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Ammonia Transformation and Utilization

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AMMONIA – A sustainable, emission-free fuel
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Space Research Institute

INTRAMICRON

Center for Microfibrous Materials Manufacturing


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Why Ammonia for Energy?

- Ammonia has many desirable features:
  - Storable with high hydrogen content (17.6%)
  - Safely transportable
- Ammonia can be synthesized from water and air
  - You don’t need fossil fuels or carbon sources
  - Eliminates greenhouse gases (CO_2, CH_4, etc.)
- NH_3 can be burned directly
  - Stirling, diesel or IC engines
- NH_3 can be reformed into H_2
  - Source of fuel for Stirling or IC engine or fuel cells
  - But NH_3 poisons PEM FCs

Background

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- As part of the effort to examine the benefits of ammonia for terrestrial applications, our first step was to:
  - » Develop processes for catalytic reformation of NH_3
  - » Utilize microfibrous materials to encapsulate reforming catalyst
- After demonstrating reformation of NH_3
  - » Studies were conducted on the stability and feasibility of burning NH_3 and burning NH_3 with synthetic reformate
  - » Given success at that point, demonstrate an NH_3 catalytic burner
- As part of the process
  - » Operate a free-piston Stirling engine (FPSE) on hydrogen reformed from ammonia (run on H_2, not on reformed NH_3 yet)

Microfibrous Materials Introduction
Benefits and Attributes

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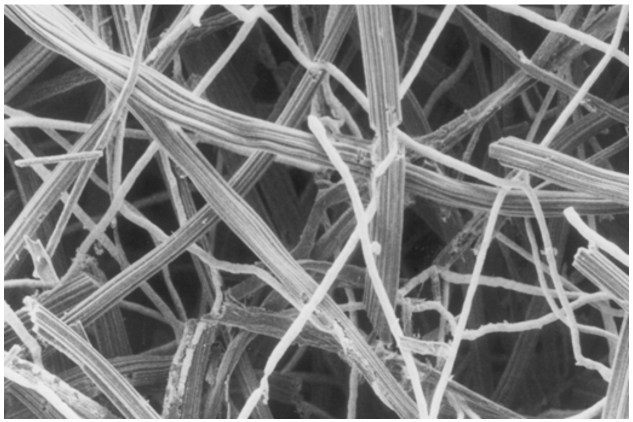
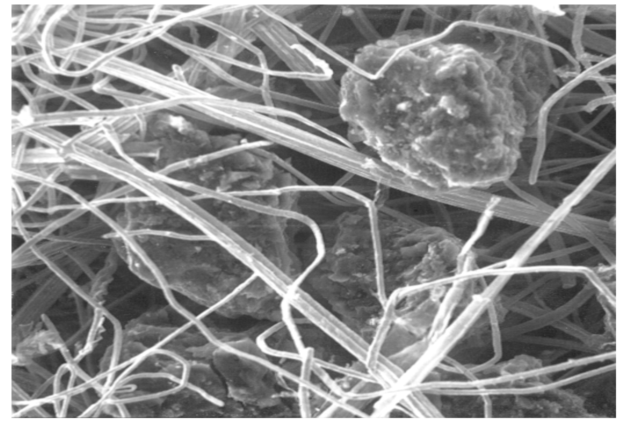


Activated Carbon Fiber and 2μm Stainless Steel



55-85 μm sorbent entrapped in 2,4,8 μm Ni fibers

- **Definition:** Microfibrous Materials provide for the mechanical and electrical entrapment of a particle or fibrous solid within sinter-locked networks of a secondary fibrous matrix
- **Attributes:** The volume loading of each phase is relatively independent of the other phase, and adjustable over a wide range compared to current SOA materials and practices

