Oxy-Fuel for Indiana

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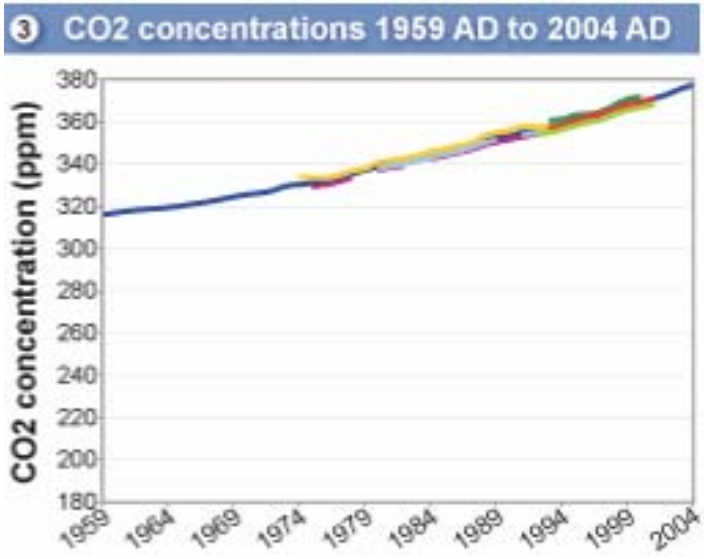
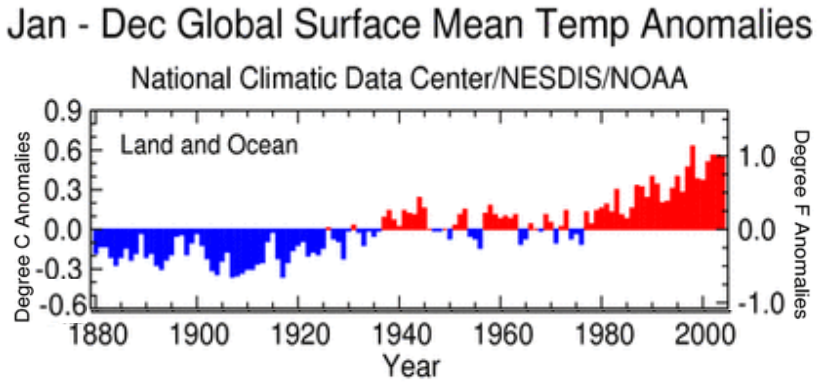
Background

- Environmental Concerns
  - Global warming
    - 1°F average increase over 20 years
    - Current rate is 0.32°F per decade
  - Greenhouse gases
    - CO_2 concentration increasing
  - NO_x contributes to Acid Rain
    - ***Acts as indirect greenhouse gases by producing the tropospheric greenhouse gas 'ozone' during their breakdown in the atmosphere***





Source: www.epa.gov

Background

- Legislation & political pressures
  - President's Clear Skies Initiative
    - Reduce NO_x 67% from 2000 levels and SO_2 73% from 2000 levels by 2018
  - Greenhouse Gas (GHG) Intensity
    - Reduce intensity (tons gas/ $M GDP) 18% by 2012
  - International Kyoto Protocol
    - UN rule to reduce GHG emissions 5% by 2012
    - Binding to countries who ratified (>55% of world emissions)
  - More legislation/political pressures likely?
- >50% energy generated in US from coal

