MOPAR: Results for the Inter-code Calibration

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MOPAR Overview

- Modeling of Pyrolysis and Ablation Response
- Uses the same formulation as a code developed at Sandia National Laboratory and North Carolina State University (Amar, Blackwell, and Edwards)
- Includes pyrolysis gas phase equation
- Includes moving boundaries using Landau coordinates
- Includes spherical and cylindrical coordinates
- Allows ablation of both sides of the domain
- Takes into account the kinetic energy of the pyrolysis gas
- Models the flow through porous media using Forchheimer's Law

Governing Equations

Mixture Energy Equation

$$\underbrace{\int_{cs} \dot{\mathbf{q}}'' \cdot \mathrm{d}\mathbf{S}}_{\text{conduction}} + \underbrace{\int_{cs} \phi \rho_g h_g \mathbf{v_g} \cdot \mathrm{d}\mathbf{S}}_{\text{gas flux}} - \underbrace{\int_{cs} \rho h \mathbf{v_{cs}} \cdot \mathrm{d}\mathbf{S}}_{\text{grid convection}} + \underbrace{\frac{d}{dt} \int_{cv} \rho e \mathrm{d}V}_{\text{energy content}} = 0$$

Solid Phase Continuity Equation

$$\underbrace{\frac{d}{dt} \int_{cv} \rho_s \mathrm{d}V}_{\text{solid mass content}} - \underbrace{\int_{cs} \rho_s \mathbf{v}_{cs} \cdot \mathrm{d}\mathbf{S}}_{\text{grid convection}} = \underbrace{\int_{cv} \dot{m}_s''' \mathrm{d}V}_{\text{solid mass source}}$$

