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Coal Electrolysis for the Production of Hydrogen and Liquid Fuels

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Clean technologies for the production of high value chemicals, such as hydrogen, liquid fuels, and refined organic and inorganic compounds, with significant impact in the different business spheres (e.g., petrochemical, polymers, and plastics) are very important for national security purposes and for preservation of the environment. Power is traditionally generated from coal by the complete combustion (oxidation) of coal. When hydrogen is desired as a product, coal gasification (partial oxidation) is employed. Most overall coal gasification schemes use a series of reactions ranging from combustion (for heat generation) to partial oxidation (for hydrogen generation), to the water-gas shift reaction and others to produce a fuel gas product stream. In order to produce a hydrogen (H_2) product from this fuel gas stream, the hydrogen must be removed from a mixture that includes carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulfide (H_2S), particulates, and other gases (perhaps including nitrogen, if an oxygen plant is not used). In addition, CO_2 needs to be captured and sequestered from the stream to reduce the emissions of this gas to the environment. These separations become an extremely complex and costly consideration. In order for CO_2 to be captured, it either must be separated from other gases in a mixture (say, CO_2 from N_2), or O_2 must be separated from air in order to be used as combustion feed to create "pure" CO_2 product. In either case, significant capital and operating expenses, as well as significant power consumption, are incurred for either kind of separation.

On the other hand, when the goal is to obtain liquid fuels from coal there are two technologies that are currently under discussion: indirect coal liquefaction (ICL, coal gasification followed by Fischer-Tropsch synthesis) and direct coal liquefaction (DCL). Both indirect and direct liquefaction technologies require high temperatures and pressures (1200 – 1450 ^{o}C, 60 –

80 atm for coal gasification; 200-350 ^{o}C, 20 – 30 atm for Fischer-Tropsch synthesis; 440 – 470 ^{o}C, 100 – 200 atm for direct liquefaction) and do not allow the utilization of renewable energy sources, such as wind and or solar power. Both ICL and DCL require significant energy and consume large amounts of water. Furthermore, in DCL systems hydrogen is required to crack the coal into syncrude, which is, perhaps, the most costly part of the DCL process.

Ohio University (OHIO) has developed a new technology (apparatus, catalyst, and method) that allows the direct conversion of coal into pure hydrogen and other high value chemicals, such as liquid fuels, and other organic materials with significant commercial potential. The technology is called the "Continuous Coal Electrolytic Cell (CEC)." In the CEC, a small amount of electric power is applied to a coal-slurry to directly convert the coal into pure clean hydrogen, liquid fuels, and organic compounds, with minimum CO_2 emissions. All this takes place at low temperatures (25-180 ^{o}C) and pressures (1-2 atm). During the CEC process, pure hydrogen is obtained while the surface of the coal particles (electrolyzed coal char) gets oxidized into lower molecular weight hydrocarbons than coal. The electrolyzed coal char is submitted to extraction with yields in excess of 20% of the dry weight coal, in order to remove the liquid fuels or/and valuable chemicals.

The CEC has the potential to outperform coal gasification, Fischer-Tropsch synthesis, and direct coal gasification because: 1. It does not require high temperatures and pressures; 2. The hydrogen generated is completely clean and inexpensive (under $3 per kg); 3. The solid product left after the electrolysis, "char", possess superior properties to that produced as a byproduct of traditional gasification (possible sulfur removal); 4. An oxygen plant is not required to generate high heating value gas (since air is not used as an oxygen source, there will be no N_2 in the off gas); 5. Gas clean up does not require particulate control; 6. Electrolysis is an environmental friendly process for the generation of hydrogen (particularly if solar energy is used); 7. There may be a significant cost reduction for preventing the emissions of CO_2 to the environment since it will be generated as a nearly pure stream (CO_2 separation is not needed); and 8. Liquid fuels and organic compounds with significant commercial value are easily extracted from the electrolyzed coal.

In order to establish the optimal parameters affecting the production of hydrogen via coal electrolysis a statistical analysis was performed. It was found that the additive addition, the temperature as well as the applied current are the most influential factors for this specific system.

With the establishment of the main parameters influencing hydrogen production, the possibility of scale up of the system seems more plausible. In addition, it was possible to perform electrolysis-extraction cycles reusing electrolyzed coal chars as well as the electrolyte. This study opens an opportunity for planning clean ways to use the coal to produce fuels, in either gas or liquid form. *The developed technology (CEC) could be very important for the coal economy.* The demonstration of electrolyzing coal for the production of hydrogen brings a potential new market for coal for fuel cell applications, e.g., it has been pointed out that in the near future about 20 to 90 million tons per year of hydrogen will be needed. This does not include the market for the production of liquid fuels and organic compounds with significant commercial value.