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EFFECT OF CHANGE IN TEMPERATURE ON THE CONCENTRATION OF FLUE GAS COMPONENTS FROM WOOD COMBUSTION

DÓRA MENTES[1] – CSABA PÓLISKA[2]

Abstract: Knowledge of the mechanism of formation of flue gas components from residential solid fuels is essential for the reduction of gaseous substances which causes climate change and are harmful to the environment.

The complexity of formation of the flue gas components was simplified during laboratory experiments. The homogeneity and mass of the sample affecting the firing was constant, and volume flow of the continuously flowing combustion air was 140 dm^3/h. The temperature of the combustion chamber was changed, it was heated to 600 °C, 700 °C and 800 °C. It was obtained an answer to how increasing the temperature of the combustion chamber affects the amount of CO, CO_2, O_2, and NO_x components formed in the flue gas as a function of time as a result.

The CO formation can be divided into two stages during combustion: the inflammatory stage and the combustion stage. During the inflammatory phase the amount of CO is affected by oxygen involved in the combustion and the amount of the excess air, while in the combustion phase it is primary influenced by temperature.

Keywords: effect of change in furnace chamber's temperature, biomass combustion, amounts of flue gas components

INTRODUCTION

One of the biggest challenges of the Anthropocene era is the crisis of air pollution, which poses a potential risk to human's health and economy growth [1]. The assessment and improvement of air quality, and the complexity and importance of the consequences of air pollution have attracted much attention among researchers. According to the source of air pollution, it can be distinguished between anthropogenic (man-made) and natural sources. The atmosphere is thus a complex chemical system in which emissions of urban pollutants are mixed with emissions from the natural environment [2]. Although many pollutants from natural activities (volcanic eruptions and scrub and forest fires in the Mediterranean countries, California and Australia, etc. [3], [4], [5]) releases in the atmosphere, anthropogenic activities are the main causes of ambient air pollution [6].

[1] Department of Combustion Technology and Thermal Energy, University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
tuzdora@uni-miskolc.hu

[2] Department of Combustion Technology and Thermal Energy, University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
tuzcsaba@uni-miskolc.hu

Emissions of the most important air pollutants in Europe decreased between 2002 and 2011, resulting in improved air quality in the region in case of some pollutants. Despite these results, not all countries and economic sectors have made satisfactory development and progress in reducing emissions [7]. However continuous progress has been observed in other sectors (such as industry), emissions from agriculture and residential solid fuel combustion have either decreased slightly (for agriculture) or not at all in the last decade (for household fuel combustion) [7].

Emission of benzo-a-pyrene (BaP), which is considered as a marker of imperfect combustion and as a representative of polycyclic aromatic compounds, increased by 11% in the EU-27 between 2002 and 2011, due to a 24% increase in emissions from residential solid fuels. BaP pollution is a growing problem in Europe, especially in areas where residential solid combustion (like coal and wood) is common [7].

Considering to the emission of particulate matter, 47.3% of total emission in Europe comes from households. This share increased by more than 6% compared to data of 2006 [8]. Poland has the highest concentration limits for particulate matter in ambient air in the EU. The PM10 is 200 $\mu g/m^3$ and the PM2.5 is 300 $\mu g/m^3$. These quantities are eight and six times higher, respectively, than the given limits found in the World Health Organization (WHO) guidelines [8].

It can be declared that biomass combustion has become one of the biggest sources of air pollution [9]. Since the wood burning is much more affordable and reachable for the households in energy poverty than for example using of solar power for heating. It is also considered a climate-friendly energy source because it is renewable and carbon-neutral [7].

The aim of the laboratory experiments is to examine how the changing of the temperature of the combustion chamber effects to concentration of flue gas components. The experiments presented in the work are preliminary experiments. Another direction of the research is to study the evolution of the amounts of flue gas components from waste combustion.

1. MATERIALS AND METHODS

1.1. Materials

In the laboratory-sized experiments, the oak sample was in an air-dry state. The sample was grounded to homogeneous in order to ensure that the heterogeneity did not affect the results of the measurements. The homogeneous sample was compressed into a puck-shape using the apparatus shown in *Figure 1*.

A sufficiently large surface area of puck-shaped fuel had got in contact the combustion air during the firing, which resulted the reduction of the emission of CO. This could be explained by increased specific surface area. If the specific surface area of the fuel was not large enough during the combustion, the air-fuel mixing quality was poor, which resulted the formation of CO [11].

