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Experimental investigation of the solar pyrolysis of waste biomass

Ph.D. thesis of

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Abstract

The Ph.D. thesis presents the results of experimental research on the solar pyrolysis of waste biomass carried out on a bench-scale test stand designed by the Author. The first chapters of the work present a literature review of solar pyrolysis and the basic theoretical issues of the process itself. In the work, the author presented a design of a solar pyrolysis reactor powered by artificial solar radiation, according to the original concept of indirect heating of biomass, responding to the problems of heat loss in reactors made of transparent materials described in the literature. Laboratory experiments were carried out for samples of three types of waste biomass: waste wood, waste straw, and sewage sludge.

On the designed test stand, the course of the biomass pyrolysis was examined and described, taking into account: the shares and quality of pyrolysis products, measurement of temperature profiles, the actual heating rates of samples during the process, and the formation of the main gas products. The shares of the products together with the determined values of the heat of combustion based on their elemental composition allowed to determine the chemical energy conversion factors of the fuel (biomass). Apart from the experimental results, the paper also presents the methodology for determining the parameters of the kinetics of the pyrolysis reaction of the tested fuels based on thermogravimetric measurements (TGA). Based on the latest literature, the current kinetic methods such as model-fitting, deconvolution, and model-free, isoconversional techniques were used.

The studies for all types of biomass showed the dominant share of the liquid fraction, the so-called bio-oils in products. Thanks to the adopted measurement methodology, it was possible to obtain pyrolysis gas rich in hydrogen, however, with a low share in the final products, with a mass fraction of less than 12%. The thesis was confirmed that solar pyrolysis may be an original method of producing high porosity char, depending on the process parameters and the type of feedstock. In the case of straw, exceeding the melting temperatures of ash during pyrolysis resulted in a significant loss of the porous surface. The increase in calorific value of solid products of solar pyrolysis of lignocellulosic biomass was denoted, concerning the primary chemical energy of biomass. Determination of the biomass chemical energy conversion indexes allowed to state that only the solar pyrolysis of wood resulted in a measurable increase in the chemical energy content in products (+ 12%), in the case of other biomass samples only the opposite effect was noted.

The proposed methodology for determining the parameters of the kinetics of the pyrolysis reaction is based on a combination of isoconversional methods and traditional methods based on reaction models. Friedman's method provided valuable information on the complexity of the pyrolysis process and the values of initial parameters for further calculations. As a result of kinetic computations, it was shown that the pyrolysis of waste wood and straw was subject to the mechanism of 3 independent reactions, the so-called pseudo-components whose physical meaning is attributed to the independent breakdown of cellulose, hemicelluloses, and lignin. The same methodology was used to select the mechanism of sewage sludge pyrolysis kinetics - a model of 10 independent reactions, the assignment of which to the decomposition of substances is problematic due to the complexity of the composition of the sludge itself. The kinetic models determined based on

the obtained parameters made it possible to predict the behavior of biomass samples in the reactor during experiments on a laboratory scale.