[](https://www.comsol.com/)

Phase c m

|  |  |
| --- | --- |
| Report date | Apr 29, 2025, 11:17:13 AM |

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# Global Definitions

|  |  |
| --- | --- |
| Date | Apr 29, 2025, 6:12:16 AM |

Global settings

|  |  |
| --- | --- |
| Name | Phase c m.mph |
| Path | C:\Users\chaud\OneDrive\c++\Desktop\phase c m.mph |
| Version | COMSOL Multiphysics 6.3 (Build: 335) |
| Unit system | SI |

Used products

|  |
| --- |
| COMSOL Multiphysics |

Computer information

|  |  |
| --- | --- |
| CPU | Intel64 Family 6 Model 140 Stepping 1, 4 cores, 7.69 GB RAM |
| Operating system | Windows 11 |

## Shared Properties

### Default Model Inputs

|  |  |
| --- | --- |
| Tag | cminpt |

# Component 1

|  |  |
| --- | --- |
| Date | Apr 28, 2025, 9:03:29 AM |

Settings

| **Description** | **Value** |
| --- | --- |
| Unit system | Same as global system (SI) |
| Geometry shape function | Automatic |
| Avoid inverted elements by curving interior domain elements | Off |

Spatial frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| x | y | z |

Material frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| X | Y | Z |

Geometry frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| Xg | Yg | Zg |

Mesh frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| Xm | Ym | Zm |

## Definitions

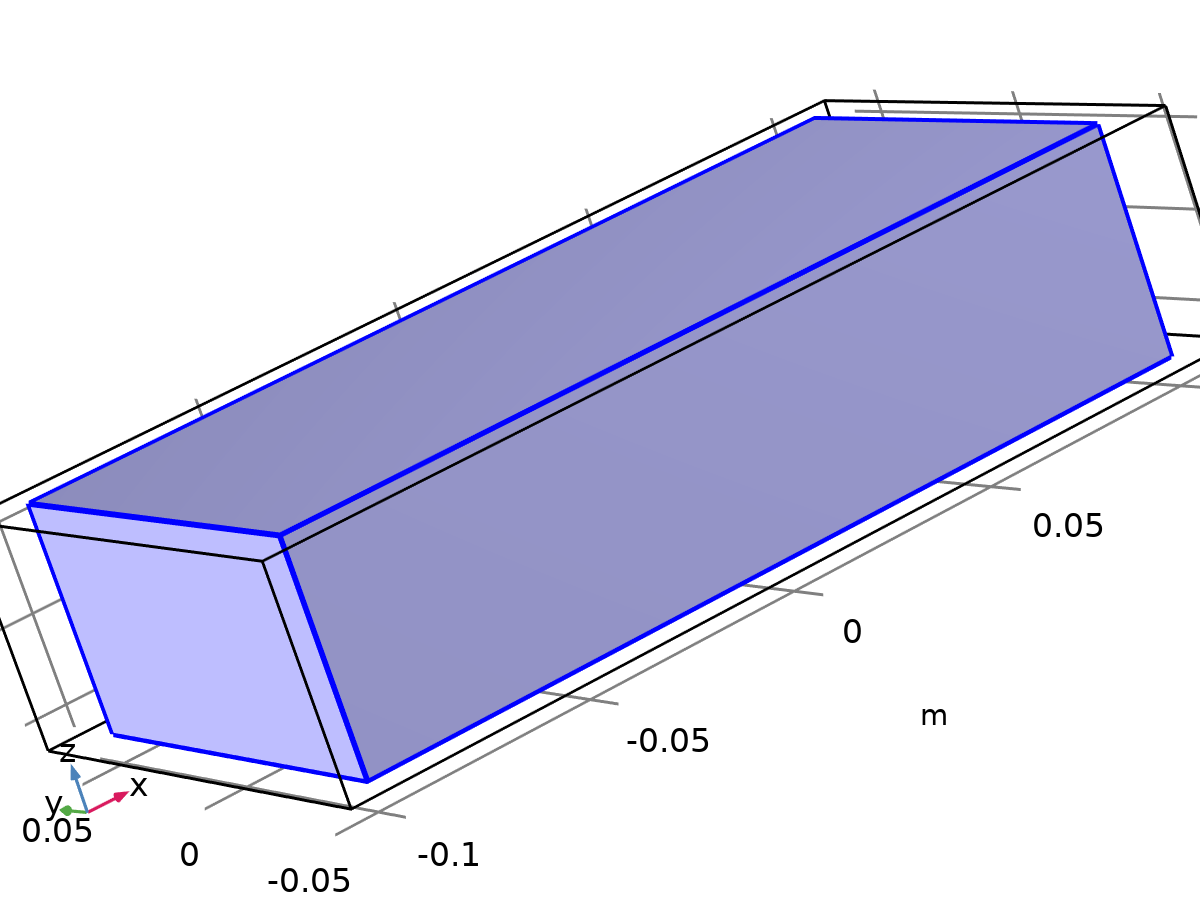
### Nonlocal Couplings

#### Average 1

|  |  |
| --- | --- |
| Coupling type | Average |
| Operator name | aveop2 |

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domain 2 |



Selection

### Coordinate Systems

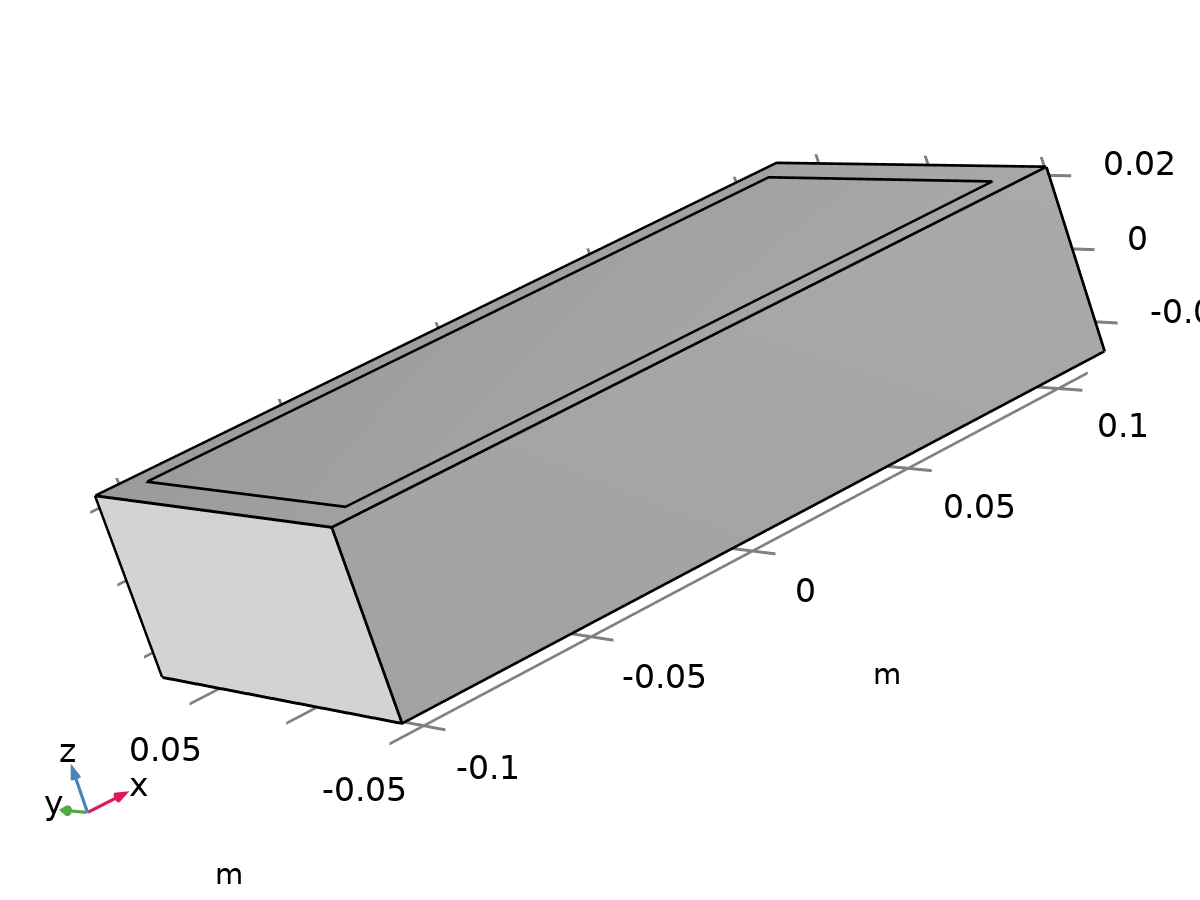
#### Boundary System 1

|  |  |
| --- | --- |
| Coordinate system type | Boundary system |
| Tag | sys1 |

Coordinate names

| **First** | **Second** | **Third** |
| --- | --- | --- |
| t1 | t2 | n |

## Geometry 1



Geometry 1

Units

|  |  |
| --- | --- |
| Length unit | m |
| Angular unit | deg |

Geometry statistics

| **Description** | **Value** |
| --- | --- |
| Space dimension | 3 |
| Number of domains | 2 |
| Number of boundaries | 12 |
| Number of edges | 24 |
| Number of vertices | 16 |

### Battery Block (blk1)

Size and shape

| **Description** | **Value** |
| --- | --- |
| Width | 0.2 |
| Depth | 0.1 |
| Height | 0.05 |

Position

| **Description** | **Value** |
| --- | --- |
| Base | Center |
| Position | {0, 0, 0} |

Axis

| **Description** | **Value** |
| --- | --- |
| Axis type | z - axis |

### PCM Layer (blk2)

Size and shape

| **Description** | **Value** |
| --- | --- |
| Width | 0.22 |
| Depth | 0.12 |
| Height | 0.05 |

Position

| **Description** | **Value** |
| --- | --- |
| Base | Center |
| Position | {0, 0, 0} |

Axis

| **Description** | **Value** |
| --- | --- |
| Axis type | z - axis |

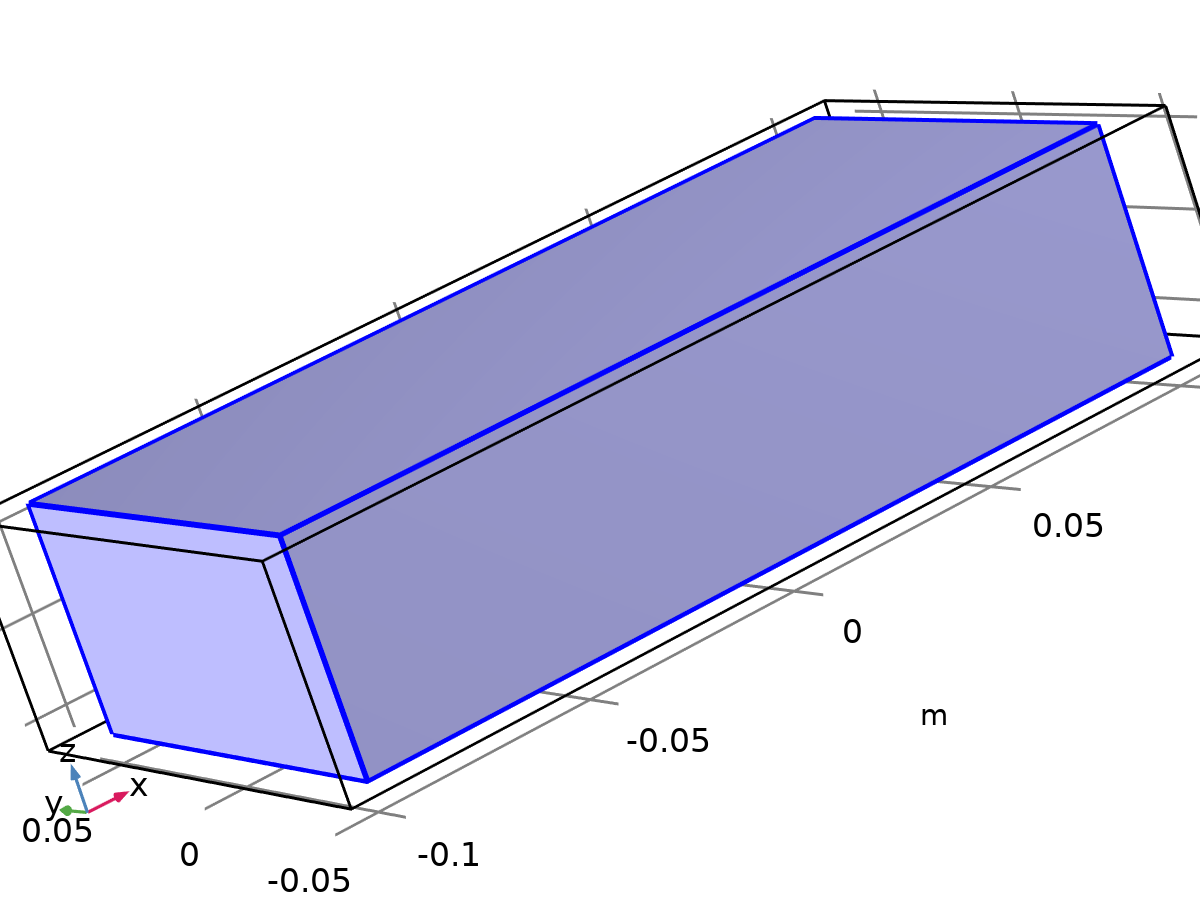
### Form Union (fin)

Information

| **Description** | **Value** |
| --- | --- |
| Build message | Formed union of 2 solid objects. Union has 2 domains, 12 boundaries, 24 edges, and 16 vertices. |

## Materials

### Battery block



Battery block

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domain 2 |

Material parameters

| **Name** | **Value** | **Unit** | **Property group** |
| --- | --- | --- | --- |
| Dynamic viscosity | eta(T) | Pa·s | Basic |
| Ratio of specific heats | 1.4 | 1 | Basic |
| Heat capacity at constant pressure | 1000 | J/(kg·K) | Basic |
| Density | 2500 | kg/m³ | Basic |
| Thermal conductivity | 1 | W/(m·K) | Basic |

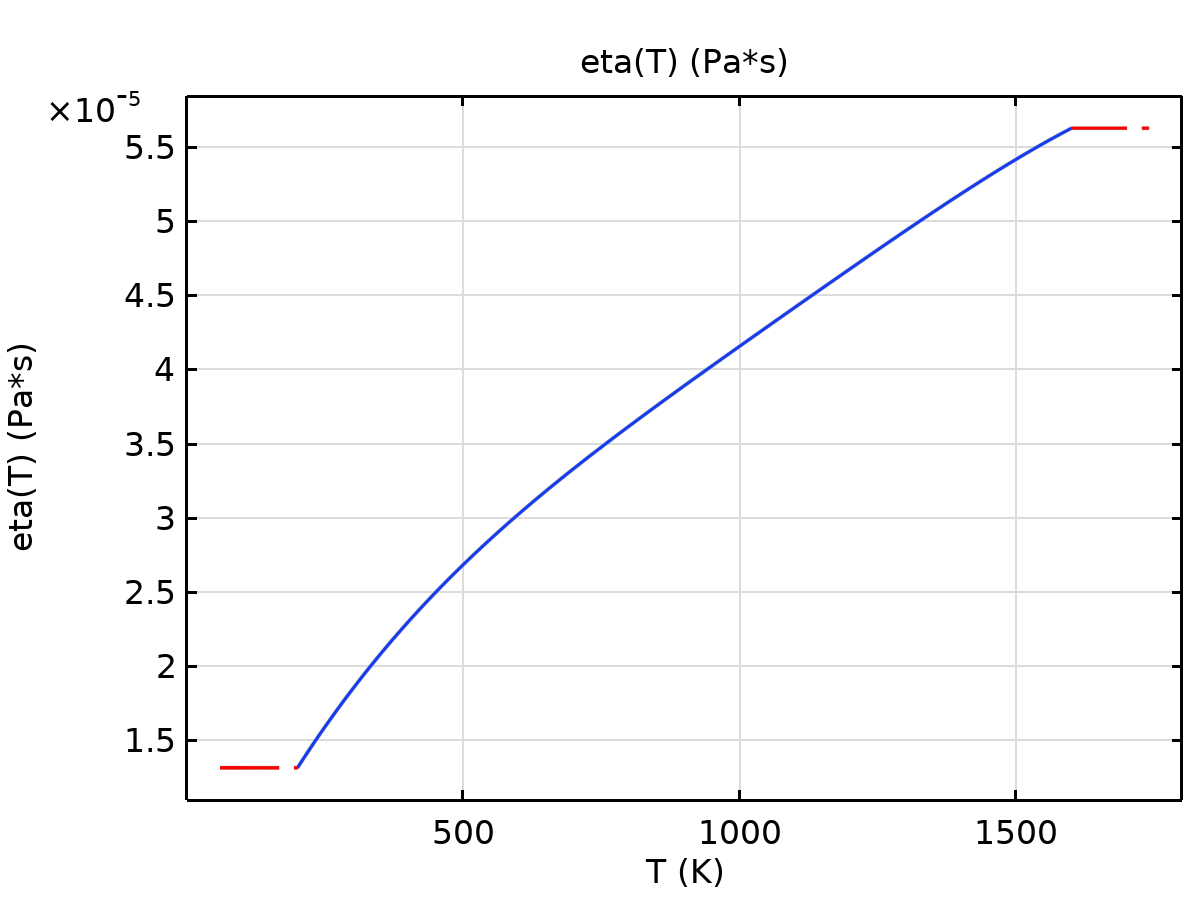
Basic

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Dynamic viscosity | eta(T) | Pa·s |
| Ratio of specific heats | 1.4 | 1 |
| Heat capacity at constant pressure | 1000 | J/(kg·K) |
| Density | 2500 | kg/m³ |
| Thermal conductivity | 1 | W/(m·K) |

Functions

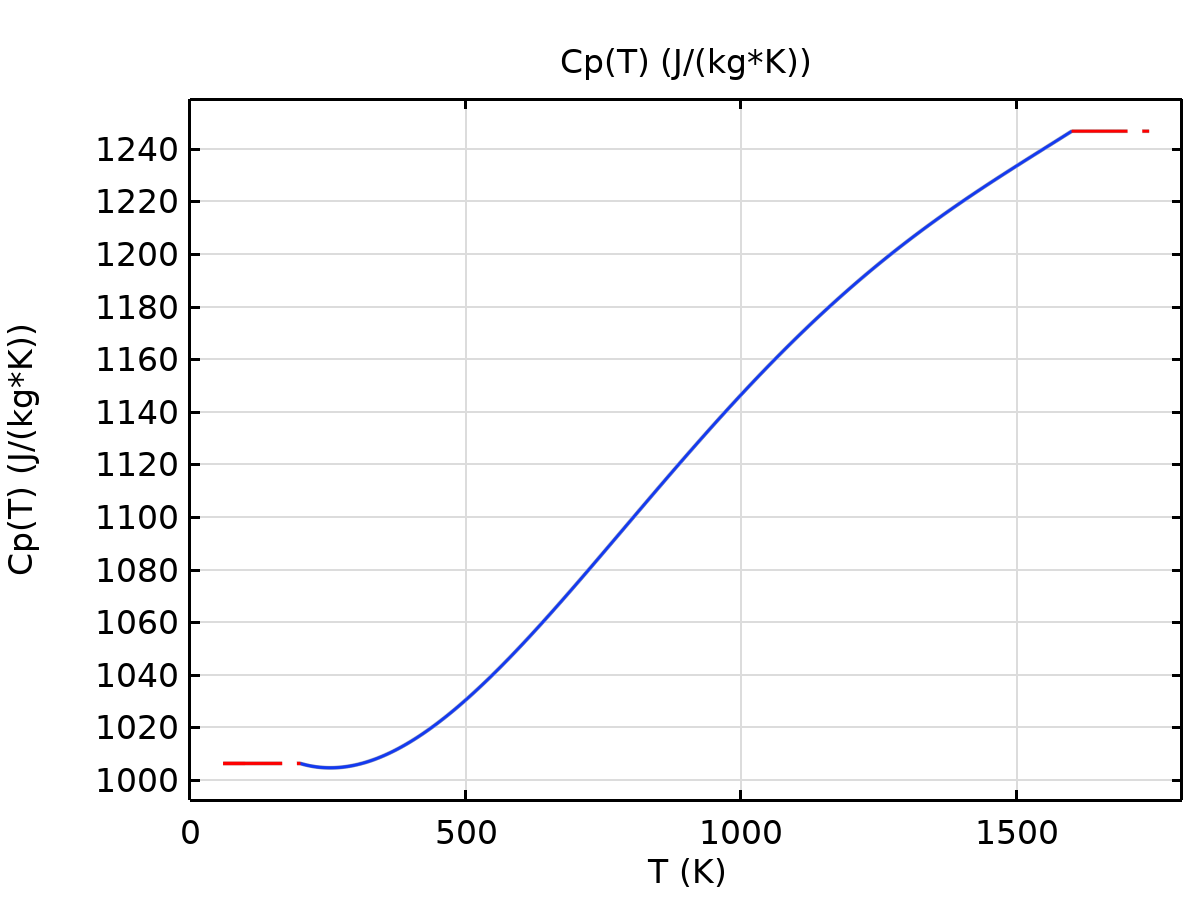
| **Function name** | **Type** |
| --- | --- |
| eta | Piecewise |
| Cp | Piecewise |
| rho | Analytic |
| k | Piecewise |
| cs | Analytic |
| alpha\_p | Analytic |
| muB | Analytic |

