A Burning Rate Emulator (BRE) for Study in Microgravity

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Acknowledgements to
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NASA GRC Award NNX10AD98G
Objective & proof of concept

Seek to emulate the steady burning conditions of condensed fuels by using a gas burner.
Method

 auposes: Burner matches properties

1. heat of gasification by flow rate and heat flux measurements
2. heat of combustion by a mixture of gaseous fuel and diluent
3. surface re-radiation by temperature measurement
4. smoke point by fuel - diluent mixture.
Tests: NASA 5.18 s

- About 53 tests Varying:
  - Diameter: 25, 50 mm
  - Fuel: CH₄, C₂H₄ w & wo N₂
  - Flow rate 3.5 to 12.7 g/m²s
  - Pressure 0.5 to 1 atm
  - Oxygen 21 to 30%

- Fix heat of combustion
- & smoke point
- Obtain L and Tₛ

<table>
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<tr>
<th>Symbol</th>
<th>Gas</th>
<th>Burning rate (g/m²·s)</th>
<th>X₂O₂</th>
<th>P (atm)</th>
<th>ΔHc (kJ/g)</th>
<th>SP (mm)</th>
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Typical Results 25 mm

Ignition 0.5s
Before 0 g

Steady at End?
Test 92 - $C_2H_4$ - 50 mm - 30% $O_2$ - 0.7 atm – compared to $C_2H_4$ - 25 mm - 30% $O_2$ - 0.7 atm

25 mm heat flux $\sim$ 3 kW/m$^2$; 50 mm $\sim$ 7 kW/m$^2$

Think radiation from gases is increasing with diameter

ASGSR 2015 Alexandria, VA
Analysis

- BRE gives surface temperature and net heat flux
- Compute heat of gasification \( \dot{m}'' L = \dot{q}'' \)
- Obtain “steady burning”?

Diffusive theory

- Heat flux \( \dot{q}'' D c_p / kL = \left( \frac{8}{\pi} \right) \ln \left( 1 + \frac{Y_{ox,\infty} \Delta h_{c,ox}}{L} \right) \)
- “Height” \( \frac{y_f}{D} \equiv \left( \frac{\pi}{8} \right) B \ln \left[ \frac{(1 + B) / (Y_{ox,\infty} / (Y_{F,o} \Delta h_c / \Delta h_{ox}) + 1)}{\ln (1 + B)} \right]^2 \)
2-D theory H. Baum

- Conservation of Mass
  \[ \nabla \cdot (\tilde{\rho} \tilde{u}) = 0 \]

- Conservation of Energy and Species
  \[ \nabla \cdot (\tilde{\rho} \tilde{u} Z) - \nabla \cdot (\tilde{\rho} \tilde{D} \nabla Z) = 0 \]

- Potential flow and diffusivity
  \[ \tilde{u} = \nabla \phi \quad (\tilde{\rho})^n \tilde{D} = (\tilde{\rho}_\infty)^n \tilde{D}_\infty \]

Same as 1-D for flat ellipse
But analytic solution for ellipsoidal flame!
Dimensionless Heat Flux

\[ \frac{\dot{q}_{\text{net}} C_p}{kL} \]

- \( k = 0.06599 \text{ W/m-K} \)
- \( C_p = 1.1674 \text{ J/g-K} \)
- for \( \text{N}_2 \) at \( T = 1000 \text{ K} \)

- 25 mm
- 50 mm

\[ \frac{8}{\pi} \ln(1 + B) \]
Dimensionless Flame Height

\[ \frac{y_f}{D} = \frac{\pi \ln\left[\frac{(1 + B)/(1 + \gamma)}{B}\right]}{8 \ln(1 + B)} \]
Mass Flux vs $L$
Radiation for 50 mm
Conclusions

- BRE gives efficient results in microgravity
- “Drop” tests show possible trend toward steady state
- A steady model correlates results over changes in fuel, pressure, oxygen, and flow rate
- Burning and heat flux depend on \( L \), heat of gasification and \( D \), diameter
- Flame size depends linear on \( D \), and on \( L \) and fuel mass fraction in the BRE flow
- Both also depend on oxygen concentration, but not apparently on pressure (Pressure effects flame height, but not in theory)
Ignition/Extinction in 1g

PhD student from U of Lund
Future

- Explore Baum 2-D solution ( & extinction)
- Compute gas radiation
- Add radiation (analytic and numerical)
- Explore 1-g BRE
- Calibrate NASA BRE burners
- Attempting new PhD student by NASA student grant