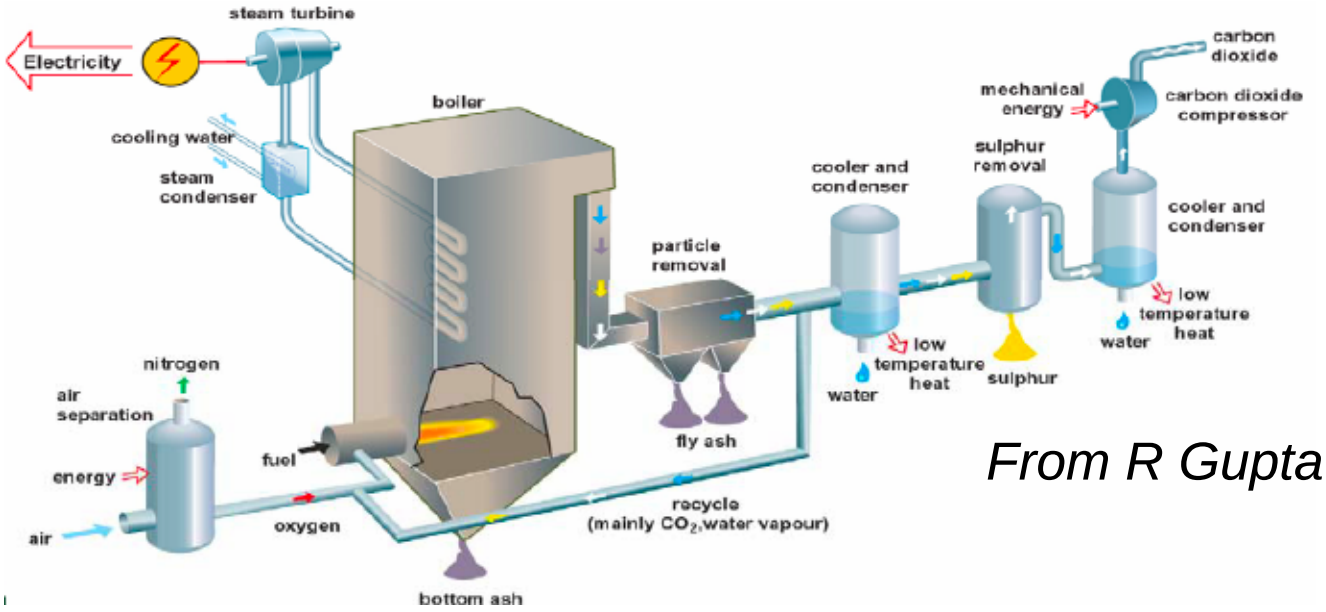
Options for Clean Coal

- Three approaches are presently seen as the front runners:
  - **Oxygen combustion (Oxyfuel)**
    - Concentrated CO_2 in products
  - **Amine (or others) scrubbing** for new or existing plants
    - Extracts the CO_2 from the flue gas using a regenerable sorbent-catalyst such as momoethanolamine (or MEA)
  - **Integrated Gasification Combined Cycle** (**IGCC)**
    - Also concentrates CO_2
    - Attractive approach, but challenges include complexity of operation
- "*Some current studies show oxygen combustion as the least costly while others lean toward IGCC, indicating that the jury is still out*." (Williams et al., BR-1779, 2006)

What is oxyfuel combustion?

- Oxyfuel
  - Pure oxygen as oxidizer (often diluted with flue gas)
  - Reduces or eliminates NOx (no Nitrogen in oxidizer flow)
- Increases CO_2 concentration
  - Easier to recover

Could be used in retrofit coal plants



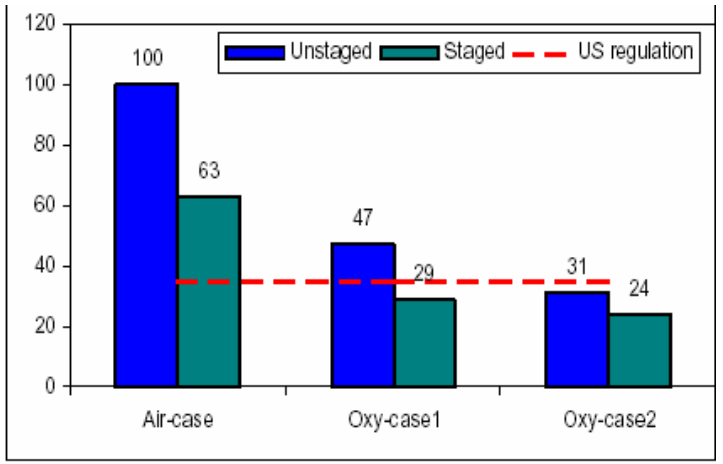
From R Gupta

Progress of Project

- Review of literature
- Survey of Indiana plants
- Construction of particle burner
- Leveraging this project with Jupiter Oxygen’s efforts
- Work is on schedule

Previous Oxyfuel Studies

- Pollutants
  - NO_x reduced
    - Can be further reduced
  - CO_2 concentrated >90%



(a) NOx emissions, normalised assuming the baseline value in air-case is 100. Dash line is US regulation 65 mg/MJ

Oxy-fuel combustion in GHG Context – Status of Research, Technology and Assessment
R Gupta, CRC for Coal in Sustainable Developement
Univ of Newcastle Australia
Advanced Coal Workshop, Brigham Young University, Provo,Utah, 15-16th March 2005

