3-step evolution modeling of the SWPS-GIPO Devolatilization Reactor

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The Sustainable Waste Power System (SWPS) is a novel method that converts low grade biowaste into power and heat. Commonly utilized fuels are wastewater sludge and similar feedstocks like chicken manure. The system consists of a set of reactors that initially reform and then gasify the feedstock. The syngas is combusted in an Internal Combustion Engine for the production of heat and power. Thus, an alternative name of the system has been "The GIPO process", i.e. "Garbage-In-Power-Out". The initial reforming takes place in the Devolatilization Reactor, where under high pressures and moderate temperatures the feedstock is converted into hydrochar, gases and water plus slurry. This process is commonly defined as hydrothermal carbonization and it upgrades significantly the quality of the input feedstock in such a way that it can subsequently be gasified and then energetically valorized. Understanding and modelling the operation of the Devolatilization Reactor is important for the further optimization of the SWPR-GIPO system. Nonetheless, the exact process of hydrothermal carbonization has not been fully understood and existing thermodynamic models cannot accurately simulate the process. The two main questions that are still not fully answered are firstly how exactly is the solid fraction produced, and secondly why is there such high CO2 concentration in the final gases. In particular, the high CO_2 concentration from the DV process has not been properly modeled or understood since more H_2 and CH_4 would be expected. There are several mechanisms that allow the evolution of oxygen from hydroxide ions due to the favorable system parameters. Also, we model the generation of hydrochar as a result of gasification char-gas reactions (Boudouard, WGS etc.). The CO_2 molar fraction is used as an indicator in order to find "how far" the process is from equilibrium and the model returns the results that correspond to the given concentration of CO_2 and the solid carbon can be calculated with a high degree of certainty. This present study uses previously mentioned parameters and presents the idea of a 3-step evolution model that has been developed in MATLAB/ Cantera. Experiments at the SWPS-GIPO system were performed at the City College of New York and the modeling results were compared with experimental results at 555 K. For modeling at 540 K the calculated gases were CO_2:95.05%, CO: 3.84 %, CH_4:1.05%, for modeling at 560 K the calculated gases were CO_2:94.93%, CO:3.84 %, CH_4:1.14% and for the experimental results at 555 K, the data were CO_2:94.71%, CO:4.79%, CH_4:0.70%. Both the model and the experiments returned a ratio of 57%-43% between solid and gaseous products. The model results are were very close to the experimental data. The ultimate scope is to further optimize the quality of the products from the DVR in order to increase the efficiency of the system. The use of Cantera software for modelling makes possible the simulation of the whole SWPS-GIPO system, including the gasification process and the power production. Clearly this study recognizes that models are only simulations of the actual case and not an exact description of the process.

Keywords Hydrothermal Carbonization, Modeling, Biowaste, Mass Balances, Combined Heat and Power