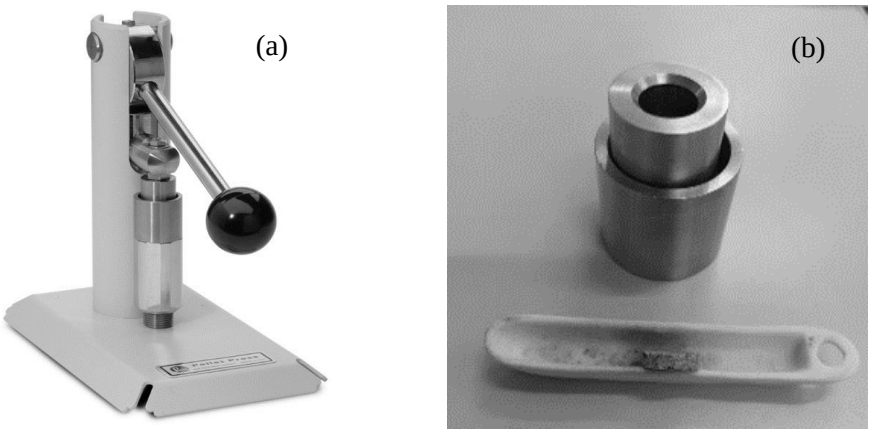

Figure 1
Picture of a pressing machine forming the shape of the sample (a) [10], *image of the sample in the boat (b)*

1.2. Measurement process of the laboratory experiment

The combustion process was tested in a Hőker Cső 350/900 type electric resistance tube furnace, which had a horizontal working chamber and a programmable temperature of the furnace temperature controller, thus allowing the temperature set at a given time to be maintained. The analysis of the concentration of the gases from the combustion process (CO_2, O_2, CO, NO_x) was performed with a Horiba PG 250 gas analyzer. The air flow rate was regulated by the compressed air tank, rotameter, and valve. The experimental setup is schematically illustrated in *Figure 2*.

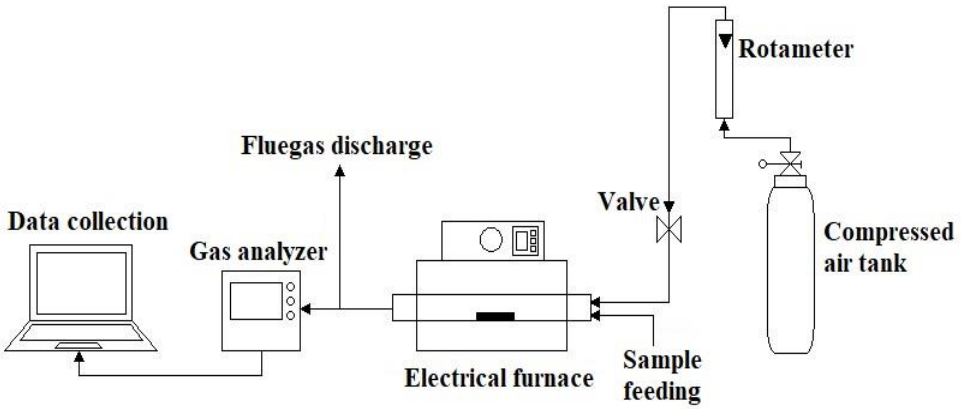

Figure 2
Measuring system

The actual combustion air flow rate was set at the beginning of the experiment. The sample in the quartz boat was pushed into the combustion zone, after the tube furnace reached the predetermined temperature of the furnace chamber. Combustion started immediately in the combustion zone, along with the recording of emission values. The experiment time lasted longer at lower temperatures than at higher temperatures.

Investigation of the combustion process happened at a combustion air volume flow of 140 dm^3/h and at a temperature of 600 °C, 700 °C, 800 °C. Three experiments were performed in each settings. The data shown in the figures are the averages of the experimental results.

A similar measuring system could be found in the literature, however the set combustion parameters and the tested fuels were different. For example Peng et al. [12] investigated emission characteristics of PAHs during MSW/coal co-combustion. Wielgosiński et. al. [13] examined the emission of CO, NOx and TOC from biomass combustion in comparison to hard coal in 5 different temperatures and at 3 different air flow rates excess air.

2. RESULTS

2.1. Evolution of the amount of flue gas components during combustion

Thermal degradation of the wood, and in particular decomposition of carbohydrates, is a complex process and it includes many different reactions occurring simultaneously, e.g. dehydration, depolymerization, fragmentation, rearrangement, repolymerization, condensation and carbonization [14].

Combustion processes are strongly influenced by the elemental and chemical composition of the fuel and the combustion parameters. The chemical composition of the wood cannot be defined precisely for a given tree species or even for a given tree. Chemical composition varies with tree part (root, stem, or branch), type of wood (i. e., normal, tension, or compression) geographic location, climate, and soil conditions [15]. Biomass is a complex material, mainly composed of hemicellulose, cellulose and lignin in addition to extractives (tannins, fatty acids, resins) and inorganic salts. Cellulose is the most important element in biomass due to its large proportion [16]. Cellulose, hemicellulose and lignin of oak proportions are 41%, 26.35% and 25.71% in general based on the literature data's [17].

