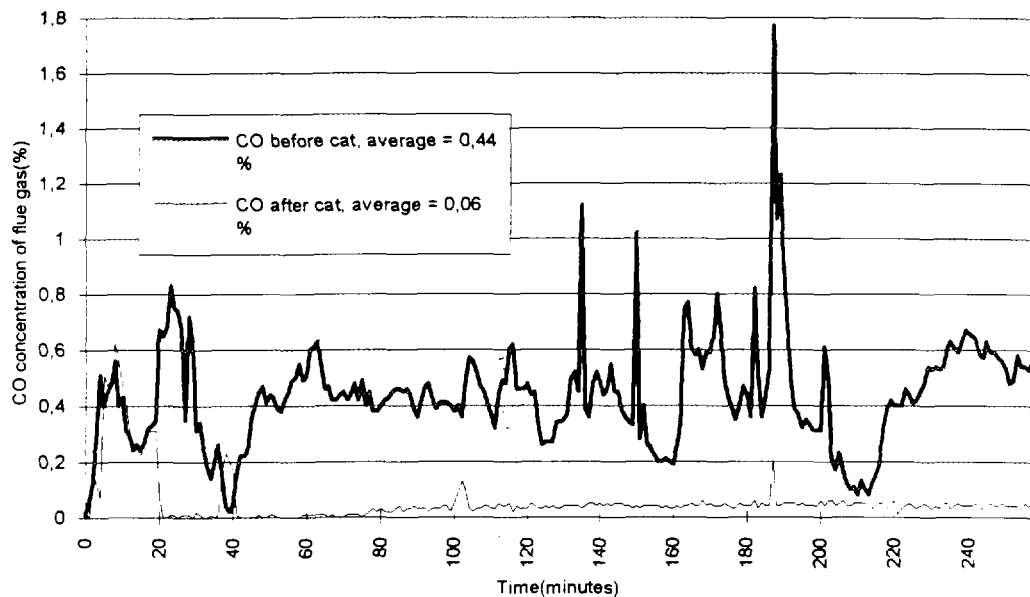


Fig 3. CO-conversion in a wood stove by means of a catalytic converter.

3 FLUE GAS SCRUBBING AT DISTRICT HEATING PLANTS

Biomass fuelled district heating plants are suitable for heat recovery from flue gas condensing systems. At the same, flue gas emissions can be also efficiently reduced. Water vapour is introduced to the boiler's combustion chamber with combustion air and with fuel moisture. Water vapour is formed also as a result of combustion of fuel hydrogen. In combustion chamber evaporation of water lowers the combustion temperature because it uses energy. This is called the heat of vaporisation. Reverse process, condensation of water vapour gives back the same amount of energy. Heat of vaporisation and heat of condensation are functions of temperature. Water vapour contains energy as sensible enthalpy and as heat of vaporisation. This energy can be transferred to boiler water with the aid of different heat transfer surfaces.

The basic idea in flue gas condensation is to get benefit of the higher heating value of a fuel that includes also the condensation of water vapour. Flue gases are cooled nearer the environment temperature so that water vapour in flue gases condenses thus giving heat. The problem of corrosive compounds can be avoided by adding to the system flue gas scrubber and by using better materials like stainless steel and plastics.

Flue gas washing is done by spraying water into the flue gases. NaOH or other neutralisation fluids can be added to the water to capture SO₂. Flue gases are cooled with the return water from district heating circulation. Water vapour in flue gases begins to condense when the temperature reaches the dew point. For example in wood and peat combustion the dew point of flue gases is about 60 - 70 °C. Heat of condensation at that temperature is about 2350 kJ/kg water.

A measurement programme at the Virrat district heating plant in Finland were carried out by VTT Energy. Sod peat and a mixture of sod peat and PDF were used as fuels in the experiments.