#### Piecewise



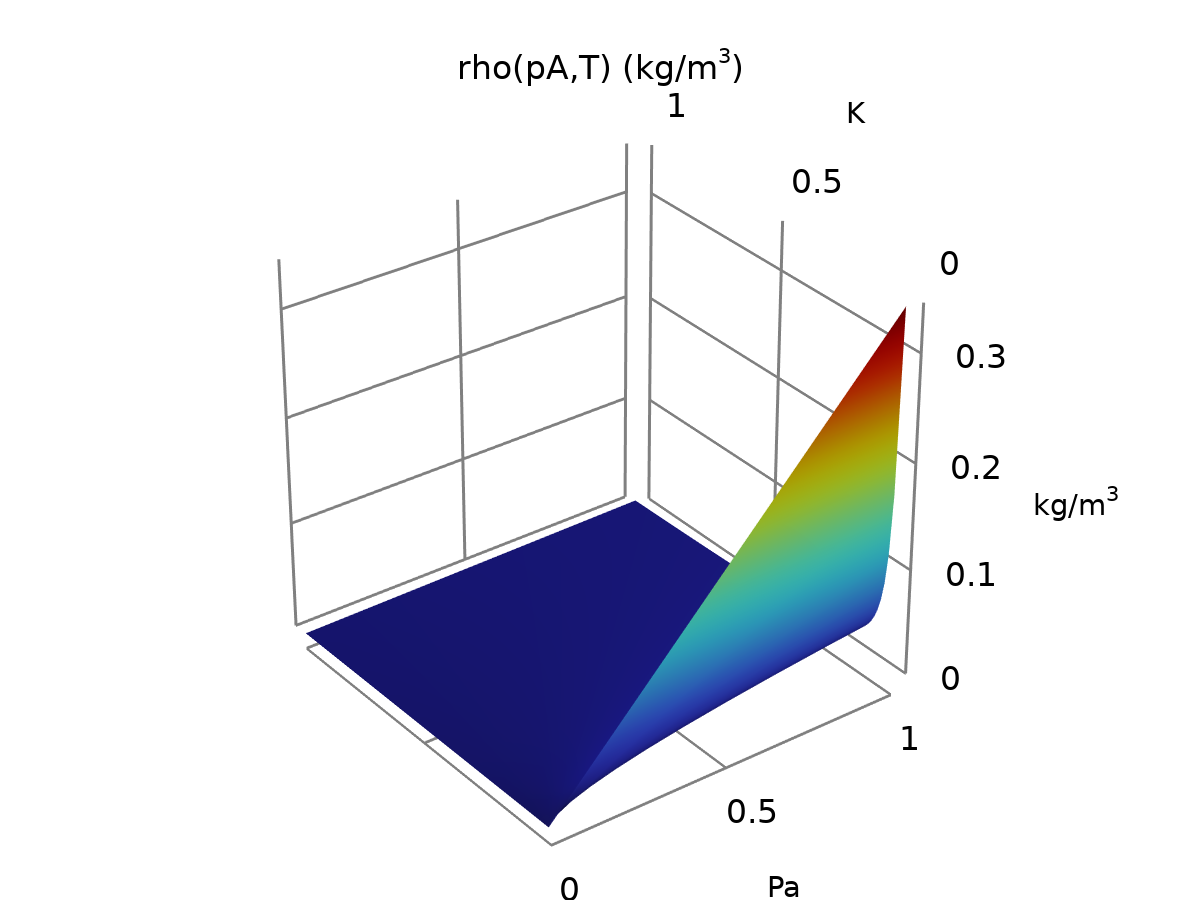
eta

#### Piecewise 2



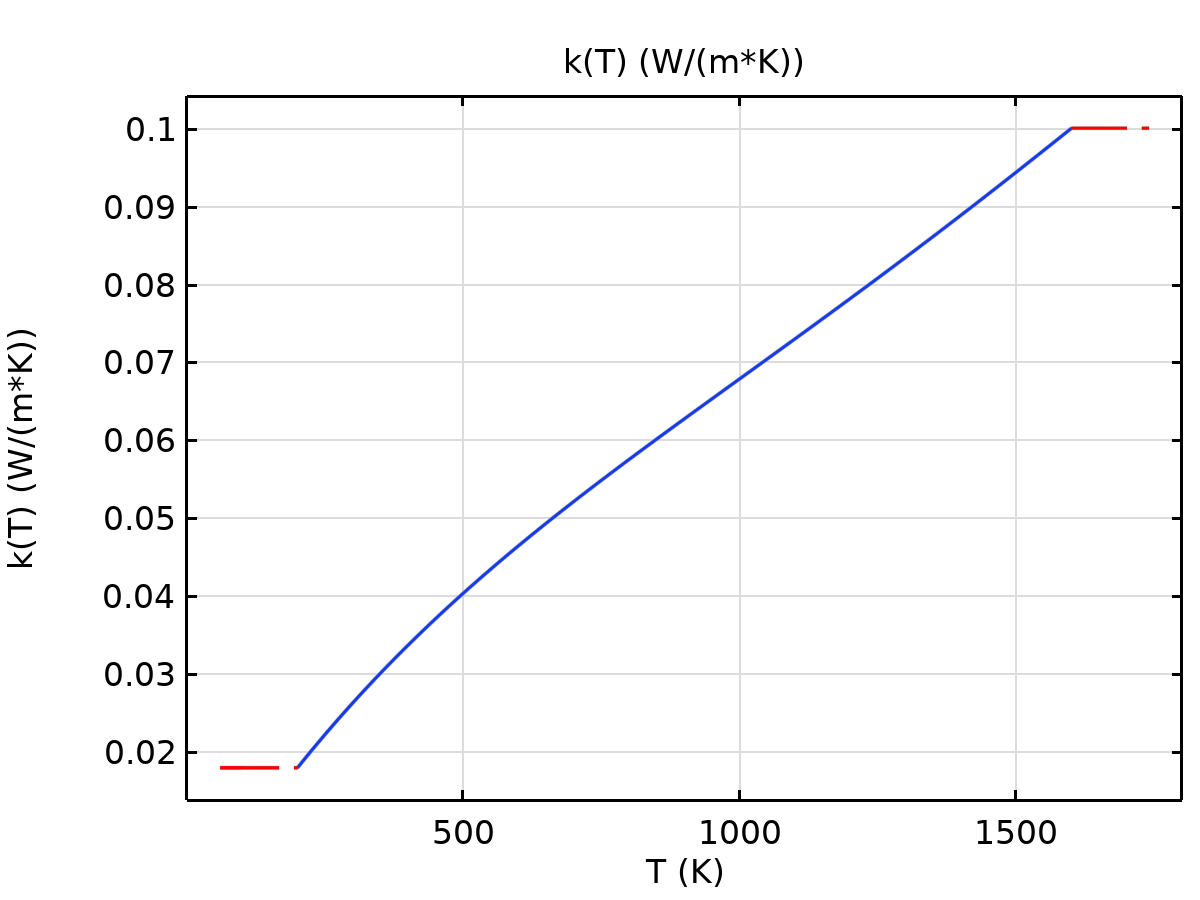
Cp

#### Analytic



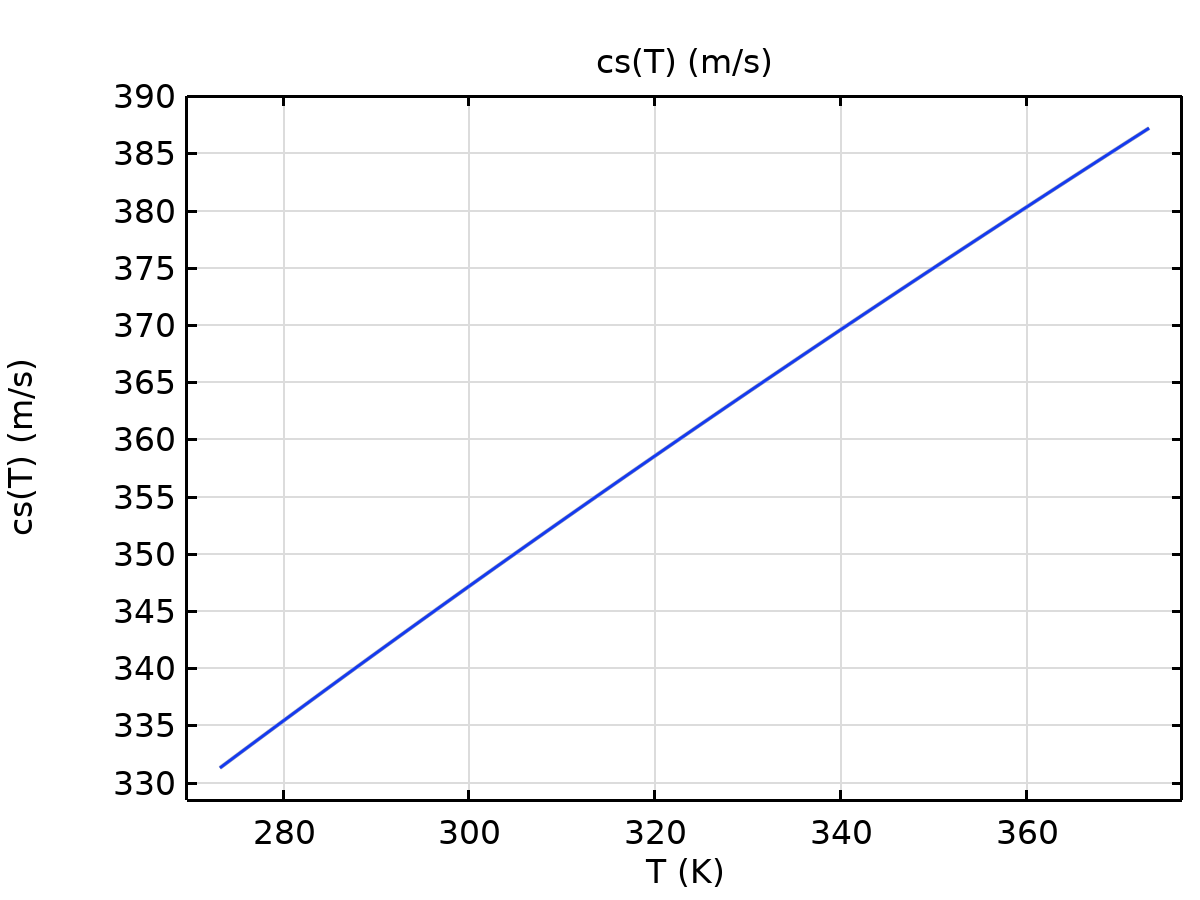
rho

#### Piecewise 3



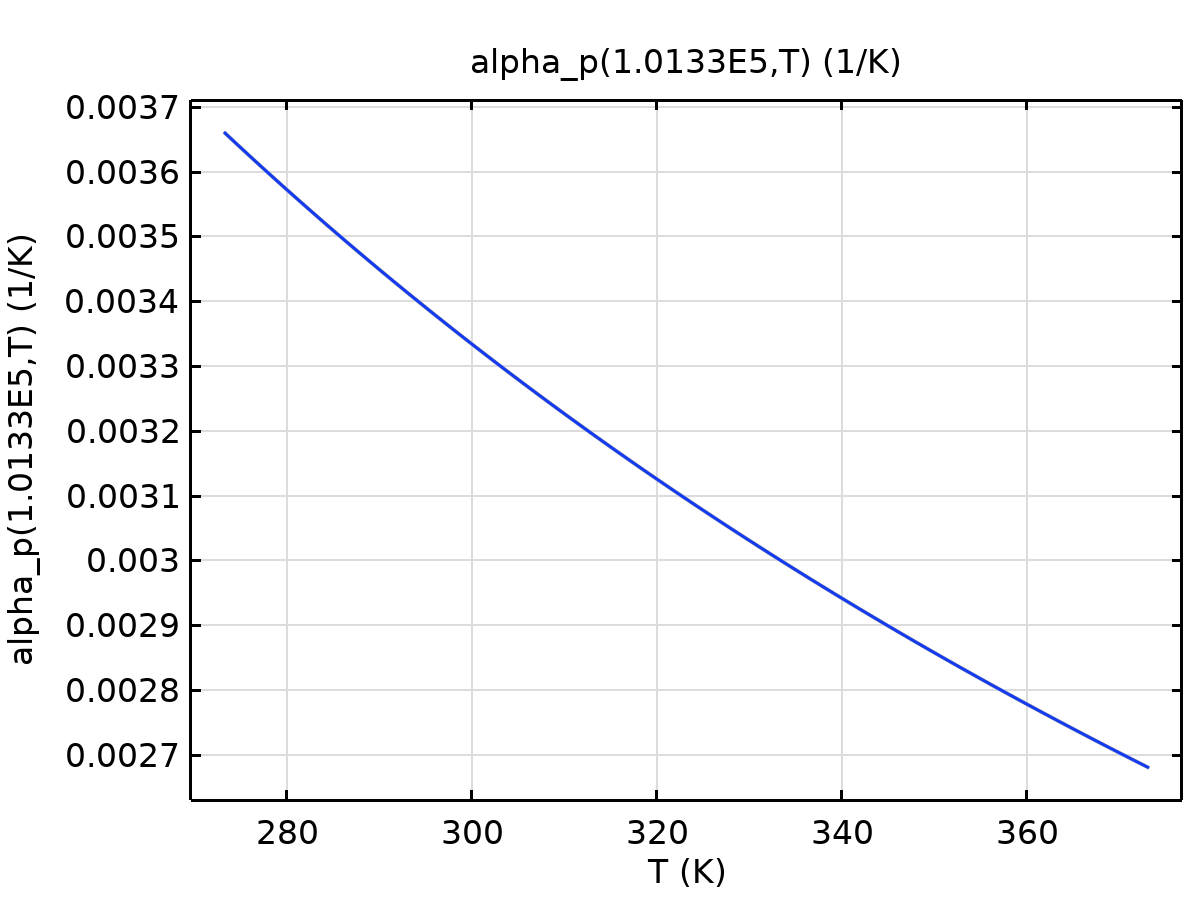
k

#### Analytic 2



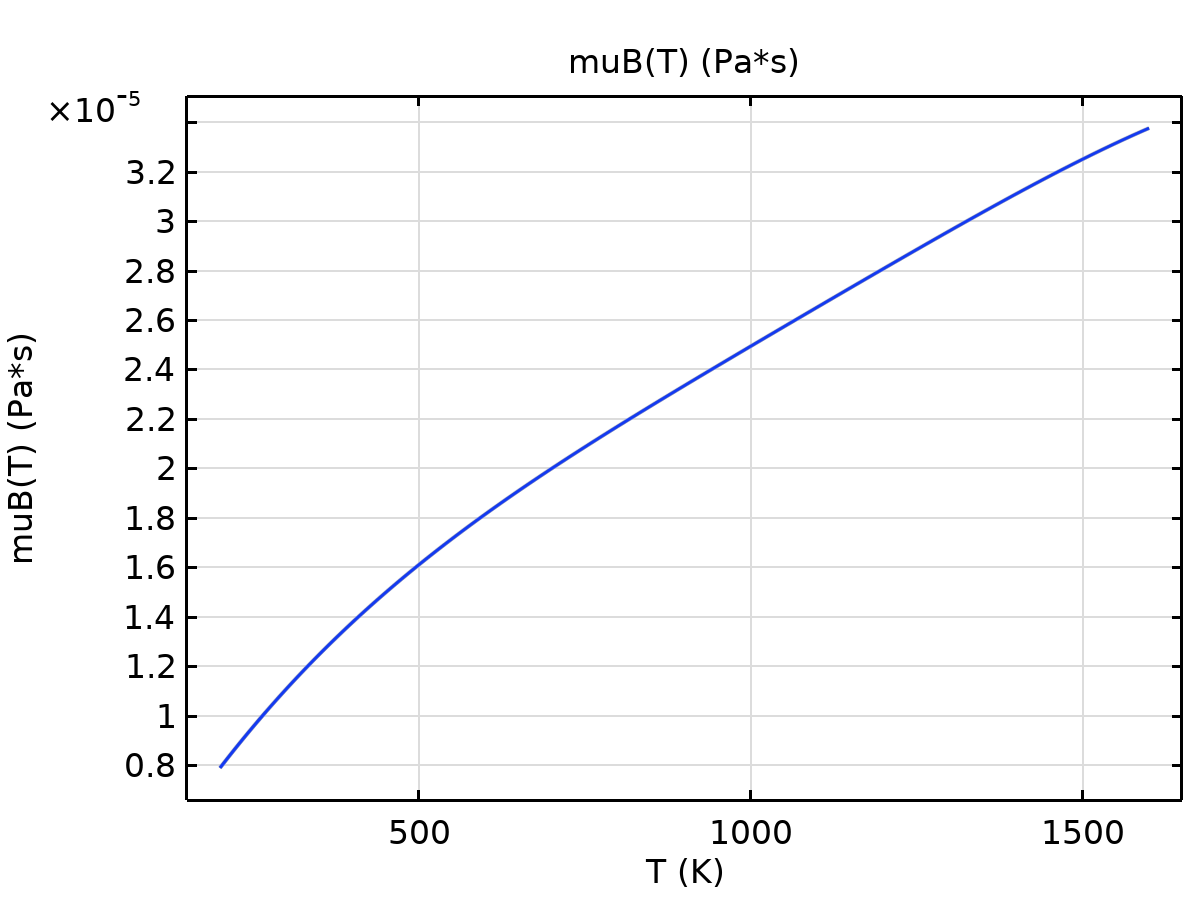
cs

#### Analytic 1



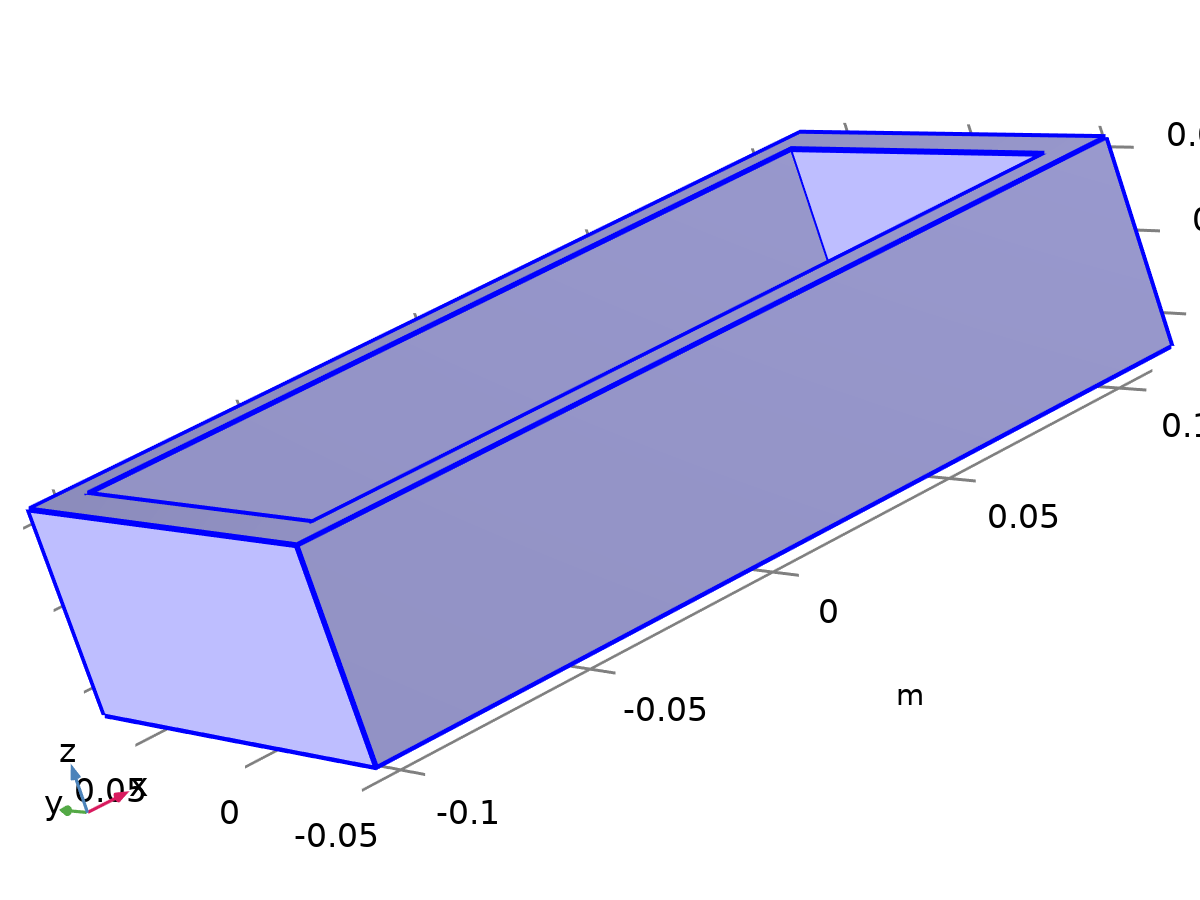
alpha\_p

#### Analytic 2a



muB

### PCM Layer



PCM Layer

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domain 1 |

Material parameters

| **Name** | **Value** | **Unit** | **Property group** |
| --- | --- | --- | --- |
| Dynamic viscosity | eta(T) | Pa·s | Basic |
| Ratio of specific heats | 1.4 | 1 | Basic |
| Heat capacity at constant pressure | 2000 | J/(kg·K) | Basic |
| Density | 800 | kg/m³ | Basic |
| Thermal conductivity | 0.2 | W/(m·K) | Basic |

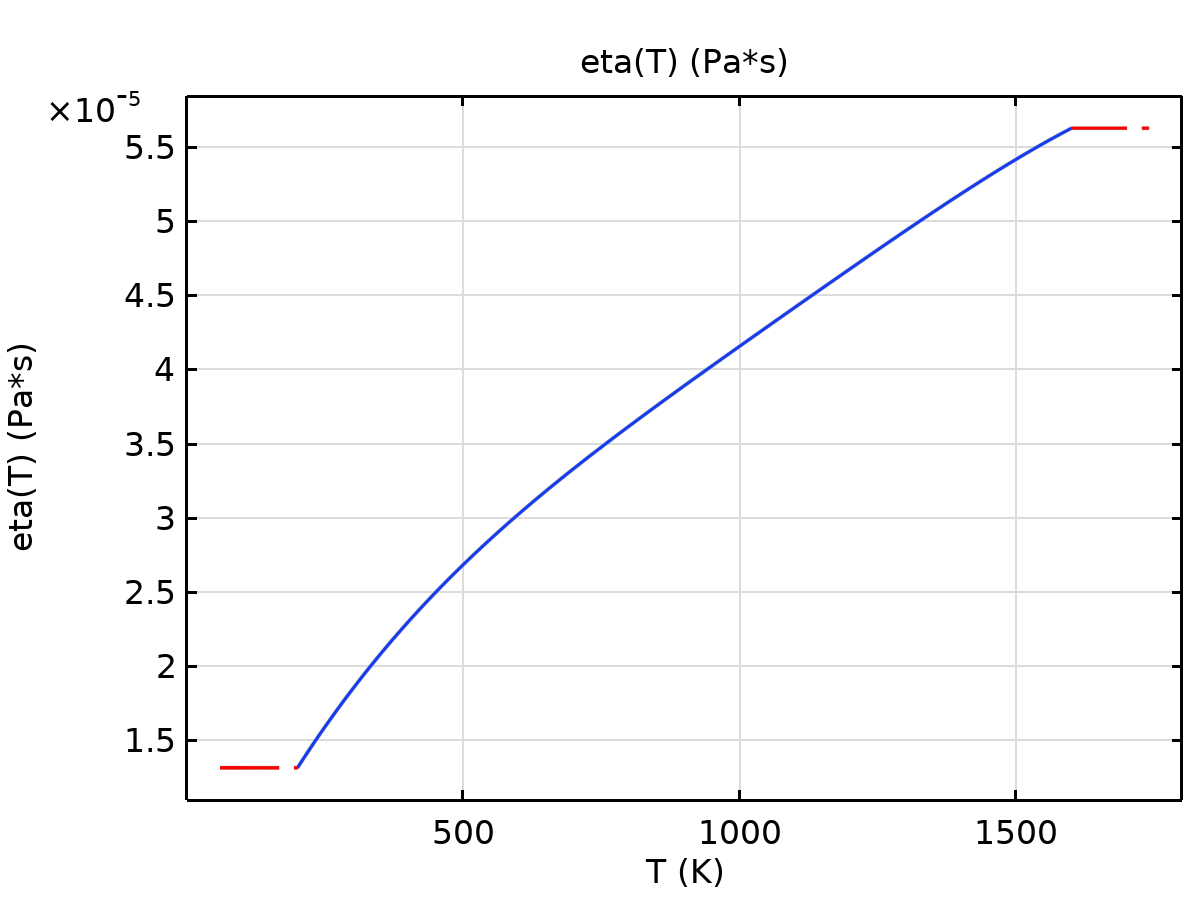
Basic

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Dynamic viscosity | eta(T) | Pa·s |
| Ratio of specific heats | 1.4 | 1 |
| Heat capacity at constant pressure | 2000 | J/(kg·K) |
| Density | 800 | kg/m³ |
| Thermal conductivity | 0.2 | W/(m·K) |

Functions

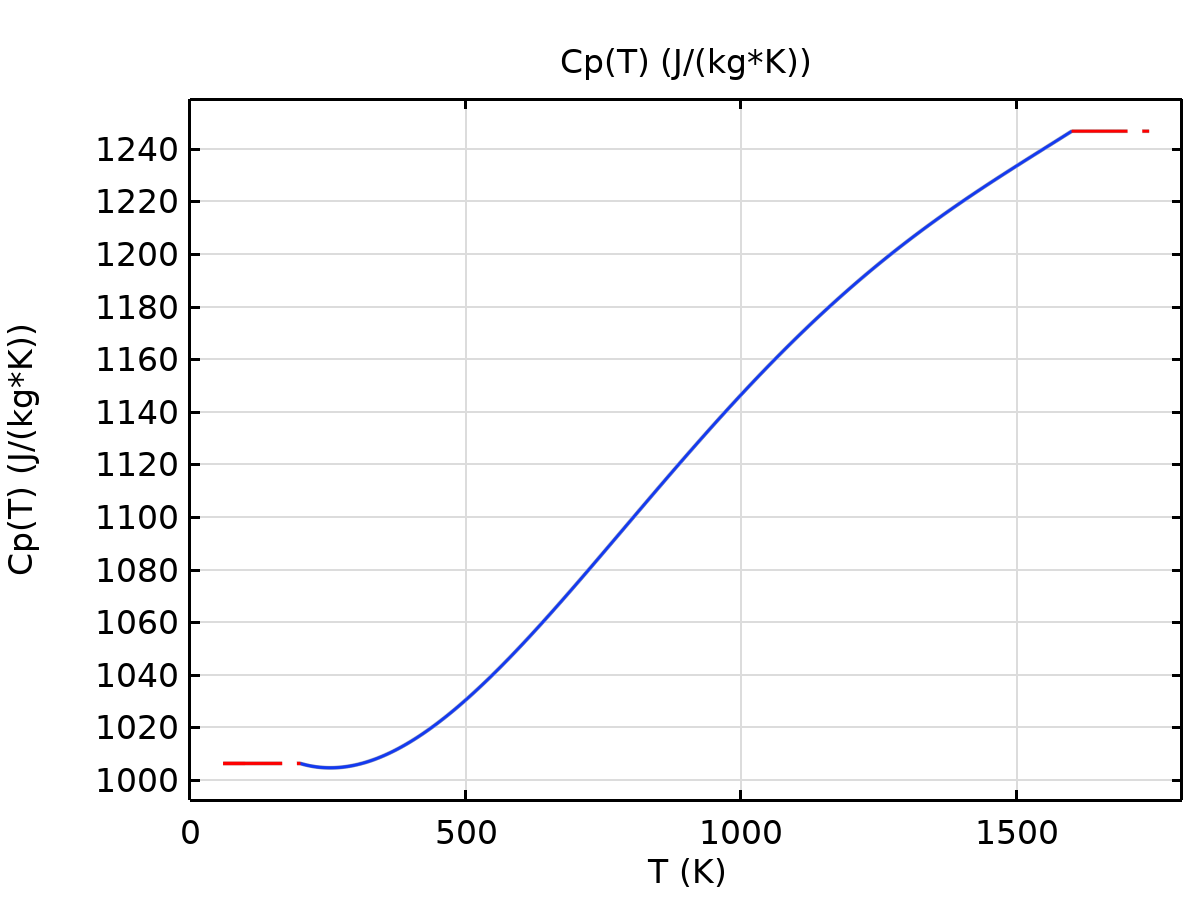
| **Function name** | **Type** |
| --- | --- |
| eta | Piecewise |
| Cp | Piecewise |
| rho | Analytic |
| k | Piecewise |
| cs | Analytic |
| alpha\_p | Analytic |
| muB | Analytic |