What's Unique About Microfibrous Materials?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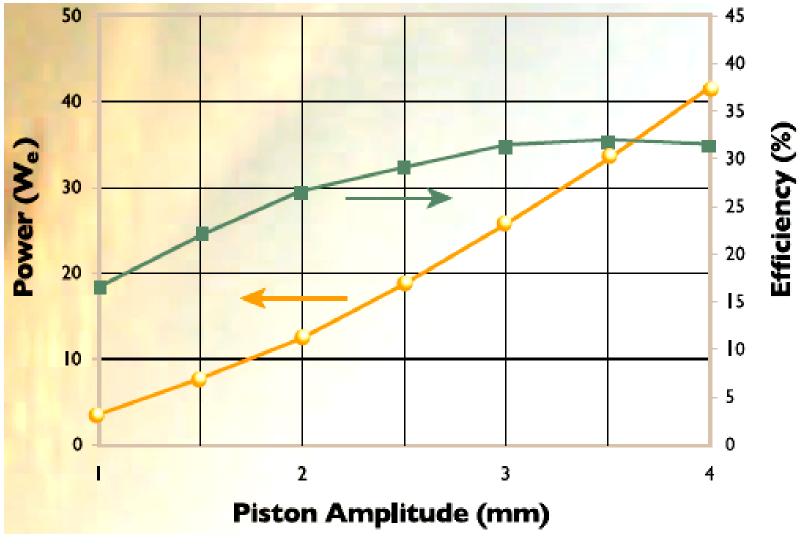
- Based on a simple, paper-making process
  - Reel-to-reel fabrication demonstrated
- Multiple materials/material combinations
  - Metals, polymers, ceramics
  - e.g. Ni, stainless steels, Ti, Hastelloy, Nicrome, FeCrAl, Cu…
- Fiber size, length options
  - Size: 1-50 µm; tow or chopped (1mm – 25 mm)
- Can include catalysts, sorbents, etc.
- Able to <u>independently control</u> properties
- Tailored 3-D structures possible

Why Free-Piston Stirling Engines?

- They require an external source of heat and can operate over a wide input temperature ranges
  - Propane, butane, gasoline, diesel, H_2, NH_3…
  - Solar, geothermal, nuclear…
- They are being used on earth and in space applications
  - Low maintenance and quiet
  - 80W convertor lifetimes over 25,000 hrs demonstrated
  - Low or no vibration when used in dual-opposed operation



Why Free-Piston Stirling Engines?

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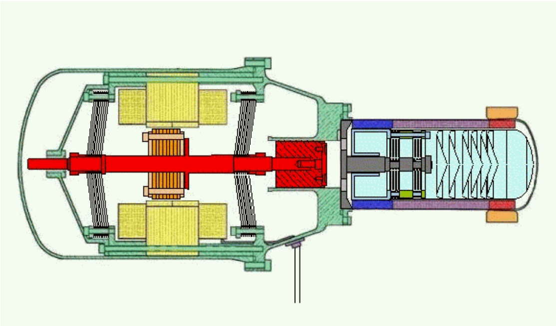
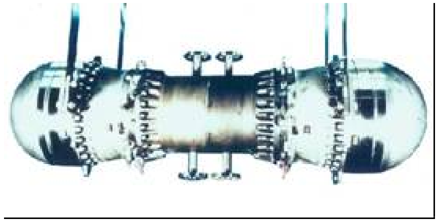
- High efficiency
  - » ~37%, depending on Th/Tc
  - » >90% alternator efficiency
- High specific mass (~100W/kg)
  - » Only two moving parts that make no contact
- Many sizes demonstrated
  - » 25 kW (1992)
  - » 35 W, 80 W, 1.2 kW
  - » New NASA 5 kW





