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Conversion of Louisiana Sugar Factories Excess Bagasse into Synthesis Gas—A Visionary Research Project

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As we entered the 21st century, the US sugar industry found itself at a cross road facing many difficult challenges: diminishing resources (fuel, water, etc.), environmental pressure, health and safety issues, regulatory compliance, nutritional values of refined sugar under attack, and global competition (WTO). To survive and prosper in this new millennium, the industry must make significant changes to remain profitable including a) reevaluating and improving conventional practices including organization/management b) simplifying manufacturing processes, c) integrating cane mill and refinery operation to produce refined sugar directly from sugar mills, d) capitalizing on the best available technologies, and e) developing value-added products to maximize profits. The work presents a novel concept for converting carbon dioxide and bagasse into hydrogen-rich synthesis gas at a sugar mill. No commercial technology currently offers the utilization of both carbon dioxide and biomass waste to produce synthesis gas.

In the United States, CO_2 accounts for 82% of the total greenhouse gases (GHG) emission.[1] To improve the rate of progress on reducing GHG emissions, additional CO_2 utilization technologies must be developed and commercialized. Currently, most CO_2 storage solutions are geographically specific (i.e., near shales, aquifers or saline formations). Therefore, a need for novel methods of producing value-added products from CO_2 will be addressed by the proposed work. Waste biomass, such as bagasse, may provide a solution to this problem. The process consists of three main steps in order to convert the two waste products into synthesis gas; (1) bagasse dryer, (2) microwave gasification unit and (3) water-gas shift reactor. In biofuel production processes, synthesis gas production is estimated to account for 50-75% of the production cost.[2] The production of synthesis gas also preserves the opportunity to generate other bio-products or direct-use as a clean gaseous fuel.

It is well known that carbonaceous materials can be reacted with CO_2 to produce carbon monoxide via the Boudouard reaction ($C + CO_2 \rightarrow 2CO$) at temperatures of 700 ºC leaving an ash residue.[3] Experiments have demonstrated that the reaction between solid carbonaceous materials and carbon dioxide can occur at 213 °C when heated by microwave irradiation.[4] This finding provides significant energy savings in the thermal conversion of the two undesired reactants. In addition, microwave heating is volumetric and is tolerable of moisture (in comparison to conventional thermal heating).

As stated in the process concept, the carbon monoxide effluent from the Boudouard reaction can be co-reacted with water, recovered from drying the bagasse, through the water-gas shift reaction ($CO + H_2O \leftrightarrow H_2 + CO_2$) over a Fe-Cr based catalyst at 500 ^oC. The Fe-Cr based WGSR system heated by microwaves has already been experimentally proven.[5] The synthesis gas can be concentrated by removing water from the product stream. The hydrogen-rich synthesis gas can be used as fuel or to make value-added bio-products or liquid biofuel.

Phenomenological experimental results have been obtained on microwave pyrolysis and oxidation of fresh (2016) and biodegraded Louisiana bagasse. Fresh bagasse oxidizes more readily due to tar production during microwave heating. The addition of activated carbon to biodegraded bagasse increase the maximum temperature reached during microwave heating. Future research objectives will include;

1. Determining the gas species production profile from the microwave-induced Boudouard reaction on bagasse,
2. Determine the effect of moisture in the bagasse on conversion by the microwave-induced Boudouard reaction;
3. Investigating the microwave-induced catalytic WGSR and catalyst performance;
4. determining the optimal hydrogen and carbon monoxide mole fractions achieved from the combined microwave-induced Boudouard reaction and WGSR steps.

The microwave-assisted pyrolysis and catalytic water-gas shift process will be unified in a single reactor design in order to operate at low temperature for higher energy efficiency. The proposed process is an on-site or transportable modular process to be used at sugar mills. Pilot scale tests on a 3 TPD bubbling fluidized bed reactor will be carried out at the University of Louisiana Energy Institute as a proof of concept. The investigation will provide a guide for the process design, carbon dioxide life-cycle analysis and economic evaluation of the technology.

[1] U.S. Greenhouse Gas Inventory Report: 1990-2014. EPA. Environmental Protection Agency, 19 Dec. 2016. Web. 31 Dec. 2016.

[2] P.L. Spath, D.C. Dayton, Preliminary Screening - Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas, NREL. (2003).

[3] S. Ergun, Kinetics of the reaction of carbon with carbon dioxide. The Journal of Physical Chemistry, 1956, 60 (4), 480-485.

[4] J. Hunt, A. Ferrari, A. Lita, M. Crosswhite, B. Ashley, A.E. Stiegman Microwave-specific enhancement of the carbon-carbon dioxide (Boudouard) reaction. The Journal of Physical Chemistry C, 2013, 117 (51), 26871-26880.

[5] W.-H. Chen, J.-G. Jheng, A.B. Yu, Hydrogen generation from a catalytic water gas shift reaction under microwave irradiation. International Journal of Hydrogen Energy, 2008, 33, 4789-4797.