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Ablation test-case series #2

Test case 2.1, 2.2, 2.3

(Version 2.8, February 6, 2012)

BE13 results

All the space you need



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- **BE13 versus CMA formulations**
- **Test case 2.1, 2.2, 2.3**
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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 (ρ^i)**

BE13 versus CMA formulations (1/3)

■ Thermal balance at wall

■ BE13

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

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

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

■ CMA

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

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

Chemical tables : $Bc'(T,P,Bg')$; $h_w(T,P,Bg')$

BE13 versus CMA formulations (2/3)

Heat transfer with pyrolysis

BE13

Mass conservation: $\nabla \cdot (\dot{m}_g) = -\frac{\partial \rho}{\partial t}$

Energy : $\frac{\partial \rho h}{\partial t} + \nabla \cdot (\dot{m}_g h_g) = \nabla \cdot (\lambda \nabla T)$

Decomposition: $\left(\frac{\partial \rho}{\partial t}\right) = \sum_i -\alpha^i \rho_v^i \left(\frac{\rho^i - \rho_c^i}{\rho_v^i}\right)^{\psi_i} A^i \exp\left(-\frac{E^i}{RT}\right)$

CMA

Mass conservation : similar expression

Energy : similar expression

Decomposition: $\left(\frac{\partial \rho}{\partial t}\right) = \Gamma \left(\frac{\partial \rho^A}{\partial t} + \frac{\partial \rho^B}{\partial t}\right) + (1 - \Gamma) \frac{\partial \rho^C}{\partial t}$

$$\left(\frac{\partial \rho^i}{\partial t}\right) = -\rho_v^i \left(\frac{\rho^i - \rho_c^i}{\rho_v^i}\right)^{\psi_i} A^i \exp\left(-\frac{E^i}{RT}\right)$$

BE13 versus CMA formulations (3/3)

■ Specific heat - Thermal conductivity

■ BE13

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

$$\xi = \frac{\rho_v - \rho}{\rho_v - \rho_c}$$

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 $C_p = xC_{p_v} + (1 - x)C_{p_c}$

$$x = \frac{\rho_v}{\rho_v - \rho_c} \left(1 - \frac{\rho_c}{\rho} \right)$$

Enthalpy : similar expression

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

Preliminary

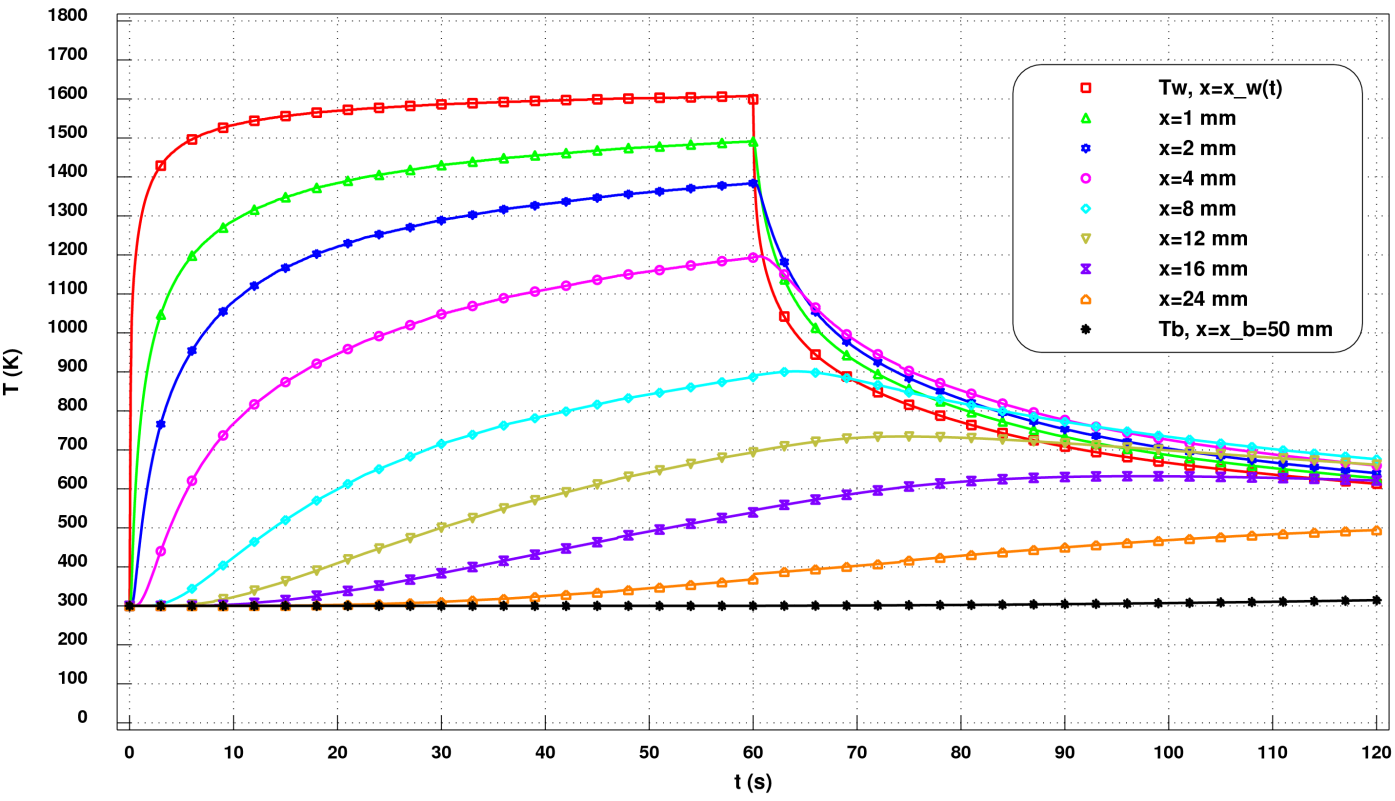
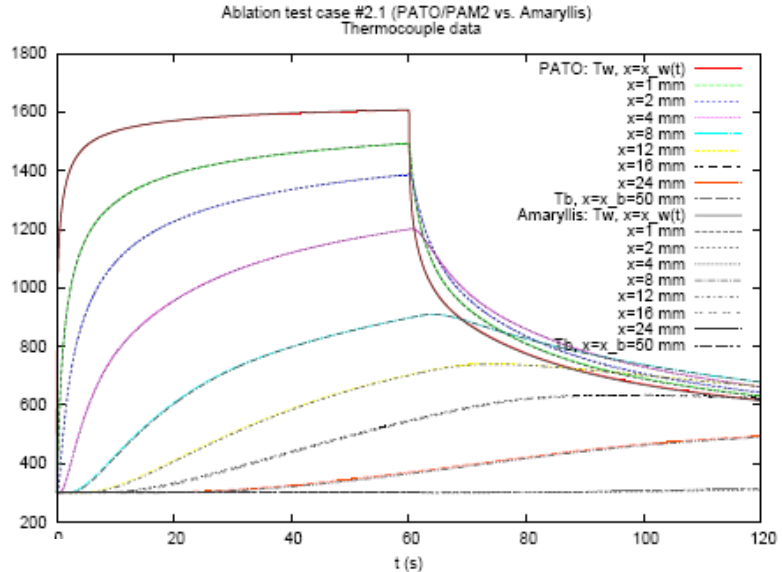
- **Parameters adaptation for test case 2**
 - **The thermal balance at wall is different between CMA (referring to CMA manual) and BE13**
 - **Necessary to adapt parameters in BE13 to insure coherence (blowing rate correction and ablation chemical tables)**