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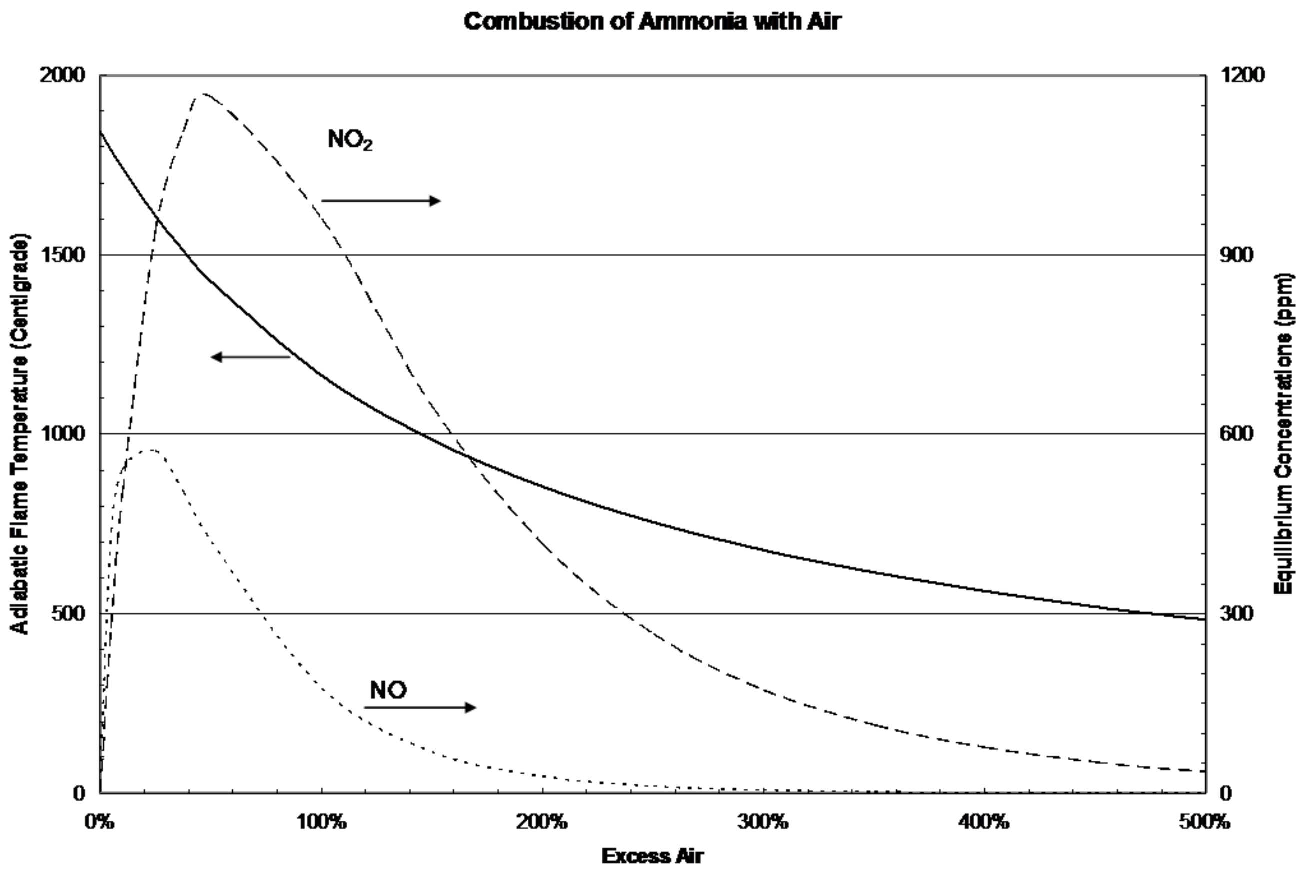
Why Ammonia-Fueled Free-Piston Stirling Engines ?

- Ammonia, containing 17.6% hydrogen by mass, could be used with high efficiency and reduced pollution
  - It is easily stored and transported safely
  - Flammability limits of NH_3 (Vol % in air) only between 15.5% and 27%
- Optimized NH_3 reforming catalysts and the means for entrapping them in a matrix exist
  - Relatively easy to reform NH_3 to H_2
    - Is full reformation the best choice?
    - Of course H_2/O_2 combustion produces a clean flame and only water
  - We have demonstrated catalytic combustors for NH_3
    - Including some percentage of H_2 in an NH_3 stream stabilizes the combustor
- We'll use partial NH_3 decomposition to show feasibility of producing temperatures that could be used by a free-piston Stirling engine