Previous Oxyfuel Studies

- Flame and Heat Transfer
  - Instabilities observed
    - Can be overcome by increasing O_2, but increases cost
    - Can this be overcome by recycling hot exhaust (flue) gas? Are optimized ignition and combustion possible?
  - Heat Transfer changed
    - No NO_x, N_2, less CO to carry heat to boiler
      - Transport properties changed
    - Radiation/convective heat transfer ratio changed
      - Oxyfuel combustion can result in higher temperatures
      - CO_2 participates actively in radiant transport
    - Can likely be made to matched air burning with recycled flue gases
    - Avoids changing plant electrical output
    - **Radiant measurements needed**
      - **Collaborating with Prof. Zheng and DOE NETL**
      - **Leveraging work with Jupiter to make measurements in Hammond facility also**

Previous Oxyfuel Studies

- Retrofit
  - Most necessary technology is fairly mature
    - Optimization and improved modeling needed
  - Must find a place for CO_2
    - No current large scale market
    - Must sequester and store
  - Can be adapted to future technological advances
    - IGCC using air separation unit from oxyfuel retrofit
  - Pilot Studies already done
    - Companies such as Air Liquide and Alstom

Jupiter Oxy-Fuel plant; Hammond, IN

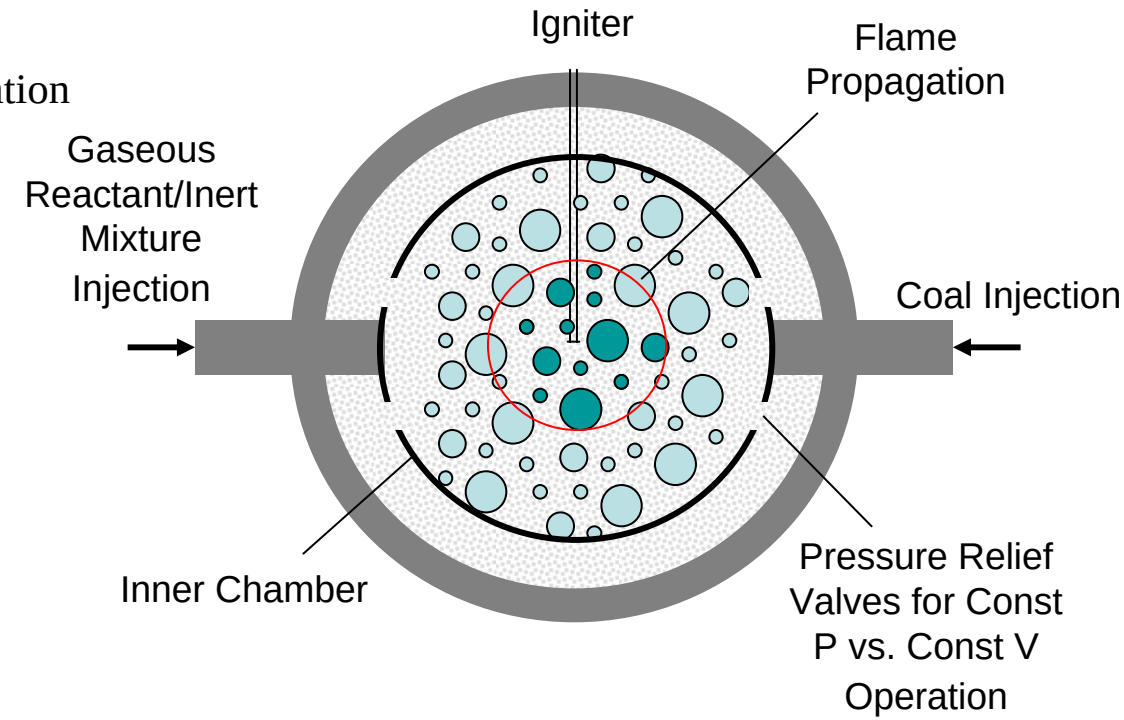
We are collaborating with Jupiter Oxygen Corporation, who is developing an oxyfuel pilot plant in Hammond, IN

Jupiter discusions with Purdue Power Plant

Combustion Studies at Purdue

Funding from Indiana CCTR supports a student

- Constant volume or pressure ignition and combustion
  - Flame and ignition characterization studies
  - Pollutant concentrations
  - RFG/O_2% optimization
  - Comparisons with Jupiter pilot reactor
  - Indiana coals considered
- Pressurized studies
  - Control flame instabilities?
  - Future technology areas?
    - IGCC pressurized syngas
    - Chemical looping
  - Radiant flux measurements (w/ Prof. Zheng)
    - Spectral and total
    - IR imaging



Can we stabilize O_2/CO_2/Coal flame with lower O_2 concentration?