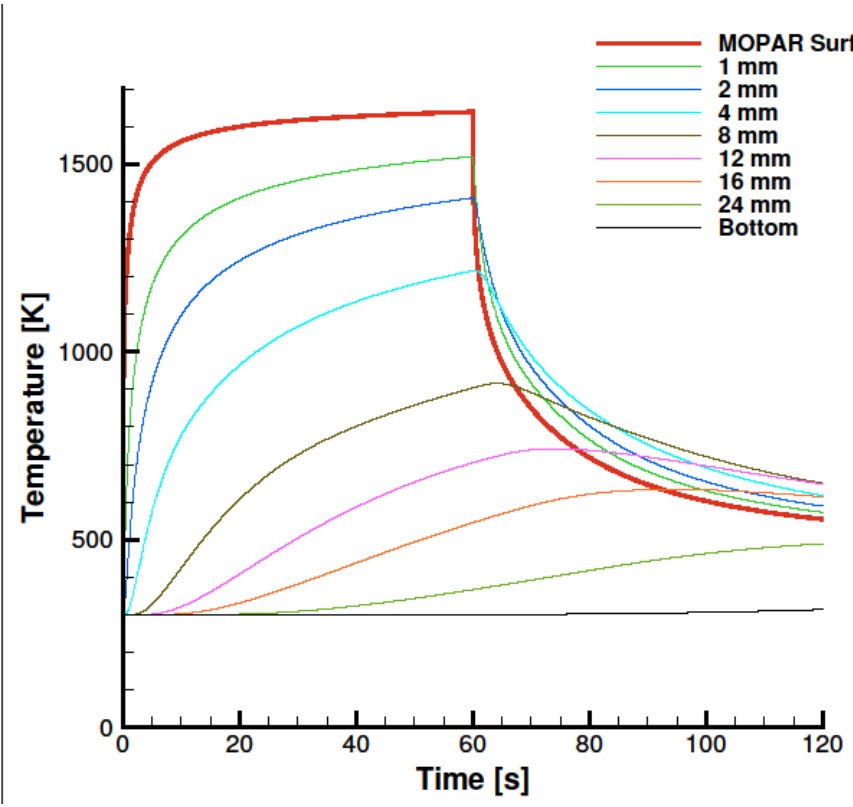
Gas Phase ContinuityEquation

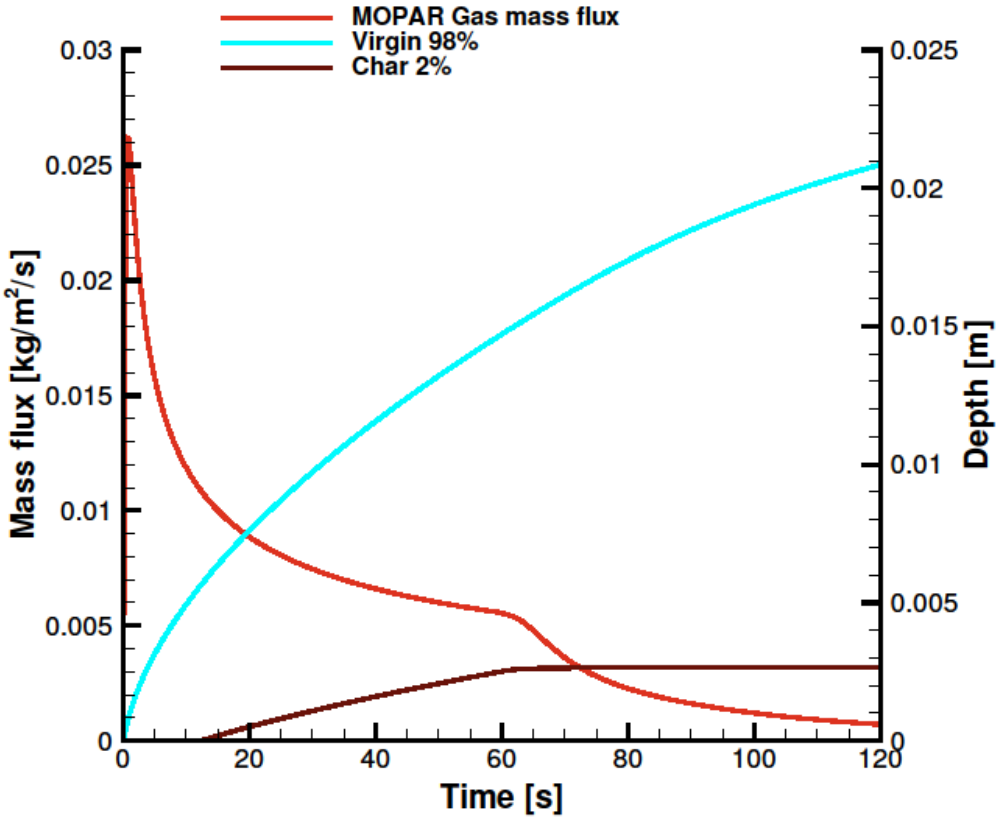
$$\underbrace{\frac{d}{dt} \int_{cv} \phi \rho_g \mathrm{d}V}_{\text{gas mass content}} + \underbrace{\int_{cs} \phi \rho_g \mathbf{v}_g \cdot \mathrm{d}\mathbf{S}}_{\text{gas flux}} - \underbrace{\int_{cs} \phi \rho_g \mathbf{v}_{cs} \cdot \mathrm{d}\mathbf{S}}_{\text{grid convection}} = \underbrace{\int_{cv} \dot{m}_g''' \mathrm{d}V}_{\text{gas mass source}}$$

Forchheimer's law

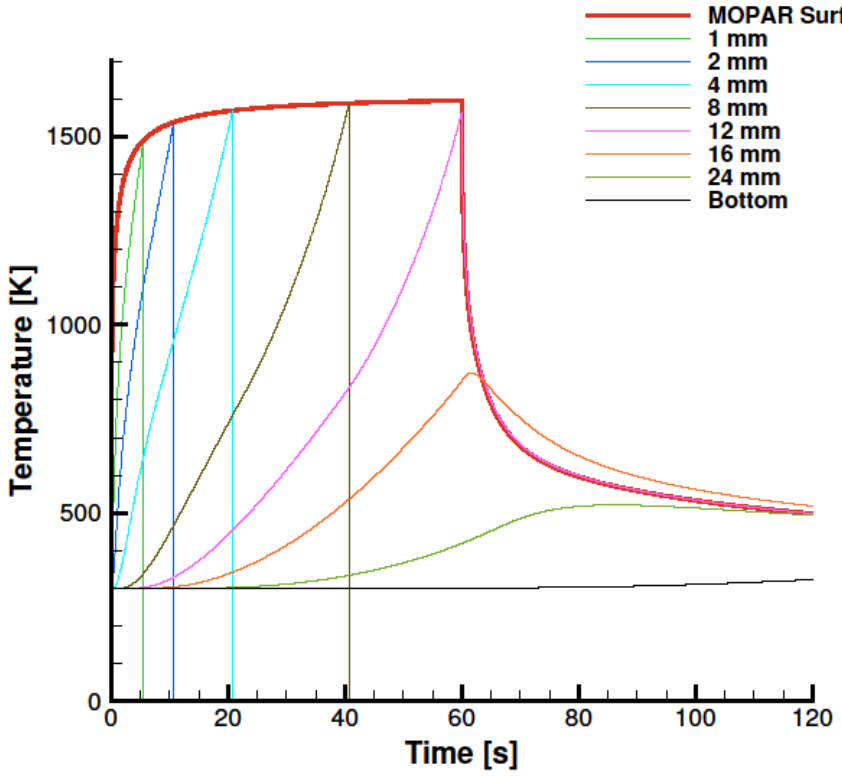
$$\frac{\partial p}{\partial x} = -\frac{\mu}{K} v_g' - \beta \rho v_g'^2$$