Flue gas scrubbing and neutralisation resulted in 87 - 94% sulphur reduction depending on pH value in scrubber and fuel sulphur content. Reduction of particulate emissions was 89 - 98%.

Chlorine removal was 92 - 98% and fluorine removal 79 - 95%. Heavy metal emissions can be lowered up to 100%. PAH reduction was 48 - 98%, PCP reduction 100%, PCBz, PCB and PCDD/F reduction 0 - 100%. Measured values were here also so low that measurement accuracy results in reduction percentages. PCDD/F concentration in flue gases after the scrubbing/condensing plant was 0.053 ng-TEQ/m³ when pure sod peat was burned and 0.017 ng-TEQ/m³ when a mixture of sod peat and PDF waste was burned. The limit for waste incineration plants is 0.1 ng-TEQ/m³. EPA-leaching test for slurry coming from the flue gas scrubber's clarifier showed that heavy metal leaching is well below the EPA-limit.

An increase of 19 - 21% to the boiler heat output was achieved by the flue gas condensing system. This resulted in overall efficiency of 106.2 - 108.6% when calculation is based on lower heating value of fuel. In practise this means that an increase in efficiency also lower emissions quite significantly because less fuel is needed to achieve the same heat output /3/.

4 COMBUSTION PROCESS CONTROL

In large plants quite sophisticated combustion control systems are used. They are normally based on continuous flue gas O₂-concentration measurements and controlling the amount of secondary or tertiary combustion air. Fuel economy is the driving force to use good combustion control systems in large plants. Even 1% increase in the efficiency means a lot of money. In smaller units, the driving force is more environmental benefits gained. Today emissions limits in some countries like Sweden, Norway, Austria etc. are so tight also for smaller plants that all means have to be considered. The use of modern combustion process control is best ways to lower emissions and higher efficiency.

VTT Energy carried out a study of optimisation of the burning process in furniture industry boilers. Reduction of noxious emissions by simple remedies and adjustments was also involved in the study. This was realised in four boilers whose initial carbon monoxide concentration (CO) in the flue gases was 1 500 - 2000 ppm (0.15 - 0.2%).

All boilers were underfeed type boilers having on - off -type heat output control system. This means that fuel feeding stops totally when the boiler water temperature reaches the desired value. This is of course simple and low cost system but results in high emissions especially in turning off phase. Combustion air fan can stop or be running.

The emissions from the boilers was reduced by adjusting the fuel stream and the primary and secondary air flows, with brickwork in the furnace over the grate and by insulating the secondary burning chamber. The flow adjustments were carried out on the basis of flue gas analysis. As a result of all the improvements, the temperature of secondary burning chamber increased 200 - 300 °C, the mixing of the gases improved, the residence time increased and the CO-concentration decreased to 50 - 300 ppm.

The emissions of one boiler were minimised by removing the turning off phase completely and changing the burning to a continuous process. This required that the boiler automation was renewed and new automation equipment. Originally CO-concentration was 1500 - 2000 ppm and O₂-concentration 13 - 14 % thus showing high amount of excess air in combustion.

The new combustion control system measures heat demand continuously and controls combustion by changing fuel feeding rate and combustion air flow. This is done by using inverters in electric motors.

Measurement campaign after the renewal showed significant improvement in combustion quality. Excess air ratio was now lower, O₂-concentration being 6 - 9%. CO-concentration was now only 200 ppm at nominal heat output. At 50% load, CO-concentration was 300 ppm and O₂-concentration 10%.

This example shows clearly the importance of good combustion control on emissions. In this case the investment costs for the new control system of this 465 kW boiler was about 50000 FIM /4/.

5 NO_x - REDUCTION

NO_x-emission from clean wood combustion is low but can be an issue when burning other biomass fuels.

