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Emission of some pollutants from biomass combustion in comparison to hard coal combustion

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A B S T R A C T

In the last decade biomass combustion has become one of the most important elements in the fight against global warming. For the sake of climate or environment protection people cut out large stretches of forests and burn them down It is widely believed that the combustion of wood and biomass is completely safe and does not cause any danger to people and the environment. Unfortunately, this is only a half truth. In fact, with considerably lower emissions of sulfur dioxide (SO_2) from biomass combustion, significant amounts of organic micro-pollutants are emitted, among which there are more toxic compounds like polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). The aim of this paper was to assess the real situation. Seven samples of biomass were investigated, i.e. rape straw, oak bark, firewood and wood pellets, shrub willow and rape cake. Pulverized hard coal samples were used for comparison. The aim of the study was to determine and compare the pollution emission factors (per unit mass of fuel) of carbon monoxide (CO), nitrogen oxide (NO) and the sum of hydrocarbons (as total organic carbon – TOC) generated in the process of biomass combustion. Further, we compared the results obtained for coal as well as the effect of process operating conditions (temperature; air flow) on the emission factors. The investigations were carried out in a laboratory chamber furnace at five different temperatures (from 700 to 1100 °C) and at three different air flow rates providing an excess of oxygen. In many cases the determined emission indicators for biomass combustion were higher than for hard coal.

1. Introduction

Biomass has been known and used by mankind as a fuel since ancient times. Today, it is particularly common, primarily as a fuel in poorer countries which lack other resources of fossil fuels, because it is a readily available and renewable solid fuel for heating and preparing meals. In recent years, biomass is increasingly used as a renewable fuel for heat and power generation on an industrial scale, replacing gradually depleting fossil fuels. On the other hand, the fact is that biomass is formed by the process of photosynthesis; plant organisms absorb carbon dioxide from the air and convert it into organic carbon, forming a basic timber which is thus a source of plant growth. This means that the combustion of biomass only releases carbon dioxide that has already been circulated in the atmosphere, without introducing new quantities. The advantages of biomass as a renewable energy source include primarily independence of the country in the sphere of supplies of fossil fuels and so-called "zero-emission" of CO_2 during the combustion of biomass.

Biomass is the third largest natural source of energy in the world. The total global potential of biomass is estimated at approx. 100–440 EJ/year, which represents approx. 30% of global energy demand. At the moment, for energy purposes approx. 40 EJ of energy from biomass is consumed per year [1–4].

Poland is a country with a climate conducive to energy crops and relatively rich in wood. The annual consumption of biomass for energy purposes is approx. 211.5 PJ with total primary energy demand of 4,480.1 PJ, which gives approx. 4.72% [5].

According to Directive 2010/75/EC of the European Parliament and Council on industrial emissions [6], the term biomass is understood as products consisting of any vegetable matter from agriculture or forestry which can be used as a fuel for the purpose of recovering its energy

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content and some waste (vegetable waste from agriculture and forestry, vegetable waste from the food processing industry, if the heat generated is recovered, fibrous vegetable waste from virgin pulp production and from production of paper from pulp, if it is co-incinerated at the place of production and the heat generated is recovered, waste cork and wood waste with the exception of wood waste which may contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coating, and which includes in particular such wood waste originating from construction and demolition waste). On the other hand, Directive 2009/28/EC of the European Parliament and Council on the promotion of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC [7] defines biomass as the biodegradable fraction of products, waste and residues (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well a biodegradable fraction of industrial and urban areas.

Biomass, as a fuel has several advantages among which the most important are its availability, renewability and "zero-emission" of CO_2. However, apart from several advantages as an energy source material, it has also some disadvantages, among which are [8–11]:

- Relatively low density of raw materials, hindering the transport, storage and dispensing,
- Wide range of biomass humidity, which makes it difficult to prepare for use for energy purposes,
- Lower than for fossil fuels energy value of raw material,
- Variability of fuel properties, resulting from changes in humidity and composition.