#### Piecewise



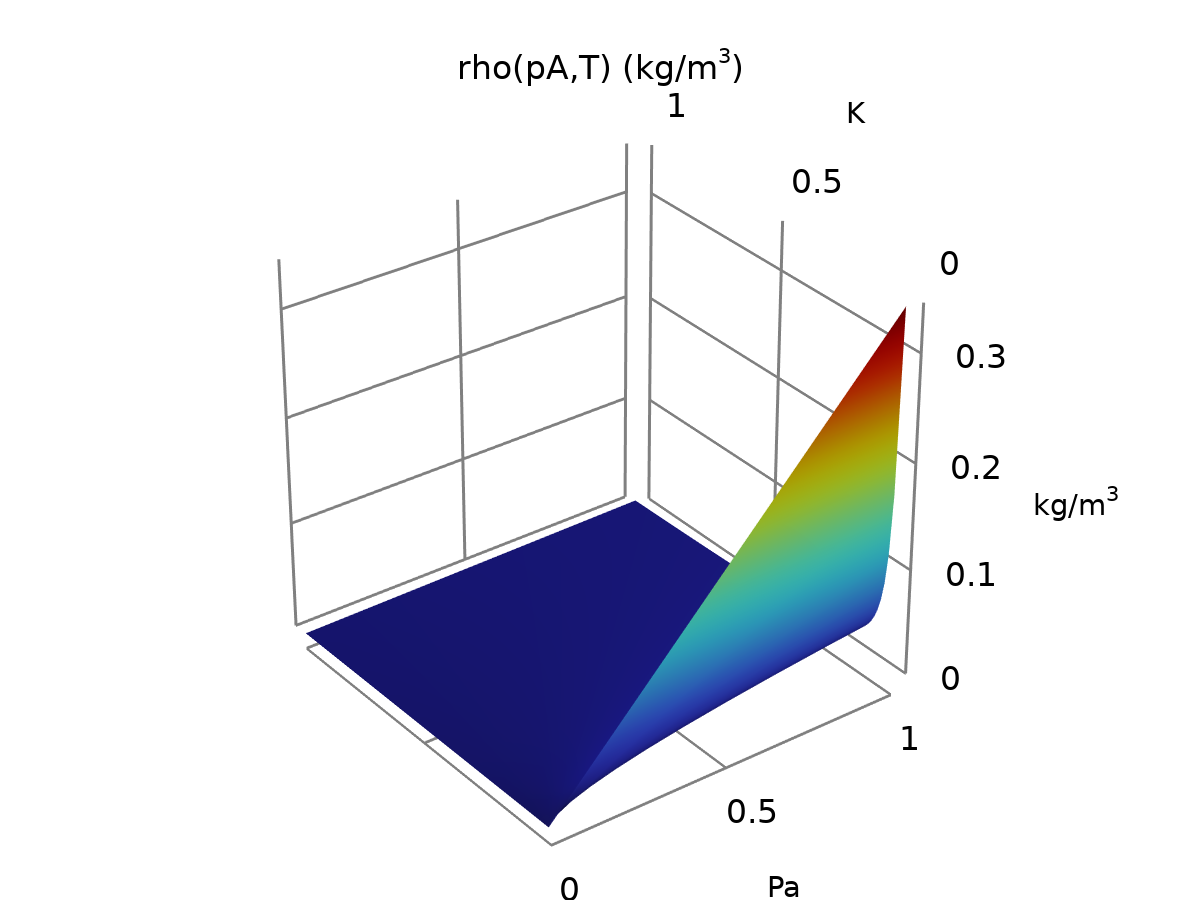
eta

#### Piecewise 2



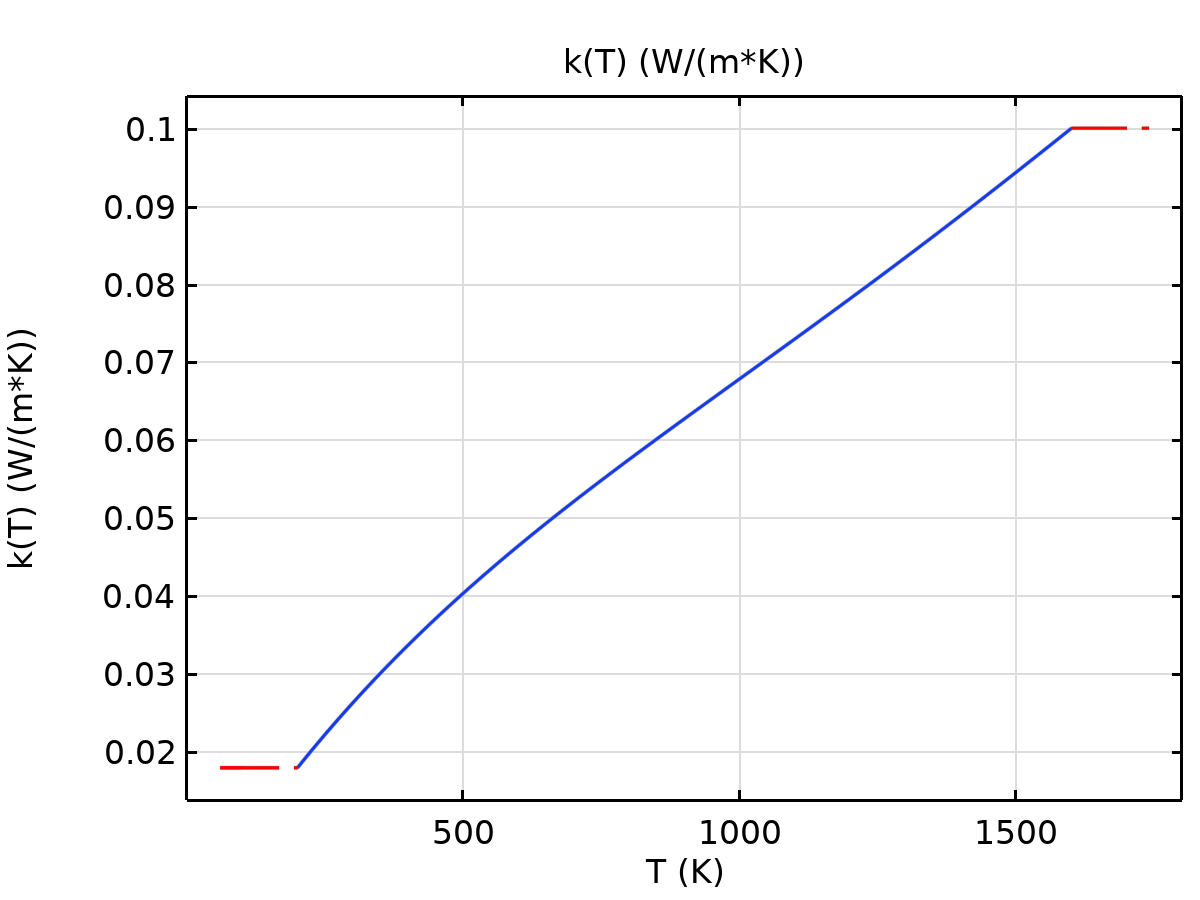
Cp

#### Analytic



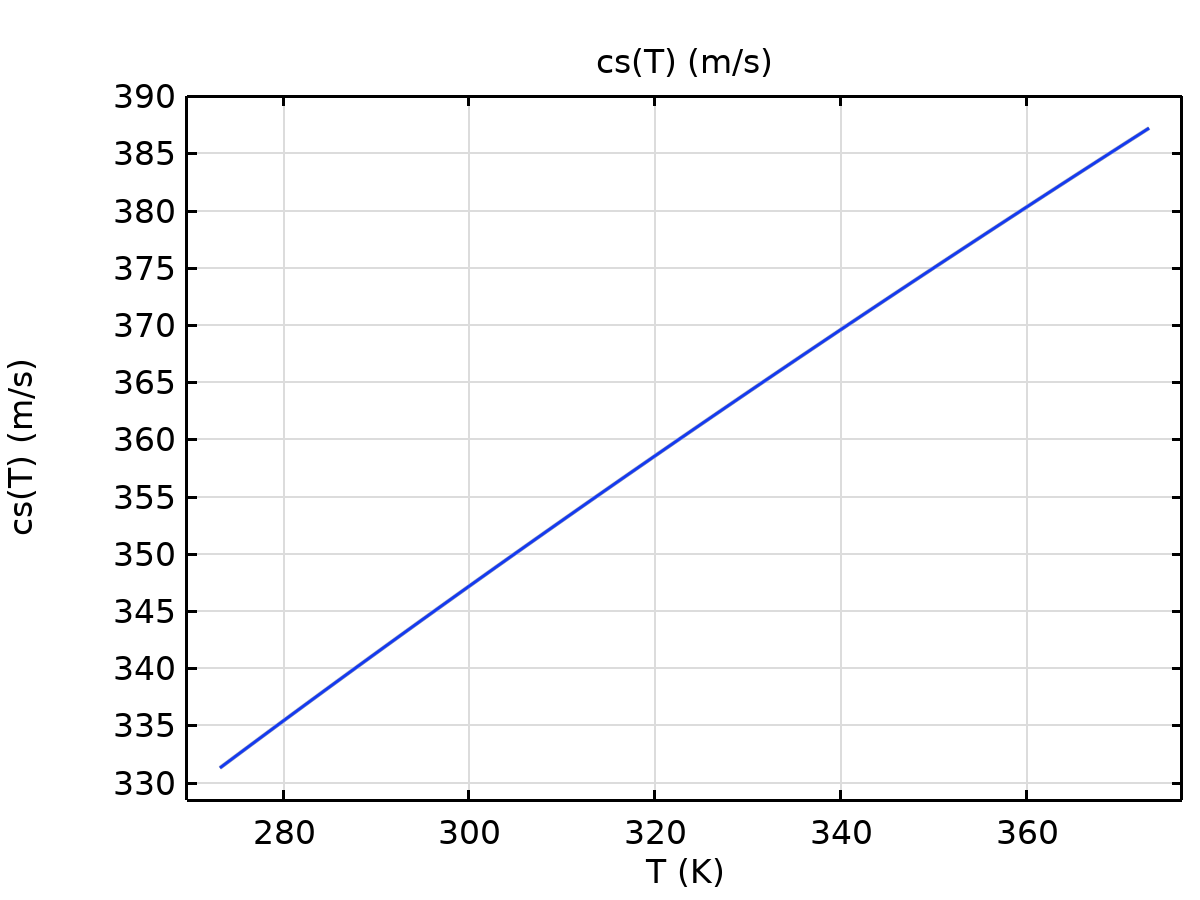
rho

#### Piecewise 3



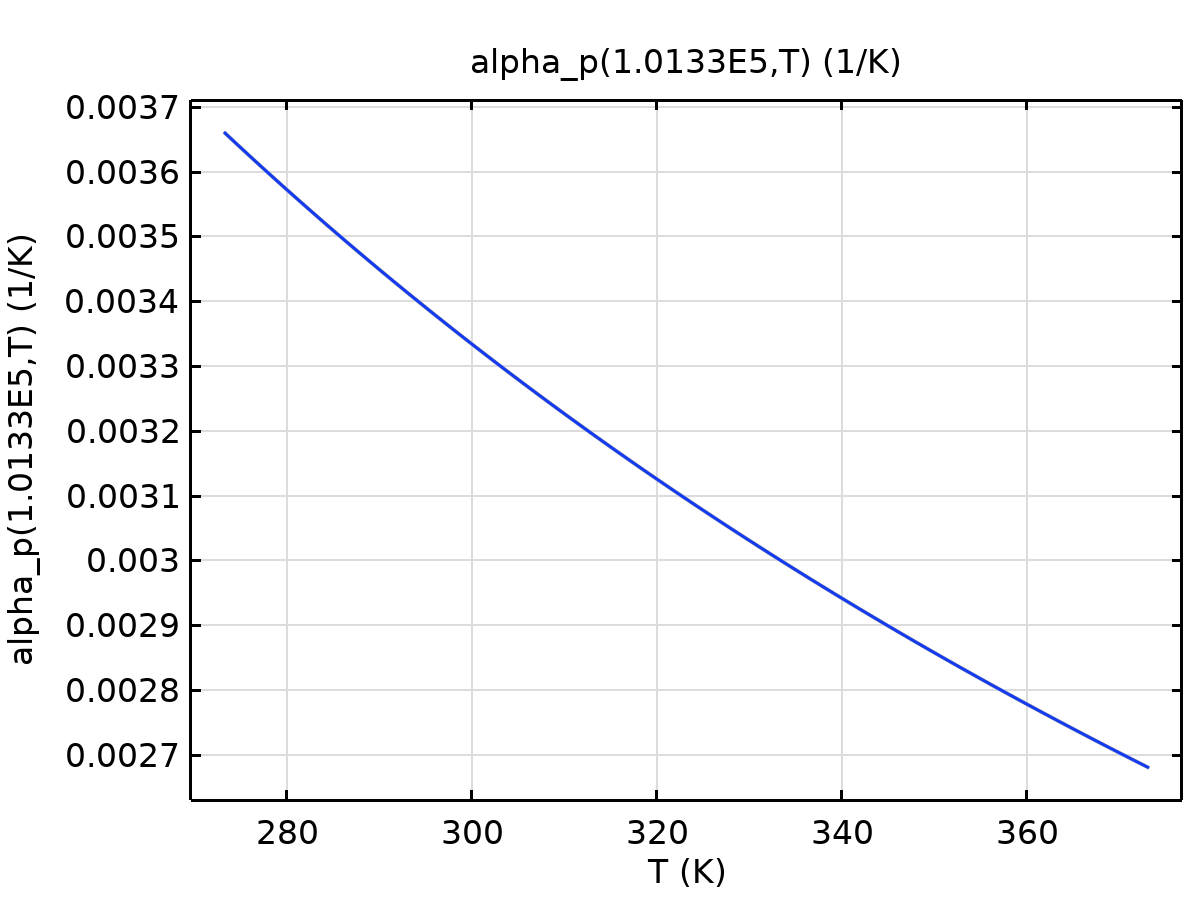
k

#### Analytic 2



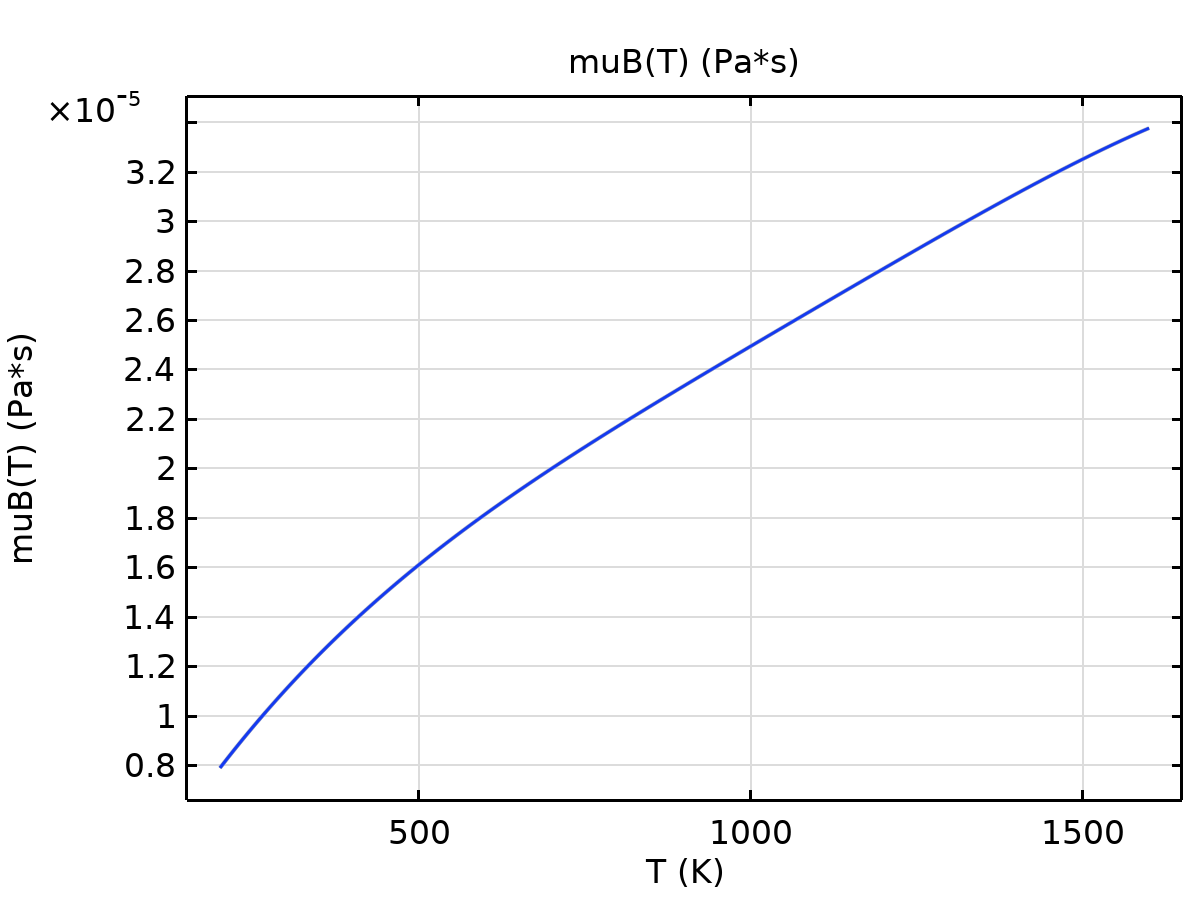
cs

#### Analytic 1



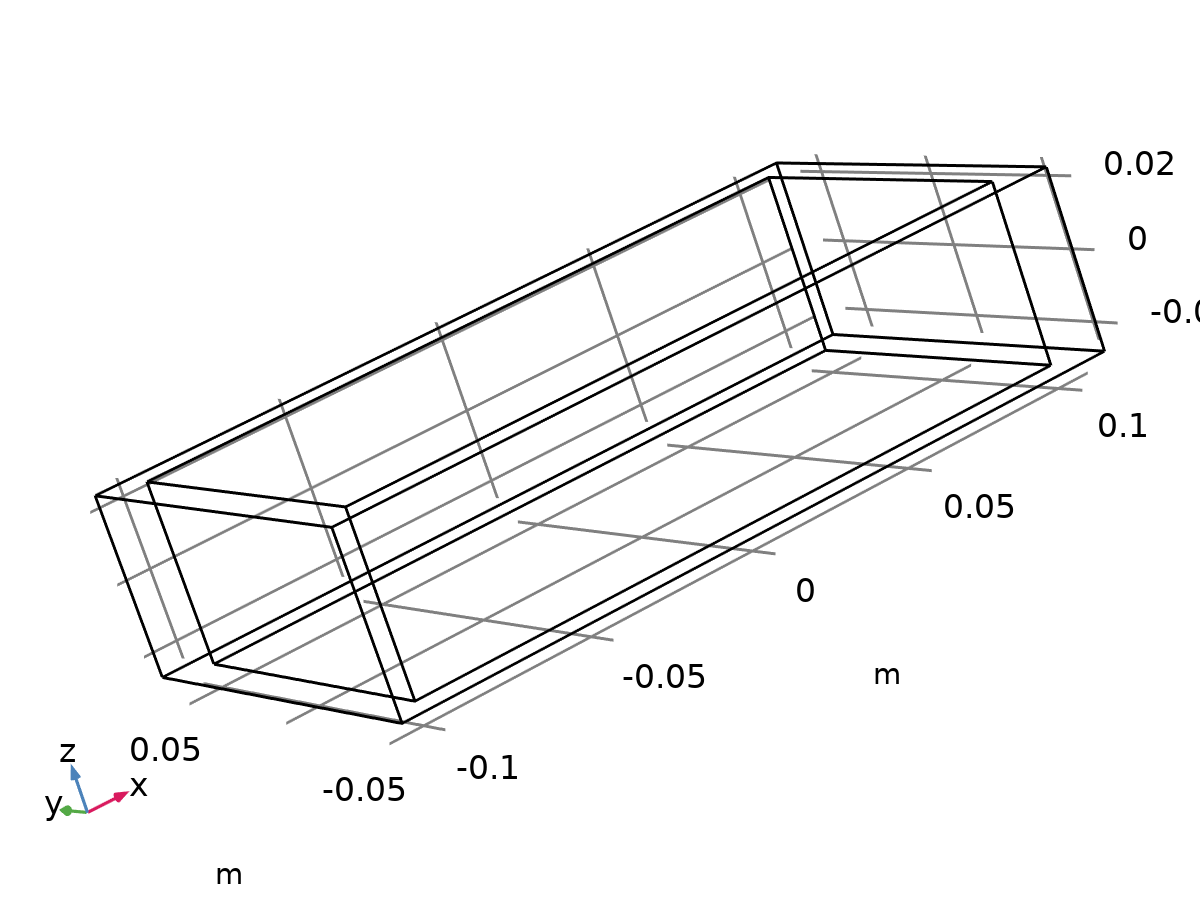
alpha\_p

#### Analytic 2a



muB

### Coolin Pipes



Coolin Pipes

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: No domains |

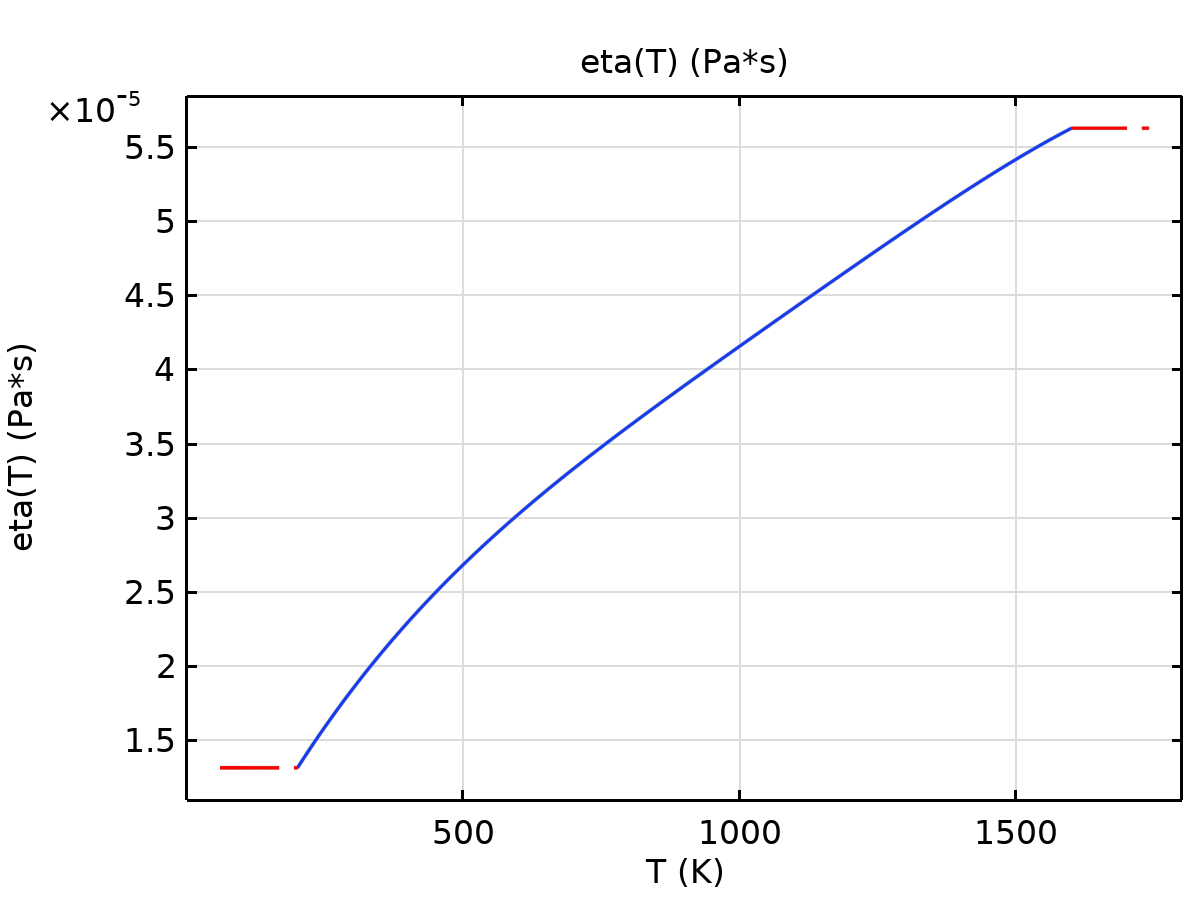
Basic

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Coefficient of thermal expansion | alpha\_p(pA, T) | 1/K |
| Mean molar mass | 0.02897 | kg/mol |
| Bulk viscosity | muB(T) | Pa·s |
| Relative permeability | 1 | 1 |
| Relative permittivity | 1 | 1 |
| Dynamic viscosity | eta(T) | Pa·s |
| Ratio of specific heats | 1.4 | 1 |
| Electric conductivity | 0 | S/m |
| Heat capacity at constant pressure | 4180 | J/(kg·K) |
| Density | 1050 | kg/m³ |
| Thermal conductivity | 0.6 | W/(m·K) |
| Speed of sound | cs(T) | m/s |

Functions

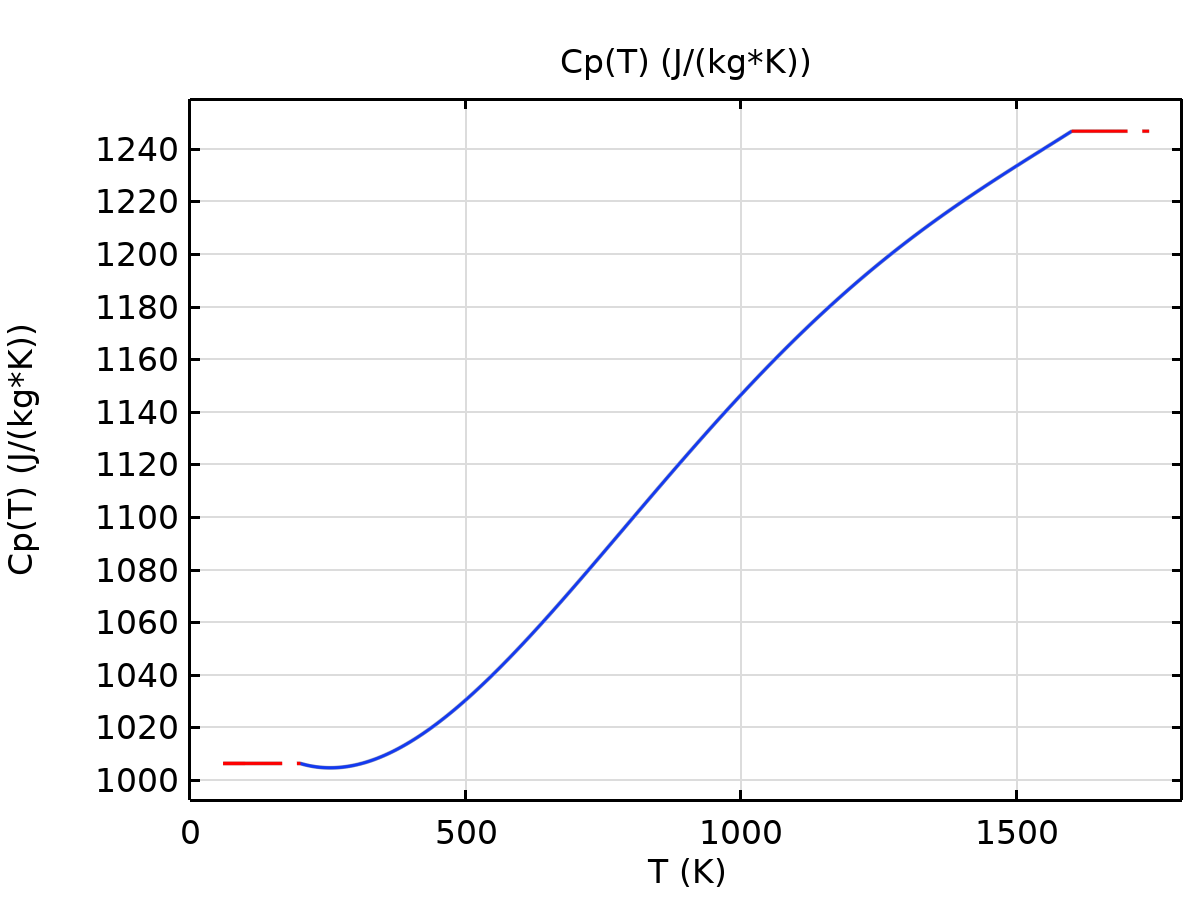
| **Function name** | **Type** |
| --- | --- |
| eta | Piecewise |
| Cp | Piecewise |
| rho | Analytic |
| k | Piecewise |
| cs | Analytic |
| alpha\_p | Analytic |
| muB | Analytic |

#### Piecewise



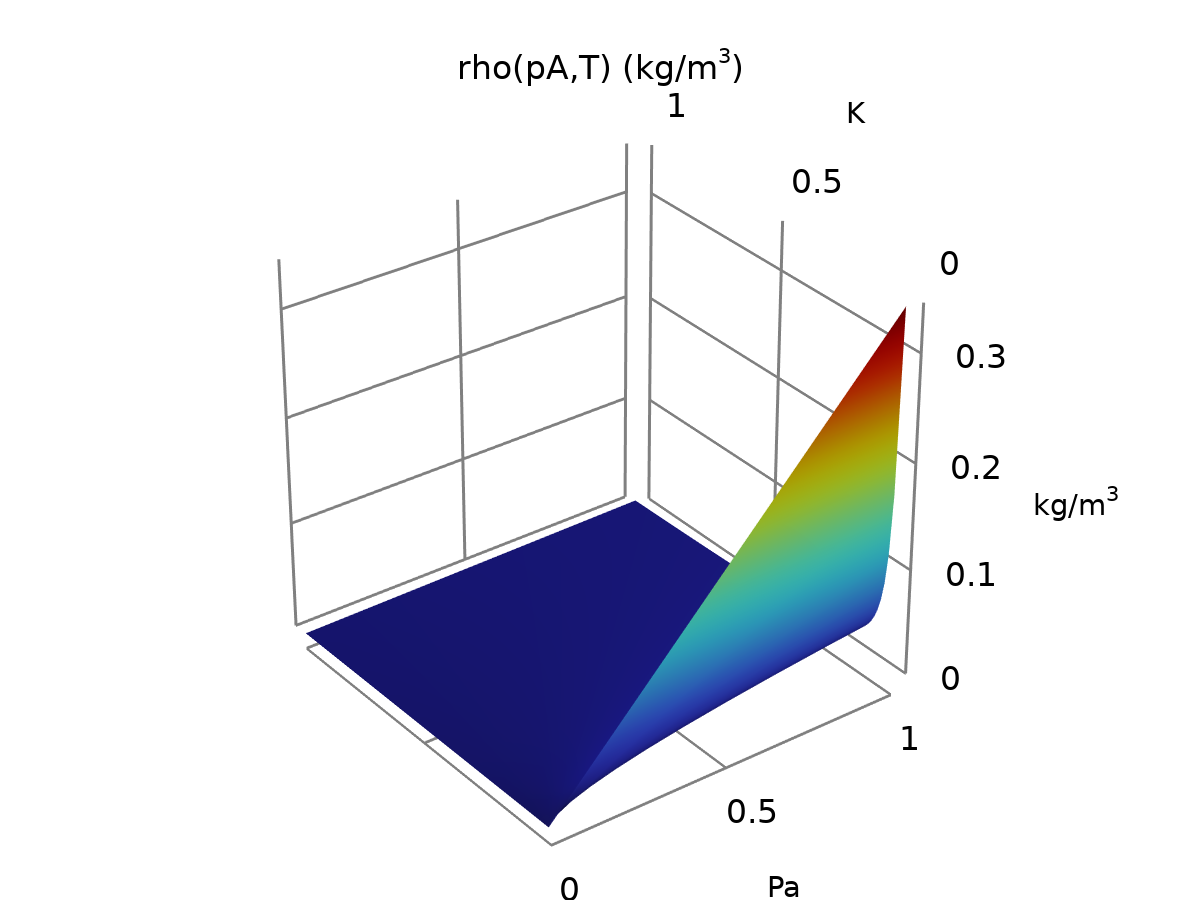
eta

#### Piecewise 2



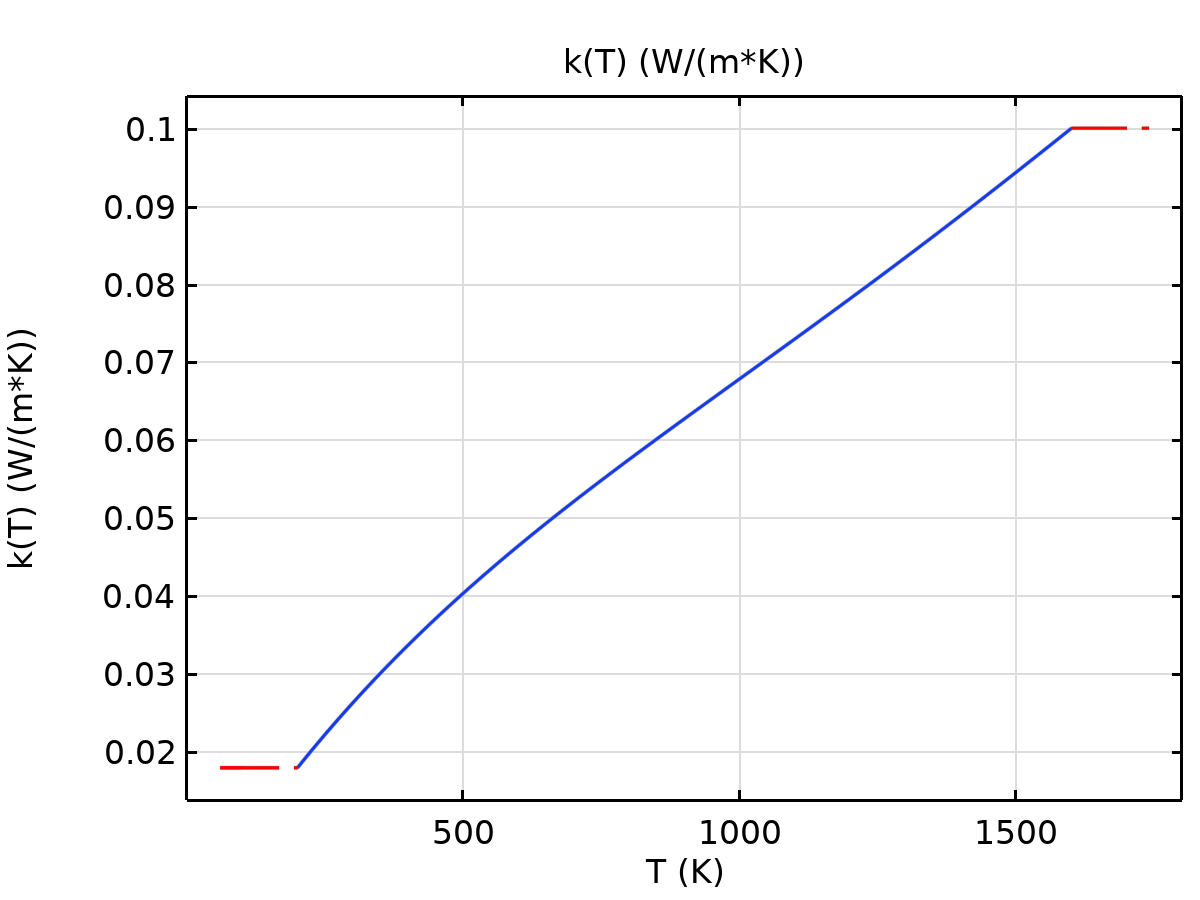
Cp

#### Analytic



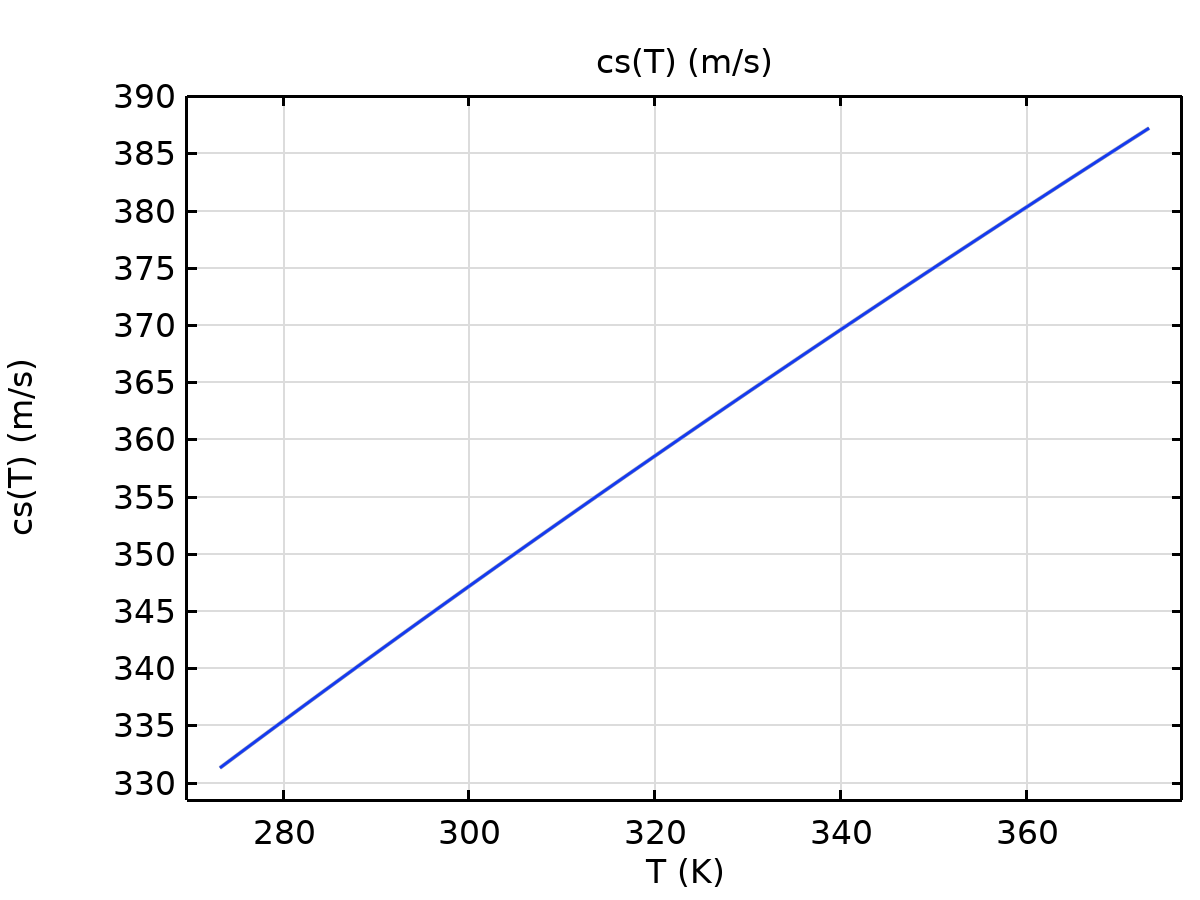
rho

#### Piecewise 3



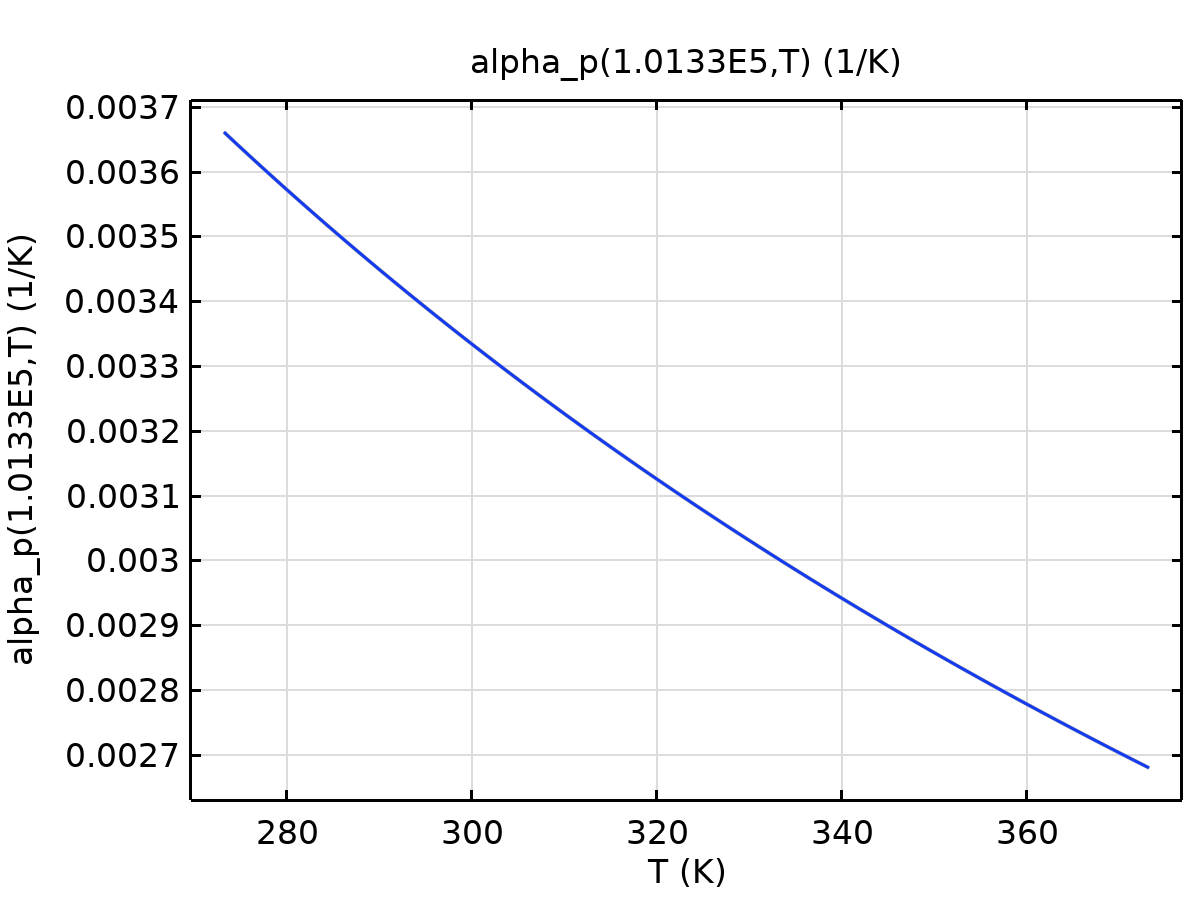
k

#### Analytic 2



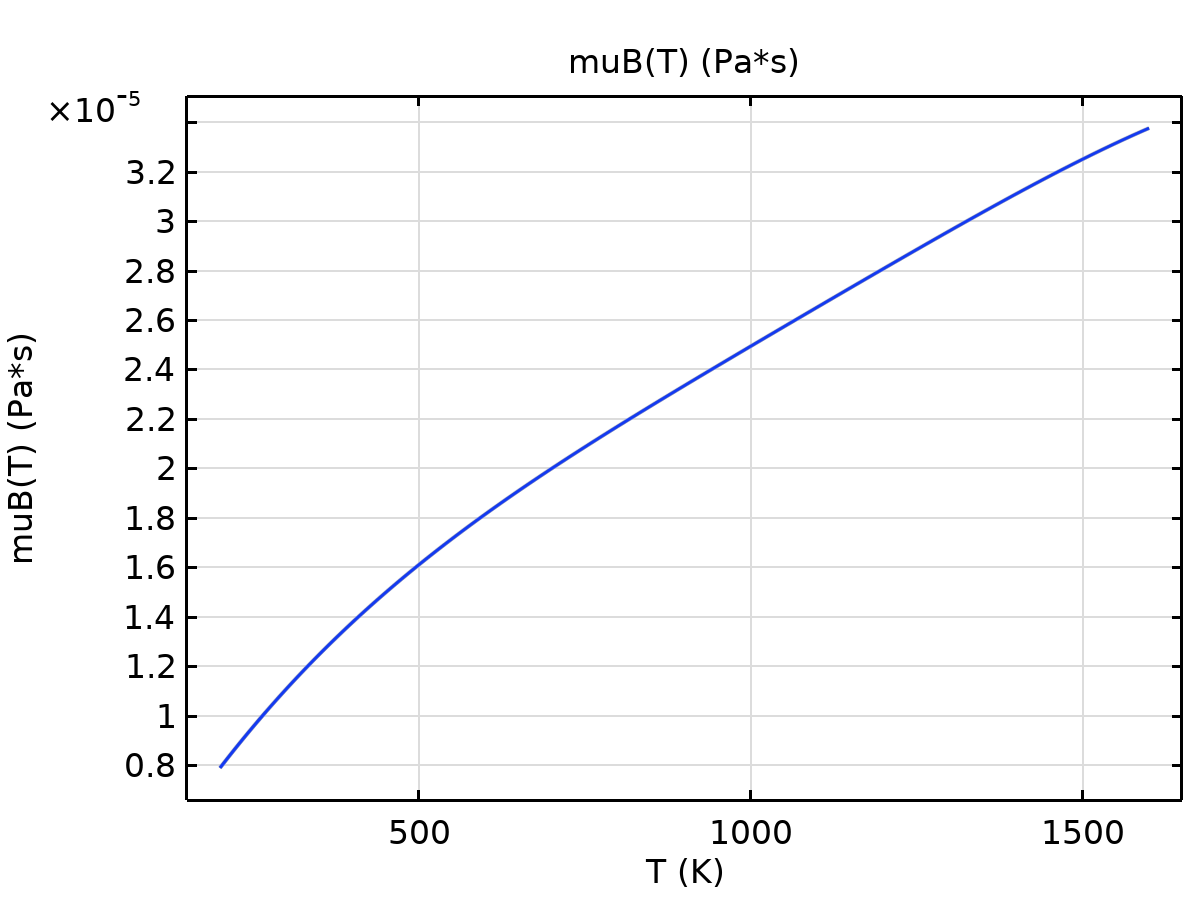
cs

#### Analytic 1



alpha\_p

#### Analytic 2a



muB

Refractive index

| **Description** | **Value** |
| --- | --- |
| Refractive index, real part | 1 |
| Refractive index, imaginary part | 0 |