Test case 2.1 - Temperature

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

BE13 - Ablation test case #2.1 - Thermocouple data

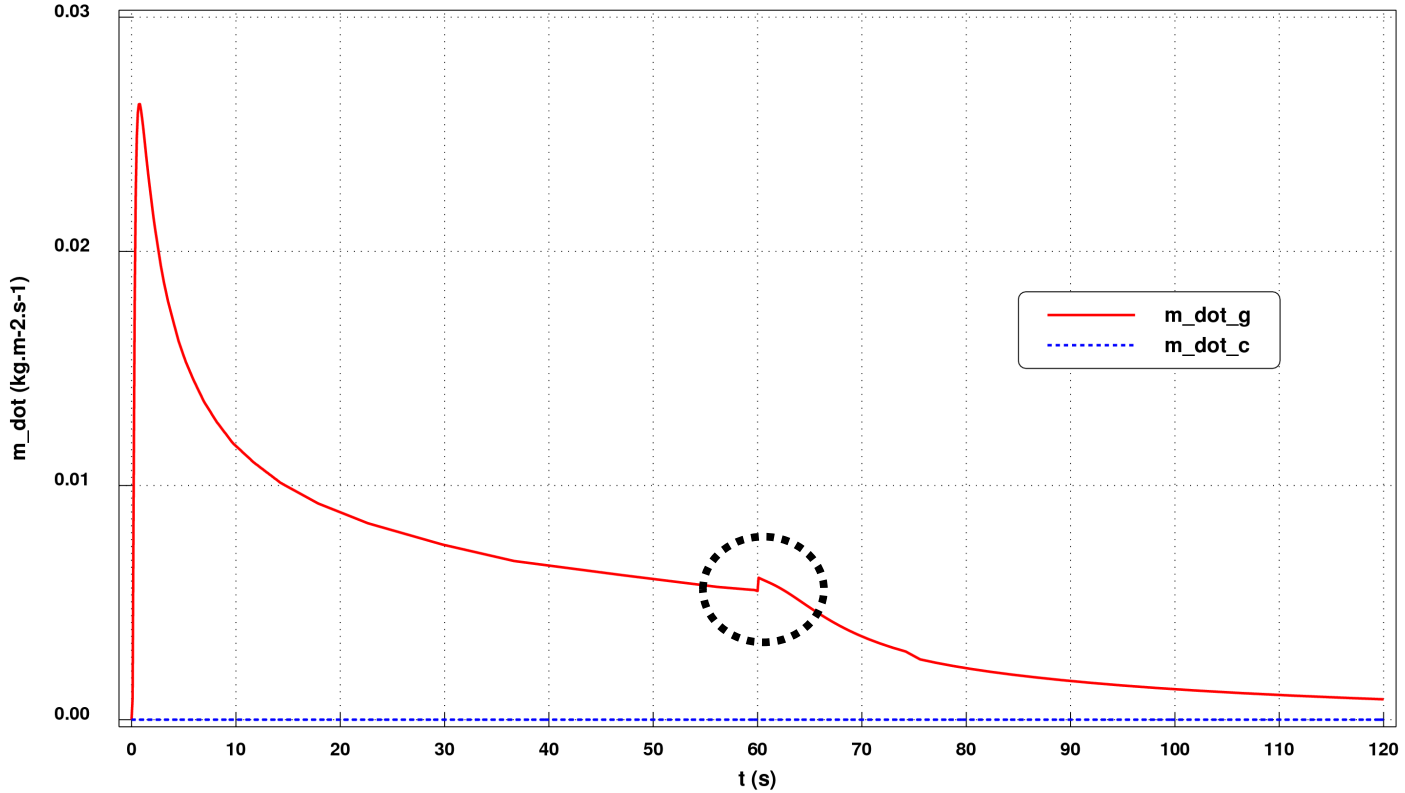
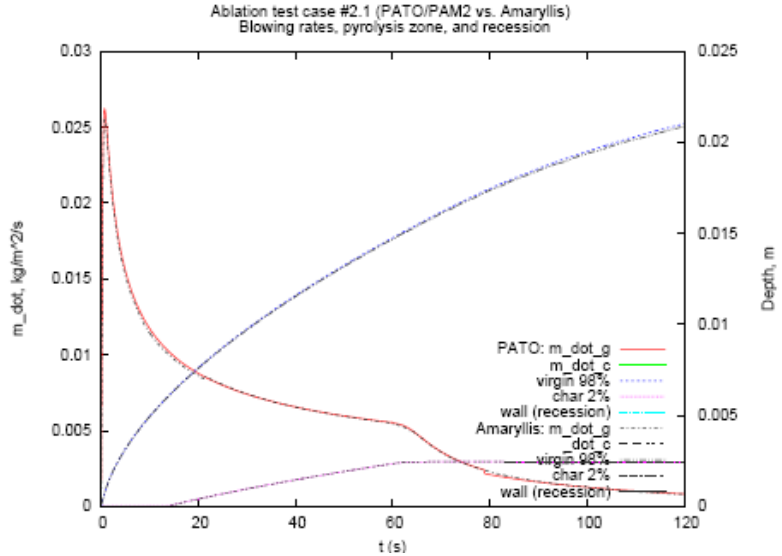