Proposed Experiments

- Flame Studies
  - Instabilities in Large Coal Cloud
    - Compare to Kiga instabilities
    - Test off-optimum conditions
  - Heat Transfer
    - CO_2/O_2 effects
    - Compare experimental to current/proposed models
    - Thermal radiation (w/ Jupiter Oxyen)
  - Emissions
    - Complete combustion in coal cloud?
    - SO_2 concentrations

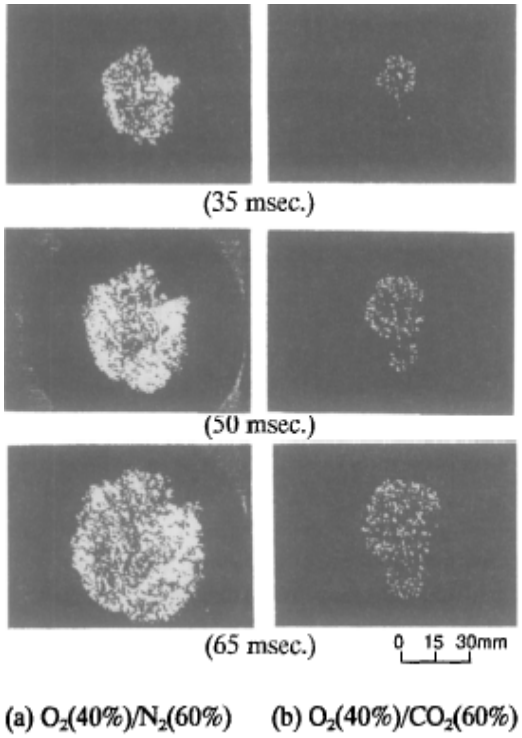
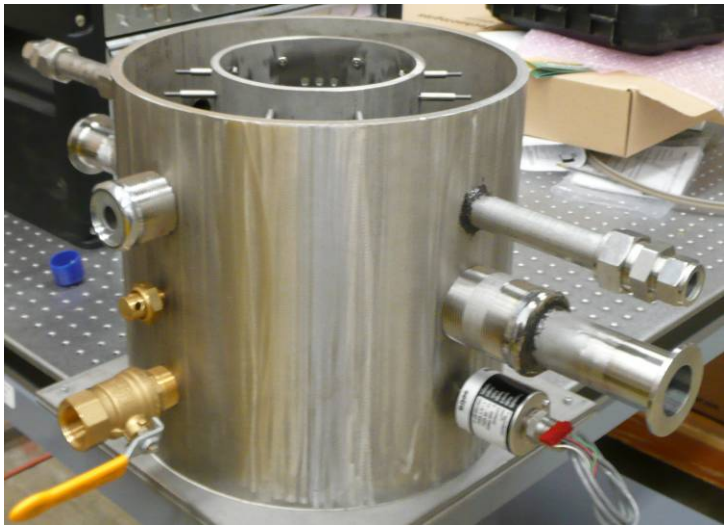


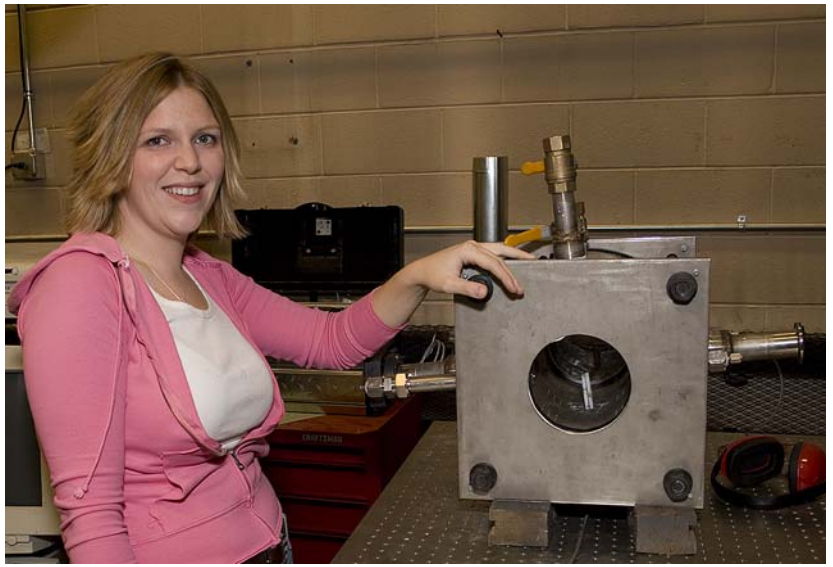
Fig. 2. Flame propagation behavior.