Ammonia-Air Combustion Products



Schematic Diagram of Test Set Up

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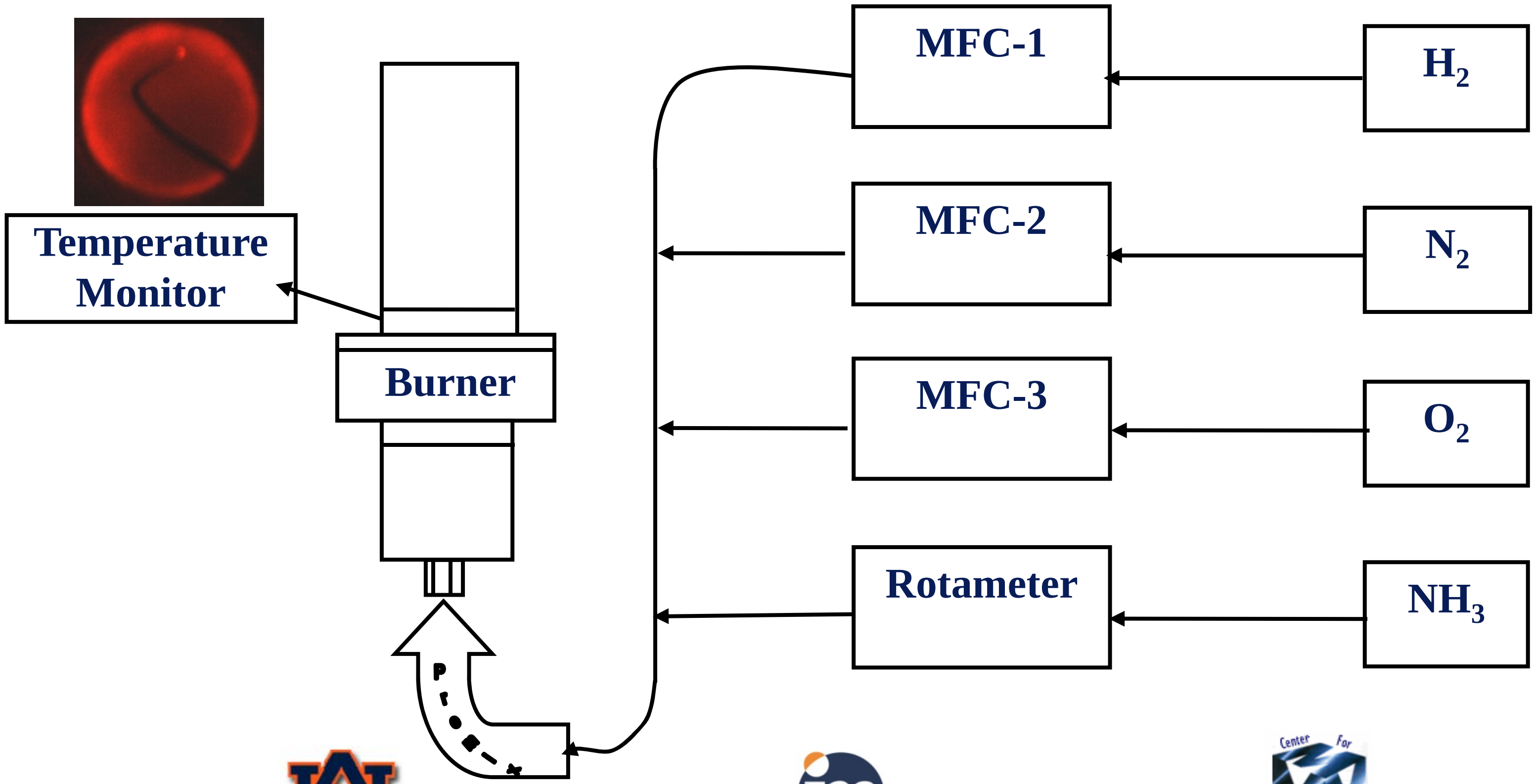
- Preliminary burner tests were done by implementing a synthesized hydrogen reforming from NH_3