Test case 2.1 – Blowing rates

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

BE13 - Ablation test case #2.1 - Blowing rates

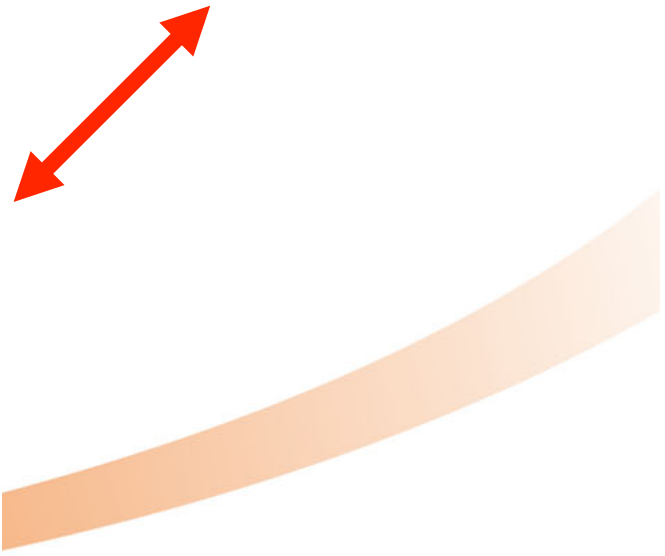
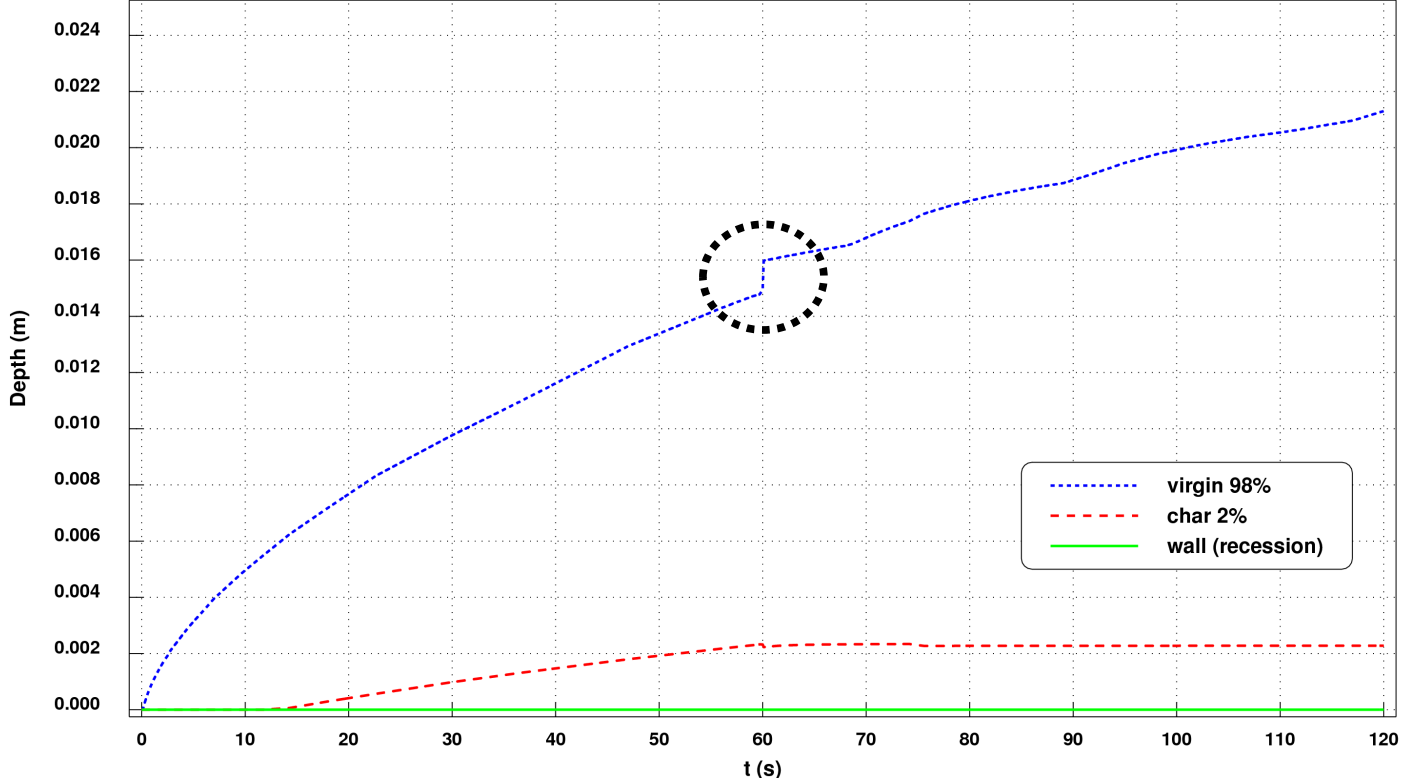
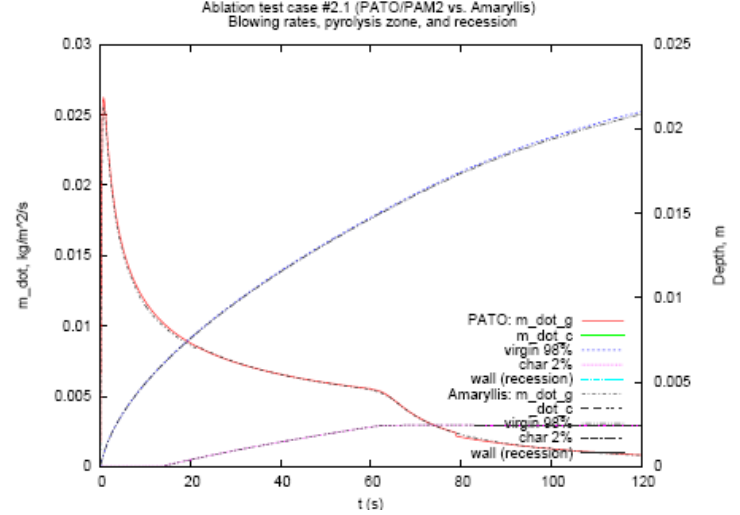


Test case 2.1 – Pyrolysis zone and recession

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

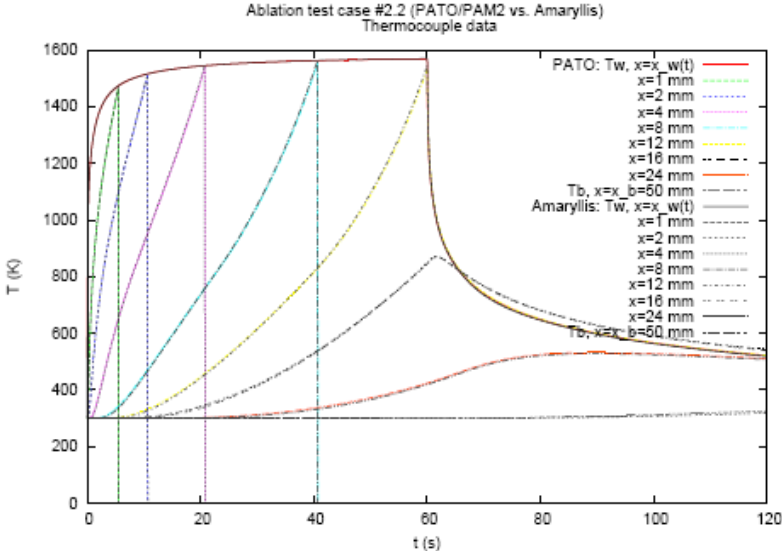
BE13 - Ablation test case #2.1 - Pyrolysis zone and recession