Kiga et al.; Energy Conversion Management 1997; 38: S129-S34

Experimental Update

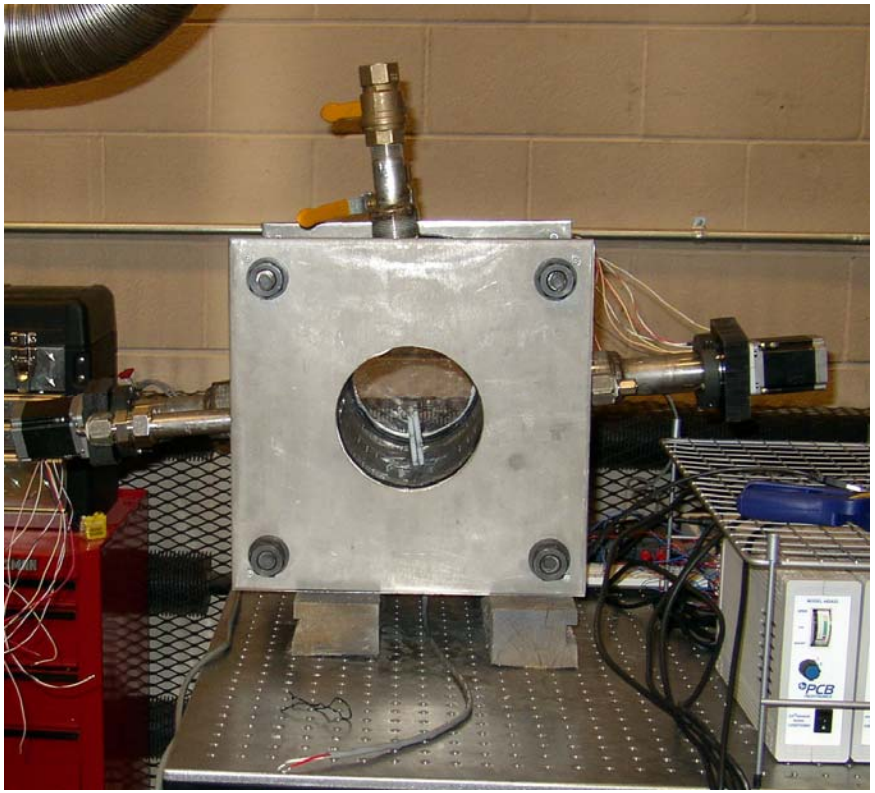
- Pressure Vessel Construction
  - Pressure Seal
    - Reusable and durable
    - Temperature resistant
  - Ignition
    - Matching minimum ignition energy to spark distance
    - Computer control and timing
  - Pulverized coal obtained from Jupiter Oxygen
  - Initial experiments planned for December-January





Experimental Update

- Coal Feed System
  - Computer control
  - Load and feed mechanism
  - Operational and tested
- Pressure Release System
  - Alignment of plates
  - Friction and sealing



Industry Survey

- Purpose is to get perspective on clean coal, and specifically views on oxyfuel in Indiana

1) What is the rated size of your power plant? _____

2) What is age of your oldest boiler? _____

3) How would you rate your company's emphasis on reduction of Greenhouse Gas emissions? 1 2 3 4 5

4) What technologies, if any, have you considered for Greenhouse Gas reduction?
(circle one): IGCC OxyFuel Amine Absorption

Other: _____

5) What level of importance is operational ease of new technologies? 1 2 3 4 5

6) How important is additional space needed for new construction? 1 2 3 4 5

7) Other than cost, what do you see as the most important factor in implementing a solution to Greenhouse Gas emissions? _____

_____

_____

8) When do you expect Greenhouse Gas regulations to be in place? _____

9) What, if any, areas would your company need help in to meet possible future Greenhouse Gas regulations?