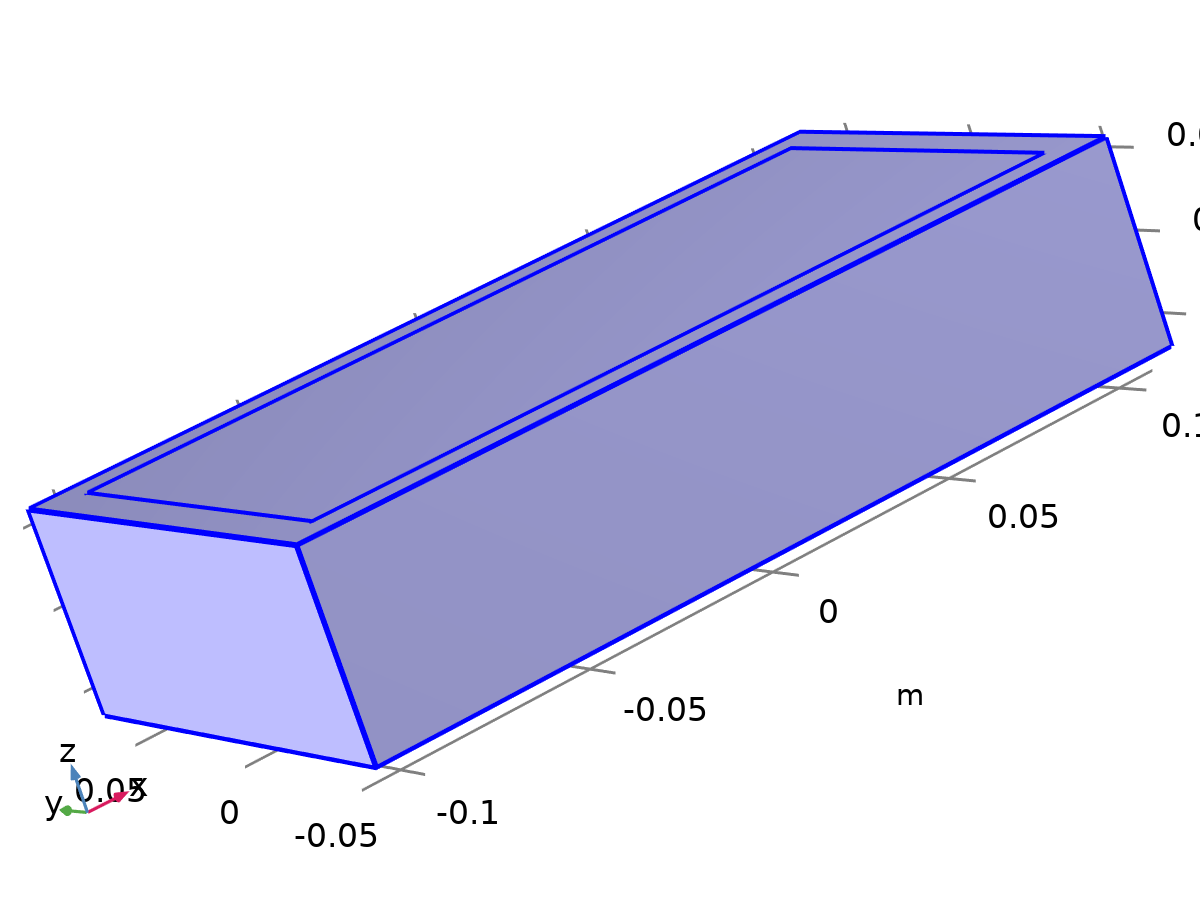
Nonlinear model

| **Description** | **Value** |
| --- | --- |
| Parameter of nonlinearity | (def.gamma + 1)/2 |

## Laminar Flow

Used products

|  |
| --- |
| COMSOL Multiphysics |

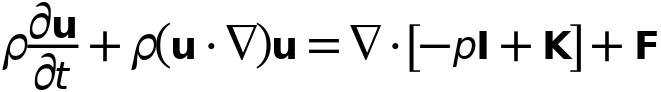


Laminar Flow

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Equations





### Interface Settings

#### Discretization

Settings

| **Description** | **Value** |
| --- | --- |
| Discretization of fluids | P1 + P1 |

Settings

| **Description** | **Value** |
| --- | --- |
| Equation form | Study controlled |

#### Physical Model

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Neglect inertial term (Stokes flow) | Off |  |
| Compressibility | Incompressible flow |  |
| Enable porous media domains | Off |  |
| Include gravity | Off |  |
| Reference temperature | User defined |  |
| Reference temperature | 293.15 | K |
| Reference pressure level | 1.0133E5 | Pa |

#### Turbulence

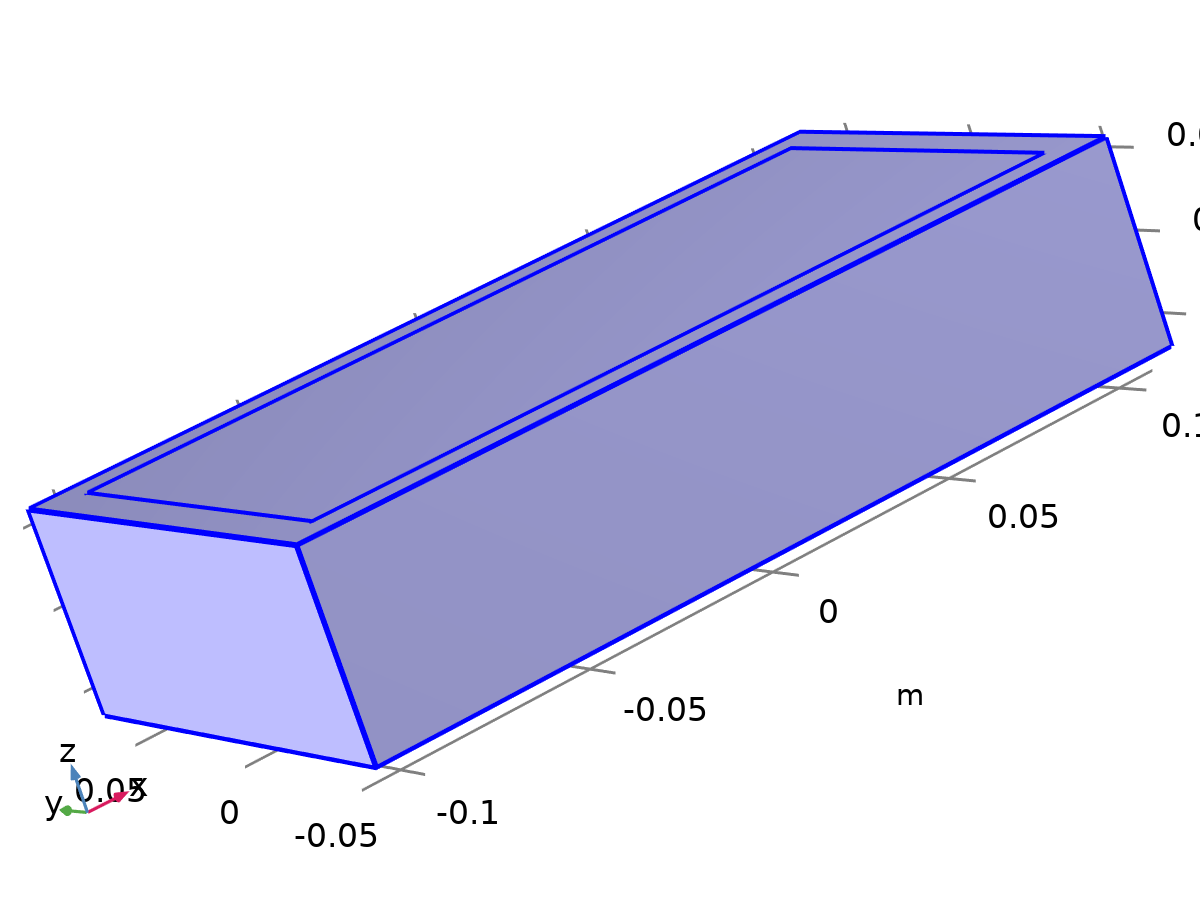
Settings

| **Description** | **Value** |
| --- | --- |
| Turbulence model type | None |

### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| spf.Tref | model.input.Tref | K | Reference temperature | Global | Meta |
| spf.dz | 1 | m | Thickness | Domains 1–2 |  |
| spf.pref | 1[atm] | Pa | Reference pressure level | Domains 1–2 |  |
| spf.pA | p+spf.pref | Pa | Absolute pressure | Domains 1–2 |  |
| spf.hasWF | 0 |  | Help variable | Boundaries 1–5, 8–9, 12 |  |
| spf.hasWF\_u | 0 |  | Help variable | Boundaries 6–7, 10–11 |  |
| spf.hasWF\_d | 0 |  | Help variable | Boundaries 6–7, 10–11 |  |
| spf.dt\_CFL | 1/max(spf.maxop(sqrt(emetric\_spatial(u-d(x,TIME),v-d(y,TIME),w-d(z,TIME)))),eps) | s | Time step, CFL=1 | Global |  |
| spf.CFL\_number | timestep/spf.dt\_CFL | 1 | CFL number | Global |  |
| spf.Qvd\_tot | spf.intop(spf.Qvd) | W | Total viscous dissipation | Global |  |
| spf.K\_stressx | spf.K\_stress\_tensorxx\*spf.nxmesh+spf.K\_stress\_tensorxy\*spf.nymesh+spf.K\_stress\_tensorxz\*spf.nzmesh | N/m² | Viscous stress, exterior boundaries, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.K\_stressy | spf.K\_stress\_tensoryx\*spf.nxmesh+spf.K\_stress\_tensoryy\*spf.nymesh+spf.K\_stress\_tensoryz\*spf.nzmesh | N/m² | Viscous stress, exterior boundaries, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.K\_stressz | spf.K\_stress\_tensorzx\*spf.nxmesh+spf.K\_stress\_tensorzy\*spf.nymesh+spf.K\_stress\_tensorzz\*spf.nzmesh | N/m² | Viscous stress, exterior boundaries, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_stressx | spf.T\_stress\_tensorxx\*spf.nxmesh+spf.T\_stress\_tensorxy\*spf.nymesh+spf.T\_stress\_tensorxz\*spf.nzmesh | N/m² | Total traction, exterior boundaries, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_stressy | spf.T\_stress\_tensoryx\*spf.nxmesh+spf.T\_stress\_tensoryy\*spf.nymesh+spf.T\_stress\_tensoryz\*spf.nzmesh | N/m² | Total traction, exterior boundaries, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_stressz | spf.T\_stress\_tensorzx\*spf.nxmesh+spf.T\_stress\_tensorzy\*spf.nymesh+spf.T\_stress\_tensorzz\*spf.nzmesh | N/m² | Total traction, exterior boundaries, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.K\_stress\_dx | down(spf.K\_stress\_tensorxx)\*spf.nxmesh+down(spf.K\_stress\_tensorxy)\*spf.nymesh+down(spf.K\_stress\_tensorxz)\*spf.nzmesh | N/m² | Viscous stress, interior boundaries, downside, x-component | Boundaries 6–7, 10–11 |  |
| spf.K\_stress\_dy | down(spf.K\_stress\_tensoryx)\*spf.nxmesh+down(spf.K\_stress\_tensoryy)\*spf.nymesh+down(spf.K\_stress\_tensoryz)\*spf.nzmesh | N/m² | Viscous stress, interior boundaries, downside, y-component | Boundaries 6–7, 10–11 |  |
| spf.K\_stress\_dz | down(spf.K\_stress\_tensorzx)\*spf.nxmesh+down(spf.K\_stress\_tensorzy)\*spf.nymesh+down(spf.K\_stress\_tensorzz)\*spf.nzmesh | N/m² | Viscous stress, interior boundaries, downside, z-component | Boundaries 6–7, 10–11 |  |
| spf.K\_stress\_dx | down(spf.K\_stress\_tensorxx)\*spf.dnxmesh+down(spf.K\_stress\_tensorxy)\*spf.dnymesh+down(spf.K\_stress\_tensorxz)\*spf.dnzmesh | N/m² | Viscous stress, interior boundaries, downside, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.K\_stress\_dy | down(spf.K\_stress\_tensoryx)\*spf.dnxmesh+down(spf.K\_stress\_tensoryy)\*spf.dnymesh+down(spf.K\_stress\_tensoryz)\*spf.dnzmesh | N/m² | Viscous stress, interior boundaries, downside, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.K\_stress\_dz | down(spf.K\_stress\_tensorzx)\*spf.dnxmesh+down(spf.K\_stress\_tensorzy)\*spf.dnymesh+down(spf.K\_stress\_tensorzz)\*spf.dnzmesh | N/m² | Viscous stress, interior boundaries, downside, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.K\_stress\_ux | -up(spf.K\_stress\_tensorxx)\*spf.nxmesh-up(spf.K\_stress\_tensorxy)\*spf.nymesh-up(spf.K\_stress\_tensorxz)\*spf.nzmesh | N/m² | Viscous stress, interior boundaries, upside, x-component | Boundaries 6–7, 10–11 |  |
| spf.K\_stress\_uy | -up(spf.K\_stress\_tensoryx)\*spf.nxmesh-up(spf.K\_stress\_tensoryy)\*spf.nymesh-up(spf.K\_stress\_tensoryz)\*spf.nzmesh | N/m² | Viscous stress, interior boundaries, upside, y-component | Boundaries 6–7, 10–11 |  |
| spf.K\_stress\_uz | -up(spf.K\_stress\_tensorzx)\*spf.nxmesh-up(spf.K\_stress\_tensorzy)\*spf.nymesh-up(spf.K\_stress\_tensorzz)\*spf.nzmesh | N/m² | Viscous stress, interior boundaries, upside, z-component | Boundaries 6–7, 10–11 |  |
| spf.T\_stress\_dx | down(spf.T\_stress\_tensorxx)\*spf.nxmesh+down(spf.T\_stress\_tensorxy)\*spf.nymesh+down(spf.T\_stress\_tensorxz)\*spf.nzmesh | N/m² | Total traction, interior boundaries, downside, x-component | Boundaries 6–7, 10–11 |  |
| spf.T\_stress\_dy | down(spf.T\_stress\_tensoryx)\*spf.nxmesh+down(spf.T\_stress\_tensoryy)\*spf.nymesh+down(spf.T\_stress\_tensoryz)\*spf.nzmesh | N/m² | Total traction, interior boundaries, downside, y-component | Boundaries 6–7, 10–11 |  |
| spf.T\_stress\_dz | down(spf.T\_stress\_tensorzx)\*spf.nxmesh+down(spf.T\_stress\_tensorzy)\*spf.nymesh+down(spf.T\_stress\_tensorzz)\*spf.nzmesh | N/m² | Total traction, interior boundaries, downside, z-component | Boundaries 6–7, 10–11 |  |
| spf.T\_stress\_dx | down(spf.T\_stress\_tensorxx)\*spf.dnxmesh+down(spf.T\_stress\_tensorxy)\*spf.dnymesh+down(spf.T\_stress\_tensorxz)\*spf.dnzmesh | N/m² | Total traction, interior boundaries, downside, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_stress\_dy | down(spf.T\_stress\_tensoryx)\*spf.dnxmesh+down(spf.T\_stress\_tensoryy)\*spf.dnymesh+down(spf.T\_stress\_tensoryz)\*spf.dnzmesh | N/m² | Total traction, interior boundaries, downside, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_stress\_dz | down(spf.T\_stress\_tensorzx)\*spf.dnxmesh+down(spf.T\_stress\_tensorzy)\*spf.dnymesh+down(spf.T\_stress\_tensorzz)\*spf.dnzmesh | N/m² | Total traction, interior boundaries, downside, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_stress\_ux | -up(spf.T\_stress\_tensorxx)\*spf.nxmesh-up(spf.T\_stress\_tensorxy)\*spf.nymesh-up(spf.T\_stress\_tensorxz)\*spf.nzmesh | N/m² | Total traction, interior boundaries, upside, x-component | Boundaries 6–7, 10–11 |  |
| spf.T\_stress\_uy | -up(spf.T\_stress\_tensoryx)\*spf.nxmesh-up(spf.T\_stress\_tensoryy)\*spf.nymesh-up(spf.T\_stress\_tensoryz)\*spf.nzmesh | N/m² | Total traction, interior boundaries, upside, y-component | Boundaries 6–7, 10–11 |  |
| spf.T\_stress\_uz | -up(spf.T\_stress\_tensorzx)\*spf.nxmesh-up(spf.T\_stress\_tensorzy)\*spf.nymesh-up(spf.T\_stress\_tensorzz)\*spf.nzmesh | N/m² | Total traction, interior boundaries, upside, z-component | Boundaries 6–7, 10–11 |  |
| spf.T\_tracx | spf.T\_stressx | N/m² | Total applied traction, exterior boundaries, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_tracy | spf.T\_stressy | N/m² | Total applied traction, exterior boundaries, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_tracz | spf.T\_stressz | N/m² | Total applied traction, exterior boundaries, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_trac\_dx | spf.T\_stress\_dx | N/m² | Total applied traction, downside boundaries, x-component | Boundaries 6–7, 10–11 |  |
| spf.T\_trac\_dy | spf.T\_stress\_dy | N/m² | Total applied traction, downside boundaries, y-component | Boundaries 6–7, 10–11 |  |
| spf.T\_trac\_dz | spf.T\_stress\_dz | N/m² | Total applied traction, downside boundaries, z-component | Boundaries 6–7, 10–11 |  |
| spf.T\_trac\_dx | spf.T\_stress\_dx | N/m² | Total applied traction, downside boundaries, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_trac\_dy | spf.T\_stress\_dy | N/m² | Total applied traction, downside boundaries, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_trac\_dz | spf.T\_stress\_dz | N/m² | Total applied traction, downside boundaries, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.T\_trac\_ux | spf.T\_stress\_ux | N/m² | Total applied traction, upside boundaries, x-component | Boundaries 6–7, 10–11 |  |
| spf.T\_trac\_uy | spf.T\_stress\_uy | N/m² | Total applied traction, upside boundaries, y-component | Boundaries 6–7, 10–11 |  |
| spf.T\_trac\_uz | spf.T\_stress\_uz | N/m² | Total applied traction, upside boundaries, z-component | Boundaries 6–7, 10–11 |  |
| spf.usePseudoTimeStepping | isrunningpseudotimestepping | 1 | Help variable | Global |  |
| spf.localCFLvalue | 1.3^min(niterCMP,9)+if(niterCMP>=25,9\*1.3^min(-25+niterCMP,9),0)+if(niterCMP>=45,90\*1.3^min(-45+niterCMP,9),0) |  | Local CFL number | Domains 1–2 |  |
| spf.locCFL | max(CFLCMP,sqrt(eps)) | 1 | Local CFL number | Global |  |
| spf.geometryLengthScale | 0.012500000000000002 | m | Geometry length scale | Domains 1–2 |  |
| spf.time\_step\_inv | max(sqrt(emetric\_spatial(u,v,w)\*2^gmg\_level^2),spf.nu/spf.geometryLengthScale^2) | Hz | Inverse time step | Domains 1–2 |  |
| spf.tsti | nojac(spf.time\_step\_inv/spf.locCFL) | 1/s | Help variable | Domains 1–2 |  |
| spf.nx | nx | 1 | Normal vector, x-component | Boundaries 6–7, 10–11 |  |
| spf.ny | ny | 1 | Normal vector, y-component | Boundaries 6–7, 10–11 |  |
| spf.nz | nz | 1 | Normal vector, z-component | Boundaries 6–7, 10–11 |  |
| spf.nx | dnx | 1 | Normal vector, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.ny | dny | 1 | Normal vector, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.nz | dnz | 1 | Normal vector, z-component | Boundaries 1–5, 8–9, 12 |  |
| spf.nxmesh | nxmesh | 1 | Normal vector, x-component | Boundaries 6–7, 10–11 |  |
| spf.nymesh | nymesh | 1 | Normal vector, y-component | Boundaries 6–7, 10–11 |  |
| spf.nzmesh | nzmesh | 1 | Normal vector, z-component | Boundaries 6–7, 10–11 |  |
| spf.nxmesh | dnxmesh | 1 | Normal vector, x-component | Boundaries 1–5, 8–9, 12 |  |
| spf.nymesh | dnymesh | 1 | Normal vector, y-component | Boundaries 1–5, 8–9, 12 |  |
| spf.nzmesh | dnzmesh | 1 | Normal vector, z-component | Boundaries 1–5, 8–9, 12 |  |

### Fluid Properties 1

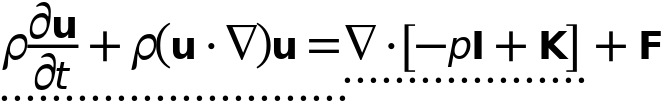


Fluid Properties 1

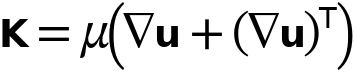
Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Equations







#### Fluid Properties

Settings

| **Description** | **Value** |
| --- | --- |
| Density | From material |
| Constitutive relation | Specify dynamic viscosity |
| Dynamic viscosity | From material |

#### Model Input

Settings

| **Description** | **Value** |
| --- | --- |
| Temperature | Common model input |

