A Burning Rate Emulator (BRE) for Study in Microgravity

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Objective & proof of concept

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

![Image of flames and measurements]
Method

Hypotheses: 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>
<thead>
<tr>
<th>Symbol</th>
<th>Gas</th>
<th>Burning rate (g/m²-s)</th>
<th>$X_{O₂}$</th>
<th>$P$ (atm)</th>
<th>$ΔH_f$ (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 \( \dot{q}''Dc_p / kL = \left( \frac{8}{\pi} \right) \ln \left( 1 + \frac{Y_{ox,\infty} \Delta h_{c,ox}}{L} \right) \)
  - “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
  \[ \nabla \cdot (\bar{\rho} \bar{u}) = 0 \]

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

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

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

\[
\frac{\dot{q}_{\text{net}} C_p D}{k L} \quad \frac{8}{\pi \ln(1 + B)}
\]

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

- 25 mm
- 50 mm

Equations:
- \( y = 0.7167 \times (25 \text{ mm}) \)
- \( y = 1.0337 \times (50 \text{ mm}) \)
Dimensionless Flame Height

\[
\frac{y_f}{D} = \frac{\pi \ln[(1 + B)/(1 + \gamma)] B}{8 \left[ \ln(1 + B) \right]^2}
\]
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