Nitric oxides from combustion processes are formed in three different ways:

- 1 Thermal NO_x are formed at high temperature by oxidation of nitrogen in combustion air
- 2 Prompt NO_x from combustion of hydrocarbon in reactions of molecular nitrogen with free radicals in the flame
- 3 Fuel NO_x are formed from fuel bound nitrogen

Since typical combustion temperatures in today's wood firings are between 800 and 1200 °C, only fuel NO_x are of great importance. Therefore nitric oxide emissions typically increase with increasing nitrogen content of the fuel.

5.1 Primary measures for NO_x reduction

Combustion air staging or fuel staging are known ways for NO_x reduction. Combustion air staging can be realised in almost all size of equipment. During the gasification of biomass fuels, HCN and NH₃ are formed. These components can react in different reactions to form molecular nitrogen. If there is a shortage of oxygen, NO_x acts as an oxidising agent for carbon monoxide (CO), methane, hydrocarbons, hydrogen and carbon. Nussbaumer et al has been investigating process conditions for optimal NO_x reduction and got following results: primary excess air ratio should be 0.7, temperature 1200 °C and residence time in that temperature at least 0.5 seconds. About 50% reduction can be obtained /5/.

Fuel staging is an other mean for NO_x reduction but can be realised only in bigger boilers.

5.2 Secondary measures for NO_x reduction

The injection of ammonia or urea can be used to NO_x reduction also for biomass boilers. The optimal temperature for SCR (selective catalytic reduction) with a catalyst is about 250 °C. NO_x reduction of 95% can be reached without significant slippage of ammonia. For the SNCR (selective non-catalytic reduction) a temperature window is 850 - 950 °C and an over stoichiometric amount of ammonia is necessary. Temperature control is important.

6 COMBUSTION OF WET BIOMASS FUELS

Quite often biomass fuels have high moisture content. This is the case for example of green biomass from forest, wood residues from pulp industry and mechanical wood processing. Combustion of wet biomass fuels sets special demands for combustion systems. Firstly to be able to burn wet fuels and secondly to burn them with low emissions. Moisture content of wood fuel residues from mechanical wood processing industry can be as high as 65%. Adiabatic combustion temperature of this kind of wood can

be not higher than about 1000 °C.

This means that to burn it efficiently, combustion process has to be divided into two parts. Drying and pyrolysis of fuel has to take place in adiabatic atmosphere meaning that in this part of the combustion plant heat is not transferred to boiler water. Because temperature is still quite low, volatile gases have to have long enough residence time burn completely. This has an effect on dimensioning of the boiler.

A Finnish company Sermet Oy has developed and patented a combustion technology (Sermet BioGrate) for wet biomass fuels (moisture content from 30 to 65 %), such as wood waste from sawmills (bark, sawdust, wood chips), plywood or fibreboard factories and wood chips from forests. Boiler plants can be factory made packages, or combinations of pre-fabricated modules and on-site construction. This ensures quick delivery time, high quality and minimises the resources reserved for the project management.

The boiler plant includes fuel storage, fuel conveyors, combustion equipment, boiler, flue gas cleaning, piping, electrification, automation and the buildings for the fuel storage and for the boiler room.

The fuel storage is equipped with bush-bar unloaders. Fuel is transferred by drag chain conveyors into the boiler room, and further into the primary combustion chamber by a stoker screw through a hole in the centre of the grate. Stable feed and effective drying of the fuel is possible, since wet fuel does not mix with already dried or burning fuel due to rotating movement of the grate sections. The primary and secondary combustion chambers are provided with refractory linings. Due to the heat restored in the linings the combustion is effective even when using a fuel with 65 % of moisture.

Combustion is introduced in two stages. Effective gas mixing is a key factor in achieving a high burnout rate of these products. From the primary combustion chamber the gas flows to the secondary combustion chamber where gaseous and solid products finally burn out. In order to achieve high burnout rate (and low emissions), sufficient particle and gas residence time and high temperature are essential in addition to effective mixing. Therefore the dimensions of the primary and secondary combustion chambers have been chosen to give sufficient residence times. High temperature is achieved due to the refractory linings since practically no heat is transferred out from primary and secondary combustion chambers and combustion takes place almost in adiabatic conditions. If the fuel moisture is for example 50 %, the temperatures in the secondary combustion chambers typically reaches 1200 oC.