Properties from material

| **Property** | **Material** | **Property group** |
| --- | --- | --- |
| Density | Battery block | Basic |
| Dynamic viscosity | Battery block | Basic |
| Density | PCM Layer | Basic |
| Dynamic viscosity | PCM Layer | Basic |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| spf.mu | material.mu | Pa·s | Dynamic viscosity | Domains 1–2 | Meta |
| spf.rho | subst(material.rho,spf.fp1.minput\_temperature,spf.Trho,spf.fp1.minput\_pressure,spf.prho) | kg/m³ | Density | Domains 1–2 | Meta |
| spf.Trho | spf.Tref | K | Temperature for density evaluation | Domains 1–2 |  |
| spf.prho | spf.pref | Pa | Pressure for the evaluation of density | Domains 1–2 |  |
| spf.rhoref | subst(material.rho,spf.fp1.minput\_temperature,spf.Tref,spf.fp1.minput\_pressure,spf.pref) | kg/m³ | Reference density | Domains 1–2 | Meta |
| spf.mumat | material.mu | Pa·s | Dynamic viscosity | Domains 1–2 | Meta |
| spf.srijxx | ux | 1/s | Strain rate tensor, xx-component | Domains 1–2 |  |
| spf.srijyx | 0.5\*(vx+uy) | 1/s | Strain rate tensor, yx-component | Domains 1–2 |  |
| spf.srijzx | 0.5\*(wx+uz) | 1/s | Strain rate tensor, zx-component | Domains 1–2 |  |
| spf.srijxy | 0.5\*(uy+vx) | 1/s | Strain rate tensor, xy-component | Domains 1–2 |  |
| spf.srijyy | vy | 1/s | Strain rate tensor, yy-component | Domains 1–2 |  |
| spf.srijzy | 0.5\*(wy+vz) | 1/s | Strain rate tensor, zy-component | Domains 1–2 |  |
| spf.srijxz | 0.5\*(uz+wx) | 1/s | Strain rate tensor, xz-component | Domains 1–2 |  |
| spf.srijyz | 0.5\*(vz+wy) | 1/s | Strain rate tensor, yz-component | Domains 1–2 |  |
| spf.srijzz | wz | 1/s | Strain rate tensor, zz-component | Domains 1–2 |  |
| spf.rrijxx | 0 | 1/s | Rotation rate tensor, xx-component | Domains 1–2 |  |
| spf.rrijyx | 0.5\*(vx-uy) | 1/s | Rotation rate tensor, yx-component | Domains 1–2 |  |
| spf.rrijzx | 0.5\*(wx-uz) | 1/s | Rotation rate tensor, zx-component | Domains 1–2 |  |
| spf.rrijxy | 0.5\*(uy-vx) | 1/s | Rotation rate tensor, xy-component | Domains 1–2 |  |
| spf.rrijyy | 0 | 1/s | Rotation rate tensor, yy-component | Domains 1–2 |  |
| spf.rrijzy | 0.5\*(wy-vz) | 1/s | Rotation rate tensor, zy-component | Domains 1–2 |  |
| spf.rrijxz | 0.5\*(uz-wx) | 1/s | Rotation rate tensor, xz-component | Domains 1–2 |  |
| spf.rrijyz | 0.5\*(vz-wy) | 1/s | Rotation rate tensor, yz-component | Domains 1–2 |  |
| spf.rrijzz | 0 | 1/s | Rotation rate tensor, zz-component | Domains 1–2 |  |
| spf.sr | sqrt(2\*spf.srijxx^2+2\*spf.srijxy^2+2\*spf.srijxz^2+2\*spf.srijyx^2+2\*spf.srijyy^2+2\*spf.srijyz^2+2\*spf.srijzx^2+2\*spf.srijzy^2+2\*spf.srijzz^2+eps) | 1/s | Shear rate | Domains 1–2 |  |
| spf.rr | sqrt(2\*spf.rrijxx^2+2\*spf.rrijxy^2+2\*spf.rrijxz^2+2\*spf.rrijyx^2+2\*spf.rrijyy^2+2\*spf.rrijyz^2+2\*spf.rrijzx^2+2\*spf.rrijzy^2+2\*spf.rrijzz^2+eps) | 1/s | Rotation rate | Domains 1–2 |  |
| spf.divu | ux+vy+wz | 1/s | Divergence of velocity field | Domains 1–2 |  |
| spf.Fx | 0 | N/m³ | Volume force, x-component | Domains 1–2 | + operation |
| spf.Fy | 0 | N/m³ | Volume force, y-component | Domains 1–2 | + operation |
| spf.Fz | 0 | N/m³ | Volume force, z-component | Domains 1–2 | + operation |
| spf.U | sqrt(u^2+v^2+w^2) | m/s | Velocity magnitude | Domains 1–2 |  |
| spf.vorticityx | wy-vz | 1/s | Vorticity field, x-component | Domains 1–2 |  |
| spf.vorticityy | -wx+uz | 1/s | Vorticity field, y-component | Domains 1–2 |  |
| spf.vorticityz | vx-uy | 1/s | Vorticity field, z-component | Domains 1–2 |  |
| spf.vort\_magn | sqrt(spf.vorticityx^2+spf.vorticityy^2+spf.vorticityz^2) | 1/s | Vorticity magnitude | Domains 1–2 |  |
| spf.cellRe | 0.25\*spf.rho\*sqrt(emetric\_spatial(u-d(x,TIME),v-d(y,TIME),w-d(z,TIME))/emetric2\_spatial)/spf.mu | 1 | Cell Reynolds number | Domains 1–2 |  |
| spf.nu | spf.mu/spf.rho | m²/s | Kinematic viscosity | Domains 1–2 |  |
| spf.betaT | 0 | 1/Pa | Isothermal compressibility coefficient | Domains 1–2 |  |
| spf.Qm | 0 | kg/(m³·s) | Source term | Domains 1–2 | + operation |
| spf.Fgtotx | 0 | N/m³ | Gravity force, x-component | Domains 1–2 | + operation |
| spf.Fgtoty | 0 | N/m³ | Gravity force, y-component | Domains 1–2 | + operation |
| spf.Fgtotz | 0 | N/m³ | Gravity force, z-component | Domains 1–2 | + operation |
| spf.Qm\_aco | 0 | kg/(m³·s) | Acoustic mass source | Domains 1–2 |  |
| spf.F\_acox | 0 | N/m³ | Acoustic volume force, x-component | Domains 1–2 |  |
| spf.F\_acoy | 0 | N/m³ | Acoustic volume force, y-component | Domains 1–2 |  |
| spf.F\_acoz | 0 | N/m³ | Acoustic volume force, z-component | Domains 1–2 |  |
| spf.gamma\_sr | sqrt(2\*spf.srijxx^2+2\*spf.srijxy^2+2\*spf.srijxz^2+2\*spf.srijyx^2+2\*spf.srijyy^2+2\*spf.srijyz^2+2\*spf.srijzx^2+2\*spf.srijzy^2+2\*spf.srijzz^2+eps) | 1/s | Shear rate | Domains 1–2 |  |
| spf.mu\_eff | spf.mu+spf.muT | Pa·s | Effective dynamic viscosity | Domains 1–2 |  |
| spf.muT | 0 | Pa·s | Turbulent dynamic viscosity | Domains 1–2 | + operation |
| spf.T\_stress\_tensorxx | spf.K\_stress\_tensorxx-p | N/m² | Total stress tensor, xx-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensoryx | spf.K\_stress\_tensoryx | N/m² | Total stress tensor, yx-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensorzx | spf.K\_stress\_tensorzx | N/m² | Total stress tensor, zx-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensorxy | spf.K\_stress\_tensorxy | N/m² | Total stress tensor, xy-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensoryy | spf.K\_stress\_tensoryy-p | N/m² | Total stress tensor, yy-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensorzy | spf.K\_stress\_tensorzy | N/m² | Total stress tensor, zy-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensorxz | spf.K\_stress\_tensorxz | N/m² | Total stress tensor, xz-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensoryz | spf.K\_stress\_tensoryz | N/m² | Total stress tensor, yz-component | Domains 1–2 | + operation |
| spf.T\_stress\_tensorzz | spf.K\_stress\_tensorzz-p | N/m² | Total stress tensor, zz-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensorxx | 2\*spf.mu\_eff\*ux | N/m² | Viscous stress tensor, xx-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensoryx | spf.mu\_eff\*(vx+uy) | N/m² | Viscous stress tensor, yx-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensorzx | spf.mu\_eff\*(wx+uz) | N/m² | Viscous stress tensor, zx-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensorxy | spf.mu\_eff\*(uy+vx) | N/m² | Viscous stress tensor, xy-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensoryy | 2\*spf.mu\_eff\*vy | N/m² | Viscous stress tensor, yy-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensorzy | spf.mu\_eff\*(wy+vz) | N/m² | Viscous stress tensor, zy-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensorxz | spf.mu\_eff\*(uz+wx) | N/m² | Viscous stress tensor, xz-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensoryz | spf.mu\_eff\*(vz+wy) | N/m² | Viscous stress tensor, yz-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensorzz | 2\*spf.mu\_eff\*wz | N/m² | Viscous stress tensor, zz-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testxx | 2\*spf.mu\_eff\*test(ux) | N/m² | Viscous stress tensor test, xx-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testyx | spf.mu\_eff\*(test(vx)+test(uy)) | N/m² | Viscous stress tensor test, yx-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testzx | spf.mu\_eff\*(test(wx)+test(uz)) | N/m² | Viscous stress tensor test, zx-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testxy | spf.mu\_eff\*(test(uy)+test(vx)) | N/m² | Viscous stress tensor test, xy-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testyy | 2\*spf.mu\_eff\*test(vy) | N/m² | Viscous stress tensor test, yy-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testzy | spf.mu\_eff\*(test(wy)+test(vz)) | N/m² | Viscous stress tensor test, zy-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testxz | spf.mu\_eff\*(test(uz)+test(wx)) | N/m² | Viscous stress tensor test, xz-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testyz | spf.mu\_eff\*(test(vz)+test(wy)) | N/m² | Viscous stress tensor test, yz-component | Domains 1–2 | + operation |
| spf.K\_stress\_tensor\_testzz | 2\*spf.mu\_eff\*test(wz) | N/m² | Viscous stress tensor test, zz-component | Domains 1–2 | + operation |
| spf.upwind\_helpx | u-d(x,TIME) | m/s | Upwind term, x-component | Domains 1–2 | + operation |
| spf.upwind\_helpy | v-d(y,TIME) | m/s | Upwind term, y-component | Domains 1–2 | + operation |
| spf.upwind\_helpz | w-d(z,TIME) | m/s | Upwind term, z-component | Domains 1–2 | + operation |
| spf.continuityEquation | spf.rho\*spf.divu-spf.Qm | kg/(m³·s) | Continuity equation | Domains 1–2 |  |
| spf.contCoeff | spf.rho | kg/m³ | Help variable | Domains 1–2 |  |
| spf.Qvd | spf.K\_stress\_tensorxx\*ux+spf.K\_stress\_tensorxy\*uy+spf.K\_stress\_tensorxz\*uz+spf.K\_stress\_tensoryx\*vx+spf.K\_stress\_tensoryy\*vy+spf.K\_stress\_tensoryz\*vz+spf.K\_stress\_tensorzx\*wx+spf.K\_stress\_tensorzy\*wy+spf.K\_stress\_tensorzz\*wz | W/m³ | Viscous dissipation | Domains 1–2 | + operation |
| spf.epsilon\_p | 1 | 1 | Porosity | Domains 1–2 |  |
| spf.epsilon\_p\_pos | max(1,sqrt(eps)) | 1 | Positive porosity | Domains 1–2 |  |
| spf.Fst\_tensorxx | 0 | N/m² | Surface tension force, xx-component | Domains 1–2 | + operation |
| spf.Fst\_tensoryx | 0 | N/m² | Surface tension force, yx-component | Domains 1–2 | + operation |
| spf.Fst\_tensorzx | 0 | N/m² | Surface tension force, zx-component | Domains 1–2 | + operation |
| spf.Fst\_tensorxy | 0 | N/m² | Surface tension force, xy-component | Domains 1–2 | + operation |
| spf.Fst\_tensoryy | 0 | N/m² | Surface tension force, yy-component | Domains 1–2 | + operation |
| spf.Fst\_tensorzy | 0 | N/m² | Surface tension force, zy-component | Domains 1–2 | + operation |
| spf.Fst\_tensorxz | 0 | N/m² | Surface tension force, xz-component | Domains 1–2 | + operation |
| spf.Fst\_tensoryz | 0 | N/m² | Surface tension force, yz-component | Domains 1–2 | + operation |
| spf.Fst\_tensorzz | 0 | N/m² | Surface tension force, zz-component | Domains 1–2 | + operation |
| spf.res\_u | spf.rho\*ut\*spf.switch\_NS+px+spf.rho\*u\*ux+spf.rho\*v\*uy+spf.rho\*w\*uz-(d(2\*ux,x)+d(uy+vx,y)+d(uz+wx,z))\*spf.mu-spf.Fx | N/m³ | Equation residual | Domains 1–2 |  |
| spf.res\_v | spf.rho\*vt\*spf.switch\_NS+spf.rho\*u\*vx+py+spf.rho\*v\*vy+spf.rho\*w\*vz-(d(vx+uy,x)+d(2\*vy,y)+d(vz+wy,z))\*spf.mu-spf.Fy | N/m³ | Equation residual | Domains 1–2 |  |
| spf.res\_w | spf.rho\*wt\*spf.switch\_NS+spf.rho\*u\*wx+spf.rho\*v\*wy+pz+spf.rho\*w\*wz-(d(wx+uz,x)+d(wy+vz,y)+d(2\*wz,z))\*spf.mu-spf.Fz | N/m³ | Equation residual | Domains 1–2 |  |
| spf.res\_p | spf.rho\*spf.divu-spf.Qm | kg/(m³·s) | Pressure equation residual | Domains 1–2 |  |

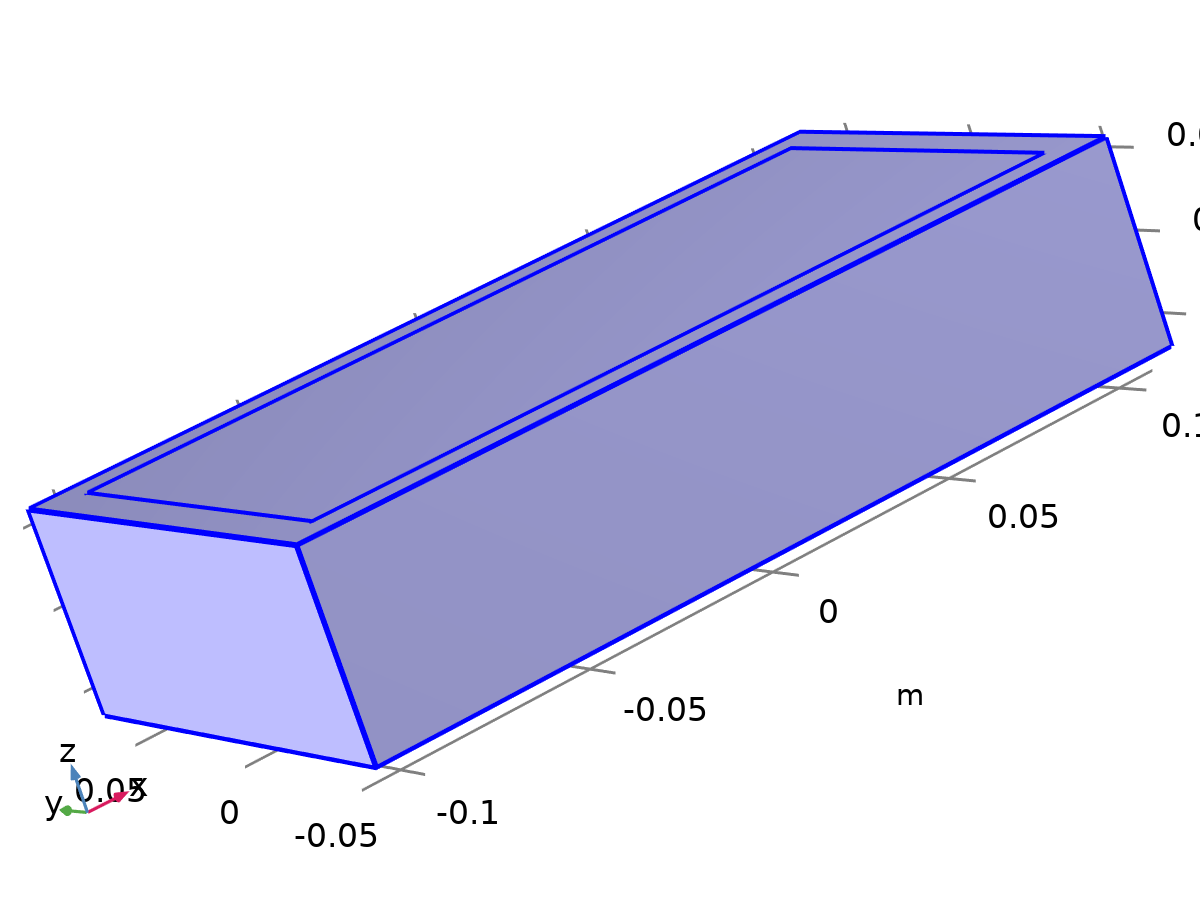
#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| u | Lagrange (Linear) | m/s | Velocity field, x-component | Spatial | Domains 1–2 |
| v | Lagrange (Linear) | m/s | Velocity field, y-component | Spatial | Domains 1–2 |
| w | Lagrange (Linear) | m/s | Velocity field, z-component | Spatial | Domains 1–2 |
| u | Lagrange (Linear) | m/s | Velocity field, x-component | Spatial | Domains 1–2 |
| v | Lagrange (Linear) | m/s | Velocity field, y-component | Spatial | Domains 1–2 |
| w | Lagrange (Linear) | m/s | Velocity field, z-component | Spatial | Domains 1–2 |
| p | Lagrange (Linear) | Pa | Pressure | Spatial | Domains 1–2 |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| spf.rho\*(-ut\*test(u)-vt\*test(v)-wt\*test(w)) | 2 | Spatial | Domains 1–2 |
| (p-spf.K\_stress\_tensorxx)\*test(ux)-spf.K\_stress\_tensorxy\*test(uy)-spf.K\_stress\_tensorxz\*test(uz)-spf.K\_stress\_tensoryx\*test(vx)+(p-spf.K\_stress\_tensoryy)\*test(vy)-spf.K\_stress\_tensoryz\*test(vz)-spf.K\_stress\_tensorzx\*test(wx)-spf.K\_stress\_tensorzy\*test(wy)+(p-spf.K\_stress\_tensorzz)\*test(wz) | 2 | Spatial | Domains 1–2 |
| spf.Fx\*test(u)+spf.Fy\*test(v)+spf.Fz\*test(w) | 2 | Spatial | Domains 1–2 |
| spf.rho\*(-(d(u,x)\*u+d(u,y)\*v+d(u,z)\*w)\*test(u)-(d(v,x)\*u+d(v,y)\*v+d(v,z)\*w)\*test(v)-(d(w,x)\*u+d(w,y)\*v+d(w,z)\*w)\*test(w)) | 2 | Spatial | Domains 1–2 |
| -spf.continuityEquation\*test(p) | 2 | Spatial | Domains 1–2 |
| spf.streamlinens | 2 | Spatial | Domains 1–2 |
| spf.crosswindns | 2 | Spatial | Domains 1–2 |

### Initial Values 1



Initial Values 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

#### Initial Values

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Velocity field, x-component | 0 | m/s |
| Velocity field, y-component | 0 | m/s |
| Velocity field, z-component | 0 | m/s |
| Pressure | 0 | Pa |

#### Coordinate System Selection

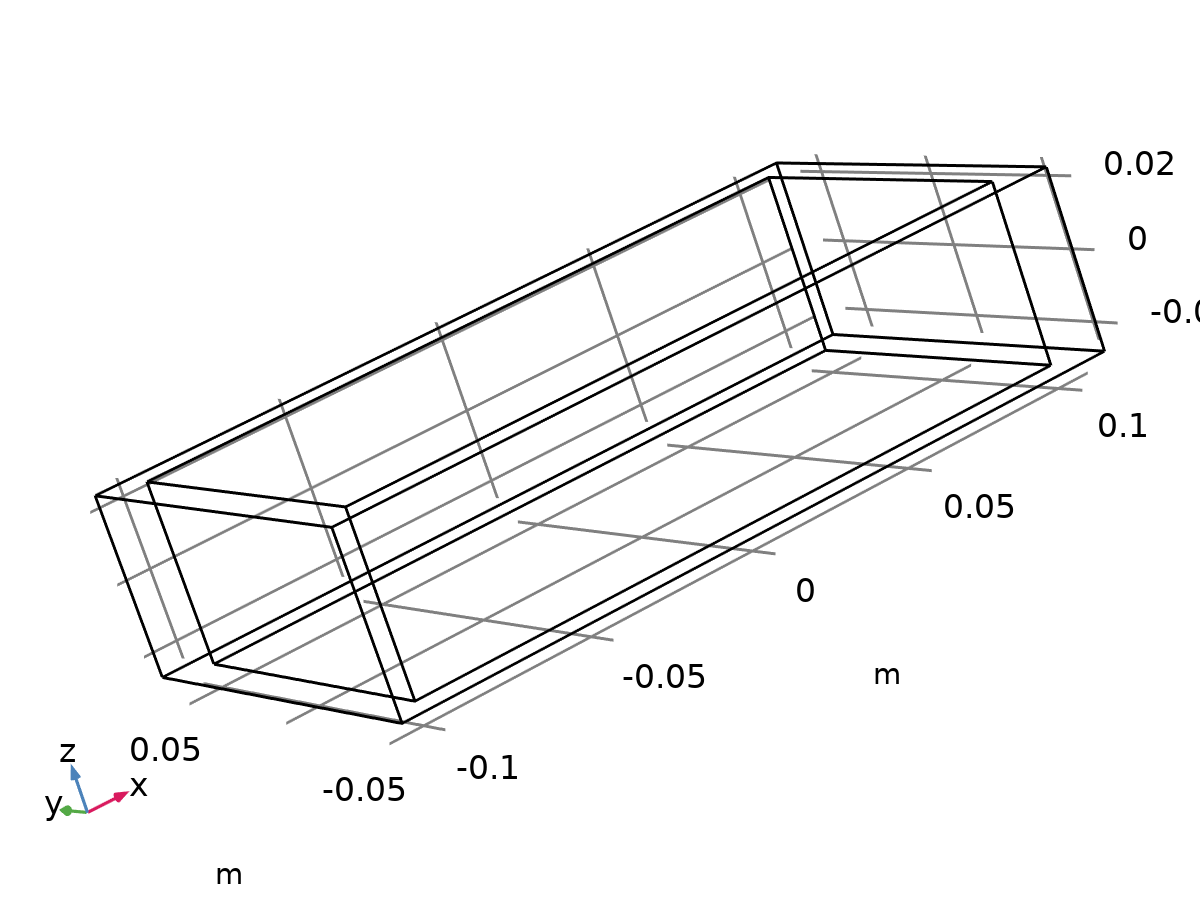
Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| spf.u\_initx | 0 | m/s | Velocity field, x-component | Domains 1–2 |
| spf.u\_inity | 0 | m/s | Velocity field, y-component | Domains 1–2 |
| spf.u\_initz | 0 | m/s | Velocity field, z-component | Domains 1–2 |
| spf.p\_init | 0 | Pa | Pressure | Domains 1–2 |

### Wall 1



Wall 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: All boundaries |

Equations



#### Boundary Condition

Settings

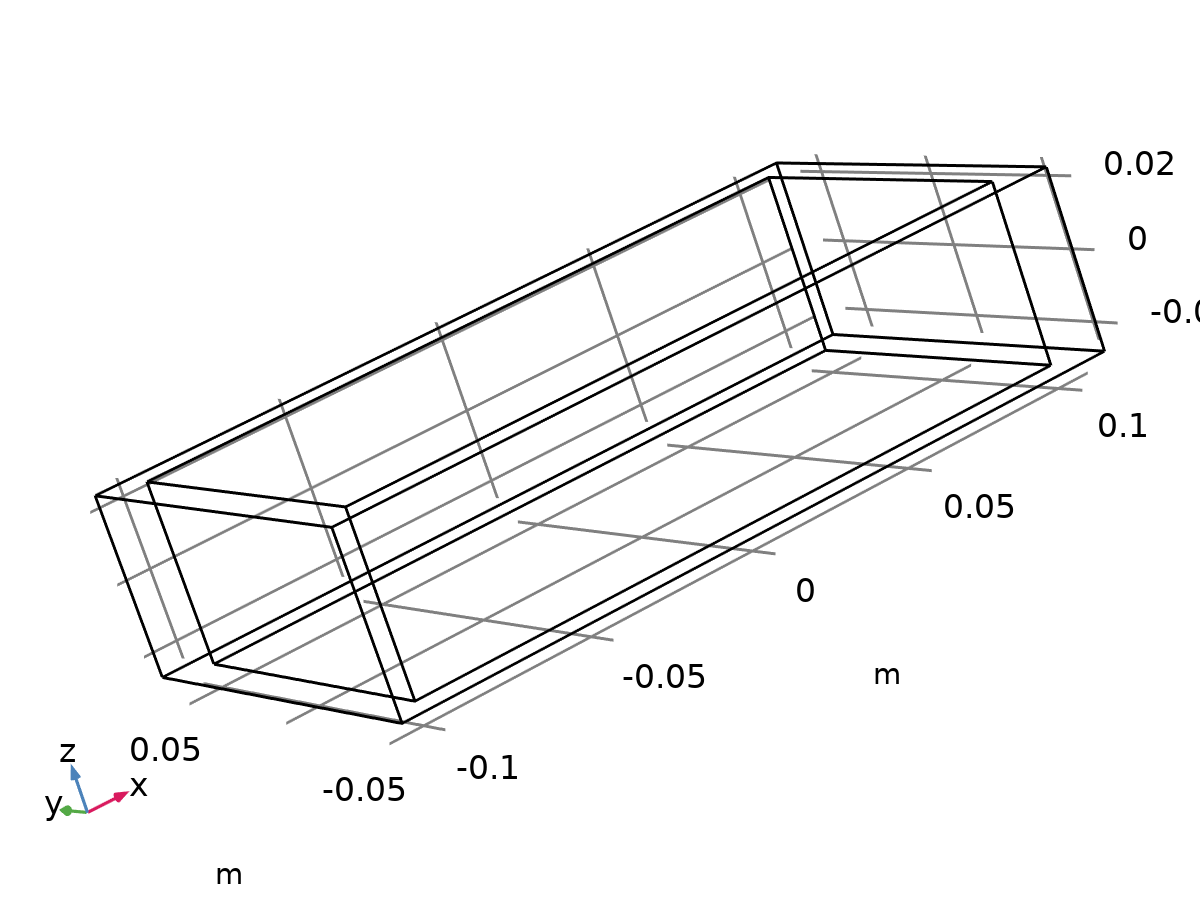
| **Description** | **Value** |
| --- | --- |
| Wall condition | No slip |

#### Wall Movement

Settings

| **Description** | **Value** |
| --- | --- |
| Translational velocity | Automatic from frame |
| Sliding wall | Off |

### Inlet 1



Inlet 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: No boundaries |

Equations



#### Boundary Condition

Settings

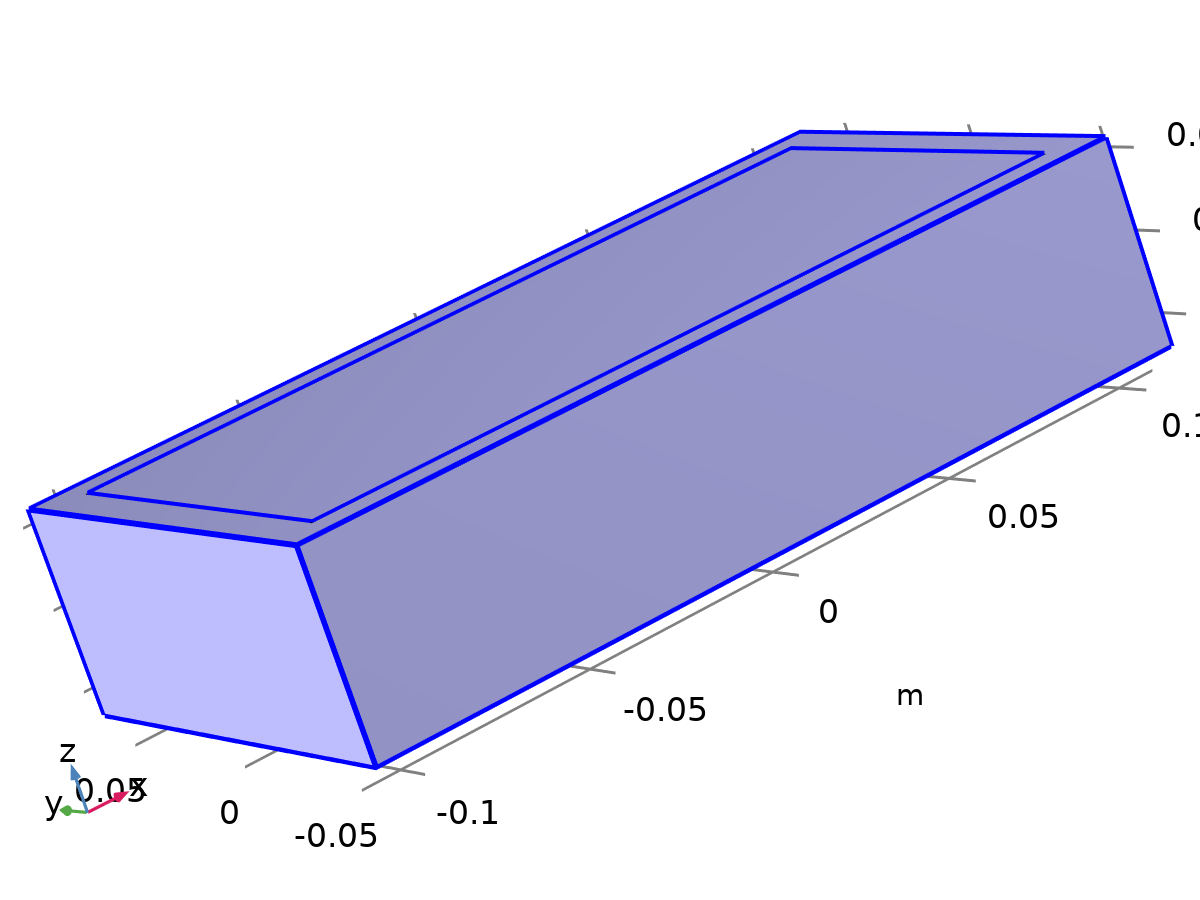
| **Description** | **Value** |
| --- | --- |
| Boundary condition | Velocity |

#### Velocity

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Velocity field componentwise | Normal inflow velocity |  |
| Normal inflow velocity | 1 | m/s |

### Outlet 1



Outlet 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: Boundaries 1–5, 8–9, 12 |

Equations





#### Boundary Condition

Settings

| **Description** | **Value** |
| --- | --- |
| Boundary condition | Pressure |

#### Pressure Conditions

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Pressure | Static |  |
| Pressure | 0 | Pa |
| Normal flow | Off |  |
| Suppress backflow | On |  |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| spf.meshVol | meshvol\_spatial | m² |  | Boundaries 1–5, 8–9, 12 |
| spf.meshVolInt | down(meshvol\_spatial) | m³ | Volume of interior mesh element | Boundaries 1–5, 8–9, 12 |
| spf.rhoFace | down(spf.rho) | kg/m³ | Density face value | Boundaries 1–5, 8–9, 12 |
| spf.umxTnFace | spf.upwind\_helpx\*spf.nxmesh+spf.upwind\_helpy\*spf.nymesh+spf.upwind\_helpz\*spf.nzmesh | m/s | Relative velocity on face | Boundaries 1–5, 8–9, 12 |
| spf.p0 | 0 | Pa | Pressure | Boundaries 1–5, 8–9, 12 |
| spf.out1.Uav | 0 | m/s | Average velocity | Global |
| spf.out1.Uavfdf | 0 | m/s | Average velocity | Global |
| spf.out1.dz | spf.dz | m | Channel thickness | Boundaries 1–5, 8–9, 12 |
| spf.out1.Mflow | spf.out1.massFlowRate | kg/s | Mass flow | Global |
| spf.f0 | spf.p0+spf.uNormal\*(spf.backflowPenaltyDiff-spf.backflowPenaltyConv)\*(spf.uNormal<0) | N/m² | Normal stress | Boundaries 1–5, 8–9, 12 |
| spf.uNormal | u\*nojac(spf.nxmesh)+v\*nojac(spf.nymesh)+w\*nojac(spf.nzmesh) | m/s | Normal velocity | Boundaries 1–5, 8–9, 12 |
| spf.out1.c\_here | 144/spf.epsilon\_p | 1 | Intermediate variable | Boundaries 1–5, 8–9, 12 |
| spf.backflowPenaltyDiff | spf.out1.c\_here\*min((down(spf.mu)+spf.muT)\*spf.meshVol/spf.meshVolInt,down(spf.rho)\*abs(spf.uNormal)/down(spf.epsilon\_p)) | Pa·s/m | Backflow penalty parameter, diffusive contribution | Boundaries 1–5, 8–9, 12 |
| spf.backflowPenaltyConv | spf.rhoFace\*spf.umxTnFace/spf.epsilon\_p^2 | kg/(m²·s) | Backflow penalty parameter, convective contribution | Boundaries 1–5, 8–9, 12 |
| spf.out1.upwind\_ns | spf.backflowPenaltyConv\*spf.uNormal | Pa | Upwind term | Boundaries 1–5, 8–9, 12 |
| spf.out1.volumeFlowRate | spf.out1.intop(u\*spf.nxmesh+v\*spf.nymesh+w\*spf.nzmesh) | m³/s | Outward volume flow rate across feature selection | Global |
| spf.out1.massFlowRate | spf.out1.intop(spf.rho\*(u\*spf.nxmesh+v\*spf.nymesh+w\*spf.nzmesh)) | kg/s | Outward mass flow rate across feature selection | Global |
| spf.out1.pAverage | spf.out1.aveop(p) | Pa | Pressure average over feature selection | Global |

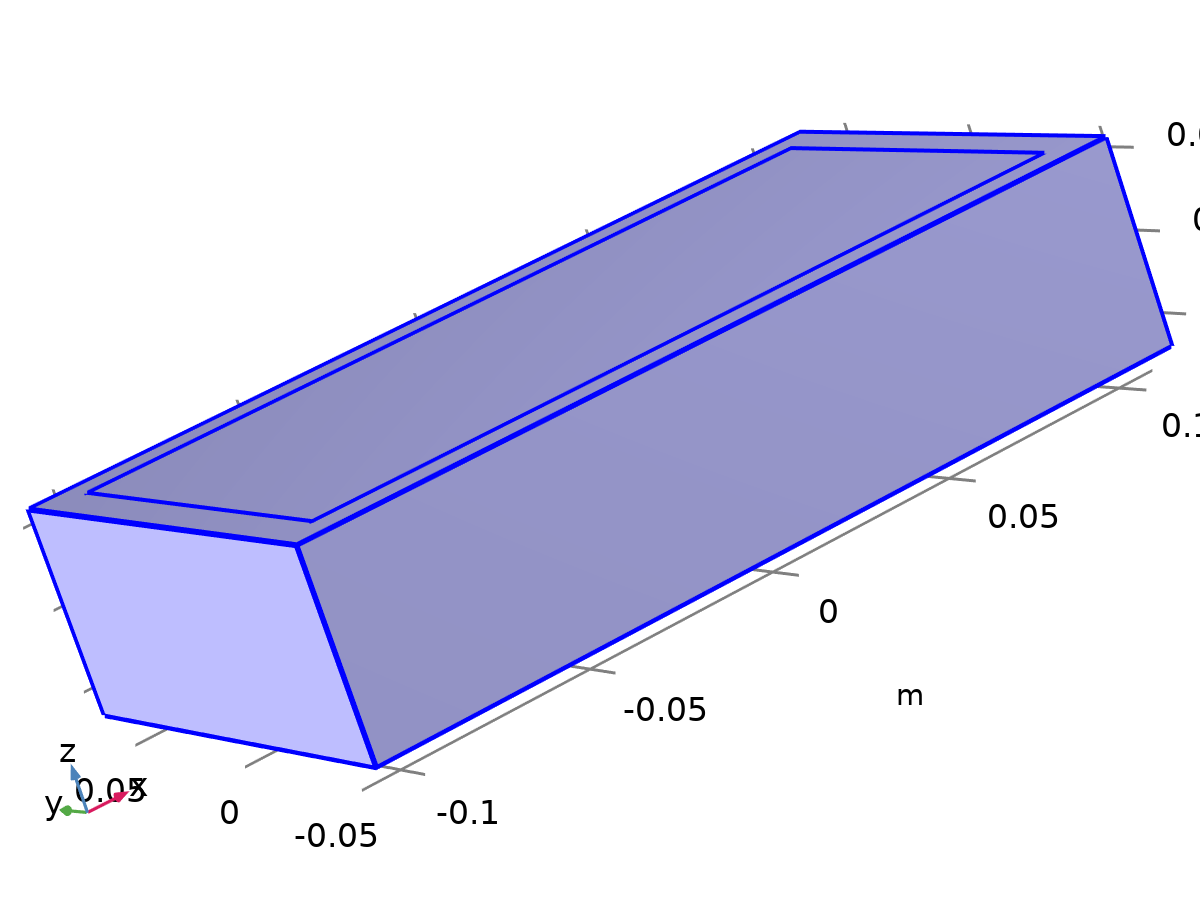
#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| -spf.f0\*(test(u)\*spf.nxmesh+test(v)\*spf.nymesh+test(w)\*spf.nzmesh) | 2 | Spatial | Boundaries 1–5, 8–9, 12 |

