THE INFLUENCE OF BIOMASS AND WASTE TORIFICATION CONDITIONS ON THE PHYSICAL AND CHEMICAL PROPERTIES OF PRODUCTS

Krystian Krochmalny

Supervisor: prof. dr hab. inż. Halina Pawlak-Kruczek
Co-supervisor: dr inż. Krzysztof Mościcki

Abstract

This work presents research results on selected issues related to the torrefaction of biomass fuels and waste fuels of biomass origin (sewage sludge). The work is divided into chapters in which subsequent experiments are described, starting with the microscale (TGA) and ending with the pilot reactor. Additionally, the paper discusses the application aspect of the torrefaction in assessing the possibility of co-firing with hard coal and lignite.

Experimental basic research focused on torrefaction of a single model particle of biomass. Research shows the effect of particle size on the exothermic effect during the process. Changes in fuel parameters occurring during the torrefaction process, as well as changes in physical parameters such as changes in the volume and density of the sample, were discussed. The kinetics was determined based on two methods - isothermal and non-isothermal, using the TGA / DTG analysis. Then, tests were performed on a specially designed test stand using the same material as in TG analysis, i.e., beech wood, with the use of spherical particles with two different diameters (12 and 30 mm). During the torrefaction process, the temperatures in the center of the sphere, in the middle of the radius and on its surface were measured. The respective temperature distributions for the two particle sizes were substantially different. For 12 mm particles, the surface-center temperature gradients were small. In the case of the model biomass particle with a diameter of 30 mm, a strong influence of physical phenomena, i.e., heat and mass transport, on the torrefaction process was observed. Exothermic reactions also turned out to be important, as they became clearly visible by obtaining temperatures inside the particle exceeding the temperature of its surface. During the research, a mass balance of torrefaction products was performed, taking into account the solid, gas and liquid fractions, consisting of compounds remaining in the liquid state under normal conditions. On the other hand, a detailed analysis of the gas fraction showed the presence of one characteristic compound, i.e. formaldehyde, which is a good marker - an indicator of the degree of torrefaction-carbonization due to the linear relationship between the concentration of this compound and the torrefied biomass parameters (including the relative shares of H and O in relation to the element C). The use of formaldehyde as a marker is a novel way to control the torrefaction process in the on-line mode, allowing the process conditions to be adjusted to possible changes in the quality of the input material. Moreover, a linear relationship between the molar proportions of H/C and O/C has been determined for torrefaction of a single particle of wood in the temperature range of 223 - 350°C. This could be used for prediction of the degree of carbonization. However, this is a *post-mortem* method and cannot be used on-line. Using the results obtained with the use of artificial neural networks, an attempt was made to describe the changes in the calorific value of torgas depending on the proportion of formaldehyde, thus providing the basis for the automation of the torgas combustion process in industrial installations.

The work also presents the results of studies on the influence of torrefaction parameters on the properties of the obtained products depending on the selected species of lignocellulosic biomass (PKS, wood chips, rape straw, olive pomace) and waste biomass (sewage sludge). The research included the determination of crucial torrefaction parameters such as mass and energy efficiency and changes in the parameters responsible for the quality of solid fuels, including the effect of dehydration and dehydroxylation of biomass, manifested by the decomposition of

hemicellulose and cellulose, which translates into a lower rate of absorption of moisture from the environment. The measurements showed the influence of temperature, residence time and initial fuel moisture on the later energy demand for the grinding process.

The tests carried out on the pilot unit allowed the determination of the influence of the initial fuel moisture on the torrefaction process in practical terms. The presented research shows that the problem of fuel moisture, and thus the impact of a significant share of water vapour in torgas, is substantial. A considerable percentage of water in the raw biomass intended for torrefaction worsened the fuel properties of the obtained torrefaction by lowering the reactor operating temperature, extending the drying time and shortening the adequate torrefaction time. In the case of sewage sludge torrefaction, studies have shown that it is possible to improve the same fuel parameters as in the case of lignocellulosic biomass. Thanks to torrefaction, an increase in calorific value, a decrease in humidity and an increase in sewage sludge carbonization were observed. The equilibrium humidity decreased with increasing torrefaction temperature, indicating an improvement in fuel storage. The addition of brown coal was used for improving the productivity of torrefaction. Blends with 10% addition of brown coal were characterized by higher energy efficiency obtained during torrefaction. The research also showed that although lignite contributes significantly to the calorific value of the fuel, the drying process of sewage sludge with its addition was slower than for the sludge itself. The experiment also investigated the effect of CaO addition to the torrefied sewage sludge. It caused a significant decrease in nitrogen and sulfur content in the solid sample. There was also an overall increase in CO2 concentration with increased amounts of CaO addition. This effect may suggest that CaO has the potential to promote hydrocarbon degradation. During the torrefaction of the sewage sludge, it was noticed that an increase in the CaO content resulted in a decrease in the share of tars. CaO contributes to reducing the volatile release rate in the case of sludge pyrolysis.

The evaluation of the application potential of torrefied wood chips was carried out in an isothermal flow reactor, adding storified fuel to the hard coal and brown coal stream. The experiment simulated the conditions prevailing during coal combustion in a pulverized coal boiler. The research has shown that it is possible to use an additional fuel in the form of torrefied wood chips, added to the stream of both reference fuels in a 10% mass share. The analysis of the ash composition of fuel mixtures and the coefficients determined on its basis, describing the risk of contamination of the boiler's heating surfaces, showed that such a risk did not increase. The co-incineration of torrefied wood chips can be seen as a way to reduce CO2 emissions as well as SO2 and, in some cases, NOx emissions.

Krystian Krochmalny