Ablation test-case series #2
Test case 2.1, 2.2, 2.3
(Version 2.8, February 6, 2012)

BE13 results
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BE13 main characteristics

- Heat transfer + pyrolysis + charring-ablation code

- Pyrolysis
  - One or several Arrhenius laws

- Ablation
  - Chemical tables

- Boundary condition
  - Convection
  - Radiation

- 1D finite difference code

- Temperature (T), density (ρ) and species density (ρᵢ)
BE13 versus CMA formulations (1/3)

- Thermal balance at wall
  - BE13

  $$- \lambda_s \nabla T_s = \alpha (h_a - h_w) + \varepsilon_1 \sigma (T_{R1}^4 - T_w^4) + \dot{m}_g \Delta H_{comb} + \dot{m}_c \Delta H_{abl}$$

  Blowing rate correction:
  $$\frac{\alpha}{\alpha_0} = 1 - \frac{\dot{m}_g}{\alpha_0} \eta_{pyr} - \frac{\dot{m}_c}{\alpha_0} \eta_{abl}$$

  Chemical tables: \(Bc'_0(T,P,Bg'_0); \Delta H_{abl}(T,P,Bg'_0); \Delta H_{comb}(T)\)

  - CMA

  $$- \lambda_s \nabla T_s = \alpha (h_a - h_w) + \alpha_w q_{rad} - F \varepsilon_1 \sigma T_w^4 + \dot{m}_g \left(h_g - h_w\right) + \dot{m}_c \left(h_c - h_w\right) \quad (Le = 1; CH = CM)$$

  Blowing rate correction:
  $$\frac{\alpha}{\alpha_0} = \frac{2\lambda B'_0}{e^{2\lambda B'_0} - 1}$$

  Chemical tables: \(Bc'(T,P,Bg'); h_w(T,P,Bg')\)
BE13 versus CMA formulations (2/3)

- Heat transfer with pyrolysis
  - BE13
    Mass conservation: \( \nabla \cdot (\bar{m}_g) = -\frac{\partial \rho}{\partial t} \)
    Energy: \( \frac{\partial \rho h}{\partial t} + \nabla \cdot (\bar{m}_g h_g) = \nabla \cdot (\lambda \nabla T) \)
    Decomposition: \( \left( \frac{\partial \rho}{\partial t} \right) = \sum_i -\alpha^i \rho^i \left( \frac{\rho^i - \rho^i_c}{\rho^i_v} \right)^{\psi_i} A^i \exp \left( - \frac{E^i}{RT} \right) \)
  - CMA
    Mass conservation: similar expression
    Energy: similar expression
    Decomposition: \( \left( \frac{\partial \rho}{\partial t} \right) = \Gamma \left( \frac{\partial \rho^A}{\partial t} + \frac{\partial \rho^B}{\partial t} \right) + (1 - \Gamma) \frac{\partial \rho^C}{\partial t} \)
    \( \left( \frac{\partial \rho^i}{\partial t} \right) = -\rho^i_v \left( \frac{\rho^i - \rho^i_c}{\rho^i_v} \right)^{\psi_i} A^i \exp \left( - \frac{E^i}{RT} \right) \)
BE13 versus CMA formulations (3/3)

- **Specific heat - Thermal conductivity**
  - **BE13**
    
    Specific heat: \[ \rho \cdot Cp = (1 - \xi) \rho_v \cdot Cp_v + \xi \rho_c \cdot Cp_c \]
    
    Enthalpy: \[ h(T) = \Delta H_f^0 + \int_{T=0}^{T=298K} CpdT \]
    
    Thermal conductivity: \[ \lambda = (1 - \xi) \lambda_v + \xi \lambda_c \]
  
  - **CMA**
    
    Specific heat: similar \[ Cp = x \cdot Cp_v + (1 - x) \cdot Cp_c \]
    
    Enthalpy: similar expression
    
    Thermal conductivity: \[ \lambda = x \lambda_v + (1 - x) \lambda_c \]
Preliminary

- Parameters adaptation for test case 2

- The thermal balance at wall is different between CMA (referring to CMA manual) and BE13
- Necessary to adapt parameters in BE13 to insure coherence (blowing rate correction and ablation chemical tables)
Test case 2.1 - Temperature

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
Test case 2.1 – Blowing rates

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
artefact at t=60s
Test case 2.1 – Pyrolysis zone and recession

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
artefact at t=60s

BE13 - Ablation test case #2.1 - Pyrolysis zone and recession
Test case 2.2 - Temperature

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)

BE13 - Ablation test case #2.2 - Thermocouple data
Test case 2.2 - Blowing rates

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
Test case 2.2 - Pyrolysis zone and recession

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)

BE13 - Ablation test case #2.2 - Pyrolysis zone and recession
Test case 2.3 - Temperature

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
Test case 2.3 - Blowing rates

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)

BE13 - Ablation test case #2.3 - Blowing rates
Test case 2.3 - Pyrolysis zone and recession

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)

BE13 - Ablation test case #2.3 - Pyrolysis zone and recession
Conclusion

- BE13 parameters have been modified to insure coherence
- Comparison between BE13 and (PATO/PAM2, Amaryllis) results seems to show good agreement for temperature, blowing rates, pyrolysis zone and recession
- However presence of artefacts (test case #2.1, t=60s) needs further analysis