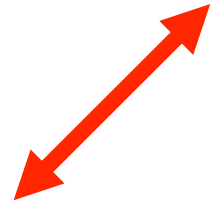
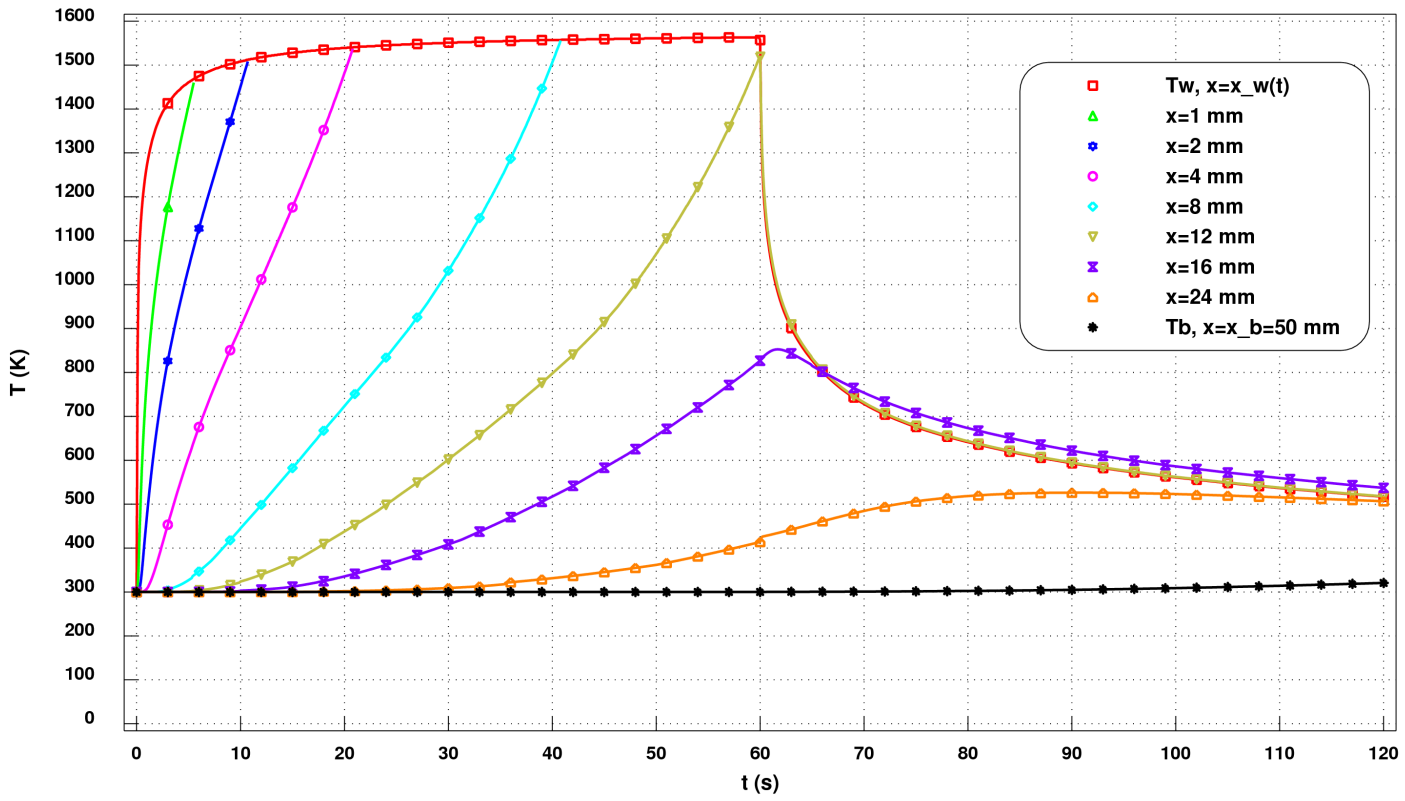
Test case 2.2 - Temperature

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Good agreement
BE13 vs (PATO/PAM2, Amaryllis)



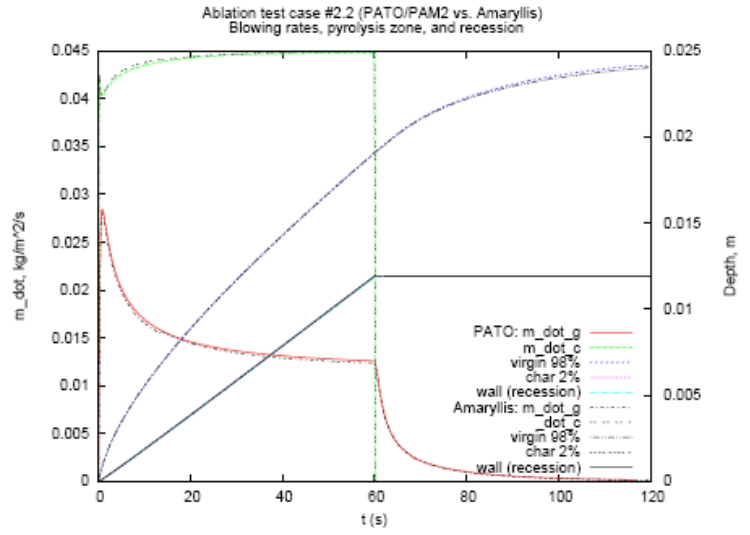
BE13 - Ablation test case #2.2 - Thermocouple data