_____

_____

Industry Survey

- Results so far
  - 12 returned
    - 10 from distributors
    - 2 from generators (both diesel)
  - Similar responses from the generators
    - Emphasis on green gas emissions (3 of possible 5, both)
    - Ease of operation important (4 of possible 5, both)
    - Space an issue (5)
    - Expect increased regulations in 3-8 years or 1-2 years
- Need more responses
  - Cards available here or give me contacts to send them

Jupiter Oxygen Collaboration/Leverage

- What they can offer us
  - Full size verification of laboratory observations
  - Proposed testing parameters arising in continuous operation
  - Some financial support
- What we can offer them
  - Verification of full scale occurrences
  - Data suitable for model generation
  - Radiation measurements

    (Working with Prof. Zheng)
    - Radiative heat flux
    - Spectral radiation intensities
    - Inversely estimates of flame temperature

Jupiter Oxygen Facility, Hammond IN

Particle Burner (PSU)

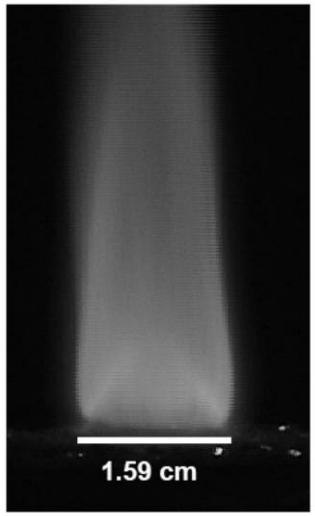
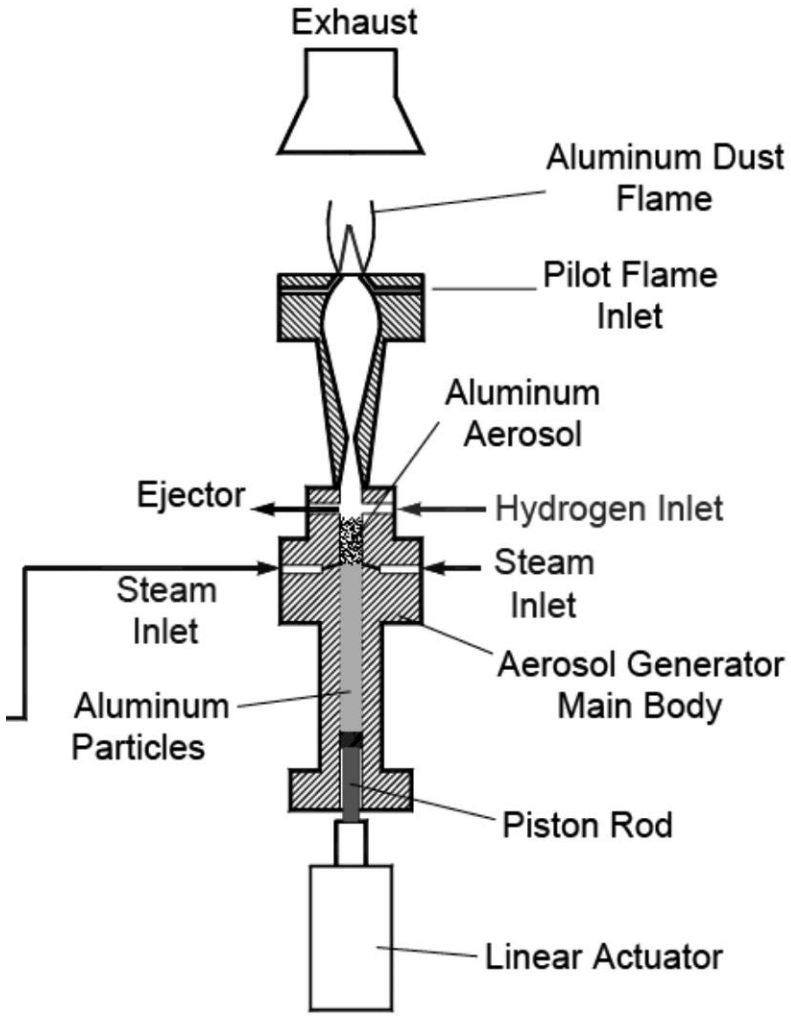


Fig. 5. Captured image of Al/steam/N_2 flame for Test No. ONR-109 at ϕ =0.900.



aluminum dust cloud experiment.

Summary of Progress

- New combustor built
  - Testing to begin
- Survey done
  - NEED MORE RESPONSES
- Obtained pulverized coal for studies
  - Will use same coals as Jupiter Oxygen
- Particle burner from Penn State shipped to Purdue
  - Will be adapted to coal combustion
  - Complements our combustor
  - Some funding from Jupiter Oxygen's DOE project to study
- Will make measurements at Jupiter Oxygen also
  - First radiation measurement scheduled on December, 12