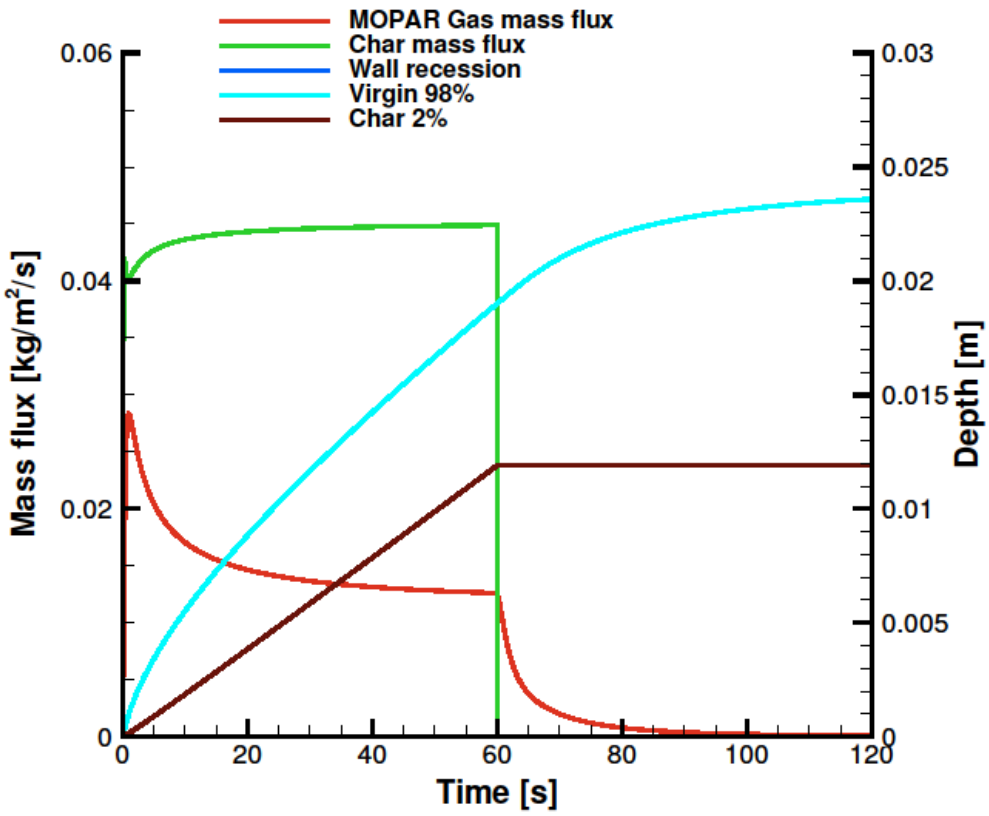
Test Case 2.1


MOPAR Surface
1 mm
2 mm
4 mm
8 mm
12 mm
16 mm
24 mm
Bottom
Temperature [K]
Time [s]
0
500
1000
1500
0
20
40
60
80
100
120