Burner Tests 1: NH_3 and Air Only

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- Cold apparatus
  - Difficult to ignite
  - NH_3 combustion short-lived

- Hot apparatus
  - NH_3 combustion ignites
  - Extinguished when air flow is stopped
  - Temperature: 740 ºC

NH_3 Decomposition Catalyst Bed

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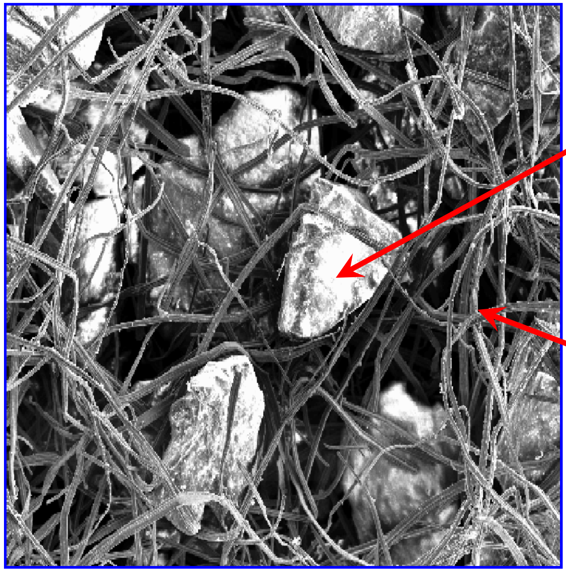
- Preparation of catalyst bed
  - Wet laid material
    - Cellulose, 4 & 8 μm Ni fibers and 150-250 micron alumina powder (1:1:3.8)
    - Two layers placed on a 120 mesh SS screen and sintered in H_2 at 1000°C
  - 8% chloroplatinic acid used for a loading of 10.8 wt % Pt on the alumina
  - Dried at 110°C and then calcined in air at 400°C



Alumina support particle (150-250μm)

