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Characterization of an entrained flow reactor for pyrolysis of coal and biomass at higher temperatures

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HIGHLIGHTS

- Use of CFD in the design of high pressure entrained flow reactor.
- Biomass residence time was higher than coal particle.
- Tar release was higher for biomass than from coal.
- Specific surface areas of coal char lower due to pore coalescence.
- Char showed less thermal annealing for biomass compared to coal.

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ABSTRACT

A laboratory-scale entrained flow reactor for gasification/pyrolysis of coal and biomass has been designed and constructed at the Pennsylvania State University. The pre-experimental numerical simulations have been used as an aid in the design of the reactor as well as understanding and explaining the experimental results. Post experimental modeling of the reactor has been carried out using the CFD package ANSYS-Fluent. Results from experiments conducted with the reactor are here presented. These initial characterization activities of the entrained flow reactor are carried out at atmospheric pressure. Modeling and experiments are conducted at three different temperatures: 1573 K, 1673 K and 1773 K. The CFD models show some particle and gas recirculation at the inlet of the reactor. The calculated residence time in the reactor is 0.5 s for biomass and 0.4 s for coal when the particles traveling distance is 0.65 m. Tar and CO are the dominant species at 1573 K in both coal and biomass conversions, however while tar reduces as the temperature increases, the CO formation increases. Fuel conversion varies significantly between coal and biomass. The minimum conversions observed during experiments were 86.7% for biomass and 56.8% for coal at 1573 K. Conversion rates as high as 90.5% were observed for biomass at 1773 K, while the maximum coal conversion observed was 64.0% at 1773 K. The BET surface area of coal chars obtained at 1573 K and 1673 K was similar and higher than that of the char obtained at 1773 K. This drop of surface area at 1773 K has been attributed to pore coalescence, following observation of the SEM images. The surface area of biomass chars does not vary significantly. The reactivity studies conducted on the chars reveal some thermal annealing at higher temperature for coal; this occurrence is observed to be less pronounced for biomass chars.

1. Introduction

The continuous depletion of fossil fuel resources and the need to curb greenhouse gas (GHG) and pollution from fossil fuels utilization has stimulated the increasing use of biomass and opportunity fuels for power generation and fuel production. Co-firing coal and biomass has been assessed by various authors [1–3] and is suggested as a viable and readily applicable option for converting biomass into power, heat and chemicals [4–6]. Although coal and biomass naturally appear in solid form, their physical properties vary substantially, causing dissimilar behavior during their thermal conversion.

High temperature gasification is well recognized for achieving high carbon conversion and producing a high quality syngas with

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low methane and tar content [7,8]. Unlike fixed-bed and fluidized-bed, entrained flow gasifiers operate at higher temperature and higher heating rates, allowing better efficiency (higher carbon conversion) and cleaner syngas. However, the operating temperature of entrained flow reactors coincides with the fusion temperature of the major mineral matters found in biomass (Na, K, Ca). Moreover, the hydrodynamics of coal and biomass particles in an entrained flow reactor are likely to differ considerably, given the disparity of their size, shape and density. Coal particles are denser, smaller in size and are spherical or nearly spherical. Biomass particle on the other hand have a lower density, are 5–10 time order of magnitude bigger than coal particles and are prolate (cylinder-like) and oblate (disk-like) spheroids. These complexities necessitate a thorough perception of the conversion mechanism of the two fuels in an entrained flow reactor. Therefore, an entrained flow reactor aimed at studying the behavior of solid fuels (coal, coke, biomass, and waste) at high temperature, high pressure has been built at the Pennsylvania State University's EMS Energy Institute. The present work outlines the development work involved in the construction of the entrained flow reactor following a simulated assisted design carried out in ANSYS Fluent and COMSOL as well as some results of experiments carried out at atmospheric pressure.

