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STEAM HYDROGASIFICATION OF COAL-WOOD MIXTURES IN A BATCH REACTOR

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Abstract:

Steam hydrogasification is a thermochemical process where a carbonaceous feedstock is gasified in the presence of hydrogen and steam. The product gas stream contains a significant amount of methane and has a high calorific value. The presence of steam during the traditional hydrogasification reaction significantly increases the rate of methane formation. The efficiency of the process and the product gas composition are governed by the feedstock composition ($H_2O/Feed$ and H_2/C ratios), temperature, pressure and residence time. The product gas stream from a steam hydrogasifier can be reformed to generate synthesis gas (H_2 and CO) that can be used in Gas to Liquid processes.

Gasification of co-mingled coal-biomass feedstocks offers several advantages such as the reduction in the net CO_2 emissions from the process. In this study, steam hydrogasification of coal-wood mixtures at various ratios have been performed in a batch reactor. Coal from the state of Utah and cedar wood have been used as the feedstock. The carbon conversions were measured at 700 and 800C at a $H_2O/Feed$ ratio of 2. Effects of water and hydrogen were also investigated.

The results demonstrate that the carbon conversion depends on the reaction temperature and the ratio of coal to wood in the feed does not influence the conversion. The carbon conversion varies from 70-80 % at 800C and 50-60 % at 700C. The data also show that the relative composition of CH_4 , CO and CO_2 vary with the coal to wood ratio. The results show that the percentage of CO in the outlet gas composition increases with the

increase in the amount of wood in the feed. This paper presents the results of these experiments and also comparison of these data with simulation results

1. Introduction

The research on commingled gasification of coal and other renewable feedstocks such as biomass, sewage sludge, etc is receiving increased attention since this offers several advantages. Coal gasification technology is considered mature and commercial CTL plants and also IGCC plants using coal feed have been operating successfully for a number of years¹. Coal has several obvious advantages as a gasification feedstock due to its high carbon content, abundance, good slurry properties, etc. However, the GHG emissions from coal based pathways are considerable higher than that of conventional gasoline and diesel. This problem can be mitigated by commingling coal with renewable feedstocks or by means of carbon capture and sequestration². A new synthesis gas production technology has been developed at CE-CERT, University of California Riverside³. This process uses a Steam Hydrogasification Reactor (SHR) and a Steam Methane Reformer (SMR) to generate syngas with an adjustable H₂/CO ratio. The SHR gasifier converts the carbonaceous feed into a product gas stream containing significant quantities of methane and it does not use air or oxygen as the gasifying agent. This paper presents the results of experimental work on the steam hydrogasification of coal and wood mixtures in a batch reactor. The carbon conversion and the rates of formation of different species have been estimated.

2. CE-CERT Process

The CE-CERT process is an integrated system of three steps. The SHR step is followed by the SMR (Steam Methane Reforming) step to produce synthesis gas (H₂+CO) and the last optional step of liquid fuel synthesis such as a Fischer-Tropsch reactor (FTR).

The SHR step utilizes a water based slurry as the source of carbonaceous feedstock and combines it with steam and recycled hydrogen to produce a methane rich gas. The reactions of the carbonaceous slurry feedstock in the SHR can be chemically represented in a simplified manner as:



Others: CO, CO₂ and C₂+

The SMR that converts products formed in reaction (1) into synthesis gas can be characterized as:



The reactions (1) – (3) are idealized reactions used for the purpose of illustration. The actual process is much more complex. However, it is important to note that the SMR step requires high temperature steam together with methane rich gas to produce the synthesis gases. Thus, there is no need to remove the steam from the SHR product gas stream after the reactor. The introduction of water in the form of slurry into the reactor is one of the most unique features of the CE-CERT process. Water acts as the carrying medium for the carbonaceous feedstock into the SHR reactor by utilizing a conventional slurry pumping technology. It also enhances the product gas yield as well as the reactivity of the

hydrogasification process as described in the previous section. Finally, it is consumed by the SMR as a feedstock to produce the synthesis gas. The SMR produces a syngas with a H_2/CO ratio higher than the value of 2.1 required by the Fischer-Tropsch process. The excess hydrogen of the SMR product gas can then be separated in a straightforward manner and fed back to the SHR, making the process self sustained (i.e., no needs for an external source of hydrogen after initial start up).

The product synthesis gas can be used as fuel gas to generate electricity or can be used as a feed for the fuel synthesis reactor that converts the synthesis gas into synthetic liquid fuels and process heat. Examples of such synthetic fuels are Fischer-Tropsch diesel, methanol and Dimethyl Ether (DME).