4 & 8μm Ni fiber

Ammonia Conversion

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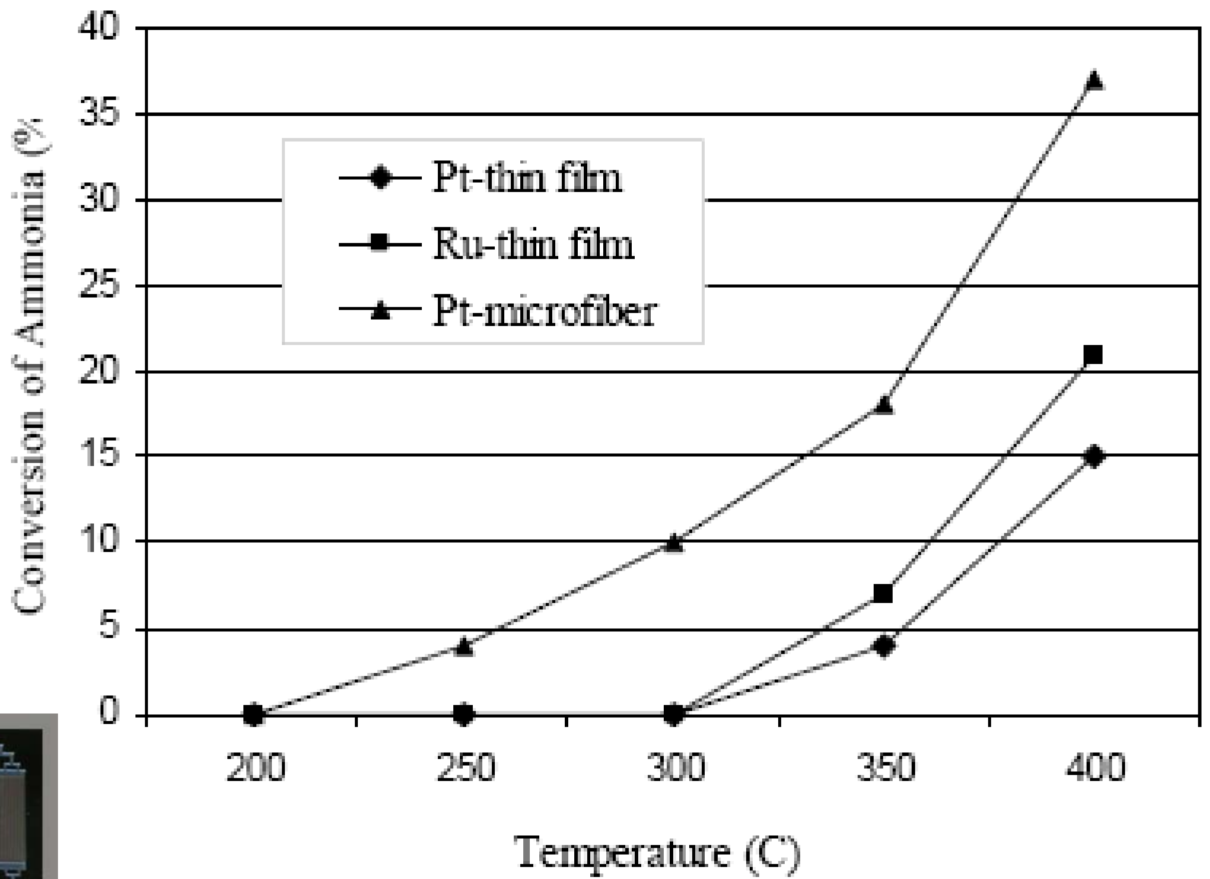
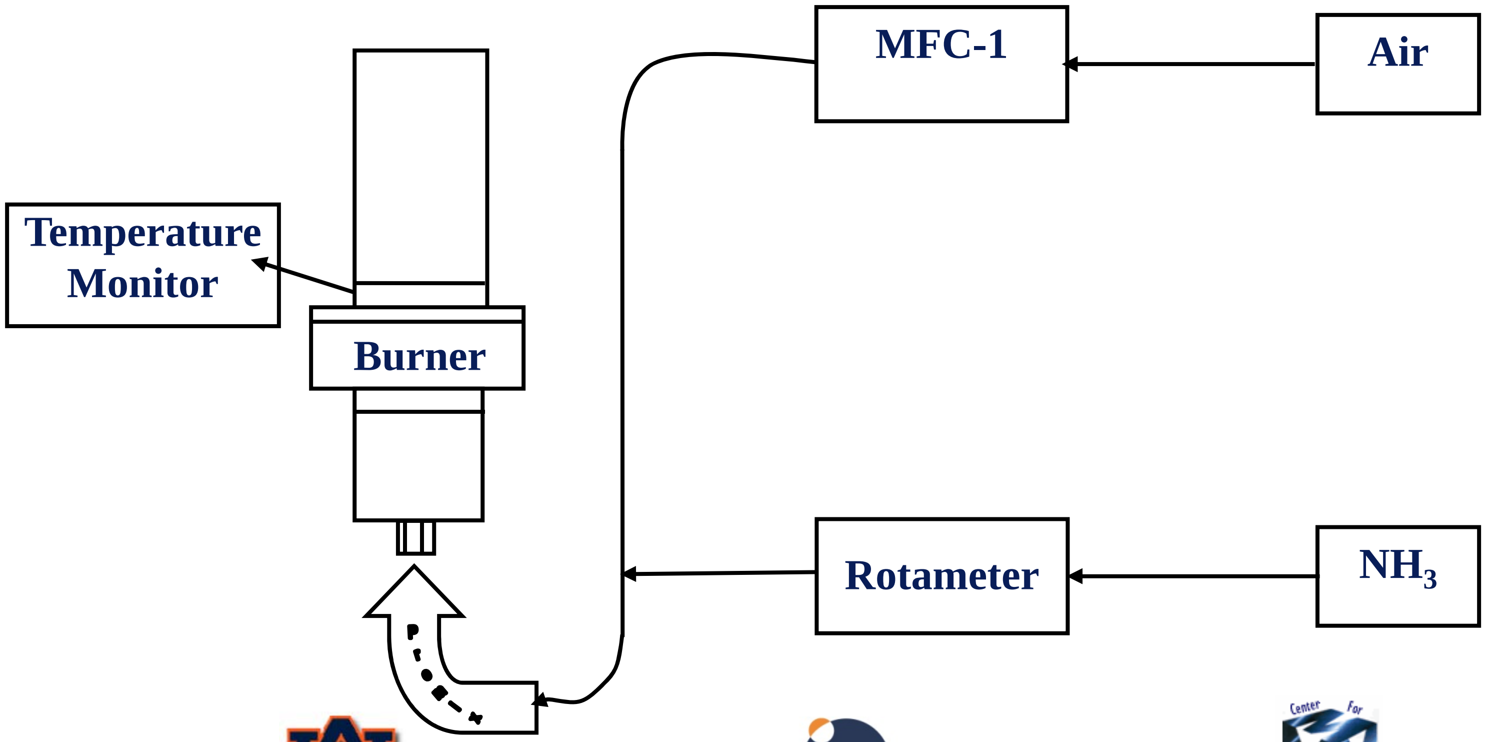