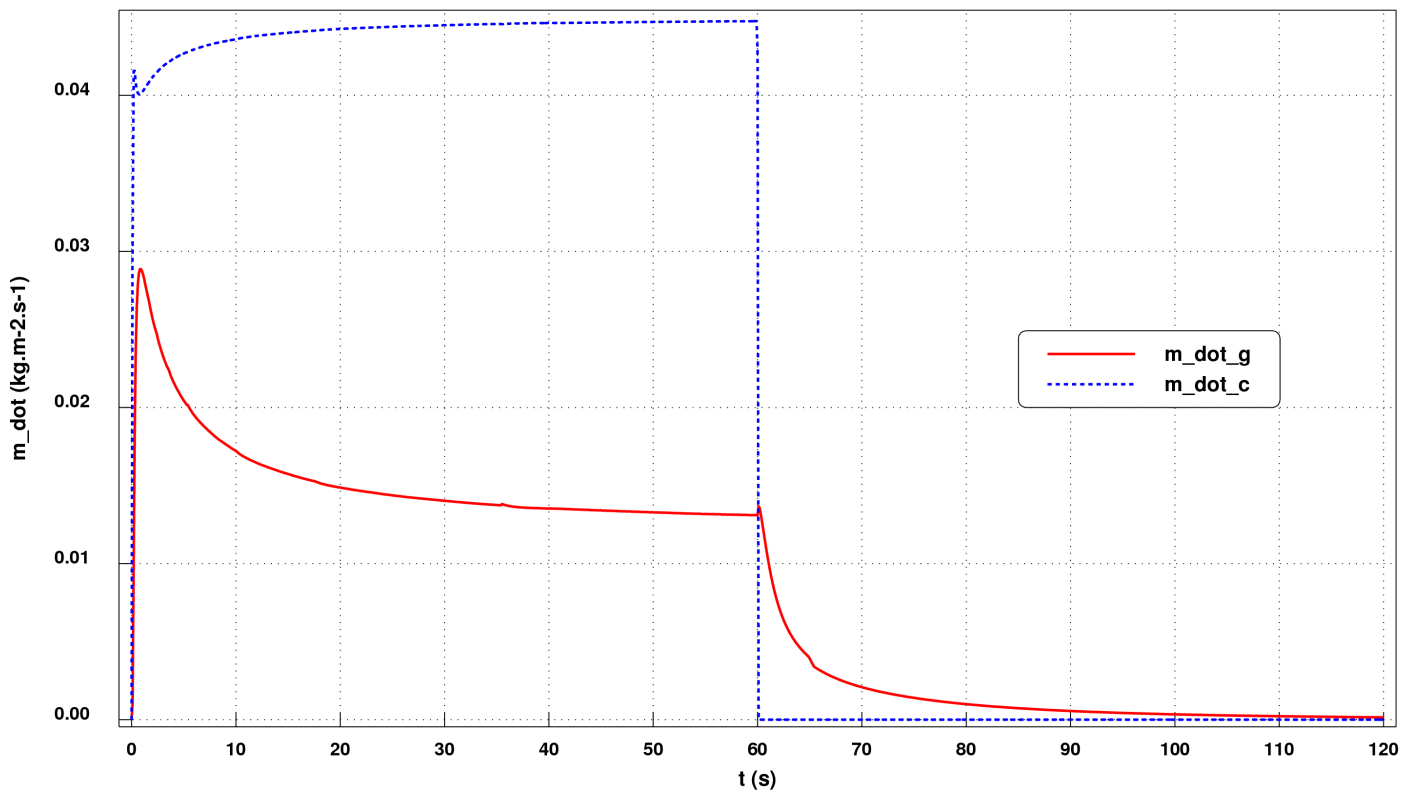
Test case 2.2 - Blowing rates

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Good agreement
BE13 vs (PATO/PAM2, Amaryllis)



BE13 - Ablation test case #2.2 - Blowing rates

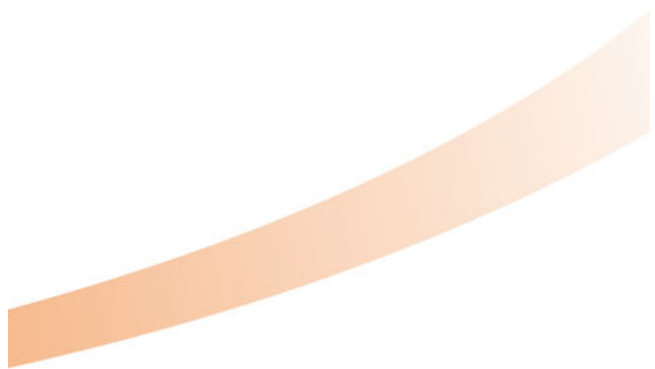
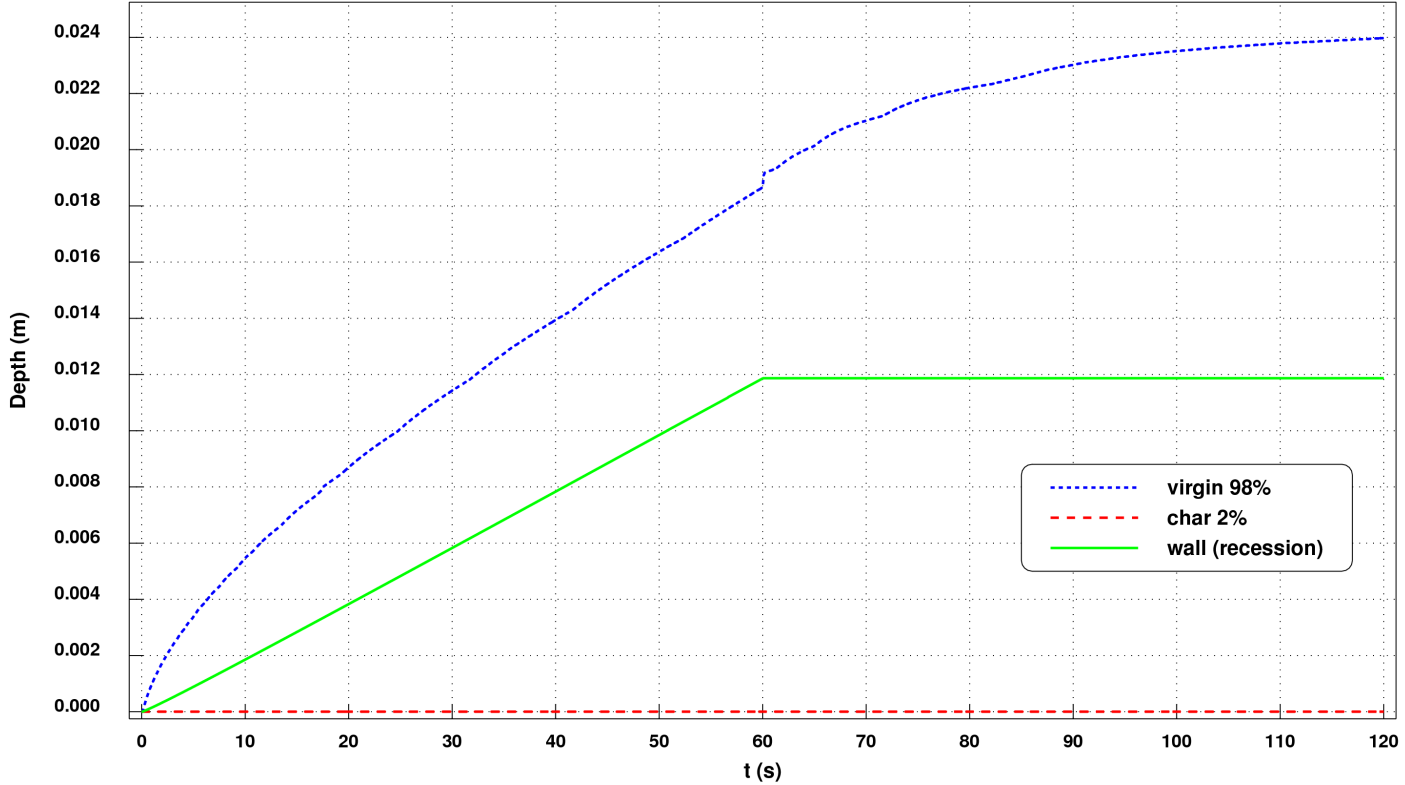
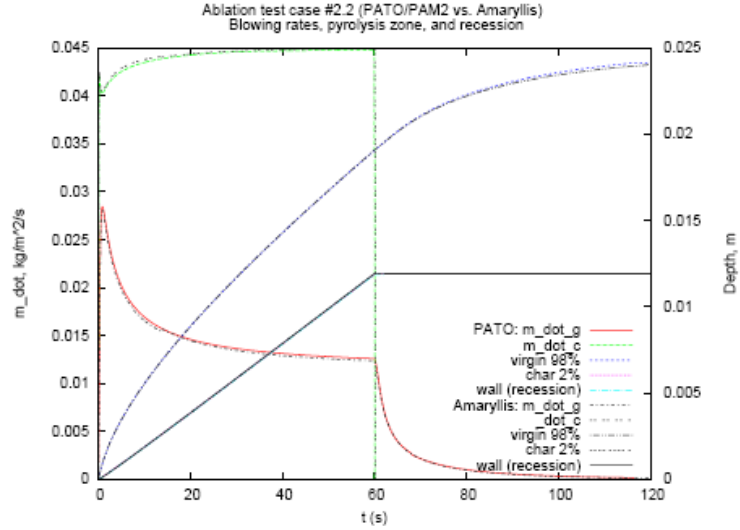