All combustion processes can be considered as emission sources, during which not only CO_2 and H_2O are produced, but as well many other components released from the perfect (SO_2) and imperfect (CO) combustion. Many formation pathways of the end products are known during combustion. Every biomass combustion start with the pyrolysis of the cellulose *(Figure 3)*.

In addition the inorganic components of the biomass react with the cellulose which leads to a wide range of reactivities, from enhancement to total inhibition of the smouldering combustion by variation in the rates of production of CO and CO_2 and the corresponding rates of heat release [19].

So knowledge of the formation mechanisms and pathways allows the so-called the use of primary methods to reduce emissions [20].

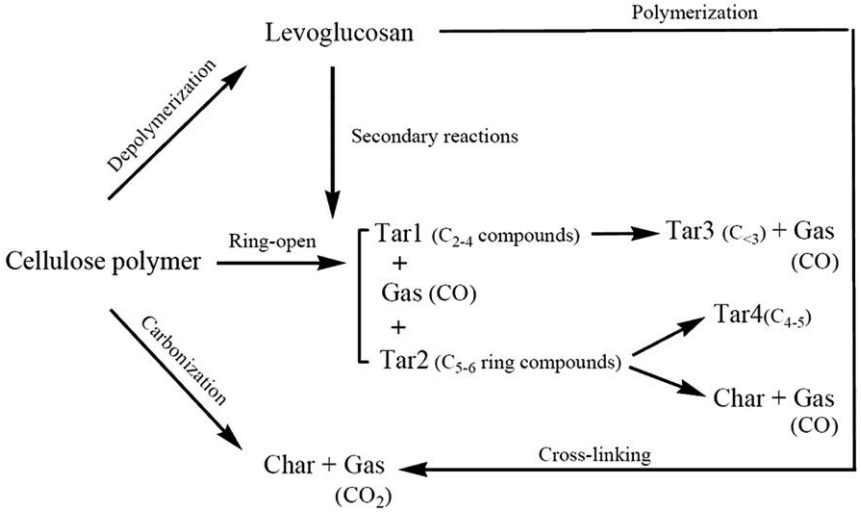

Figure 3

Kinetic scheme proposed by Shen et al. [18] *for fast pyrolysis of cellulose*

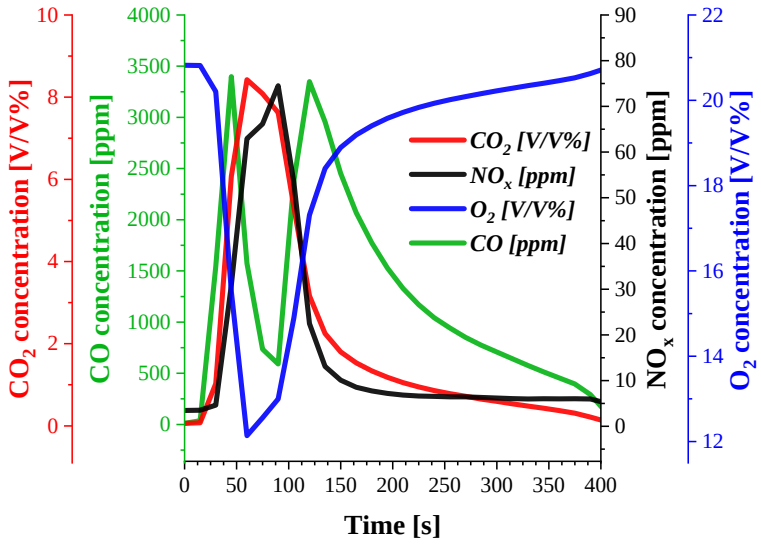

Figure 4

Evolution of the amount of flue gas components during combustion (140 dm^3/h, 600 °C)

Cereceda-Balic et al. [21] obtained similar curve in experiments with two hardwood and one softwood compared to the *Figure 4*.

In the case of CO concentration, two peaks can be observed:

- up to the first peak, the inflammatory stage is visible, where volatile substances leave the biomass,
- the rest of the curve indicates combustion stage.

Firstly, during the primary attack by oxygen on hydrocarbons, CO is formed by a fast reaction mechanism shown in simplified *Equation (1)*. The subsequent reaction of CO to CO_2 in simplified *Equation (2)* is slow and requires adequate residence time to achieve completion. Thus, in a poorly designed or overloaded stove, it is possible to produce significant CO emissions even in the presence of large amounts of excess air [22]:

$$C_{(s)} + 0{,}5\ 0_{2\,(g)} \leftrightarrow CO_{(g)} \tag{1}$$

$$CO_{(g)} + 0{,}5\ O_{2\,(g)} \leftrightarrow CO_{2\,(g)} \tag{2}$$

During the intensive combustion stage, the concentration of carbon dioxide increases, and then decreases as the amount of carbon monoxide in the flue gas begins to increase. It can be argued that the production of carbon monoxide (CO) decreases with increasing temperature at the expense of higher production of carbon dioxide (CO_2) [23]. The minimum of the O_2 curve and the maximum of the CO_2 curve indicate the phase of intense combustion.