Ammonia-Air Catalytic Burner

- A disc of microfibrous porous media was used to decompose NH_3 into H_2 and N_2



Burner Tests 3: Catalyzed Bed

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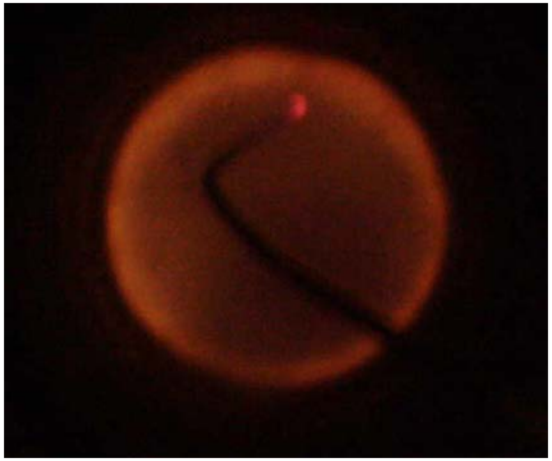
- NH_3 plus air thru catalyzed bed, hot apparatus
  - Flame confined to media
  - Temperature: 750 ºC

- NH_3 plus air thru catalyzed bed, hot apparatus
  - Flame goes into media
  - Temperature: 765 ºC

Burner Tests 3a: Catalyst Compared to Synthetic Reformate

- Synthesized reformate of NH_3 , air and H_2
  - Ni media
  - Stable flame
  - Temperature: 990ºC



- NH_3 plus air thru catalyzed bed with 4.5 µm media
  - Stable combustion
  - Temperature: 940ºC

Burner Tests 4: Catalyzed Bed

- NH_3 plus air thru catalyzed bed, 4.5 µm Ni media to prevent flame front going into media
  - » Stable burning
  - » Temperature: 940 °C

- NH_3 plus air thru catalyzed bed, 4.5 µm Ni media to prevent flame front going into media
  - » Stable burning
  - » Temperature: 940 °C
  - » Temper probe shown

Summary and Conclusions

- Favorable conditions for flame stability of combustion of hydrogen reformed from ammonia through a catalyst-impregnated microfibrous porous media were obtained
  - Stable catalytic combustion demonstrated
  - Temperatures of 940ºC were obtained
- Feasibility of ignition and combustion of ammonia depends on:
  - Temperature of the catalyst bed
  - Porosity and pore size of microfibrous media
  - Flow rates of NH_3 and air
- The microfibrous media can be shaped to conform to the head of a Free-Piston Stirling Engine
  - Multilayer media that controls NOx emissions can also be produced

Thanks for Your Attention

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"Ammonia! Ammonia!"