Test case 2.2 - Pyrolysis zone and recession

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Good agreement
 BE13 vs (PATO/PAM2, Amaryllis)

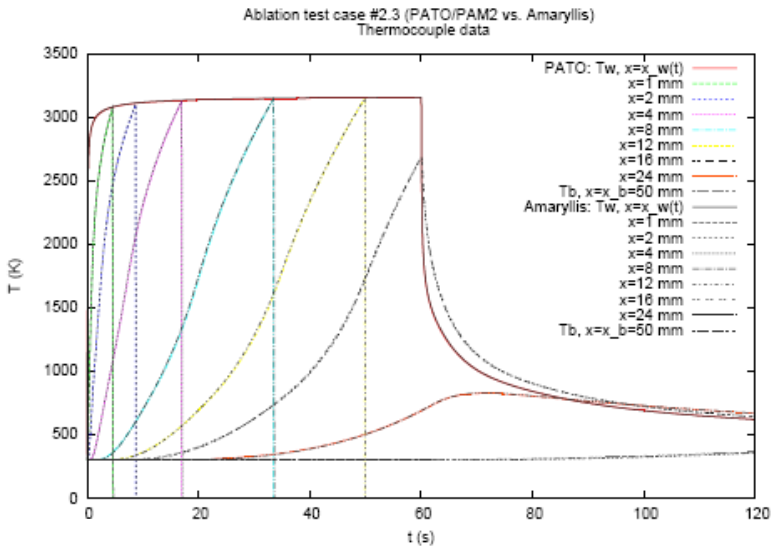
BE13 - Ablation test case #2.2 - Pyrolysis zone and recession



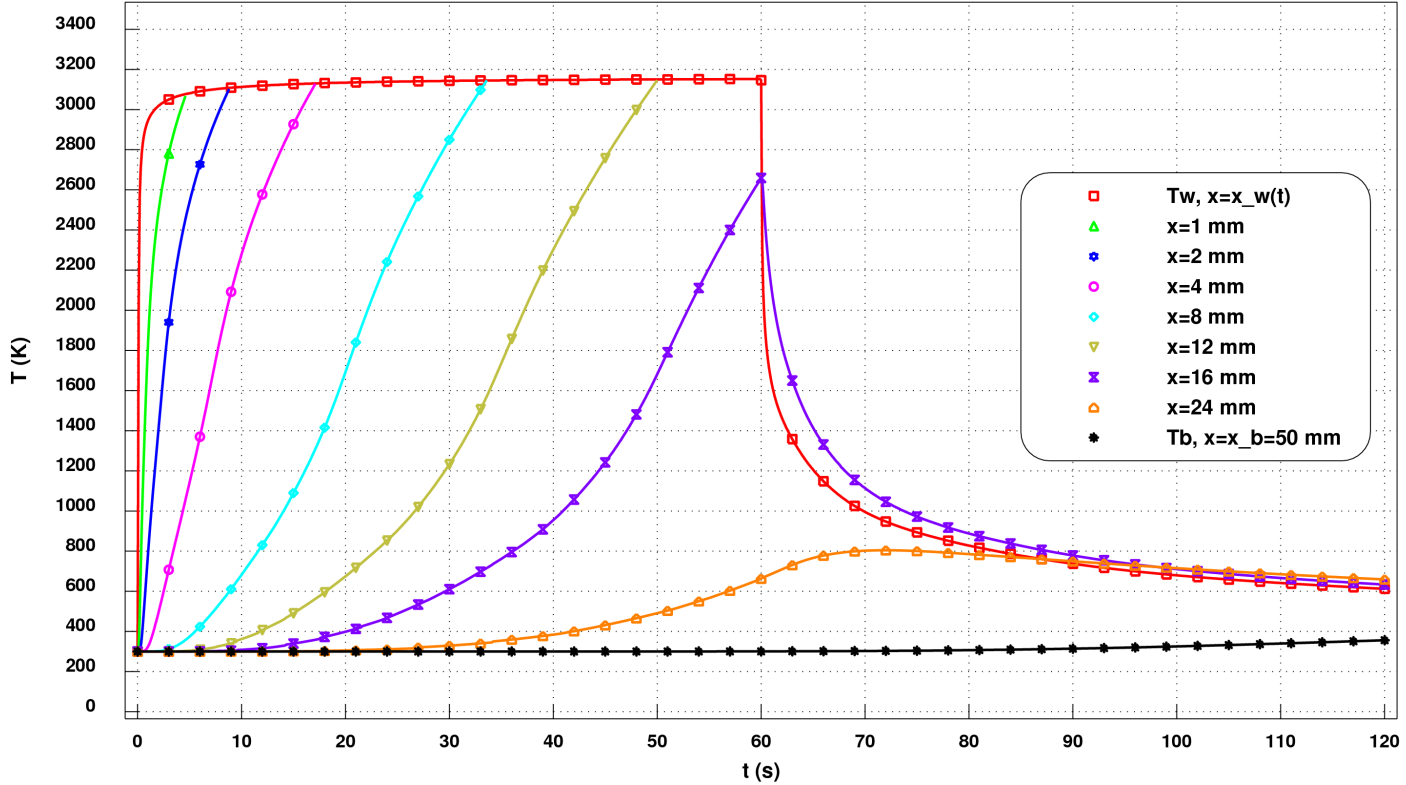
Test case 2.3 - Temperature

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Good agreement
BE13 vs (PATO/PAM2, Amaryllis)