## Heat Transfer in Solids 2

Used products

|  |
| --- |
| COMSOL Multiphysics |

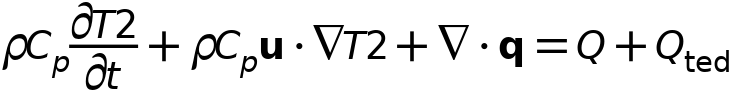


Heat Transfer in Solids 2

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domains 1–2 |

Equations





### Interface Settings

#### Discretization

Settings

| **Description** | **Value** |
| --- | --- |
| Temperature | Quadratic Lagrange |

Settings

| **Description** | **Value** |
| --- | --- |
| Equation form | Study controlled |

#### Physical Model

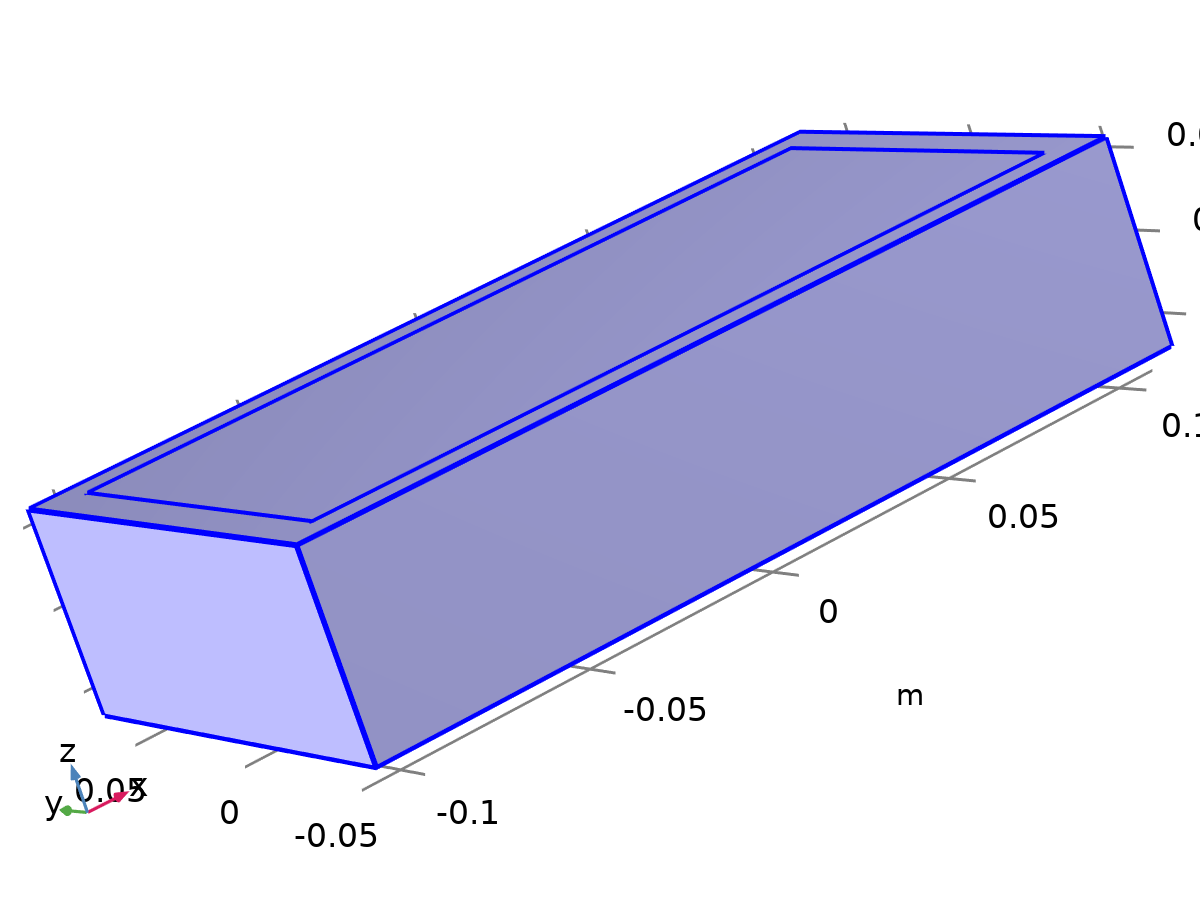
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Reference temperature | User defined |  |
| Reference temperature | 293.15 | K |

### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ht2.Tref | model.input.Tref | K | Reference temperature | Global | Meta |
| ht2.C\_effExt | 0 | J/(m³·K) | Effective volumetric heat capacity | Domains 1–2 | + operation |
| ht2.EMatExt | 0 | Pa | Young's modulus | Domains 1–2 | + operation |
| ht2.Tvar | T2 | K | Temperature | Domains 1–2 |  |
| ht2.Tvar | T2 | K | Temperature | Boundaries 1–12 |  |
| ht2.Tvar | T2 | K | Temperature | Edges 1–24 |  |
| ht2.Tvar | T2 | K | Temperature | Points 1–16 |  |
| ht2.nknExt | 0 | W/(m·K) | Help variable | Domains 1–2 | + operation |
| ht2.TextFace | 0 | K | External temperature | Domains 1–2 | + operation |
| ht2.nuMatExt | 0 | 1 | Poisson's ratio | Domains 1–2 | + operation |
| ht2.d | 1 | 1 | Thickness | Domains 1–2 |  |
| ht2.chiT | 0 | 1/Pa | Isothermal compressibility coefficient | Domains 1–2 |  |
| ht2.HRef | 0 | J/kg | Reference enthalpy | Domains 1–2 |  |
| ht2.alphap | 0 | 1/K | Isobaric compressibility coefficient | Domains 1–2 |  |
| ht2.DeltaH | ht2.DeltaH\_add | J/kg | Sensible enthalpy | Domains 1–2 |  |
| ht2.DeltaH\_cst | ht2.DeltaH\_add\_cst | J/kg | Sensible enthalpy, constant material properties | Domains 1–2 |  |
| ht2.DeltaH\_add | 0 | J/kg | Sensible enthalpy | Domains 1–2 | + operation |
| ht2.DeltaH\_add\_cst | 0 | J/kg | Sensible enthalpy, constant material properties | Domains 1–2 | + operation |
| ht2.H | 0 | J/kg | Enthalpy | Domains 1–2 | + operation |
| ht2.H\_cst | 0 | J/kg | Enthalpy, constant material properties | Domains 1–2 | + operation |
| ht2.H0 | ht2.H+ht2.Ek | J/kg | Total enthalpy | Domains 1–2 |  |
| ht2.H0\_cst | ht2.H\_cst+ht2.Ek | J/kg | Total enthalpy, constant material properties | Domains 1–2 |  |
| ht2.Ei | 0 | J/kg | Internal energy | Domains 1–2 | + operation |
| ht2.Ei\_cst | 0 | J/kg | Internal energy, constant material properties | Domains 1–2 | + operation |
| ht2.Ei0 | ht2.Ei+ht2.Ek | J/kg | Total internal energy | Domains 1–2 |  |
| ht2.Ei0\_cst | ht2.Ei\_cst+ht2.Ek | J/kg | Total internal energy, constant material properties | Domains 1–2 |  |
| ht2.Ek | 0 | J/kg | Kinetic energy | Domains 1–2 | + operation |
| ht2.dfluxx | 0 | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht2.dfluxy | 0 | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht2.dfluxz | 0 | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht2.dfluxx | mean(ht2.dfluxx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 | + operation |
| ht2.dfluxy | mean(ht2.dfluxy) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 | + operation |
| ht2.dfluxz | mean(ht2.dfluxz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 | + operation |
| ht2.dfluxtestx | 0 | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht2.dfluxtesty | 0 | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht2.dfluxtestz | 0 | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht2.dfluxtestx | mean(ht2.dfluxtestx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 | + operation |
| ht2.dfluxtesty | mean(ht2.dfluxtesty) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 | + operation |
| ht2.dfluxtestz | mean(ht2.dfluxtestz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 | + operation |
| ht2.dfluxMag | sqrt(ht2.dfluxx^2+ht2.dfluxy^2+ht2.dfluxz^2) | W/m² | Conductive heat flux magnitude | Domains 1–2 |  |
| ht2.cfluxx | 0 | W/m² | Convective heat flux, x-component | Domains 1–2 | + operation |
| ht2.cfluxy | 0 | W/m² | Convective heat flux, y-component | Domains 1–2 | + operation |
| ht2.cfluxz | 0 | W/m² | Convective heat flux, z-component | Domains 1–2 | + operation |
| ht2.cfluxMag | sqrt(ht2.cfluxx^2+ht2.cfluxy^2+ht2.cfluxz^2) | W/m² | Convective heat flux magnitude | Domains 1–2 |  |
| ht2.tfluxx | ht2.dfluxx+ht2.cfluxx | W/m² | Total heat flux, x-component | Domains 1–2 |  |
| ht2.tfluxy | ht2.dfluxy+ht2.cfluxy | W/m² | Total heat flux, y-component | Domains 1–2 |  |
| ht2.tfluxz | ht2.dfluxz+ht2.cfluxz | W/m² | Total heat flux, z-component | Domains 1–2 |  |
| ht2.tfluxMag | sqrt(ht2.tfluxx^2+ht2.tfluxy^2+ht2.tfluxz^2) | W/m² | Total heat flux magnitude | Domains 1–2 |  |
| ht2.tefluxx | 0 | W/m² | Total energy flux, x-component | Domains 1–2 | + operation |
| ht2.tefluxy | 0 | W/m² | Total energy flux, y-component | Domains 1–2 | + operation |
| ht2.tefluxz | 0 | W/m² | Total energy flux, z-component | Domains 1–2 | + operation |
| ht2.teflux\_cstx | 0 | W/m² | Total energy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht2.teflux\_csty | 0 | W/m² | Total energy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht2.teflux\_cstz | 0 | W/m² | Total energy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht2.tefluxMag | sqrt(ht2.tefluxx^2+ht2.tefluxy^2+ht2.tefluxz^2) | W/m² | Total energy flux magnitude | Domains 1–2 |  |
| ht2.thfluxx | 0 | W/m² | Total enthalpy flux, x-component | Domains 1–2 | + operation |
| ht2.thfluxy | 0 | W/m² | Total enthalpy flux, y-component | Domains 1–2 | + operation |
| ht2.thfluxz | 0 | W/m² | Total enthalpy flux, z-component | Domains 1–2 | + operation |
| ht2.thflux\_cstx | 0 | W/m² | Total enthalpy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht2.thflux\_csty | 0 | W/m² | Total enthalpy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht2.thflux\_cstz | 0 | W/m² | Total enthalpy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht2.thfluxMag | sqrt(ht2.thfluxx^2+ht2.thfluxy^2+ht2.thfluxz^2) | W/m² | Total enthalpy flux magnitude | Domains 1–2 |  |
| ht2.dflux\_ux | up(ht2.dfluxx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht2.dflux\_uy | up(ht2.dfluxy) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht2.dflux\_uz | up(ht2.dfluxz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht2.dflux\_dx | down(ht2.dfluxx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht2.dflux\_dy | down(ht2.dfluxy) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht2.dflux\_dz | down(ht2.dfluxz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht2.dfluxtest\_ux | up(ht2.dfluxtestx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht2.dfluxtest\_uy | up(ht2.dfluxtesty) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht2.dfluxtest\_uz | up(ht2.dfluxtestz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht2.dfluxtest\_dx | down(ht2.dfluxtestx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht2.dfluxtest\_dy | down(ht2.dfluxtesty) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht2.dfluxtest\_dz | down(ht2.dfluxtestz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht2.rflux | 0 | W/m² | Radiative heat flux | Boundaries 1–12 | + operation |
| ht2.ncflux | mean(ht2.cfluxx)\*ht2.nxmesh+mean(ht2.cfluxy)\*ht2.nymesh+mean(ht2.cfluxz)\*ht2.nzmesh | W/m² | Normal convective heat flux | Boundaries 1–12 |  |
| ht2.ncflux\_u | up(ht2.cfluxx)\*ht2.unxmesh+up(ht2.cfluxy)\*ht2.unymesh+up(ht2.cfluxz)\*ht2.unzmesh | W/m² | Internal normal convective heat flux, upside | Boundaries 1–12 |  |
| ht2.ncflux\_d | down(ht2.cfluxx)\*ht2.dnxmesh+down(ht2.cfluxy)\*ht2.dnymesh+down(ht2.cfluxz)\*ht2.dnzmesh | W/m² | Internal normal convective heat flux, downside | Boundaries 1–12 |  |
| ht2.ndflux | 0.5\*(ht2.ndflux\_d-ht2.ndflux\_u) | W/m² | Normal conductive heat flux | Boundaries 1–12 | + operation |
| ht2.ndflux\_u | -ht2.ndflux\_d | W/m² | Internal normal conductive heat flux, upside | Boundaries 1–5, 8–9, 12 | + operation |
| ht2.ndflux\_u | 0 | W/m² | Internal normal conductive heat flux, upside | Boundaries 6–7, 10–11 | + operation |
| ht2.ndflux\_d | 0 | W/m² | Internal normal conductive heat flux, downside | Boundaries 1–12 | + operation |
| ht2.ntflux | ht2.ndflux+ht2.ncflux | W/m² | Normal total heat flux | Boundaries 1–12 |  |
| ht2.ntflux\_cst | ht2.ndflux+ht2.ncflux | W/m² | Normal total heat flux, constant material properties | Boundaries 1–12 |  |
| ht2.ntflux\_u | ht2.ndflux\_u+ht2.ncflux\_u | W/m² | Internal normal total flux, upside | Boundaries 1–12 |  |
| ht2.ntflux\_cst\_u | ht2.ndflux\_u+ht2.ncflux\_u | W/m² | Internal normal total heat flux, constant material properties, upside | Boundaries 1–12 |  |
| ht2.ntflux\_d | ht2.ndflux\_d+ht2.ncflux\_d | W/m² | Internal normal total flux, downside | Boundaries 1–12 |  |
| ht2.ntflux\_cst\_d | ht2.ndflux\_d+ht2.ncflux\_d | W/m² | Internal normal total heat flux, constant material properties, downside | Boundaries 1–12 |  |
| ht2.nteflux | mean(ht2.tefluxx)\*ht2.nxmesh+mean(ht2.tefluxy)\*ht2.nymesh+mean(ht2.tefluxz)\*ht2.nzmesh-mean(ht2.dfluxx)\*ht2.nxmesh-mean(ht2.dfluxy)\*ht2.nymesh-mean(ht2.dfluxz)\*ht2.nzmesh+ht2.ndflux | W/m² | Normal total energy flux | Boundaries 1–12 |  |
| ht2.nteflux\_cst | mean(ht2.teflux\_cstx)\*ht2.nxmesh+mean(ht2.teflux\_csty)\*ht2.nymesh+mean(ht2.teflux\_cstz)\*ht2.nzmesh-mean(ht2.dfluxx)\*ht2.nxmesh-mean(ht2.dfluxy)\*ht2.nymesh-mean(ht2.dfluxz)\*ht2.nzmesh+ht2.ndflux | W/m² | Normal total energy flux, constant material properties | Boundaries 1–12 |  |
| ht2.nteflux\_u | up(ht2.tefluxx)\*ht2.unxmesh+up(ht2.tefluxy)\*ht2.unymesh+up(ht2.tefluxz)\*ht2.unzmesh-up(ht2.dfluxx)\*ht2.unxmesh-up(ht2.dfluxy)\*ht2.unymesh-up(ht2.dfluxz)\*ht2.unzmesh+ht2.ndflux\_u | W/m² | Internal normal total energy flux, upside | Boundaries 1–12 |  |
| ht2.nteflux\_cst\_u | up(ht2.teflux\_cstx)\*ht2.unxmesh+up(ht2.teflux\_csty)\*ht2.unymesh+up(ht2.teflux\_cstz)\*ht2.unzmesh-up(ht2.dfluxx)\*ht2.unxmesh-up(ht2.dfluxy)\*ht2.unymesh-up(ht2.dfluxz)\*ht2.unzmesh+ht2.ndflux\_u | W/m² | Internal normal total energy flux, constant material properties, upside | Boundaries 1–12 |  |
| ht2.nteflux\_d | down(ht2.tefluxx)\*ht2.dnxmesh+down(ht2.tefluxy)\*ht2.dnymesh+down(ht2.tefluxz)\*ht2.dnzmesh-down(ht2.dfluxx)\*ht2.dnxmesh-down(ht2.dfluxy)\*ht2.dnymesh-down(ht2.dfluxz)\*ht2.dnzmesh+ht2.ndflux\_d | W/m² | Internal normal total energy flux, downside | Boundaries 1–12 |  |
| ht2.nteflux\_cst\_d | down(ht2.teflux\_cstx)\*ht2.dnxmesh+down(ht2.teflux\_csty)\*ht2.dnymesh+down(ht2.teflux\_cstz)\*ht2.dnzmesh-down(ht2.dfluxx)\*ht2.dnxmesh-down(ht2.dfluxy)\*ht2.dnymesh-down(ht2.dfluxz)\*ht2.dnzmesh+ht2.ndflux\_d | W/m² | Internal normal total energy flux, constant material properties, downside | Boundaries 1–12 |  |
| ht2.nthflux | mean(ht2.thfluxx)\*ht2.nxmesh+mean(ht2.thfluxy)\*ht2.nymesh+mean(ht2.thfluxz)\*ht2.nzmesh | W/m² | Normal total enthalpy flux | Boundaries 1–12 |  |
| ht2.nthflux\_cst | mean(ht2.thflux\_cstx)\*ht2.nxmesh+mean(ht2.thflux\_csty)\*ht2.nymesh+mean(ht2.thflux\_cstz)\*ht2.nzmesh | W/m² | Normal total enthalpy flux, constant material properties | Boundaries 1–12 |  |
| ht2.nthflux\_u | up(ht2.thfluxx)\*ht2.unxmesh+up(ht2.thfluxy)\*ht2.unymesh+up(ht2.thfluxz)\*ht2.unzmesh | W/m² | Internal normal total enthalpy flux, upside | Boundaries 1–12 |  |
| ht2.nthflux\_cst\_u | up(ht2.thflux\_cstx)\*ht2.unxmesh+up(ht2.thflux\_csty)\*ht2.unymesh+up(ht2.thflux\_cstz)\*ht2.unzmesh | W/m² | Internal normal total enthalpy flux, constant material properties, upside | Boundaries 1–12 |  |
| ht2.nthflux\_d | down(ht2.thfluxx)\*ht2.dnxmesh+down(ht2.thfluxy)\*ht2.dnymesh+down(ht2.thfluxz)\*ht2.dnzmesh | W/m² | Internal normal total enthalpy flux, downside | Boundaries 1–12 |  |
| ht2.nthflux\_cst\_d | down(ht2.thflux\_cstx)\*ht2.dnxmesh+down(ht2.thflux\_csty)\*ht2.dnymesh+down(ht2.thflux\_cstz)\*ht2.dnzmesh | W/m² | Internal normal total enthalpy flux, constant material properties, downside | Boundaries 1–12 |  |
| ht2.Qm | 0 | kg/(m³·s) | Mass source | Domains 1–2 |  |
| ht2.Q | 0 | W/m³ | Heat source | Domains 1–2 | + operation |
| ht2.Qoop | 0 | W/m³ | Out-of-plane heat source | Domains 1–2 | + operation |
| ht2.Qtot | 0 | W/m³ | Total heat source | Domains 1–2 | + operation |
| ht2.Qbtot | 0 | W/m² | Total boundary heat source | Boundaries 1–12 | + operation |
| ht2.ntflux\_contrib | 0 | W/m² | Boundary sources and fluxes contribution | Domains 1–2 | + operation |
| ht2.Qitot | 0 | W/m² | Total interface source | Domains 1–2 | + operation |
| ht2.qs | 0 | W/(m³·K) | Production/absorption coefficient | Domains 1–2 | + operation |
| ht2.qs\_oop | 0 | W/(m³·K) | Out-of-plane production/absorption coefficient | Domains 1–2 | + operation |
| ht2.Qltot | 0 | W/m | Total line heat source | Edges 1–24 | + operation |
| ht2.Qlrtot | 0 | W/m | Total line heat source with radius | Edges 1–24 | + operation |
| ht2.Qptot | 0 | W | Total point heat source | Points 1–16 | + operation |
| ht2.Qprtot | 0 | W | Total point heat source with radius | Points 1–16 | + operation |
| ht2.q0 | 0 | W/m² | Inward heat flux | Boundaries 1–5, 8–9, 12 | + operation |
| ht2.Tu | up(T2) | K | Temperature | Boundaries 6–7, 10–11 |  |
| ht2.Tu | T2 | K | Temperature | Boundaries 1–5, 8–9, 12 |  |
| ht2.Td | down(T2) | K | Temperature | Boundaries 6–7, 10–11 |  |
| ht2.Td | T2 | K | Temperature | Boundaries 1–5, 8–9, 12 |  |
| ht2.TuIsDown | 0 | 1 | Help variable | Boundaries 6–7, 10–11 |  |
| ht2.TuIsDown | 0 | 1 | Help variable | Boundaries 1–5, 8–9, 12 |  |
| ht2.TdIsUp | 0 | 1 | Help variable | Boundaries 6–7, 10–11 |  |
| ht2.TdIsUp | 0 | 1 | Help variable | Boundaries 1–5, 8–9, 12 |  |
| ht2.du | up(ht2.d) | 1 | Thickness | Boundaries 6–7, 10–11 |  |
| ht2.du | ht2.d | 1 | Thickness | Boundaries 1–5, 8–9, 12 |  |
| ht2.dd | down(ht2.d) | 1 | Thickness | Boundaries 6–7, 10–11 |  |
| ht2.dd | ht2.d | 1 | Thickness | Boundaries 1–5, 8–9, 12 |  |
| ht2.nx | nx | 1 | Normal vector, x-component | Boundaries 6–7, 10–11 |  |
| ht2.ny | ny | 1 | Normal vector, y-component | Boundaries 6–7, 10–11 |  |
| ht2.nz | nz | 1 | Normal vector, z-component | Boundaries 6–7, 10–11 |  |
| ht2.nx | dnx | 1 | Normal vector, x-component | Boundaries 1–5, 8–9, 12 |  |
| ht2.ny | dny | 1 | Normal vector, y-component | Boundaries 1–5, 8–9, 12 |  |
| ht2.nz | dnz | 1 | Normal vector, z-component | Boundaries 1–5, 8–9, 12 |  |
| ht2.nxmesh | nxmesh | 1 | Normal vector (mesh), x-component | Boundaries 6–7, 10–11 |  |
| ht2.nymesh | nymesh | 1 | Normal vector (mesh), y-component | Boundaries 6–7, 10–11 |  |
| ht2.nzmesh | nzmesh | 1 | Normal vector (mesh), z-component | Boundaries 6–7, 10–11 |  |
| ht2.nxmesh | dnxmesh | 1 | Normal vector (mesh), x-component | Boundaries 1–5, 8–9, 12 |  |
| ht2.nymesh | dnymesh | 1 | Normal vector (mesh), y-component | Boundaries 1–5, 8–9, 12 |  |
| ht2.nzmesh | dnzmesh | 1 | Normal vector (mesh), z-component | Boundaries 1–5, 8–9, 12 |  |
| ht2.dnx | dnx | 1 | Normal vector down direction, x-component | Boundaries 1–12 |  |
| ht2.dny | dny | 1 | Normal vector down direction, y-component | Boundaries 1–12 |  |
| ht2.dnz | dnz | 1 | Normal vector down direction, z-component | Boundaries 1–12 |  |
| ht2.dnxmesh | dnxmesh | 1 | Normal vector down direction (mesh), x-component | Boundaries 1–12 |  |
| ht2.dnymesh | dnymesh | 1 | Normal vector down direction (mesh), y-component | Boundaries 1–12 |  |
| ht2.dnzmesh | dnzmesh | 1 | Normal vector down direction (mesh), z-component | Boundaries 1–12 |  |
| ht2.unx | unx | 1 | Normal vector up direction, x-component | Boundaries 1–12 |  |
| ht2.uny | uny | 1 | Normal vector up direction, y-component | Boundaries 1–12 |  |
| ht2.unz | unz | 1 | Normal vector up direction, z-component | Boundaries 1–12 |  |
| ht2.unxmesh | unxmesh | 1 | Normal vector up direction (mesh), x-component | Boundaries 1–12 |  |
| ht2.unymesh | unymesh | 1 | Normal vector up direction (mesh), y-component | Boundaries 1–12 |  |
| ht2.unzmesh | unzmesh | 1 | Normal vector up direction (mesh), z-component | Boundaries 1–12 |  |
| ht2.dEiInt | 0 | W | Total accumulated heat rate | Global | + operation |
| ht2.dEiInt\_cst | 0 | W | Total accumulated heat rate, constant material properties | Global | + operation |
| ht2.dEi0Int | 0 | W | Total accumulated energy rate | Global | + operation |
| ht2.dEi0Int\_cst | 0 | W | Total accumulated energy rate, constant material properties | Global | + operation |
| ht2.ntfluxInt | ht2.intExtBnd(ht2.ntflux\*ht2.varIntSpa)+ht2.intIntBnd(ht2.ncflux\_u\*up(ht2.varIntSpa)+ht2.ncflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate | Global |  |
| ht2.ntfluxInt\_cst | ht2.intExtBnd(ht2.ntflux\_cst\*ht2.varIntSpa)+ht2.intIntBnd(ht2.ncflux\_u\*up(ht2.varIntSpa)+ht2.ncflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate, constant material properties | Global |  |
| ht2.ntefluxInt | ht2.intExtBnd(ht2.nteflux\*ht2.varIntSpa)+ht2.intIntBnd(ht2.nthflux\_u\*up(ht2.varIntSpa)+ht2.nthflux\_d\*down(ht2.varIntSpa)) | W | Total net energy rate | Global |  |
| ht2.ntefluxInt\_cst | ht2.intExtBnd(ht2.nteflux\_cst\*ht2.varIntSpa)+ht2.intIntBnd(ht2.nthflux\_cst\_u\*up(ht2.varIntSpa)+ht2.nthflux\_cst\_d\*down(ht2.varIntSpa)) | W | Total net energy rate, constant material properties | Global |  |
| ht2.QInt | ht2.intDom(ht2.Qtot\*ht2.varIntSpa)+ht2.intIntLine(ht2.Qltot\*ht2.varIntSpa)+ht2.intLine(ht2.Qlrtot\*ht2.varIntSpa)+ht2.intIntPnt(ht2.Qptot)+ht2.intPnt(ht2.Qprtot)-ht2.intIntBnd(ht2.ndflux\_u\*up(ht2.varIntSpa)+ht2.ndflux\_d\*down(ht2.varIntSpa)) | W | Total heat source | Global |  |
| ht2.QInt\_cst | ht2.intDom(ht2.Qtot\*ht2.varIntSpa)+ht2.intIntLine(ht2.Qltot\*ht2.varIntSpa)+ht2.intLine(ht2.Qlrtot\*ht2.varIntSpa)+ht2.intIntPnt(ht2.Qptot)+ht2.intPnt(ht2.Qprtot)-ht2.intIntBnd(ht2.ndflux\_u\*up(ht2.varIntSpa)+ht2.ndflux\_d\*down(ht2.varIntSpa)) | W | Total heat source, constant material properties | Global |  |
| ht2.Wstr | 0 | W/m³ | Total stress power | Domains 1–2 | + operation |
| ht2.WstrInt | 0 | W | Total stress power | Global | + operation |
| ht2.WstrInt\_cst | 0 | W | Total stress power, constant material properties | Global | + operation |
| ht2.Wtot | 0 | W/m³ | Total work source | Domains 1–2 | + operation |
| ht2.WBndTot\_u | 0 | W/m² | Total work source, upside | Boundaries 6–7, 10–11 | + operation |
| ht2.WBndTot\_d | 0 | W/m² | Total work source, downside | Boundaries 1–12 | + operation |
| ht2.WInt | 0 | W | Total work source | Global | + operation |
| ht2.WInt\_cst | 0 | W | Total work source, constant material properties | Global | + operation |
| ht2.heatBalance | ht2.dEiInt+ht2.ntfluxInt+ht2.WstrInt-ht2.QInt | W | Heat balance | Global |  |
| ht2.heatBalance\_cst | ht2.dEiInt\_cst+ht2.ntfluxInt\_cst+ht2.WstrInt\_cst-ht2.QInt\_cst | W | Heat balance, constant material properties | Global |  |
| ht2.energyBalance | ht2.dEi0Int+ht2.ntefluxInt-ht2.WInt-ht2.QInt | W | Energy balance | Global |  |
| ht2.energyBalance\_cst | ht2.dEi0Int\_cst+ht2.ntefluxInt\_cst-ht2.WInt\_cst-ht2.QInt\_cst | W | Energy balance, constant material properties | Global |  |
| ht2.id | 1 | 1 | Physics indicator | Domains 1–2 |  |
| ht2.varIntSpa | ht2.d | 1 | Intermediate variable | Domains 1–2 | Meta |

### Solid 1

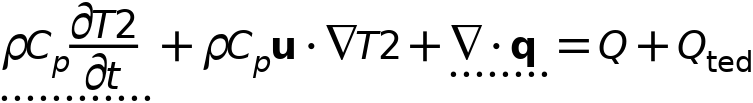


Solid 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Equations





#### Heat Conduction, Solid

Settings

| **Description** | **Value** |
| --- | --- |
| Thermal conductivity | From material |

#### Thermodynamics, Solid

Settings

| **Description** | **Value** |
| --- | --- |
| Density | From material |
| Heat capacity at constant pressure | From material |

