A Burning Rate Emulator (BRE) for Study in Microgravity

A. Markan, P.B. Sunderland, J.G. Quintiere*, J. DeRis, D.P. Stocker

1Dept. of Fire Protection Engineering, University of Maryland, College Park, MD 20742, USA
2retired, FM Global, Norwood, MA 02062, USA
3NASA Glenn Research Center, Cleveland, OH 44135, USA

Acknowledgements to
F. Takahashi4, P.V. Ferkul5

4Case Western Reserve University, Cleveland, OH 44106, USA
5Universities Space Research Assoc, NASA Glenn Research Center, Cleveland, OH 44135, USA

NASA GRC Award NNX10AD98G
Objective & proof of concept

Seek to emulate the steady burning conditions of condensed fuels by using a gas burner.
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: CH$_4$, C$_2$H$_4$ w & wo N$_2$
  - Flow rate 3.5 to 12.7 g/m$^2$s
  - Pressure 0.5 to 1 atm
  - Oxygen 21 to 30%
  - Fix heat of combustion
  - & smoke point
  - Obtain $L$ and $T_s$
Typical Results 25 mm

Ignition 0.5s
Before 0 g

Steady at End?
Test 92 - $\text{C}_2\text{H}_4$ - 50 mm - 30\% $\text{O}_2$ - 0.7 atm – compared to $\text{C}_2\text{H}_4$ - 25 mm - 30\% $\text{O}_2$ - 0.7 atm

- 25 mm heat flux ~ 3 kW/m$^2$; 50 mm ~ 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

Obtain “steady burning”?

Diffusive theory

Heat flux

“Height”

\[
\frac{y_f}{D} \equiv \left( \frac{\pi}{8} \right) B \ln \left[ \frac{(1 + B) / (Y_{ox,\infty} / (Y_{F,0} \Delta h_c / \Delta h_{ox}) + 1)}{\ln(1 + B)} \right]^2
\]

\[
\dot{m}''L = \dot{q}''
\]
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
  \[ \tilde{u} = \nabla \tilde{\phi} \quad (\tilde{\rho})^n \tilde{D} = (\tilde{\rho}_\infty)^n \tilde{D}_\infty \]

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

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

\[ \frac{\dot{q}_{\text{net}}C_p}{kL} = \frac{8}{\pi \ln(1 + B)} \]

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

- Blue dots: 25 mm
- Orange dots: 50 mm

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

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