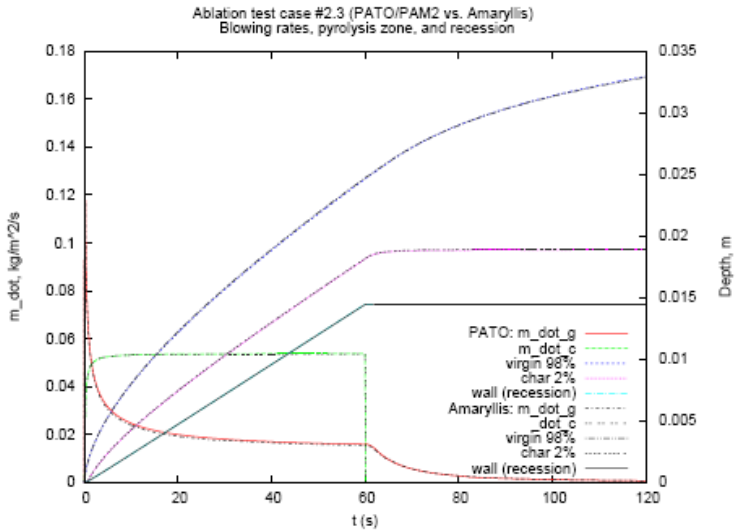
BE13 - Ablation test case #2.3 - Thermocouple data



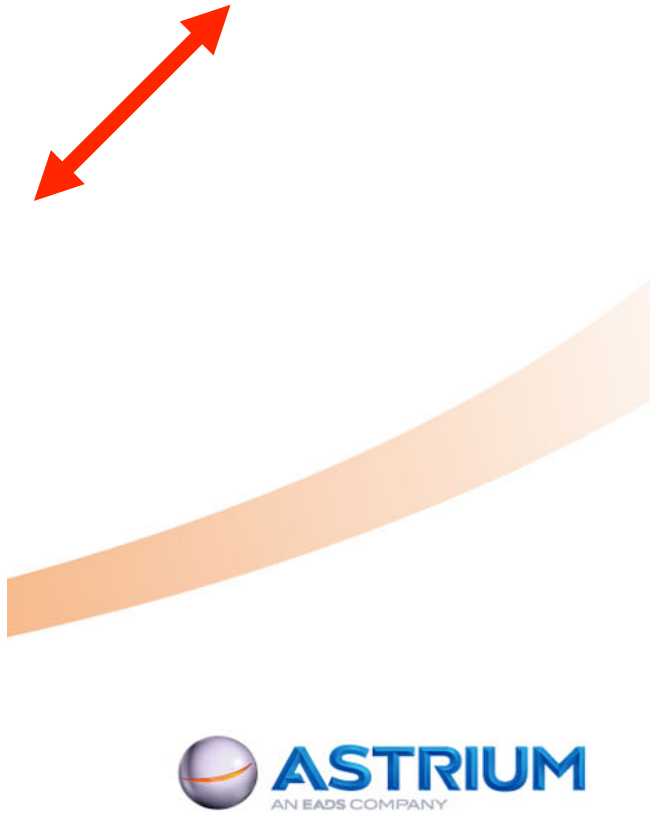
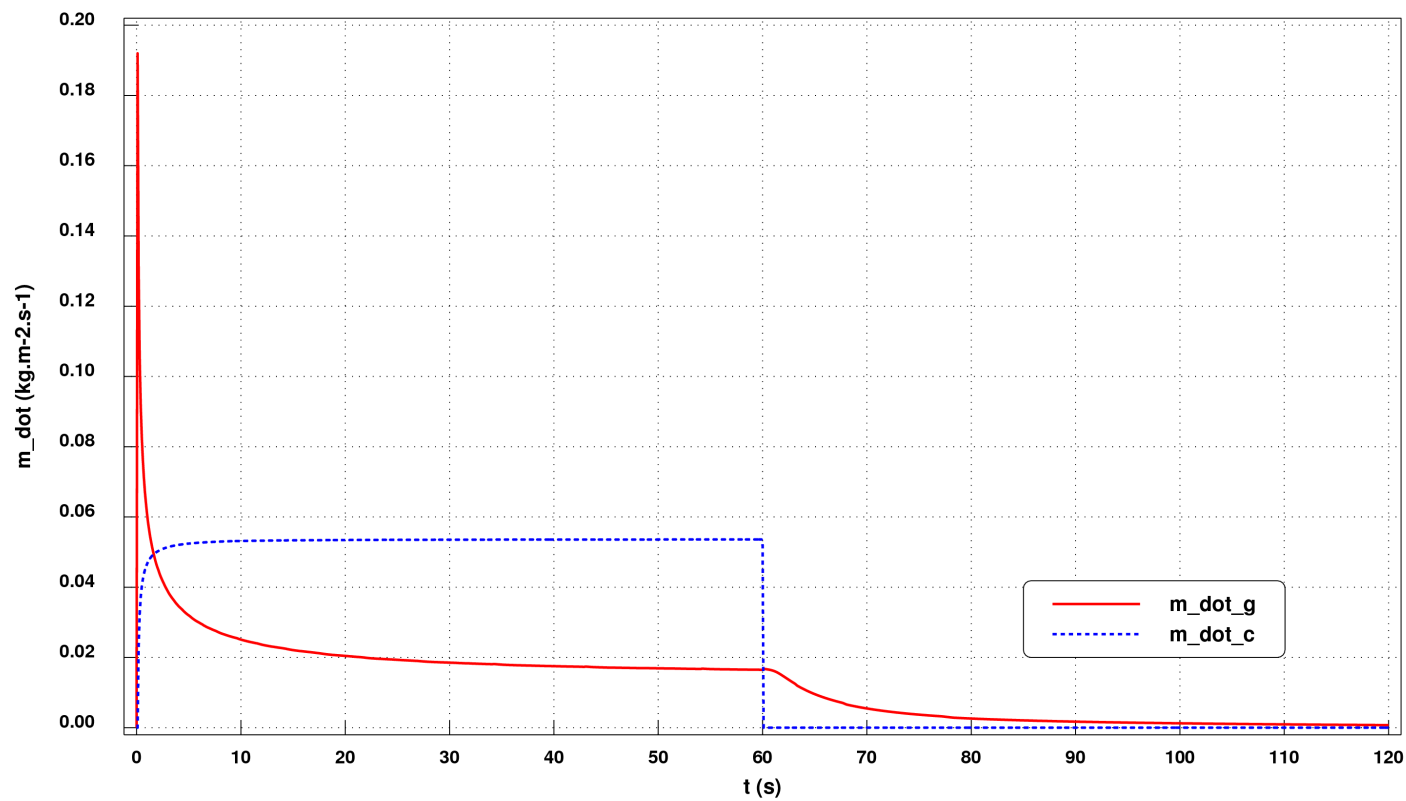
Test case 2.3 - Blowing rates