#### Coordinate System Selection

Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Model Input

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Volume reference temperature | Common model input |  |
| Absolute pressure | User defined |  |
| Absolute pressure | 1.0133E5 | Pa |

Properties from material

| **Property** | **Material** | **Property group** |
| --- | --- | --- |
| Thermal conductivity | Battery block | Basic |
| Density | Battery block | Basic |
| Heat capacity at constant pressure | Battery block | Basic |
| Thermal conductivity | PCM Layer | Basic |
| Density | PCM Layer | Basic |
| Heat capacity at constant pressure | PCM Layer | Basic |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| domflux.T2x | ht2.dfluxx\*ht2.d | W/m² | Domain flux, x-component | Domains 1–2 |  |
| domflux.T2y | ht2.dfluxy\*ht2.d | W/m² | Domain flux, y-component | Domains 1–2 |  |
| domflux.T2z | ht2.dfluxz\*ht2.d | W/m² | Domain flux, z-component | Domains 1–2 |  |
| ht2.chiT | 0 | 1/Pa | Isothermal compressibility coefficient | Domains 1–2 |  |
| ht2.alphap | -d(ht2.rho,T2)/max(ht2.rho,eps) | 1/K | Isobaric compressibility coefficient | Domains 1–2 |  |
| ht2.DeltaH\_add | integrate(ht2.CpInt,ht2.TInt,ht2.DeltaH\_Tlow,T2) | J/kg | Sensible enthalpy | Domains 1–2 | + operation |
| ht2.DeltaH\_add\_cst | ht2.Cp\*(T2-ht2.DeltaH\_Tlow) | J/kg | Sensible enthalpy, constant material properties | Domains 1–2 | + operation |
| ht2.H | ht2.HRef+ht2.DeltaH | J/kg | Enthalpy | Domains 1–2 | + operation |
| ht2.H\_cst | ht2.HRef+ht2.DeltaH\_cst | J/kg | Enthalpy, constant material properties | Domains 1–2 | + operation |
| ht2.Ei | ht2.H | J/kg | Internal energy | Domains 1–2 | + operation |
| ht2.Ei\_cst | ht2.H\_cst | J/kg | Internal energy, constant material properties | Domains 1–2 | + operation |
| ht2.Ek | 0.5\*(ht2.ux^2+ht2.uy^2+ht2.uz^2) | J/kg | Kinetic energy | Domains 1–2 | + operation |
| ht2.dfluxx | -ht2.k\_effxx\*T2x-ht2.k\_effxy\*T2y-ht2.k\_effxz\*T2z | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht2.dfluxy | -ht2.k\_effyx\*T2x-ht2.k\_effyy\*T2y-ht2.k\_effyz\*T2z | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht2.dfluxz | -ht2.k\_effzx\*T2x-ht2.k\_effzy\*T2y-ht2.k\_effzz\*T2z | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht2.dfluxtestx | -ht2.k\_effxx\*test(T2x)-ht2.k\_effxy\*test(T2y)-ht2.k\_effxz\*test(T2z) | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht2.dfluxtesty | -ht2.k\_effyx\*test(T2x)-ht2.k\_effyy\*test(T2y)-ht2.k\_effyz\*test(T2z) | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht2.dfluxtestz | -ht2.k\_effzx\*test(T2x)-ht2.k\_effzy\*test(T2y)-ht2.k\_effzz\*test(T2z) | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht2.cfluxx | ht2.rho\*ht2.ux\*ht2.Ei | W/m² | Convective heat flux, x-component | Domains 1–2 | + operation |
| ht2.cfluxy | ht2.rho\*ht2.uy\*ht2.Ei | W/m² | Convective heat flux, y-component | Domains 1–2 | + operation |
| ht2.cfluxz | ht2.rho\*ht2.uz\*ht2.Ei | W/m² | Convective heat flux, z-component | Domains 1–2 | + operation |
| ht2.tefluxx | ht2.dfluxx+ht2.thfluxx | W/m² | Total energy flux, x-component | Domains 1–2 | + operation |
| ht2.tefluxy | ht2.dfluxy+ht2.thfluxy | W/m² | Total energy flux, y-component | Domains 1–2 | + operation |
| ht2.tefluxz | ht2.dfluxz+ht2.thfluxz | W/m² | Total energy flux, z-component | Domains 1–2 | + operation |
| ht2.teflux\_cstx | ht2.dfluxx+ht2.thflux\_cstx | W/m² | Total energy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht2.teflux\_csty | ht2.dfluxy+ht2.thflux\_csty | W/m² | Total energy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht2.teflux\_cstz | ht2.dfluxz+ht2.thflux\_cstz | W/m² | Total energy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht2.thfluxx | ht2.rho\*ht2.ux\*ht2.H0 | W/m² | Total enthalpy flux, x-component | Domains 1–2 | + operation |
| ht2.thfluxy | ht2.rho\*ht2.uy\*ht2.H0 | W/m² | Total enthalpy flux, y-component | Domains 1–2 | + operation |
| ht2.thfluxz | ht2.rho\*ht2.uz\*ht2.H0 | W/m² | Total enthalpy flux, z-component | Domains 1–2 | + operation |
| ht2.thflux\_cstx | ht2.rho\*ht2.ux\*ht2.H0\_cst | W/m² | Total enthalpy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht2.thflux\_csty | ht2.rho\*ht2.uy\*ht2.H0\_cst | W/m² | Total enthalpy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht2.thflux\_cstz | ht2.rho\*ht2.uz\*ht2.H0\_cst | W/m² | Total enthalpy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht2.ndflux\_u | -uflux\_spatial(T2)/up(ht2.varIntSpa) | W/m² | Internal normal conductive heat flux, upside | Boundaries 6–7, 10–11 | + operation |
| ht2.ndflux\_d | -dflux\_spatial(T2)/down(ht2.varIntSpa) | W/m² | Internal normal conductive heat flux, downside | Boundaries 6–7, 10–11 | + operation |
| ht2.ndflux\_d | -dflux\_spatial(T2)/down(ht2.varIntSpa) | W/m² | Internal normal conductive heat flux, downside | Boundaries 1–5, 8–9, 12 | + operation |
| ht2.dEiInt | ht2.solid1.dEiInt | W | Total accumulated heat rate | Global | + operation |
| ht2.dEiInt\_cst | ht2.solid1.dEiInt\_cst | W | Total accumulated heat rate, constant material properties | Global | + operation |
| ht2.dEi0Int | ht2.solid1.dEi0Int | W | Total accumulated energy rate | Global | + operation |
| ht2.dEi0Int\_cst | ht2.solid1.dEi0Int\_cst | W | Total accumulated energy rate, constant material properties | Global | + operation |
| ht2.Wstr | ht2.pA\*(d(ht2.ux,x)+d(ht2.uy,y)+d(ht2.uz,z)) | W/m³ | Total stress power | Domains 1–2 | + operation |
| ht2.WstrInt | ht2.solid1.WstrInt | W | Total stress power | Global | + operation |
| ht2.WstrInt\_cst | ht2.solid1.WstrInt\_cst | W | Total stress power, constant material properties | Global | + operation |
| ht2.WInt | ht2.solid1.WInt | W | Total work source | Global | + operation |
| ht2.WInt\_cst | ht2.solid1.WInt\_cst | W | Total work source, constant material properties | Global | + operation |
| ht2.rho | material.rho | kg/m³ | Density | Domains 1–2 | Meta |
| ht2.kxx | material.k11 | W/(m·K) | Thermal conductivity, xx-component | Domains 1–2 | Meta |
| ht2.kyx | material.k21 | W/(m·K) | Thermal conductivity, yx-component | Domains 1–2 | Meta |
| ht2.kzx | material.k31 | W/(m·K) | Thermal conductivity, zx-component | Domains 1–2 | Meta |
| ht2.kxy | material.k12 | W/(m·K) | Thermal conductivity, xy-component | Domains 1–2 | Meta |
| ht2.kyy | material.k22 | W/(m·K) | Thermal conductivity, yy-component | Domains 1–2 | Meta |
| ht2.kzy | material.k32 | W/(m·K) | Thermal conductivity, zy-component | Domains 1–2 | Meta |
| ht2.kxz | material.k13 | W/(m·K) | Thermal conductivity, xz-component | Domains 1–2 | Meta |
| ht2.kyz | material.k23 | W/(m·K) | Thermal conductivity, yz-component | Domains 1–2 | Meta |
| ht2.kzz | material.k33 | W/(m·K) | Thermal conductivity, zz-component | Domains 1–2 | Meta |
| ht2.Cp | material.Cp | J/(kg·K) | Heat capacity at constant pressure | Domains 1–2 | Meta |
| ht2.solid1.pref | 1[atm] | Pa | Reference pressure level | Domains 1–2 |  |
| ht2.k\_iso | if(material.k12==0&&material.k13==0&&material.k21==0&&material.k22==material.k11&&material.k23==0&&material.k31==0&&material.k32==0&&material.k33==material.k11,material.k11,error('Failed to evaluate an isotropic value of an anisotropic tensor')) | W/(m·K) | Thermal conductivity, isotropic value | Domains 1–2 | Meta |
| ht2.pA | ht2.pref | Pa | Absolute pressure | Domains 1–2 |  |
| ht2.C\_eff | ht2.rho\*ht2.Cp | J/(m³·K) | Effective volumetric heat capacity | Domains 1–2 |  |
| ht2.cellPe | 0.5\*ht2.rho\*ht2.Cp\*h\*sqrt(ht2.ux^2+ht2.uy^2+ht2.uz^2)/ht2.kmean | 1 | Cell Péclet number | Domains 1–2 |  |
| ht2.ux | 0 | m/s | Velocity field, x-component | Domains 1–2 | + operation |
| ht2.uy | 0 | m/s | Velocity field, y-component | Domains 1–2 | + operation |
| ht2.uz | 0 | m/s | Velocity field, z-component | Domains 1–2 | + operation |
| ht2.Qmet | 0 | W/m³ | Metabolic heat source | Domains 1–2 | + operation |
| ht2.rhoInit | subst(ht2.rho,T2,ht2.Tinit,minput.pA,ht2.pref) | kg/m³ | Initial density | Domains 1–2 |  |
| ht2.rho\_eff | ht2.rho | kg/m³ | Effective density | Domains 1–2 |  |
| ht2.k\_effxx | ht2.kxx | W/(m·K) | Effective thermal conductivity, xx-component | Domains 1–2 |  |
| ht2.k\_effyx | ht2.kyx | W/(m·K) | Effective thermal conductivity, yx-component | Domains 1–2 |  |
| ht2.k\_effzx | ht2.kzx | W/(m·K) | Effective thermal conductivity, zx-component | Domains 1–2 |  |
| ht2.k\_effxy | ht2.kxy | W/(m·K) | Effective thermal conductivity, xy-component | Domains 1–2 |  |
| ht2.k\_effyy | ht2.kyy | W/(m·K) | Effective thermal conductivity, yy-component | Domains 1–2 |  |
| ht2.k\_effzy | ht2.kzy | W/(m·K) | Effective thermal conductivity, zy-component | Domains 1–2 |  |
| ht2.k\_effxz | ht2.kxz | W/(m·K) | Effective thermal conductivity, xz-component | Domains 1–2 |  |
| ht2.k\_effyz | ht2.kyz | W/(m·K) | Effective thermal conductivity, yz-component | Domains 1–2 |  |
| ht2.k\_effzz | ht2.kzz | W/(m·K) | Effective thermal conductivity, zz-component | Domains 1–2 |  |
| ht2.kappaTxx | 0 | W/(m·K) | Turbulent thermal conductivity, xx-component | Domains 1–2 |  |
| ht2.kappaTyx | 0 | W/(m·K) | Turbulent thermal conductivity, yx-component | Domains 1–2 |  |
| ht2.kappaTzx | 0 | W/(m·K) | Turbulent thermal conductivity, zx-component | Domains 1–2 |  |
| ht2.kappaTxy | 0 | W/(m·K) | Turbulent thermal conductivity, xy-component | Domains 1–2 |  |
| ht2.kappaTyy | 0 | W/(m·K) | Turbulent thermal conductivity, yy-component | Domains 1–2 |  |
| ht2.kappaTzy | 0 | W/(m·K) | Turbulent thermal conductivity, zy-component | Domains 1–2 |  |
| ht2.kappaTxz | 0 | W/(m·K) | Turbulent thermal conductivity, xz-component | Domains 1–2 |  |
| ht2.kappaTyz | 0 | W/(m·K) | Turbulent thermal conductivity, yz-component | Domains 1–2 |  |
| ht2.kappaTzz | 0 | W/(m·K) | Turbulent thermal conductivity, zz-component | Domains 1–2 |  |
| ht2.kmean | (ht2.k\_effxx+ht2.k\_effyy+ht2.k\_effzz)/3 | W/(m·K) | Mean effective thermal conductivity | Domains 1–2 |  |
| ht2.alphaTdxx | ht2.k\_effxx/ht2.C\_eff | m²/s | Thermal diffusivity, xx-component | Domains 1–2 |  |
| ht2.alphaTdyx | ht2.k\_effyx/ht2.C\_eff | m²/s | Thermal diffusivity, yx-component | Domains 1–2 |  |
| ht2.alphaTdzx | ht2.k\_effzx/ht2.C\_eff | m²/s | Thermal diffusivity, zx-component | Domains 1–2 |  |
| ht2.alphaTdxy | ht2.k\_effxy/ht2.C\_eff | m²/s | Thermal diffusivity, xy-component | Domains 1–2 |  |
| ht2.alphaTdyy | ht2.k\_effyy/ht2.C\_eff | m²/s | Thermal diffusivity, yy-component | Domains 1–2 |  |
| ht2.alphaTdzy | ht2.k\_effzy/ht2.C\_eff | m²/s | Thermal diffusivity, zy-component | Domains 1–2 |  |
| ht2.alphaTdxz | ht2.k\_effxz/ht2.C\_eff | m²/s | Thermal diffusivity, xz-component | Domains 1–2 |  |
| ht2.alphaTdyz | ht2.k\_effyz/ht2.C\_eff | m²/s | Thermal diffusivity, yz-component | Domains 1–2 |  |
| ht2.alphaTdzz | ht2.k\_effzz/ht2.C\_eff | m²/s | Thermal diffusivity, zz-component | Domains 1–2 |  |
| ht2.alphaTdMean | ht2.kmean/ht2.C\_eff | m²/s | Mean thermal diffusivity | Domains 1–2 |  |
| ht2.gradTx | T2x | K/m | Temperature gradient, x-component | Domains 1–2 |  |
| ht2.gradTy | T2y | K/m | Temperature gradient, y-component | Domains 1–2 |  |
| ht2.gradTz | T2z | K/m | Temperature gradient, z-component | Domains 1–2 |  |
| ht2.gradTmag | sqrt(ht2.gradTx^2+ht2.gradTy^2+ht2.gradTz^2) | K/m | Temperature gradient magnitude | Domains 1–2 |  |
| ht2.pref | ht2.solid1.pref | Pa | Reference pressure level | Domains 1–2 |  |
| ht2.DeltaH\_Tlow | ht2.Tref | K | Temperature lower bound for enthalpy evaluation | Domains 1–2 |  |
| ht2.DeltaH\_plow | ht2.pref | Pa | Pressure lower bound for enthalpy evaluation | Domains 1–2 |  |
| ht2.dHdp | 0 | m³/kg | Intermediate variable | Domains 1–2 |  |
| ht2.mujtT | 0 | K/Pa | Isothermal Joule-Thomson coefficient | Domains 1–2 |  |
| ht2.alphapT | ht2.alphap\*T2 | 1 | Help variable | Domains 1–2 |  |
| ht2.dEi | material.dt(ht2.rho\*ht2.Ei) | W/m³ | Total accumulated heat rate density | Domains 1–2 |  |
| ht2.dEi\_cst | material.dt(ht2.rho\*ht2.Ei\_cst) | W/m³ | Total accumulated heat rate density, constant material properties | Domains 1–2 |  |
| ht2.dEi0 | material.dt(ht2.rho\*ht2.Ei0) | W/m³ | Total accumulated energy rate density | Domains 1–2 |  |
| ht2.dEi0\_cst | material.dt(ht2.rho\*ht2.Ei0\_cst) | W/m³ | Total accumulated energy rate density, constant material properties | Domains 1–2 |  |
| ht2.solid1.dEiInt | ht2.solid1.intDom((ht2.dEi-ht2.Qm\*ht2.Ei)\*ht2.varIntSpa) | W | Total accumulated heat rate | Global |  |
| ht2.solid1.dEiInt\_cst | ht2.solid1.intDom((ht2.dEi\_cst-ht2.Qm\*ht2.Ei\_cst)\*ht2.varIntSpa) | W | Total accumulated heat rate, constant material properties | Global |  |
| ht2.solid1.dEi0Int | ht2.solid1.intDom((ht2.dEi0-ht2.Qm\*ht2.H)\*ht2.varIntSpa) | W | Total accumulated energy rate | Global |  |
| ht2.solid1.dEi0Int\_cst | ht2.solid1.intDom((ht2.dEi0\_cst-ht2.Qm\*ht2.H\_cst)\*ht2.varIntSpa) | W | Total accumulated energy rate, constant material properties | Global |  |
| ht2.solid1.QInt | ht2.solid1.intDom(ht2.Qtot\*ht2.varIntSpa)+ht2.solid1.intIntLine(ht2.Qltot\*ht2.varIntSpa)+ht2.intLine(subst(ht2.Qlrtot,ht2.id,isdefined(ht2.solid1.id))\*ht2.varIntSpa)+ht2.solid1.intIntPnt(ht2.Qptot)+ht2.intPnt(subst(ht2.Qprtot,ht2.id,isdefined(ht2.solid1.id)))-ht2.solid1.intIntBnd(ht2.ndflux\_u\*up(ht2.varIntSpa)+ht2.ndflux\_d\*down(ht2.varIntSpa)) | W | Total heat source | Global |  |
| ht2.solid1.QInt\_cst | ht2.solid1.intDom(ht2.Qtot\*ht2.varIntSpa)+ht2.solid1.intIntLine(ht2.Qltot\*ht2.varIntSpa)+ht2.intLine(subst(ht2.Qlrtot,ht2.id,isdefined(ht2.solid1.id))\*ht2.varIntSpa)+ht2.solid1.intIntPnt(ht2.Qptot)+ht2.intPnt(subst(ht2.Qprtot,ht2.id,isdefined(ht2.solid1.id)))-ht2.solid1.intIntBnd(ht2.ndflux\_u\*up(ht2.varIntSpa)+ht2.ndflux\_d\*down(ht2.varIntSpa)) | W | Total heat source, constant material properties | Global |  |
| ht2.solid1.WstrInt | ht2.solid1.intDom(ht2.Wstr\*ht2.varIntSpa) | W | Total stress power | Global |  |
| ht2.solid1.WstrInt\_cst | ht2.solid1.intDom(ht2.Wstr\*ht2.varIntSpa) | W | Total stress power, constant material properties | Global |  |
| ht2.solid1.WInt | ht2.solid1.intDom(ht2.Wtot\*ht2.varIntSpa)+ht2.solid1.intBndUp(ht2.WBndTot\_u\*up(ht2.varIntSpa))+ht2.solid1.intBndDown(ht2.WBndTot\_d\*down(ht2.varIntSpa)) | W | Total work source | Global |  |
| ht2.solid1.WInt\_cst | ht2.solid1.intDom(ht2.Wtot\*ht2.varIntSpa)+ht2.solid1.intBndUp(ht2.WBndTot\_u\*up(ht2.varIntSpa))+ht2.solid1.intBndDown(ht2.WBndTot\_d\*down(ht2.varIntSpa)) | W | Total work source, constant material properties | Global |  |
| ht2.solid1.ntfluxInt | ht2.solid1.intExtBnd(ht2.ntflux\*ht2.varIntSpa)+ht2.solid1.intExtBndUp(ht2.ntflux\_u\*up(ht2.varIntSpa))+ht2.solid1.intExtBndDown(ht2.ntflux\_d\*down(ht2.varIntSpa))+ht2.solid1.intIntBnd(ht2.ncflux\_u\*up(ht2.varIntSpa)+ht2.ncflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate | Global |  |
| ht2.solid1.ntfluxInt\_cst | ht2.solid1.intExtBnd(ht2.ntflux\_cst\*ht2.varIntSpa)+ht2.solid1.intExtBndUp(ht2.ntflux\_cst\_u\*up(ht2.varIntSpa))+ht2.solid1.intExtBndDown(ht2.ntflux\_cst\_d\*down(ht2.varIntSpa))+ht2.solid1.intIntBnd(ht2.ncflux\_u\*up(ht2.varIntSpa)+ht2.ncflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate, constant material properties | Global |  |
| ht2.solid1.ntefluxInt | ht2.solid1.intExtBnd(ht2.nteflux\*ht2.varIntSpa)+ht2.solid1.intExtBndUp(ht2.nteflux\_u\*up(ht2.varIntSpa))+ht2.solid1.intExtBndDown(ht2.nteflux\_d\*down(ht2.varIntSpa))+ht2.solid1.intIntBnd(ht2.nthflux\_u\*up(ht2.varIntSpa)+ht2.nthflux\_d\*down(ht2.varIntSpa)) | W | Total net energy rate | Global |  |
| ht2.solid1.ntefluxInt\_cst | ht2.solid1.intExtBnd(ht2.nteflux\_cst\*ht2.varIntSpa)+ht2.solid1.intExtBndUp(ht2.nteflux\_cst\_u\*up(ht2.varIntSpa))+ht2.solid1.intExtBndDown(ht2.nteflux\_cst\_d\*down(ht2.varIntSpa))+ht2.solid1.intIntBnd(ht2.nthflux\_cst\_u\*up(ht2.varIntSpa)+ht2.nthflux\_cst\_d\*down(ht2.varIntSpa)) | W | Total net energy rate, constant material properties | Global |  |
| ht2.solid1.heatBalance | ht2.solid1.dEiInt+ht2.solid1.ntfluxInt+ht2.solid1.WstrInt-ht2.solid1.QInt | W | Heat balance | Global |  |
| ht2.solid1.heatBalance\_cst | ht2.solid1.dEiInt\_cst+ht2.solid1.ntfluxInt\_cst+ht2.solid1.WstrInt\_cst-ht2.solid1.QInt\_cst | W | Heat balance, constant material properties | Global |  |
| ht2.solid1.energyBalance | ht2.solid1.dEi0Int+ht2.solid1.ntefluxInt-ht2.solid1.WInt-ht2.solid1.QInt | W | Energy balance | Global |  |
| ht2.solid1.energyBalance\_cst | ht2.solid1.dEi0Int\_cst+ht2.solid1.ntefluxInt\_cst-ht2.solid1.WInt\_cst-ht2.solid1.QInt\_cst | W | Energy balance, constant material properties | Global |  |
| ht2.Tradu | ht2.Tu | K | Upside temperature | Domains 1–2 |  |
| ht2.Tradu | ht2.Tu | K | Upside temperature | Boundaries 1–12 |  |
| ht2.Tradd | ht2.Td | K | Downside temperature | Domains 1–2 |  |
| ht2.Tradd | ht2.Td | K | Downside temperature | Boundaries 1–12 |  |
| ht2.timeDerivative | material.dt(T2) | K/s | Temperature, first time derivative | Domains 1–2 |  |
| ht2.gamma | 1 | 1 | Ratio of specific heats | Domains 1–2 |  |
| ht2.Trho | ht2.Tref | K | Temperature for density evaluation | Domains 1–2 |  |
| ht2.CpInt | subst(material.Cp,ht2.solid1.minput\_pressure,ht2.pref,ht2.solid1.minput\_temperature,ht2.TInt) | J/(kg·K) | Specific heat capacity for integration | Domains 1–2 | Meta |
| ht2.Cp\_ref | subst(material.Cp,ht2.solid1.minput\_pressure,ht2.pref,ht2.solid1.minput\_temperature,ht2.Tref) | J/(kg·K) | Reference heat capacity | Domains 1–2 | Meta |

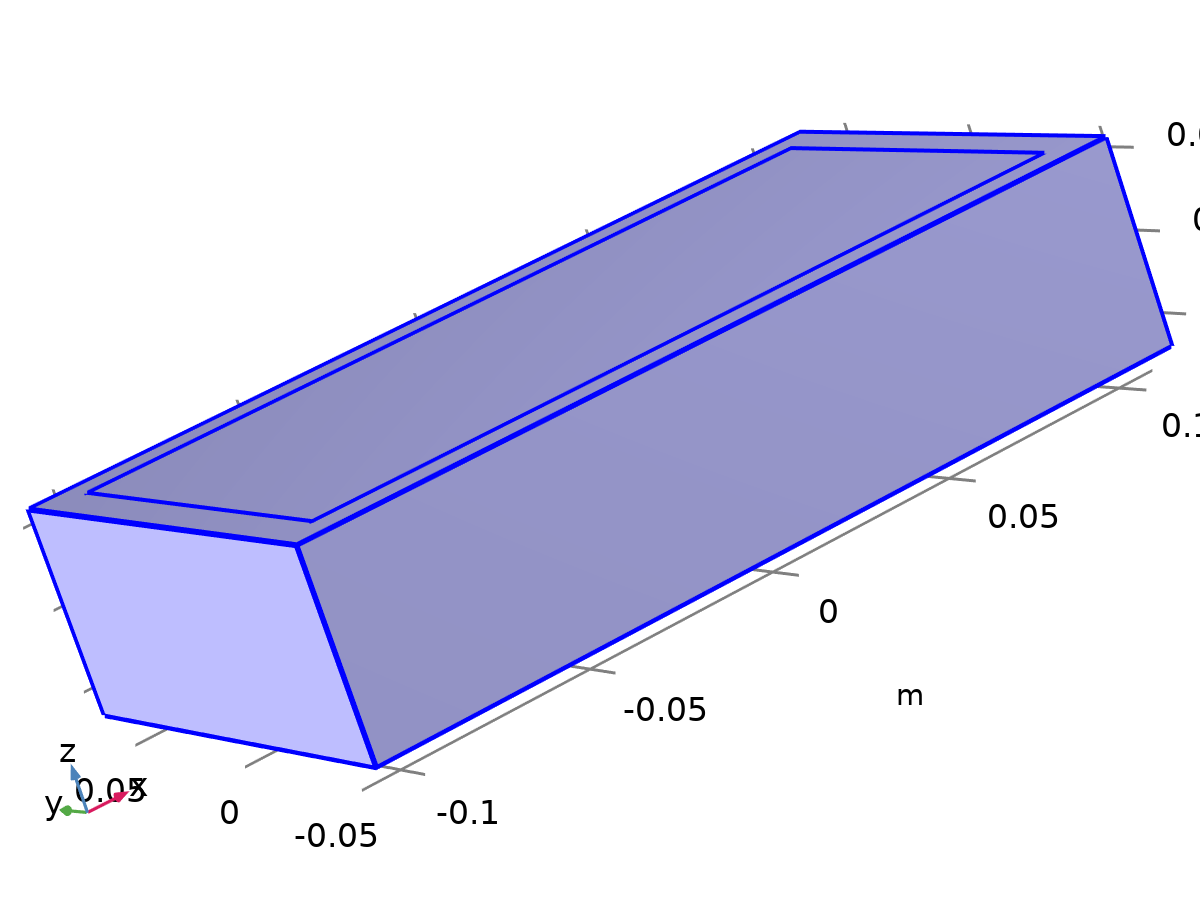
#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| T2 | Lagrange (Quadratic) | K | Temperature | Material | Domains 1–2 |
| T2 | Lagrange (Quadratic) | K | Temperature | Spatial | Domains 1–2 |
| T2 | Lagrange (Quadratic) | K | Temperature | Geometry | Domains 1–2 |
| T2 | Lagrange (Quadratic) | K | Temperature | Mesh | Domains 1–2 |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| (ht2.dfluxx\*test(T2x)+ht2.dfluxy\*test(T2y)+ht2.dfluxz\*test(T2z))\*ht2.d | 4 | Spatial | Domains 1–2 |
| -ht2.C\_eff\*ht2.timeDerivative\*test(T2)\*ht2.d | 4 | Spatial | Domains 1–2 |

### Initial Values 1



Initial Values 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

#### Initial Values

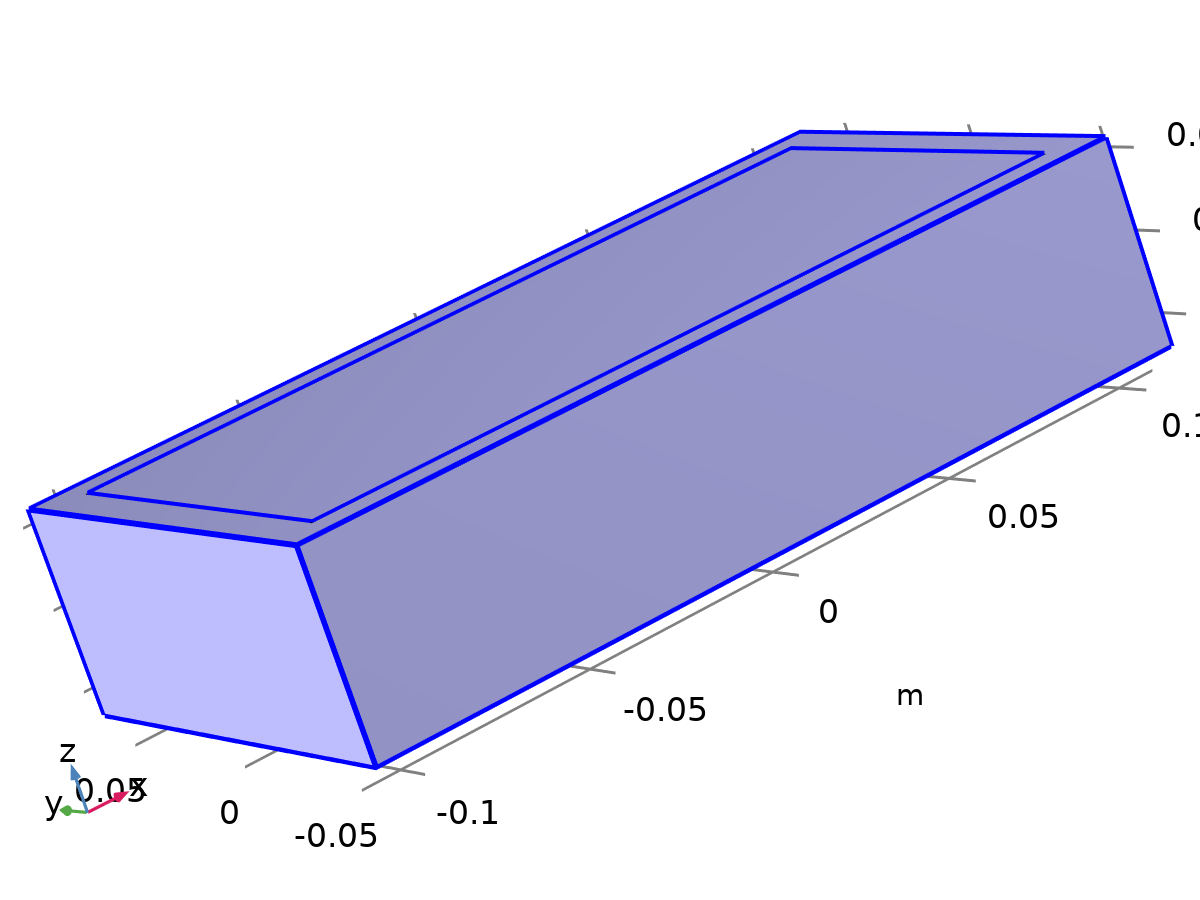
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Temperature | User defined |  |
| Temperature | 293.15 | K |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| ht2.Tinit | 293.15[K] | K | Initial temperature | Domains 1–2 |

