Bosch Reactor Catalysts

Author: Matthew Duchek PI: Dr. Morgan B. Abney School: University of Illinois at Urbana-Champaign MSFC Org: ES22

The Bosch Reactor

•Current air revitalization systems on the International Space Station remove CO_2 from the air and vent it overboard. This means that valuable oxygen molecules are continuously lost and the station must be resupplied with oxygen for the crew to breathe.

•The Bosch reactor is one option NASA is considering to "close the loop" in the air revitalization system

•The Bosch reaction, $CO_2+2H_2 \rightarrow 2H_2O+C$, uses hydrogen to reduce the CO_2 from the air and produces water, from which all of the oxygen and hydrogen can be recovered. This means that nothing is vented overboard and the spacecraft does not need to be resupplied with oxygen!

Potential Bosch catalysts

Why Research Catalysts?

•Previous Bosch reactors have used steel wool as the catalyst for the Bosch reaction.

•During the reaction, carbon deposits on the catalyst, which eventually slows and then stops the reaction.

•Using steel wool, the catalyst cartridge would have to be replaced every few days to ensure that the CO_2 is continually processed. This presents the problem of having to resupply a spacecraft with catalyst.

•There is no way to recover used steel wool catalyst so that it could be used again. However, other catalysts such as nickel and cobalt have the potential to be recovered after carbon has deposited on them. This would eliminate the need to resupply catalyst.

•With steel wool catalyst, the reactor must reach temperatures near 650°C to efficiently remove carbon. Other catalysts, such as nickel and cobalt, have the potential to operate at lower temperatures, thus reducing the power required by the reactor.

Objective

To investigate the rate of carbon deposition on nickel wool, nickel foam, and steel wool catalysts

The Bosch Reaction

$CO_2+2H_2 \rightarrow 2H_2O+C$,

The Bosch reaction is actually composed of three simpler reactions.

Reverse Water-Gas Shift

$CO_2 + H_2 \rightarrow CO + H_2O$

Boudouard Reaction

$2CO \rightarrow C + CO_2$

Hydrogenation Reaction

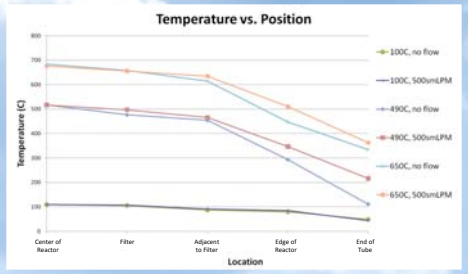
$H_2 + CO \rightarrow C + H_2O$

B-CaTS

The Bosch Catalyst Test Stand is designed as a singles pass version of a Bosch reactor. It can be used to test different catalysts at various temperatures, pressures, and concentrations of the reactant gases.

B-CaTS Temperature Study

To ensure that the reactants were reaching the expected temperatures and to characterize the behavior of the B-CaTS system, a temperature profile of the reactor was determined experimentally.



Results of Temperature Study

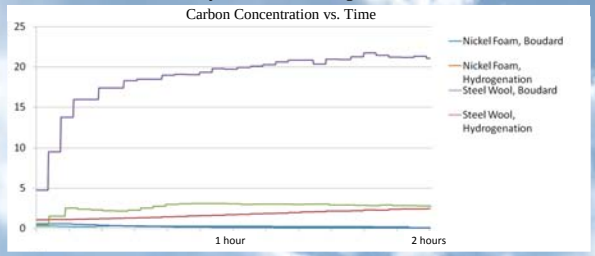
•The catalyst reached the expected temperature at the center of the reactor

•The temperature quickly dropped as a function of distance from the center of the reactor

•Introducing gas flow into the system increased the temperature away from the center of the reactor.

Catalyst Testing Methods

Catalyst research was conducted by flowing pure CO (Boudouard Reaction) and a mixture of 50% CO and 50% H_2 (Hydrogenation Reaction) over steel wool, nickel wool, and nickel foam catalysts at 500°C with no pretreatment of the materials. The amount of carbon production was determined by measuring the mass of carbon deposited after the test was completed. The amount of CO_2 being produced was also measured by a gas chromatographer (GC) during the tests. This data is presented in the table below. However, because the concentrations measured for three of the tests are so small, this data may be within the margin of error of the GC.



Catalyst Testing Results

Mass of carbon deposited in 2 hours

Material	Carbon Formed in Boudouard Reaction	Carbon Formed in Hydrogenation Reaction
Steel Wool	0.3791 g	2.572 g
Nickel Wool	none	none
Nickel Foam	0.040 g	0.4975 g

Rate of carbon deposition (g Carbon/(g Catalyst * min))

Material	Boudouard Reaction Rate	Hydrogenation Reaction Rate
Steel Wool	2.04E-04	1.33E-3
Nickel Wool	0	0
Nickel Foam	1.48E-05	1.51E-04

Nickel foam before and after test

Steel wool before and after reaction

Conclusions

Steel wool begins to form carbon faster than nickel catalysts at the temperature and pressure of the tests and without any pretreatment.

More carbon deposits on non-pretreated steel wool than on non-pretreated nickel catalysts when at 500°C and 16psi for two hours.

Nickel has the potential to be recovered and used again as a catalyst, steel wool does not.

More research is needed to determine the optimal temperature, flow rate, and relative concentration of the reactants for nickel catalysis.

References

Holmes, R. F., E. E. Keller and C. D. King. A Carbon Dioxide Reduction Unit Using Bosch Reaction and Expendable Cartridges. General Dynamics Corporation. 1970.