2.2. Effect of the furnace chamber's temperature on the flue gas components

Figure 5 shows that in the inflammatory phase, the concentration maximum of the CO component decreases to a certain optimum with increasing temperature of the combustion chamber (700 °C) and then begins to increase again after the optimum is reached. CO is generated in two ways in the inflammatory phase:

- when the oxygen is less than the theoretical amount of oxygen required for complete combustion supplied,
- or when there is too much excess air in the combustion process, which decreases the temperature of the combustion chamber.

In the combustion phase, the CO concentration maximum decreases with increasing temperature, which means that the reaction between CO and O_2 is promoted by the temperature of the combustion chamber.

NO is a product of high-temperature combustion processes that is further oxidized to NO_2 at temperatures below 650 °C [24]. Since the temperature of the combustion chamber was set to less than 1,300 °C during the experiments, only NO formation from the nitrogen content of the fuel should be taken into account [25], [26]. In general, all the factors that increase the temperature of the flame increase the amount of NO formed too [27].

The concentration of carbon dioxide reaches a maximum when concentration of oxygen is zero. Increasing the temperature of the combustion chamber promotes the formation of CO_2 formed during the reaction according to *Equation (2) (Figure 5)*.

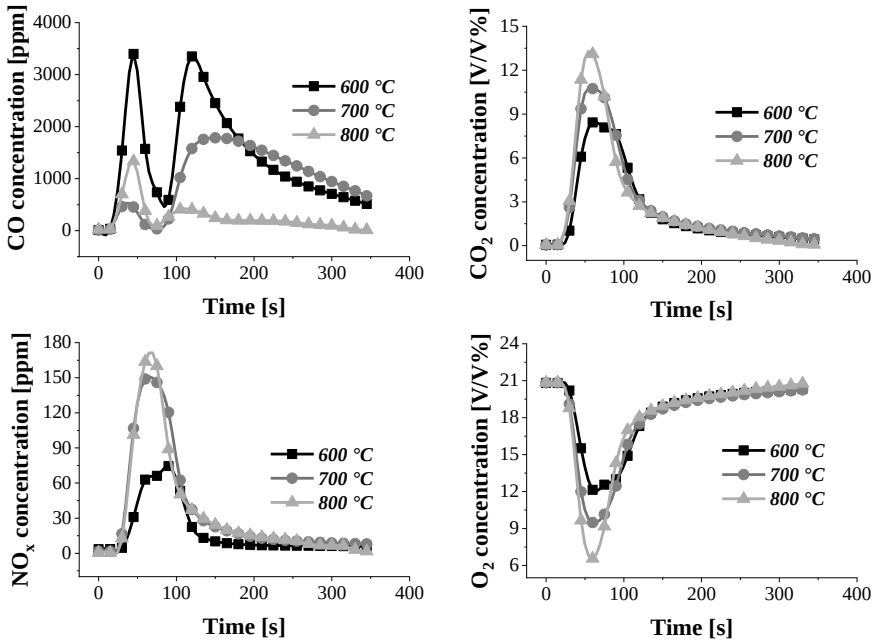

Figure 5
Effect of furnace chamber's temperature change on concentration of the flue gas components

CONCLUSION

One of the aims of this research was to reduce the CO emissions of a newly purchased residential solid fuel boiler below the emission limit values set out in Regulation 2015/1185 issued by the European Commission. The results and experience gained from laboratory-scale experiments would help to reduce the concentration of CO mentioned above.

Based on the results, it could be clearly concluded that the evolution of CO concentration could be divided into two stages. The first stage was the inflammatory stage. The minimum of the CO concentration could be reached at the optimum combustion temperature of the furnace chamber.

When the oxygen was less than the theoretical amount of oxygen required for complete combustion supplied, CO was a final product of the reaction. Otherwise too much excess air led to lower temperature of combustion chamber. This could be explained by the fact that the oxygen and nitrogen – that were not involved in the combustion – absorbed usable heat and carried it out of the chamber. This process promoted the formation of CO. The second stage was characterized by the temperature of the furnace chamber. The reaction between CO and O_2 is promoted by the temperature.

The concentration of NO_x and CO_2 components increased with increasing temperature of the combustion chamber, while the concentration of O_2 decreased. These results indicated that more O_2 was involved in combustion reactions at higher temperatures.

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