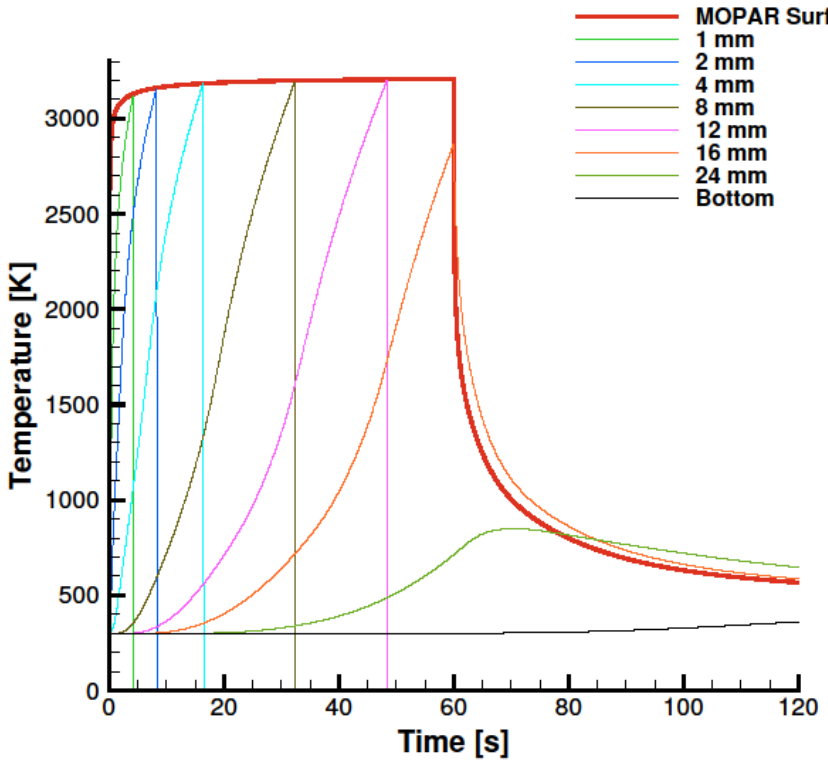

MOPAR Gas mass flux
Virgin 98%
Char 2%
Mass flux [kg/m²/s]
Depth [m]
Time [s]
0
0.005
0.01
0.015
0.02
0.025
0.03
0
20
40
60
80
100
120

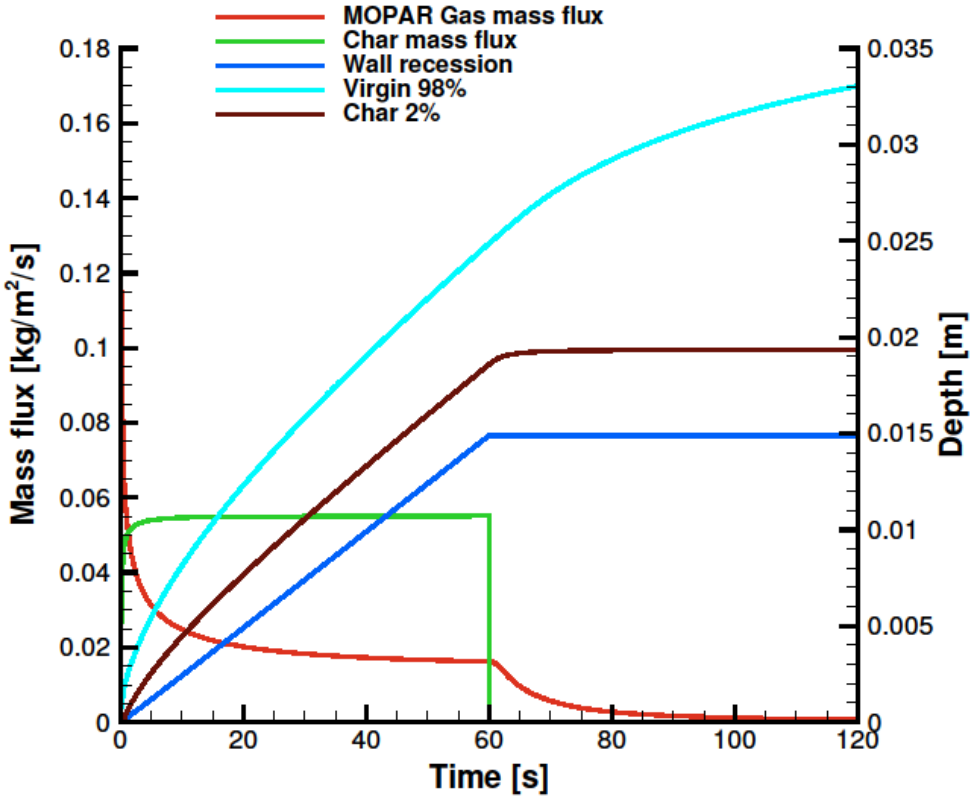
Test Case 2.2


MOPAR Surface
1 mm
2 mm
4 mm
8 mm
12 mm
16 mm
24 mm
Bottom
Temperature [K]
Time [s]
0
500
1000
1500
0
20
40
60
80
100
120


MOPAR Gas mass flux
Char mass flux
Wall recession
Virgin 98%
Char 2%
Mass flux [kg/m²/s]
Depth [m]
Time [s]
0
0.02
0.04
0.06
0.005
0.01
0.015
0.02
0.025
0.03
0
20
40
60
80
100
120

Test Case 2.3


MOPAR Surface
1 mm
2 mm
4 mm
8 mm
12 mm
16 mm
24 mm
Bottom
Temperature [K]
Time [s]
0
500
1000
1500
2000
2500
3000
0
20
40
60
80
100
120


MOPAR Gas mass flux
Char mass flux
Wall recession
Virgin 98%
Char 2%
Mass flux [kg/m²/s]
Depth [m]
Time [s]
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0
20
40
60
80
100
120

Comments

- Needed to set recession rate to 0.0 after 60s for case 2.3 to prevent negative recession during cool down
- Other cases ran robustly without specifying recession rate