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



BE13 - Ablation test case #2.3 - Blowing rates

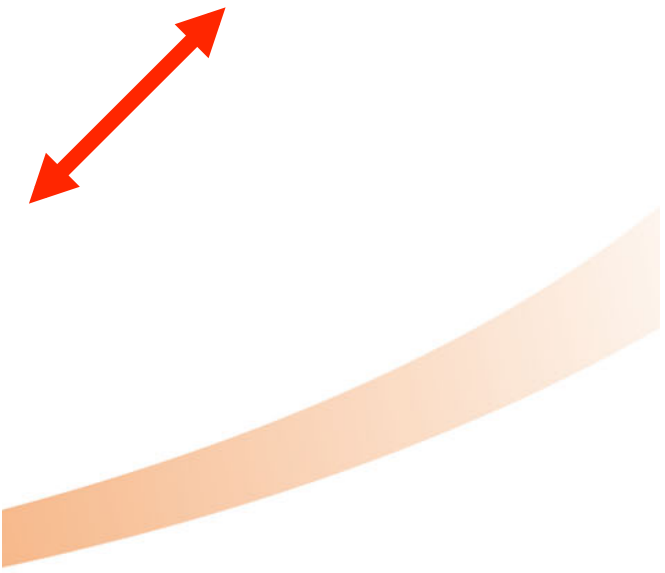
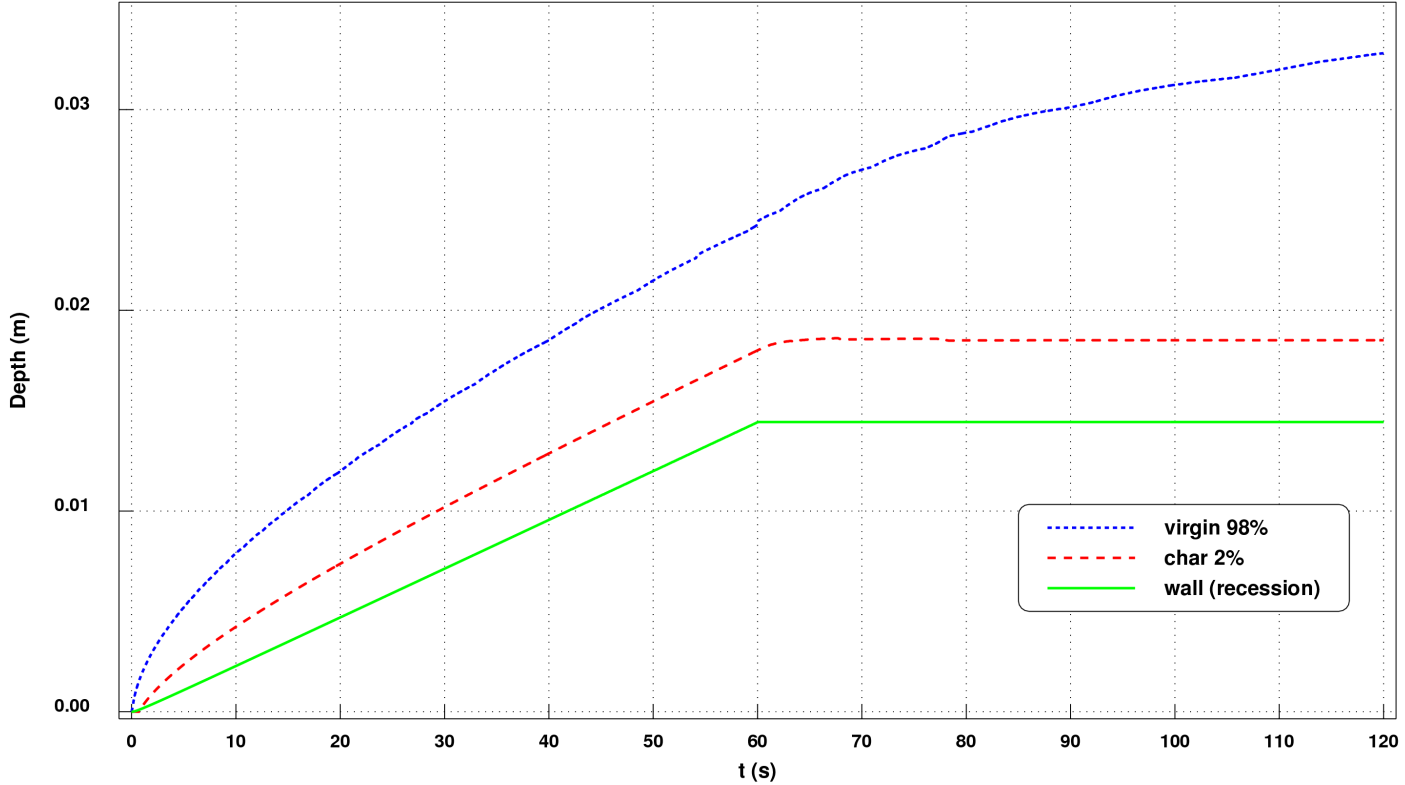
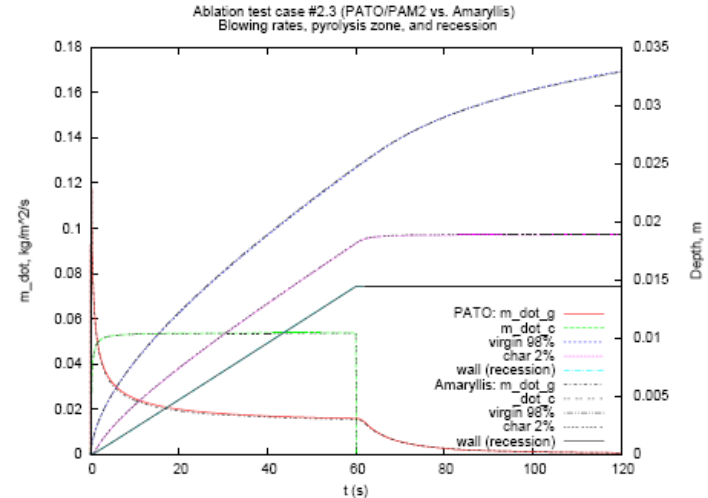


Test case 2.3 - Pyrolysis zone and recession

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**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**