A Low-Pressure Reactor Design for Solar Thermochemical Ammonia Production

Xiang Gao[1], Ivan Ermanoski[2], Andrea Ambrosini[3], Alberto de la Calle[1] and Ellen B. Stechel[4]

[1] ASU LightWorks®, Arizona State University, PO Box 875402, Tempe, AZ 85287-5402, USA
[2] ASU LightWorks® and the School of Sustainability, Arizona State University, PO Box 875402, Tempe, AZ 85287-5402, USA
[3] Sandia National Laboratories, PO Box 5800, MS 0734, Albuquerque, NM 87185, USA
[4] ASU LightWorks® and the School of Molecular Sciences, Arizona State University, PO Box 875402, Tempe, AZ 85287-5402, USA

Background

Ammonia (NH_3) is one of the most commonly produced industrial chemicals worldwide. Fertilizer for agriculture accounts for about 80% of NH_3 production. Furthermore, NH_3 is in consideration as a hydrogen carrier or as an energy vector in a deeply decarbonized energy system.

What are the drawbacks of the current Haber-Bosch (H-B) process?

- An energy-demanding conversion from H_2 and N_2 at 150-250 bar;
- The major source of H_2 and N_2, by reforming and combusting hydrocarbons, is highly carbon-intensive;
- The energy to provide process heat and pressure for NH_3 production also requires combustion of methane.

There is a strong incentive to develop a sustainable NH_3 synthesis pathway. For example, using concentrating solar irradiation for process heat and pursuing relatively low-pressure operating conditions will significantly help mitigate greenhouse gas emissions and enable flexible operations at a smaller scale than H-B.

Method

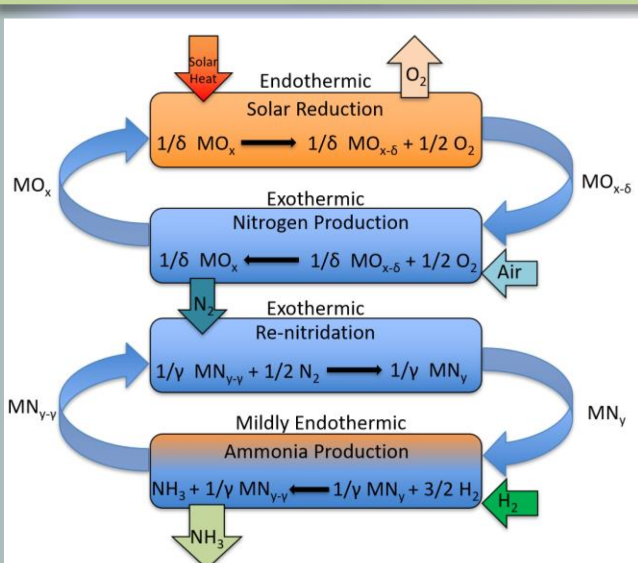

Figure 1: A solar thermochemical looping technology to produce and store N_2 from air for the subsequent production of NH_3 via an advanced two-state process.

What is the proposed NH_3 production method?

- Concentrated solar irradiation first drives the reduction of redox-active metal oxide particles; metal oxides are then re-oxidized by air, resulting in nearly O_2-free N_2 gas; H_2 can be produced from a net carbon-neutral process;
- H_2 reacts with a metal nitride to produce NH_3 and a nitrogen deficient nitride;
- The nitrogen deficient nitride reacts with sustainable N_2 to regenerate the initial nitride.

The target pressure for the NH_3 synthesis looping cycle is an order of magnitude lower than the H-B process.

Design Philosophy and Results

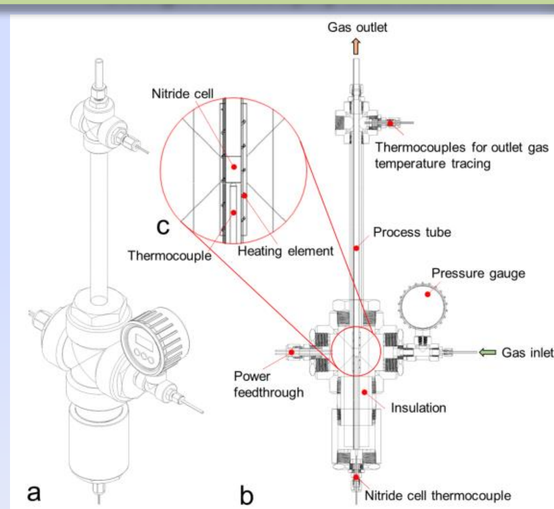

Figure 2: Illustration of the NH_3 synthesis reactor (ASR). (a) Isometric view. (b) Front cut-plane view with major components labeled. (c) Heated reaction zone.

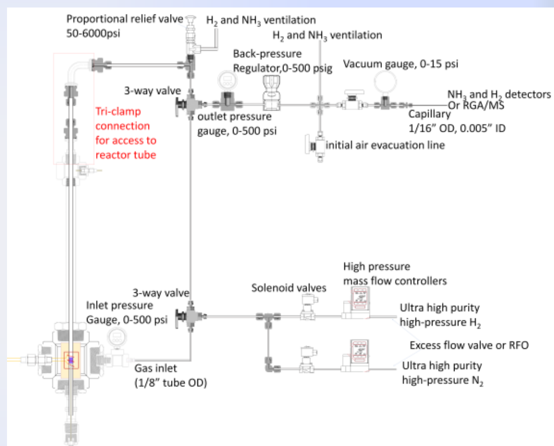

Figure 3: The process and instrumentation design for the ASR system.

Design of the benchtop NH_3 synthesis test reactor:

- NH_3 synthesis and re-nitridation reactions are achieved in one reactor cyclically by switching between pressurized (up to 30 bar) H_2 and N_2 inlet gas flows;
- The design purposely maximizes the utilization of commercial off-the-shelf components;
- Unnecessary dead volume in the pressurized zone is significantly minimized;
- The reactor volume (< 2L) captures the design features of a scaled-up unit to simulate heat transfer and material reactivity losses during cyclic operations.

The ASR enables cool inlet H_2/N_2 gases that fill an annulus between the "hot-wall" process tube and the "cold-wall" pressure vessel, to decouple the compound risk of high pressure and high temperature.

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