2. Reactor description and design motive

2.1. Basic layout and operation of the reactor

The present reactor (Fig. 1) consists of five sub-systems: the feeding sub-system, the gas preheating and steam generator sub-system, the reaction sub-system, the species sampling and analysis sub-system and the reactor control and cooling sub-system. Fig. 2 shows a simplified 3D representation of the reactor created in order to facilitate modeling into Comsol Multiphisics. The raw coal and biomass used for these experiments were dried in an oven maintained at 60 °C for 24 h in order to get rid of any adsorbed moisture. The dried coal or biomass is loaded in the feeder which controls the feed rate of the particles into the reactor. The primary gas (transport gas), together with coal/biomass particles travel through the water cooled injection probe and are injected into the reactor with an initial velocity (Vp_0). This initial particle velocity is controlled by the flow rate of the primary gas. Upon injection into the reactor, the particles travel the heated zone of 0.65 m length where reaction takes place. The secondary gas, including steam, passes through the preheater where it is heated and injected into the reaction section. The reaction section is electrically heated, using six Molybdenum disilicide ($MoSi_2$) heating

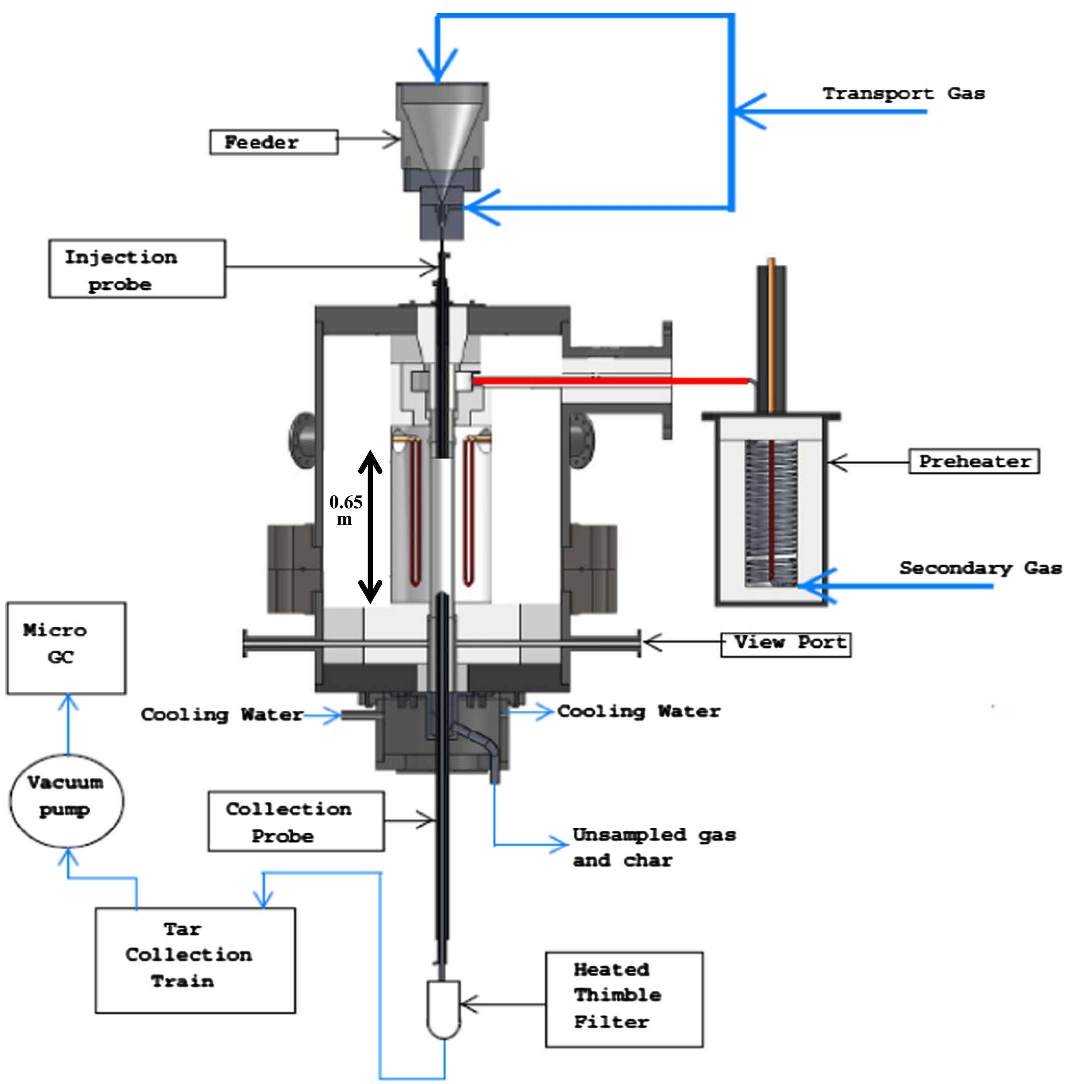

Fig. 1. Schematic of the reactor.