Catalyst Loading and Dispersion Study for Catalytic Gasification of Lignite

David J. Marchand,1 Erik Schneider,1 Jinhong Kim,2 Gyu Tae Kim,2 Jae-wook Shin,2 Yong L. Joo,3 and Seong H. Kim.1 *

1 Department of Chemical Engineering, Pennsylvania State University, University Park, Pennsylvania
2 Green Coal Lab, SK Innovation Global Technology, Daejeon, Korea
3 School of Chemical and Biomolecular Engineering, Cornell University, Ithaca, New York

ABSTRACT

Rising oil prices and growing environmental concerns have led to renewed interest in the catalytic gasification of low rank coals such as lignite. Despite decades of research the structure and dispersion of the catalytic species under reaction conditions, and the effect of the changing structure of the coal on these, are still not fully understood. This talk will outline new insights about potassium carbonate catalyst in lignite that have been gained by the application of a suite of characterization techniques to this complex material. Surface and bulk elemental analyses give hints about the dispersion and migration of the catalyst, while these are given context through their effects on the pore structure through surface area measurements. Vibrational spectroscopy is employed to understand the chemistry of the catalyst and its interactions with the coal structure, and the oxygen functional groups in the coal are characterized and quantified to understand their interaction with the catalyst.

KEY WORDS: Lignite; gasification; catalyst; dispersion.

RESULTS AND DISCUSSION

K2CO3 was wet impregnated into lignite to make a series of samples with a range of K loading levels. Characterization data for this series of samples comes from a few techniques: Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS), an FT-IR technique for powder samples; X-ray Photoelectron Spectroscopy (XPS), which gives elemental information about the top ~10 nm of the sample; and Energy Dispersive X-ray spectroscopy (EDX), which also gives elemental information but probes the sample to a depth of about 3 µm.

Fig. 1 shows the concentration of K in the K2CO3 samples as detected by EDX (~3 µm information depth, open circles) and XPS (~10 nm information depth, solid squares). The x axis is the actual concentration of K, known from the mass balance, while the y axis is the detected concentration. The dot-dashed line with slope equal to 1 indicates perfect detection. The EDX data falls close to line, showing that it accurately detects the bulk concentration. The XPS data for low amounts of loading also follow this line very closely, indicating no preference for the catalyst to concentrate in the surface region. At catalyst loading above ~10 wt%, however, XPS detects a significantly higher concentration of catalyst in the surface region than in the bulk. This increase in surface concentration indicates that the coal is saturated with catalyst in the bulk; any additional catalyst beyond this point will deposit on the surface as precipitate from the impregnation solution.

INTRODUCTION

Coal gasification is an industrial process for producing synthesis gas (syngas, an industrially useful mixture of carbon monoxide and hydrogen) from coal. Gasification is especially suitable for use with low-rank coals, for which the low energy density and high impurity content makes traditional coal-fired power plants economically and environmentally unattractive (Bell, Towler, Fan, 2011). To avoid the need for very high reaction temperatures, catalysts are used to increase the reaction rate; K2CO3 is used as the industrial catalyst of choice because it is highly active yet inexpensive. However, many questions remained about the form and dispersion of the catalyst, the reaction mechanism, and how these properties are affected by the coal structure (Starsinic, Otake, Walker, Painter, 1984; Chen and Yang, 1993).

This talk will outline how the application of a suite of bulk and surface analysis techniques could provide a better understanding of the catalyst behavior in the coal and how it relates to the coal structure, both initially and during the changes due to the pyrolysis and gasification conditions. This knowledge could allow for the design of better catalysts and loading methods to produce higher activity, which allows either less catalyst to be used or for the gasifier to run at a milder temperature, ultimately reducing operating or capital costs.

Fig. 1 Elemental concentration of K-loaded lignite: amount detected via