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.
Method

万亿元：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
Typical Results 25 mm

Ignition 0.5s
Before 0 g

Steady at End?
Test 92 - C₂H₄ - 50 mm - 30% O₂ - 0.7 atm – compared to C₂H₄ - 25 mm - 30% O₂ - 0.7 atm

- 25 mm heat flux ~ 3 kW/m²; 50 mm ~ 7 kW/m²

Think radiation from gases is increasing with diameter

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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 \( \dot{q}'' Dc_p / kL = \left( \frac{8}{\pi} \right) \ln(1 + \frac{Y_{ox,\infty} \Delta h_{c,ox}}{L}) \)
  - “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
  \[ \tilde{u} = \nabla \tilde{\phi} \quad (\tilde{\rho})^n \tilde{D} = (\tilde{\rho}_\infty)^n \tilde{D}_\infty \]

\[ \dot{m}'' = \frac{2k}{c_p R} \ln(1 + B) / \left( \frac{\pi}{2} - \arctan(\xi_o) \right) \]

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

\[ \frac{\dot{q} - CpD}{kL} \]

- \( k = 0.06599 \text{ W/m-K} \)
- \( Cp = 1.1674 \text{ J/g-K} \)
- for \( N_2 \) at \( T = 1000 \text{ K} \)

- Blue circles: 25 mm
- Orange circles: 50 mm

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

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