Catalyst design for two reactions: turning carbon dioxide and biomass into renewable fuel

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Introduction

This project had two goals:

1. To design a carbon dioxide adsorbent material that could be used to convert carbon dioxide into renewable fuel (methane derived from CO2)
2. To characterize and test catalysts designed to convert an invasive plant species, phragmites, into biofuel.

Thus, the project was split into two parts, both focusing on converting "waste" materials into fuels by using catalysts (and thus reducing the conversion energy)

Materials Synthesis

Carbon Dioxide Project Catalyst Design:

- Catalyst name: calcium oxide on aluminum oxide
- Impregnated 1.44M solution of calcium nitrate on aluminum oxide
- Sample was dried in air for one hour at 110˚C
- Sample was calcined in air for one hour at 800˚C

Biofuel Project Catalyst Design:

- Catalyst name: copper oxide on mole sieve
- Impregnated solution of copper oxide on aluminum oxide
- Sample was dried in air for one hour at 110˚C
- Sample was calcined in air for two hours at 600˚C

- Catalyst name: copper:iron:zinc (81:6:13) on mole sieve
- Impregnated solution of copper nitrate on aluminum oxide
- Then impregnated solution of ferric nitrate on copper on aluminum oxide
- Then impregnated solution of zinc chloride on copper:iron on aluminum oxide
- Sample was dried in air for one hour at 110˚C
- Sample was calcined in air for two hours at 600˚C

Materials Testing

The main instrument which will be used is known as the Thermogravimmetric Analysis and Differential Scanning Calorimetry (TGA/DSC). This instrument is one of the most efficient and accurate way to conduct a thermal analysis of a certain material. The scale inside this instrument is extremely sensitive that it can recognized a weight change of 0.0001 mg. Therefore, it can measure the physical and chemical properties of a material as a function of temperature and/or time.

Figure 1: Thermogravimmetric Analysis / Differential Scanning Calorimetry

Results

Carbon Dioxide Project Results

The following graphs show the structure of the catalyst and the adsorption of CO_2

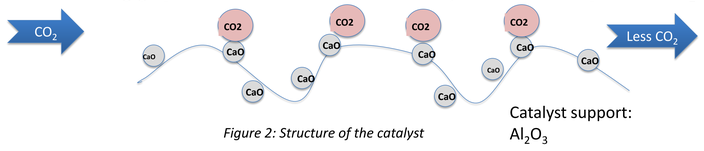

Figure 2: Structure of the catalyst

Catalyst support: Al_2O_3

After the catalyst was dried and calcined, a pre-reduction step was necessary to get rid of most of the non-metals. Once the pre-reduction was completed, the CO_2 adsorption test was conducted in the TGA/DSC. The temperature at which the adsorption started was 350˚C.

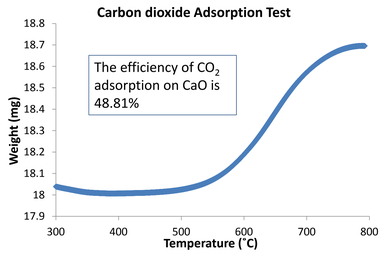

Figure 3: Carbon Dioxide Adsorption Test

Biofuel Project Results:

The following graphs represent the calcination curves for pure copper catalyst, copper:iron:zinc catalyst, and mole sieve. And the adsorption energy of hydrogen on the two catalysts.

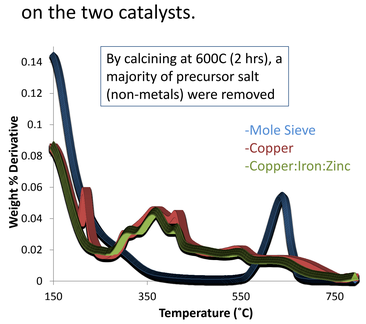

Figure 4: Dry & Calcination of Cu, Alloy catalyst and MoleSieve

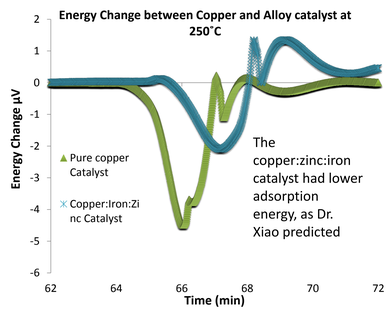

Figure 5: Adsorption Energy of Cu and Alloy Catalyst

Collaborator Dr. Dequan Xiao used computational chemistry methods to calculate that copper:zinc:iron would be a better catalyst to turn biomass into fuel instead of copper catalyst, based on a lower hydrogen adsorption/desorption energy. We sought to verify this experimentally. The hydrogen adsorption in figure 5 was performed at 250˚C. Using integration, the area under the curve was calculated to determine the total adsorption energy for both of the catalysts. The total adsorption energy for copper catalyst was -239.22 µV and the total adsorption energy for the copper:iron:zinc catalyst was -129.69 µV. Thus, proving that Dr. Dequan Xiao's theory was correct

Conclusion

Carbon Dioxide Project:

There were three lessons learned from this project. Firstly, the temperature at which carbon dioxide adsorption began was 350˚C. Secondly, the efficiency of carbon dioxide adsorption on calcium oxide was 48.8%. Finally, a pre-reduction step was necessary before the carbon dioxide adsorption to start the adsorption at a lower temperature with more efficiency.

Biofuel Project:

This project successfully demonstrated that we could measure hydrogen adsorption energy for catalysts using Differential Scanning Calorimetry at the conditions desired. Not only was the method successful, but our results confirmed the theoretical calculations done for these catalyst preformed by Dr. Dequan Xiao. Therefore, the adsorption energy of the copper:zinc:iron catalyst had a lower adsorption energy as predicted.

Further Studies

- Reproduce data with newly improved test setup to minimize background noise
- Analyze materials using the x-ray diffraction instrument to determine particle sizes of the supported material
- Design new catalysts and measure hydrogen adsorption energy
  - Cu:Zn = 60:40
  - Cu:Zn = 80:20
  - Cu:Fe:Zn = 60:20:20
  - Cu:Fe:Zn = 40:20:40

References

- Duyar, Melis S., Martha A. Arellano Treviño, and Robert J. Farrauto. "Dual Function Materials for CO2 Capture and Conversion Using Renewable H2." *Applied Catalysis B: Environmental* 168-169 (2015): 370-76. Web. <http://www.sciencedirect.com/science/article/pii/S0926337314007991>.

- Janke, C., M.s. Duyar, M. Hoskins, and R. Farrauto. "Catalytic and Adsorption Studies for the Hydrogenation of CO2 to Methane." Applied Catalysis B: Environmental 152-153 (2014): 184-91. Web. <http://www.sciencedirect.com/science/article/pii/S0926337314000228>.

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