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

BE13 results
Contents

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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

  \[-\lambda_s \nabla T_s = \alpha (h_a - h_w) + \varepsilon_T (T_R^4 - T_w^4) + \dot{m}_g \Delta H_{comb} + \dot{m}_c \Delta H_{abl}\]

  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

  \[-\lambda_s \nabla T_s = \alpha (h_a - h_w) + \alpha_w q_{rad} - F \varepsilon_T T_w^4 + \dot{m}_g (h_g - h_w) + \dot{m}_c (h_c - h_w)\]  
  \((Le = 1; CH = CM)\)

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

- **Specific heat - Thermal conductivity**
  - **BE13**
    
    Specific heat: \[ \rho C_p = (1 - \xi) \rho_v C_{p_v} + \xi \rho_c C_{p_c} \]
    
    Enthalpy: \[ h(T) = \Delta H_f^0 + \int_{T=298K}^{T} C_p dT \]
    
    Thermal conductivity: \[ \lambda = (1 - \xi) \lambda_v + \xi \lambda_c \]

  - **CMA**
    
    Specific heat: similar \[ C_p = x C_{p_v} + (1 - x) C_{p_c} \]
    
    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)

BE13 - Ablation test case #2.1 - Thermocouple data
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
Test case 2.2 - Temperature

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
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)**

**BE13 - Ablation test case #2.3 - Thermocouple data**
Test case 2.3 - Blowing rates

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
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