Biomass utilization for energy – heat and power production – is a subject of numerous studies and many publications in recent years. They cover both the combustible properties of biomass [12–15] and energy generation technologies. Direct combustion [16–19] and co-combustion with coal [20–25] is the well-known oldest way of using biomass as a source of energy [26,27]. Biomass thermo-chemical conversion technologies such as pyrolysis and gasification are certainly not the most important options at present; combustion is responsible for over 97% of the world's bio-energy production [12]. However, co-firing of biomass and coal (both bituminous and sub-bituminous coal and lignite) has technical, economical, and environmental advantages over the other options. Technical issues that can lead to doubt about of biomass co-firing with coal are being resolved through testing and experience [28]. The main current biomass technologies include [29–32]:

- Destructive carbonization of woody biomass to charcoal,
- Gasification of biomass to gaseous products,
- Pyrolysis of biomass and solid wastes to liquid, solid and gaseous products,
- Supercritical fluid extractions of biomass to liquid products,
- Liquefaction of biomass to liquid products,
- Hydrolysis of biomass to sugars and ethanol,
- Anaerobic digestion of biomass to gaseous products,
- Biomass power for generating electricity by direct combustion or gasification and pyrolysis
- Co-firing of biomass with coal,
- Biological conversion of biomass and waste (biogas production, wastewater treatment),
- Biomass densification (briquetting, pelleting),
- Domestic cook stoves and heating appliances of fuel wood,
- Biomass energy conservation in households and industry,
- Solar photovoltaic and biomass based rural electrification,
- Conversion of biomass to a pyrolytic oil (biofuel) for vehicle fuel,
- Conversion of biomass to methanol and ethanol for internal combustion engines.

However, despite the possibility of such large biomass conversion and utilization technologies, its simple combustion or co-combustion with coal still dominates [29].

Combustion is a complex phenomenon involving simultaneous coupled heat and mass transfer with chemical reaction and fluid flow. Its chemistry can be described by the following reaction scheme, where the simplified chemical structure of biomass is presented as a first reactant [13]:

$$C_{x1}H_{x2}O_{x3}N_{x4}S_{x5}Cl_{x6}Si_{x7}K_{x8}Ca_{x9}Mg_{x10}Na_{x11}P_{x12}Fe_{x13}Al_{x14}Ti_{x15} + n_1H_2O + n_2(1+e)(O_2 + 3,76N_2) \underset{Combustion}{\rightarrow} n_3CO_2 + n_4H_2O + n_5O_2$$
$$+ n_6N_2 + n_7CO + n_8CH_4 + n_9NO + n_{10}NO_2 + n_{11}SO_2 + n_{12}HCl + n_{13}KCl + n_{14}K_2SO_4 + n_{15}C + \ldots$$

It is evident that biomass combustion process will be accompanied by the emission of many pollutants. Primary pollutants formed are particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x, principally NO and NO_2), and oxides of sulfur (SO_x, principally as SO_2). Acid gases, such as hydrochloric acid (HCl), may also be emitted, as may lead and other heavy metals. CO and HC, including volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH), are products of incomplete combustion [33]. These species are largely controlled by stoichiometry and proper fuel moisture control.

Biomass has a significantly lower heating value than most coal. This is in part due to the generally higher moisture content and in part due to the high oxygen content. It was observed that the investigated biomass materials showed different combustion characteristics. Results of the structural, proximate and ultimate analyses of biomass and wastes differ considerably. And of course we must remember that coal and biomass fuels are quite different in elemental composition and combustion properties.

The greatest advantage of biomass is that it is a renewable fuel. The application of biomass as a fuel would increase energetic safety and stability in the market of fuels and energy [34,35]. Nonetheless, up to the present, no technology has been developed which allows energy to be acquired 100% ecologically. This is because the processing of raw materials, (either non-renewable or renewable) is connected with a smaller or larger impact on the particular environmental components (the air, water, soil, etc). All precautions are taken so that the negative