After the secondary combustion chamber gas flows into a convection boiler where heat from flue gas is transferred to water. Instead of a hot water or steam boiler, a thermo-oil boiler can be used also. After the convection boiler flue gases enter to cleaner where solid particles are separated. The cleaner can be chosen to be a cyclone, bag-house, scrubber or an electric precipitator, depending on the fuel and emission values to be reached.

Efficiency and Emissions

The efficiency losses due to high moisture content (up to 65%) of bark and sawdust are minimised by the effective heat recovery (low flue gas temperature) and low excess air ratio over the whole capacity range. The conventional flue gas emissions can be summarised as the following:

NO ₂	< 120	mg/MJ _{fuel}
COI	< 120	mg/MJ _{fuel}
Solids	< 50 , 100 or 200 ¹⁾	mg/MJ _{fuel}

1) depends on the selected flue gas cleaner)

Several combustion test periods using bark, sawdust and mixtures of packaging waste, annual crop, sod peat and biosludge from forest industry with bark and sawdust have shown low emissions levels of hydrocarbons, polycyclic aromatic hydrocarbons, polychlorinated dibenzo-p-dioxines and - furans as well as heavy metals. Even under the strict emission levels co-combustion of these waste materials and biomass can be used in a boiler plant /6/.

Schematic drawing of the Sermet BioGrate boiler is shown in figure 4.

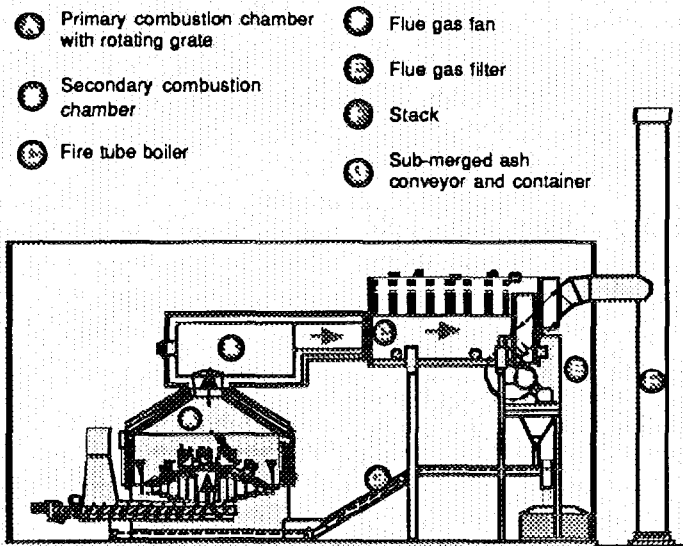


Fig. 4. Schematic drawing of the Sermet BioGrate boiler for wet biomass fuels.

REFERENCES

- 1 Hupa, M. et al. 1988. Emissions from energy production in Finland. KTM Series D:162. 50 p. + app. 8.
- 2 Boström, S. et al. 1992. Greenhouse gas emissions in Finland 1988 and 1990. In si-nööritoimisto Prosessikemia. 62 p.
- 3 Oravainen, H., Flue gas condensing at district heating plants. Proceedings of the IEA Biomass Combustion Conference. Cambridge 1994. 16 p. + app. 2p.
- 4 Larjava, Kari et al., Optimisation of the burning process in furniture industry boilers. Espoo 1995. Technical Research Centre of Finland, VTT Research notes 1709. 47 p. + app. 6 p.
- 5 Nussbaumer, T., Overview of small scale commercial combustion systems for bio-mass. Proceedings of the IEA-meeting in Vienna, May 2 1995.

**NEXT PAGE(S)
left BLANK**