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CO_2 Enhanced Steam Gasification of Biomass Fuels

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Abstract

The current study involves an experimental investigation of the decomposition of various biomass feedstocks and their conversion to gaseous fuels such as hydrogen. The steam gasification process resulted in higher levels of H_2 and CO for various CO_2 input ratios. With increasing rates of CO_2 introduced into the feed stream, enhanced char conversion and increased CO levels were observed. While CH_4 evolution was present throughout the gasification process at consistently low concentrations, H_2 evolution was at significantly higher levels though it was detected only at elevated gasification temperatures: above 500^o C for the herbaceous and non-wood samples and above 650^oC for the wood biomass fuels studied.

The biomass feedstocks were studied through the use of Thermo Gravimetric Analysis (TGA), Gas Chromatography, Calorimetry, Atomic Absorption Spectrophotometry (AAS), and the Scanning Electron Microscope with Energy Dispersive X-Ray Analysis (SEM/EDX). The chemical composition of the various biomass fuels and their combustion and gasification ash residues, in addition to the mass decay and gaseous evolution behavior were investigated as a function of temperature.

The thermal treatment of biomass fuels involves pyrolysis and gasification with combustion occurring at the higher temperatures. In the gasification environment, when combustion processes are occurring, gaseous components evolve from the fuel and react with oxygen either released from the biomass structure itself, or from the injected steam and CO_2. These high temperature reactions are responsible for the enhanced burnout of the carbon (charcoal) structure that is produced during the low temperature pyrolytic breakdown of the biomass. Since the ligno-cellulosic biomass component typically found in U.S. MSW is greater than 50%, techniques to enhance the thermal treatment of biomass feedstocks can also aid in the processing of MSW.

Gas evolution as a function of temperature was monitored for H_2, CH_4, CO_2 and CO for several biomass fuels that included woods, grasses and other ligno-cellulosic samples. These included oak, sugar maple, poplar, spruce, white pine, Douglas fir, alfalfa, cordgrass, beachgrass, maple bark, pine needles, blue noble fir needles, pecan shells, almond shells, walnut shells, wheat straw, and green olive pit. The TGA mass decay curves showed similar behavior for the woods, grasses and agricultural residues, where most of the mass loss occurred before 500oC. Most feedstocks exhibited 2 constant mass steps though several exhibited a third with completed mass loss by 900^o-1000^oC. Two distinct mass decay regimes were found to correlate well with two distinct gas evolution regimes exhibited in the curves for CO, H_2 and CH_4. Most of the mass loss occurred during pyrolysis, with the remaining degradation to ash or char occurring in the high temperature gasification regime.

One characteristic of biomass samples is the highly variable nature of the mineral composition. SEM/EDX analyses indicated high levels of potassium, magnesium and phosphorus in the ash residue. The devitrification and embrittlement of the quartz furnace and balance rods were attributed to the high mineral content of many of the biomass feedstocks, with the high alkaline oxide levels of the grasses being particularly destructive. While mineral content may exert a beneficial effect through enhanced char reactivity with the possibility for a more thorough processing of the feedstock, the potential for corrosion and slagging would necessitate the judicious selection and possible pretreatment of biomass fuels. A major advantage of thermal treatment through gasification prior to combustion is the ability to remove many of the corrosive volatiles and ash elements such as potassium, sodium and chlorine to avert damage to the process equipment.

1. Introduction

Rising energy demands, heightened awareness of man's impact on the global climate system, and the inherent instability of energy geopolitics have led to a greater awareness of the importance of developing sources of energy that can either augment the capacity or replace the use of fossil fuels. One of the more promising renewable energy sources is biomass fuels. They can address both energy security and, being a carbon neutral energy source, environmental sustainability and corporate accountability. Though currently less than 3% of the U.S. energy production is through the use of renewable energy sources, about one third of this