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)
- 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

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

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

#### Specific heat - Thermal conductivity

- **BE13**

  Specific heat: \( \rho C_p = (1 - \xi) \rho_v C_{p_v} + \xi \rho_c C_{p_c} \)

  Enthalpy: \( h(T) = \Delta H_f^0 + \int_{T_0=298K}^{T} C_p dT \)

  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: \( \lambda = x \lambda_v + (1 - x) \lambda_c \)
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)

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

Good agreement
BE13 vs (PATO/PAM2, Amaryllis)

BE13 - Ablation test case #2.2 - Blowing rates
Good agreement
BE13 vs (PATO/PAM2, Amaryllis)
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)

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