Figure 1 presents a block flow diagram of the CE-CERT process with the addition of the fuel synthesis step. Synthetic fuel (methanol, DME or FT diesel) is generated from the synthesis gas made in the SHR & SMR reactors coupled with a warm gas cleanup unit.

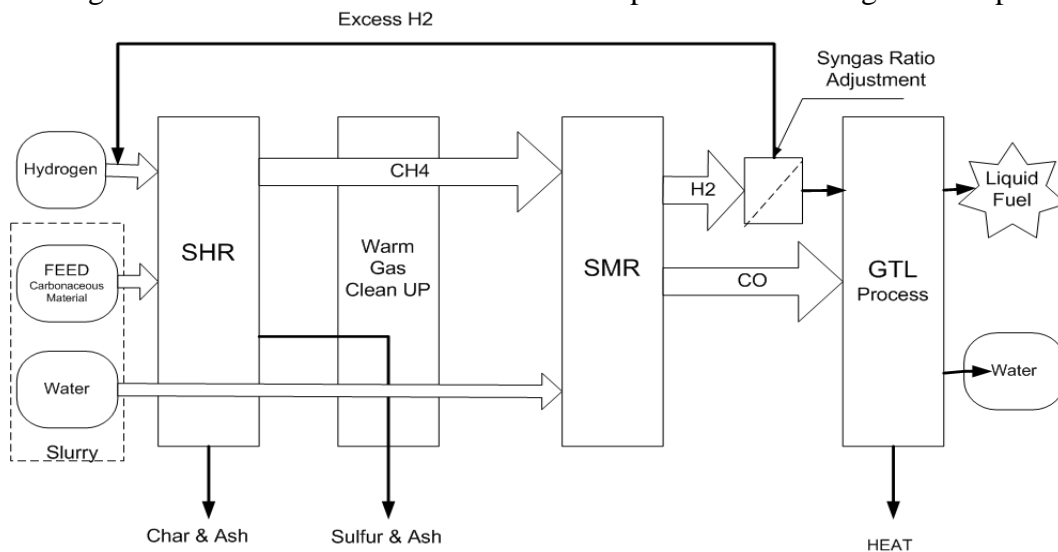


Figure 1 Process Flow Diagram of the CE-CERT Process

3. Experimental Work

The experimental work was performed on a standalone batch scale SHR gasifier. A batch reactor setup with a reactor volume of 220 CC was used for this investigation. The reactor was specifically designed to enable continuous stirring under high pressures. The reactor is made of Inconel® alloy and can be operated under pressures and temperatures as high as 400 psi and 800 C respectively. The reactor setup is comprised of a heating system, a batch reactor, a water trap, a capillary line that allows on-line analysis of product gases, an electron ionization mass spectrometer (MS) and a data acquisition (DAQ) system monitored by using LabVIEW software. The DAQ registers reaction parameters such as temperature, pressure and heater duty into a computer.

Finely ground cedar wood was used as the sample feedstock in the forestry category. Bituminous coal from the southern Utah region was commingled with the cedar dust. The feedstock was ground to a size of 150 microns. The reactor was loaded with 0-2 g of

cedar dust along with 0-2 g of coal and 0-4 g water. The amount of coal, cedar wood and water for each test was decided on the basis of the desired H₂O/C ratio of the feed. The weighed feedstock and water were placed in the reaction vessel and the vessel was attached to the top flange housing consisting of the impeller shaft and magnetic drive stirrer system using bolts, nuts and locking washers. Once tightened, the reactor was opened up to a vacuum pump and was flushed three times with H₂ to remove any other gases present and was tested for leaks. The impeller and cooling systems were switched on at this time. The reactor was brought up to the reaction temperature by immersion into an electrical heater. The reaction was then monitored for the necessary time, normally from 20 to 30 minutes.

3. Results and Discussion

Figure 2 shows the carbon conversion results for coal wood mixtures of varying compositions at 700 and 800 C. The carbon conversion is defined as the amount of carbon in the feed that is converted to gaseous products. The conversion is estimated by weighing the unconverted char and ash after the tests.

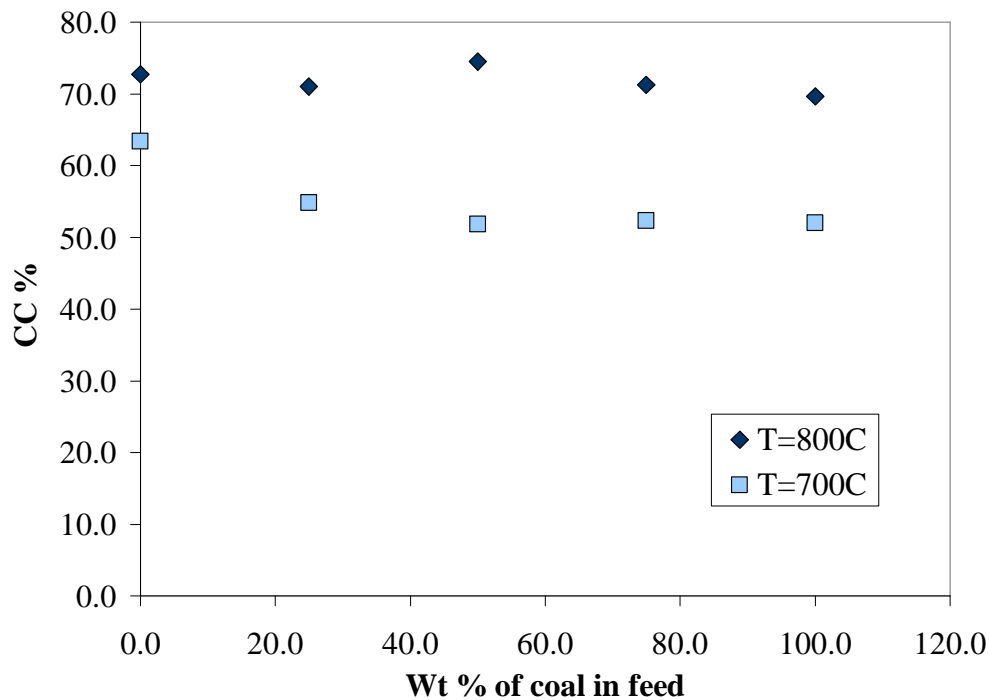


Figure 2 Carbon conversion results for coal-biomass co-feed gasification experiments

The figure shows that the carbon conversion is slightly higher for experiments using a feed with higher biomass content. Similar results for steam pyrolysis and air blown gasification tests have been reported in the literature. The improvement in carbon conversion is attributed to the higher volatile matter content of biomass feedstocks including a higher oxygen and hydrogen content. Hence, commingling of coal and biomass material provides several advantages including reduced GHG emissions.

Figure 3 shows the rates of formation of CH₄, CO and CO₂ during the gasification tests. The calculation methods for the estimation of the kinetic rate constants have been described elsewhere⁴. The results show that the rates of formation are relatively higher for higher wood/coal feed ratios, especially for carbon monoxide. These higher rates can be attributed to the higher volatile content of the biomass feedstock compared to coal.

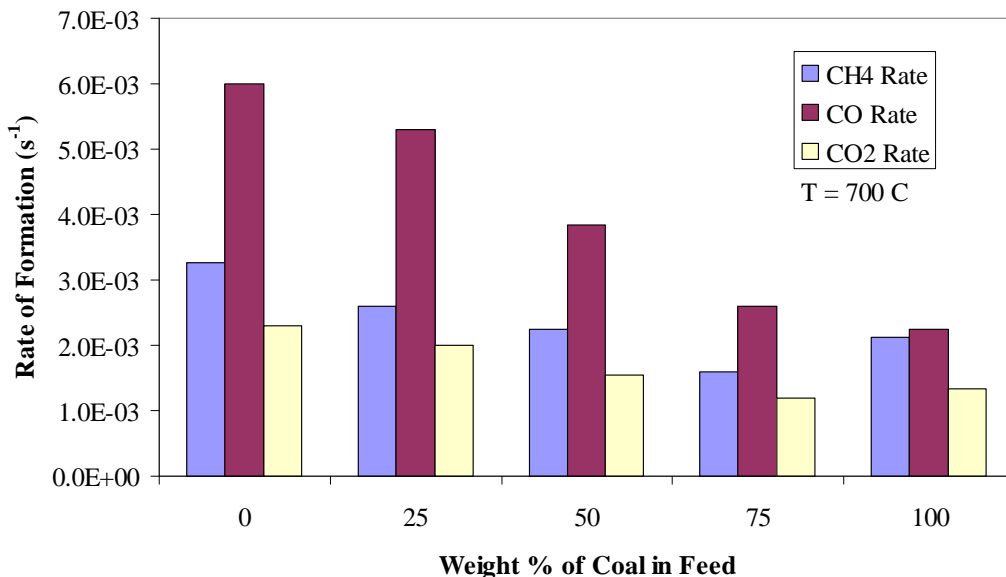


Figure 3 Rate of formation of the gasification products

From the experimental results, it can be seen that the commingling of biomass with coal may improve the gasification properties of the feedstock such as the carbon conversion. However, other issues related to biomass feedstocks such as feedstock harvest, handling and transportation, cost and availability, etc must be issued in order to advance to commercial gasifiers using a commingled feedstock. Currently, CE-CERT is performing experimental and simulation work to address key issues associated with biomass and commingled feedstocks.

4. References

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