### Thermal Insulation 1



Thermal Insulation 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: All boundaries |

Equations



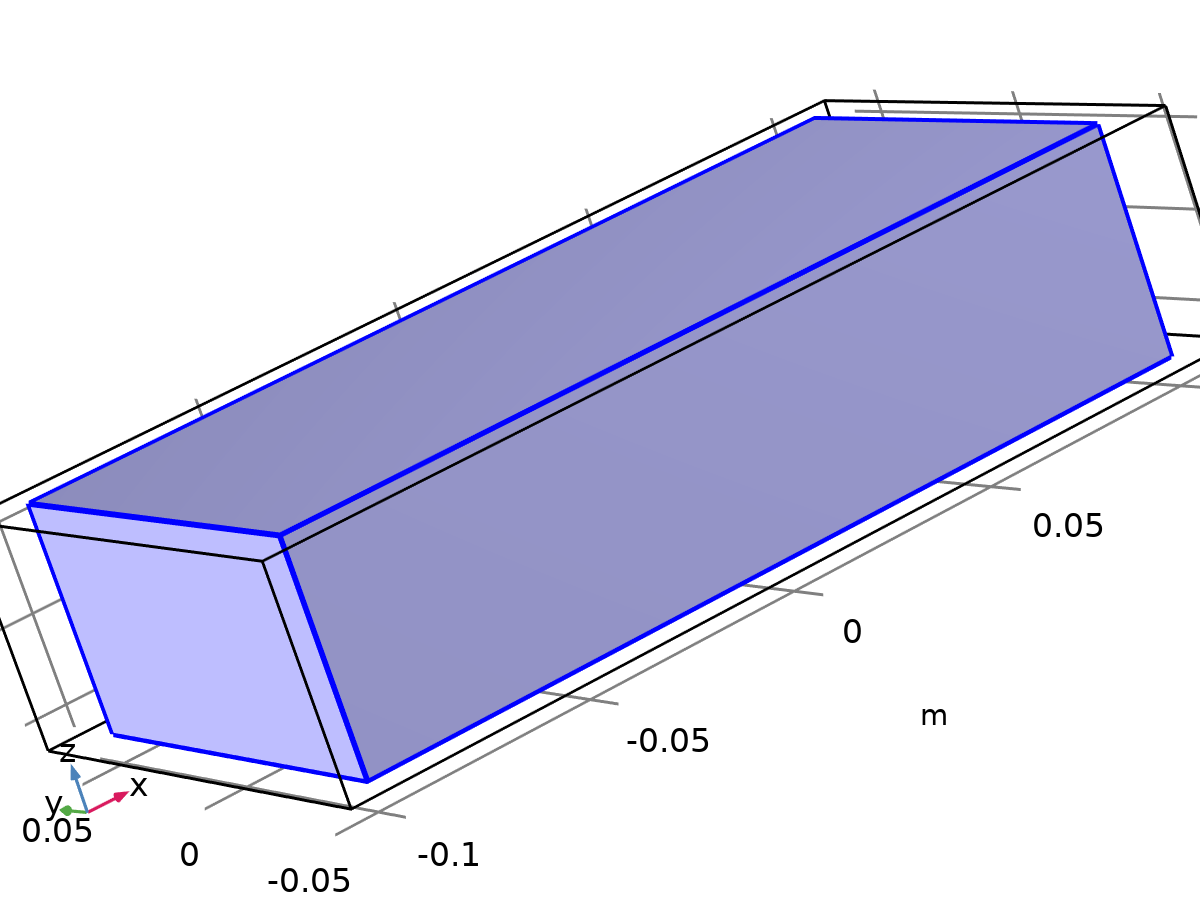
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| ht2.ins1.ntfluxInt | ht2.ins1.intExtBnd(ht2.ntflux\*ht2.varIntSpa)+ht2.ins1.intIntBnd(ht2.ncflux\_u\*up(ht2.varIntSpa)+ht2.ncflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate | Global |
| ht2.ins1.ntfluxInt\_cst | ht2.ins1.intExtBnd(ht2.ntflux\*ht2.varIntSpa)+ht2.ins1.intIntBnd(ht2.ncflux\_u\*up(ht2.varIntSpa)+ht2.ncflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate, constant material properties | Global |
| ht2.ins1.ntefluxInt | ht2.ins1.intExtBnd(ht2.nteflux\*ht2.varIntSpa)+ht2.ins1.intIntBnd(ht2.nthflux\_u\*up(ht2.varIntSpa)+ht2.nthflux\_d\*down(ht2.varIntSpa)) | W | Total net energy rate | Global |
| ht2.ins1.ntefluxInt\_cst | ht2.ins1.intExtBnd(ht2.nteflux\_cst\*ht2.varIntSpa)+ht2.ins1.intIntBnd(ht2.nthflux\_cst\_u\*up(ht2.varIntSpa)+ht2.nthflux\_cst\_d\*down(ht2.varIntSpa)) | W | Total net energy rate, constant material properties | Global |
| ht2.ins1.ntfluxInt\_u | ht2.ins1.intIntBnd(ht2.ntflux\_u\*up(ht2.varIntSpa)) | W | Total net heat rate, upside | Global |
| ht2.ins1.ntfluxInt\_cst\_u | ht2.ins1.intIntBnd(ht2.ntflux\_u\*up(ht2.varIntSpa)) | W | Total net heat rate, constant material properties, upside | Global |
| ht2.ins1.ntefluxInt\_u | ht2.ins1.intIntBnd(ht2.nteflux\_u\*up(ht2.varIntSpa)) | W | Total net energy rate, upside | Global |
| ht2.ins1.ntefluxInt\_cst\_u | ht2.ins1.intIntBnd(ht2.nteflux\_cst\_u\*up(ht2.varIntSpa)) | W | Total net energy rate, constant material properties, upside | Global |
| ht2.ins1.ntfluxInt\_d | ht2.ins1.intIntBnd(ht2.ntflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate, downside | Global |
| ht2.ins1.ntfluxInt\_cst\_d | ht2.ins1.intIntBnd(ht2.ntflux\_d\*down(ht2.varIntSpa)) | W | Total net heat rate, constant material properties, downside | Global |
| ht2.ins1.ntefluxInt\_d | ht2.ins1.intIntBnd(ht2.nteflux\_d\*down(ht2.varIntSpa)) | W | Total net energy rate, downside | Global |
| ht2.ins1.ntefluxInt\_cst\_d | ht2.ins1.intIntBnd(ht2.nteflux\_cst\_d\*down(ht2.varIntSpa)) | W | Total net energy rate, constant material properties, downside | Global |
| ht2.ins1.Tave | nojac(ht2.ins1.intBnd(ht2.varIntSpa\*ht2.rho\*ht2.Cp\*T2\*max(abs(ht2.ux\*ht2.nxmesh+ht2.uy\*ht2.nymesh+ht2.uz\*ht2.nzmesh),eps)))/nojac(ht2.ins1.intBnd(ht2.varIntSpa\*ht2.rho\*ht2.Cp\*max(abs(ht2.ux\*ht2.nxmesh+ht2.uy\*ht2.nymesh+ht2.uz\*ht2.nzmesh),eps))) | K | Weighted average temperature | Global |

#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- | --- |
| T2 | Lagrange (Quadratic) | K | Temperature | Spatial | No boundaries | Slit |
| T2 | Lagrange (Quadratic) | K | Temperature | Material | No boundaries | Slit |
| T2 | Lagrange (Quadratic) | K | Temperature | Geometry | No boundaries | Slit |
| T2 | Lagrange (Quadratic) | K | Temperature | Mesh | No boundaries | Slit |

### Heat Source 1



Heat Source 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domain 2 |

Equations



#### Heat Source

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Heat source | General source |  |
| Heat source | User defined |  |
| Heat source | 5000 | W/m³ |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ht2.Q | ht2.hs1.Q\*spatial.detInvF | W/m³ | Heat source | Domain 2 | + operation |
| ht2.Qtot | ht2.hs1.Q\*spatial.detInvF | W/m³ | Total heat source | Domain 2 | + operation |
| ht2.hs1.Q0 | 5000 | W/m³ | Heat source | Domain 2 |  |
| ht2.hs1.Q | ht2.hs1.Q0 | W/m³ | Heat source | Domain 2 |  |

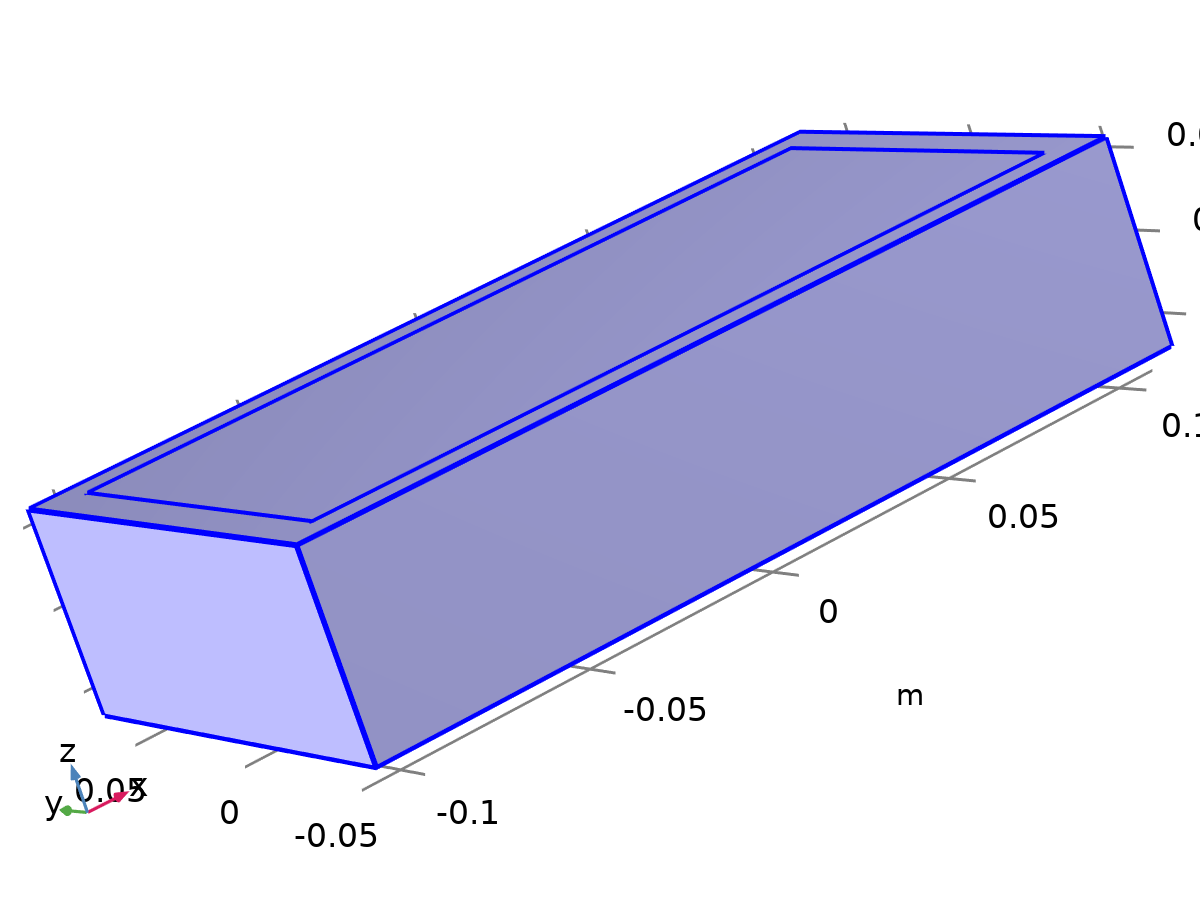
#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| ht2.hs1.Q\*test(T2)\*ht2.d | 4 | Material | Domain 2 |

## Heat Transfer in Fluids 3

Used products

|  |
| --- |
| COMSOL Multiphysics |

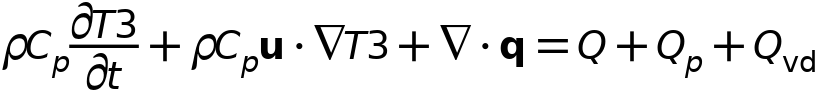


Heat Transfer in Fluids 3

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domains 1–2 |

Equations





### Interface Settings

#### Discretization

Settings

| **Description** | **Value** |
| --- | --- |
| Temperature | Linear |

Settings

| **Description** | **Value** |
| --- | --- |
| Equation form | Study controlled |

#### Physical Model

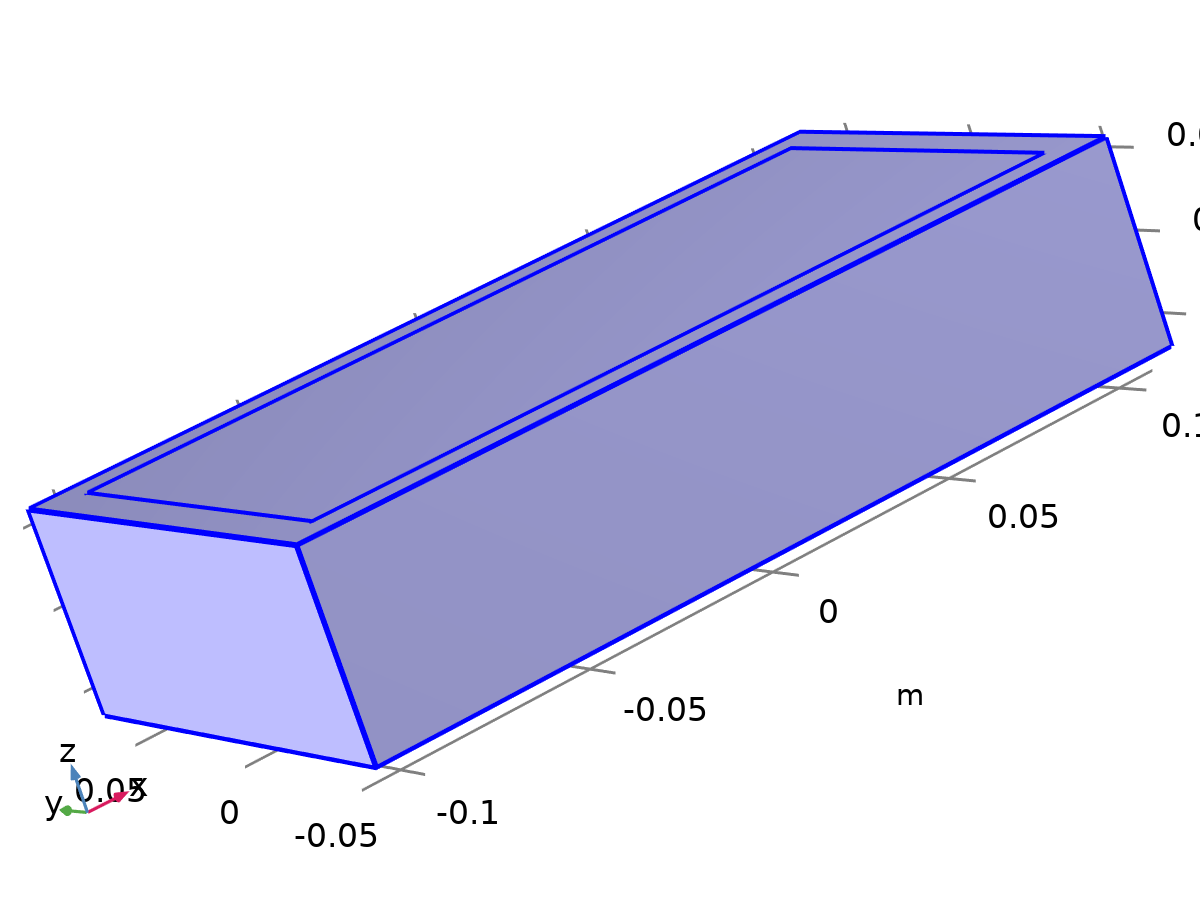
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Reference temperature | User defined |  |
| Reference temperature | 293.15 | K |

### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ht3.Tref | model.input.Tref | K | Reference temperature | Global | Meta |
| ht3.C\_effExt | 0 | J/(m³·K) | Effective volumetric heat capacity | Domains 1–2 | + operation |
| ht3.EMatExt | 0 | Pa | Young's modulus | Domains 1–2 | + operation |
| ht3.Tvar | T3 | K | Temperature | Domains 1–2 |  |
| ht3.Tvar | T3 | K | Temperature | Boundaries 1–12 |  |
| ht3.Tvar | T3 | K | Temperature | Edges 1–24 |  |
| ht3.Tvar | T3 | K | Temperature | Points 1–16 |  |
| ht3.nknExt | 0 | W/(m·K) | Help variable | Domains 1–2 | + operation |
| ht3.TextFace | 0 | K | External temperature | Domains 1–2 | + operation |
| ht3.nuMatExt | 0 | 1 | Poisson's ratio | Domains 1–2 | + operation |
| ht3.d | 1 | 1 | Thickness | Domains 1–2 |  |
| ht3.chiT | 0 | 1/Pa | Isothermal compressibility coefficient | Domains 1–2 |  |
| ht3.HRef | 0 | J/kg | Reference enthalpy | Domains 1–2 |  |
| ht3.alphap | 0 | 1/K | Isobaric compressibility coefficient | Domains 1–2 |  |
| ht3.DeltaH | ht3.DeltaH\_add | J/kg | Sensible enthalpy | Domains 1–2 |  |
| ht3.DeltaH\_cst | ht3.DeltaH\_add\_cst | J/kg | Sensible enthalpy, constant material properties | Domains 1–2 |  |
| ht3.DeltaH\_add | 0 | J/kg | Sensible enthalpy | Domains 1–2 | + operation |
| ht3.DeltaH\_add\_cst | 0 | J/kg | Sensible enthalpy, constant material properties | Domains 1–2 | + operation |
| ht3.H | 0 | J/kg | Enthalpy | Domains 1–2 | + operation |
| ht3.H\_cst | 0 | J/kg | Enthalpy, constant material properties | Domains 1–2 | + operation |
| ht3.H0 | ht3.H+ht3.Ek | J/kg | Total enthalpy | Domains 1–2 |  |
| ht3.H0\_cst | ht3.H\_cst+ht3.Ek | J/kg | Total enthalpy, constant material properties | Domains 1–2 |  |
| ht3.Ei | 0 | J/kg | Internal energy | Domains 1–2 | + operation |
| ht3.Ei\_cst | 0 | J/kg | Internal energy, constant material properties | Domains 1–2 | + operation |
| ht3.Ei0 | ht3.Ei+ht3.Ek | J/kg | Total internal energy | Domains 1–2 |  |
| ht3.Ei0\_cst | ht3.Ei\_cst+ht3.Ek | J/kg | Total internal energy, constant material properties | Domains 1–2 |  |
| ht3.Ek | 0 | J/kg | Kinetic energy | Domains 1–2 | + operation |
| ht3.dfluxx | 0 | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht3.dfluxy | 0 | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht3.dfluxz | 0 | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht3.dfluxx | mean(ht3.dfluxx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 | + operation |
| ht3.dfluxy | mean(ht3.dfluxy) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 | + operation |
| ht3.dfluxz | mean(ht3.dfluxz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 | + operation |
| ht3.dfluxtestx | 0 | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht3.dfluxtesty | 0 | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht3.dfluxtestz | 0 | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht3.dfluxtestx | mean(ht3.dfluxtestx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 | + operation |
| ht3.dfluxtesty | mean(ht3.dfluxtesty) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 | + operation |
| ht3.dfluxtestz | mean(ht3.dfluxtestz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 | + operation |
| ht3.dfluxMag | sqrt(ht3.dfluxx^2+ht3.dfluxy^2+ht3.dfluxz^2) | W/m² | Conductive heat flux magnitude | Domains 1–2 |  |
| ht3.cfluxx | 0 | W/m² | Convective heat flux, x-component | Domains 1–2 | + operation |
| ht3.cfluxy | 0 | W/m² | Convective heat flux, y-component | Domains 1–2 | + operation |
| ht3.cfluxz | 0 | W/m² | Convective heat flux, z-component | Domains 1–2 | + operation |
| ht3.cfluxMag | sqrt(ht3.cfluxx^2+ht3.cfluxy^2+ht3.cfluxz^2) | W/m² | Convective heat flux magnitude | Domains 1–2 |  |
| ht3.tfluxx | ht3.dfluxx+ht3.cfluxx | W/m² | Total heat flux, x-component | Domains 1–2 |  |
| ht3.tfluxy | ht3.dfluxy+ht3.cfluxy | W/m² | Total heat flux, y-component | Domains 1–2 |  |
| ht3.tfluxz | ht3.dfluxz+ht3.cfluxz | W/m² | Total heat flux, z-component | Domains 1–2 |  |
| ht3.tfluxMag | sqrt(ht3.tfluxx^2+ht3.tfluxy^2+ht3.tfluxz^2) | W/m² | Total heat flux magnitude | Domains 1–2 |  |
| ht3.tefluxx | 0 | W/m² | Total energy flux, x-component | Domains 1–2 | + operation |
| ht3.tefluxy | 0 | W/m² | Total energy flux, y-component | Domains 1–2 | + operation |
| ht3.tefluxz | 0 | W/m² | Total energy flux, z-component | Domains 1–2 | + operation |
| ht3.teflux\_cstx | 0 | W/m² | Total energy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht3.teflux\_csty | 0 | W/m² | Total energy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht3.teflux\_cstz | 0 | W/m² | Total energy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht3.tefluxMag | sqrt(ht3.tefluxx^2+ht3.tefluxy^2+ht3.tefluxz^2) | W/m² | Total energy flux magnitude | Domains 1–2 |  |
| ht3.thfluxx | 0 | W/m² | Total enthalpy flux, x-component | Domains 1–2 | + operation |
| ht3.thfluxy | 0 | W/m² | Total enthalpy flux, y-component | Domains 1–2 | + operation |
| ht3.thfluxz | 0 | W/m² | Total enthalpy flux, z-component | Domains 1–2 | + operation |
| ht3.thflux\_cstx | 0 | W/m² | Total enthalpy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht3.thflux\_csty | 0 | W/m² | Total enthalpy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht3.thflux\_cstz | 0 | W/m² | Total enthalpy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht3.thfluxMag | sqrt(ht3.thfluxx^2+ht3.thfluxy^2+ht3.thfluxz^2) | W/m² | Total enthalpy flux magnitude | Domains 1–2 |  |
| ht3.dflux\_ux | up(ht3.dfluxx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht3.dflux\_uy | up(ht3.dfluxy) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht3.dflux\_uz | up(ht3.dfluxz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht3.dflux\_dx | down(ht3.dfluxx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht3.dflux\_dy | down(ht3.dfluxy) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht3.dflux\_dz | down(ht3.dfluxz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht3.dfluxtest\_ux | up(ht3.dfluxtestx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht3.dfluxtest\_uy | up(ht3.dfluxtesty) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht3.dfluxtest\_uz | up(ht3.dfluxtestz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht3.dfluxtest\_dx | down(ht3.dfluxtestx) | W/m² | Conductive heat flux, x-component | Boundaries 1–12 |  |
| ht3.dfluxtest\_dy | down(ht3.dfluxtesty) | W/m² | Conductive heat flux, y-component | Boundaries 1–12 |  |
| ht3.dfluxtest\_dz | down(ht3.dfluxtestz) | W/m² | Conductive heat flux, z-component | Boundaries 1–12 |  |
| ht3.rflux | 0 | W/m² | Radiative heat flux | Boundaries 1–12 | + operation |
| ht3.ncflux | mean(ht3.cfluxx)\*ht3.nxmesh+mean(ht3.cfluxy)\*ht3.nymesh+mean(ht3.cfluxz)\*ht3.nzmesh | W/m² | Normal convective heat flux | Boundaries 1–12 |  |
| ht3.ncflux\_u | up(ht3.cfluxx)\*ht3.unxmesh+up(ht3.cfluxy)\*ht3.unymesh+up(ht3.cfluxz)\*ht3.unzmesh | W/m² | Internal normal convective heat flux, upside | Boundaries 1–12 |  |
| ht3.ncflux\_d | down(ht3.cfluxx)\*ht3.dnxmesh+down(ht3.cfluxy)\*ht3.dnymesh+down(ht3.cfluxz)\*ht3.dnzmesh | W/m² | Internal normal convective heat flux, downside | Boundaries 1–12 |  |
| ht3.ndflux | 0.5\*(ht3.ndflux\_d-ht3.ndflux\_u) | W/m² | Normal conductive heat flux | Boundaries 1–12 | + operation |
| ht3.ndflux\_u | -ht3.ndflux\_d | W/m² | Internal normal conductive heat flux, upside | Boundaries 1–5, 8–9, 12 | + operation |
| ht3.ndflux\_u | 0 | W/m² | Internal normal conductive heat flux, upside | Boundaries 6–7, 10–11 | + operation |
| ht3.ndflux\_d | 0 | W/m² | Internal normal conductive heat flux, downside | Boundaries 1–12 | + operation |
| ht3.ntflux | ht3.ndflux+ht3.ncflux | W/m² | Normal total heat flux | Boundaries 1–12 |  |
| ht3.ntflux\_cst | ht3.ndflux+ht3.ncflux | W/m² | Normal total heat flux, constant material properties | Boundaries 1–12 |  |
| ht3.ntflux\_u | ht3.ndflux\_u+ht3.ncflux\_u | W/m² | Internal normal total flux, upside | Boundaries 1–12 |  |
| ht3.ntflux\_cst\_u | ht3.ndflux\_u+ht3.ncflux\_u | W/m² | Internal normal total heat flux, constant material properties, upside | Boundaries 1–12 |  |
| ht3.ntflux\_d | ht3.ndflux\_d+ht3.ncflux\_d | W/m² | Internal normal total flux, downside | Boundaries 1–12 |  |
| ht3.ntflux\_cst\_d | ht3.ndflux\_d+ht3.ncflux\_d | W/m² | Internal normal total heat flux, constant material properties, downside | Boundaries 1–12 |  |
| ht3.nteflux | mean(ht3.tefluxx)\*ht3.nxmesh+mean(ht3.tefluxy)\*ht3.nymesh+mean(ht3.tefluxz)\*ht3.nzmesh-mean(ht3.dfluxx)\*ht3.nxmesh-mean(ht3.dfluxy)\*ht3.nymesh-mean(ht3.dfluxz)\*ht3.nzmesh+ht3.ndflux | W/m² | Normal total energy flux | Boundaries 1–12 |  |
| ht3.nteflux\_cst | mean(ht3.teflux\_cstx)\*ht3.nxmesh+mean(ht3.teflux\_csty)\*ht3.nymesh+mean(ht3.teflux\_cstz)\*ht3.nzmesh-mean(ht3.dfluxx)\*ht3.nxmesh-mean(ht3.dfluxy)\*ht3.nymesh-mean(ht3.dfluxz)\*ht3.nzmesh+ht3.ndflux | W/m² | Normal total energy flux, constant material properties | Boundaries 1–12 |  |
| ht3.nteflux\_u | up(ht3.tefluxx)\*ht3.unxmesh+up(ht3.tefluxy)\*ht3.unymesh+up(ht3.tefluxz)\*ht3.unzmesh-up(ht3.dfluxx)\*ht3.unxmesh-up(ht3.dfluxy)\*ht3.unymesh-up(ht3.dfluxz)\*ht3.unzmesh+ht3.ndflux\_u | W/m² | Internal normal total energy flux, upside | Boundaries 1–12 |  |
| ht3.nteflux\_cst\_u | up(ht3.teflux\_cstx)\*ht3.unxmesh+up(ht3.teflux\_csty)\*ht3.unymesh+up(ht3.teflux\_cstz)\*ht3.unzmesh-up(ht3.dfluxx)\*ht3.unxmesh-up(ht3.dfluxy)\*ht3.unymesh-up(ht3.dfluxz)\*ht3.unzmesh+ht3.ndflux\_u | W/m² | Internal normal total energy flux, constant material properties, upside | Boundaries 1–12 |  |
| ht3.nteflux\_d | down(ht3.tefluxx)\*ht3.dnxmesh+down(ht3.tefluxy)\*ht3.dnymesh+down(ht3.tefluxz)\*ht3.dnzmesh-down(ht3.dfluxx)\*ht3.dnxmesh-down(ht3.dfluxy)\*ht3.dnymesh-down(ht3.dfluxz)\*ht3.dnzmesh+ht3.ndflux\_d | W/m² | Internal normal total energy flux, downside | Boundaries 1–12 |  |
| ht3.nteflux\_cst\_d | down(ht3.teflux\_cstx)\*ht3.dnxmesh+down(ht3.teflux\_csty)\*ht3.dnymesh+down(ht3.teflux\_cstz)\*ht3.dnzmesh-down(ht3.dfluxx)\*ht3.dnxmesh-down(ht3.dfluxy)\*ht3.dnymesh-down(ht3.dfluxz)\*ht3.dnzmesh+ht3.ndflux\_d | W/m² | Internal normal total energy flux, constant material properties, downside | Boundaries 1–12 |  |
| ht3.nthflux | mean(ht3.thfluxx)\*ht3.nxmesh+mean(ht3.thfluxy)\*ht3.nymesh+mean(ht3.thfluxz)\*ht3.nzmesh | W/m² | Normal total enthalpy flux | Boundaries 1–12 |  |
| ht3.nthflux\_cst | mean(ht3.thflux\_cstx)\*ht3.nxmesh+mean(ht3.thflux\_csty)\*ht3.nymesh+mean(ht3.thflux\_cstz)\*ht3.nzmesh | W/m² | Normal total enthalpy flux, constant material properties | Boundaries 1–12 |  |
| ht3.nthflux\_u | up(ht3.thfluxx)\*ht3.unxmesh+up(ht3.thfluxy)\*ht3.unymesh+up(ht3.thfluxz)\*ht3.unzmesh | W/m² | Internal normal total enthalpy flux, upside | Boundaries 1–12 |  |
| ht3.nthflux\_cst\_u | up(ht3.thflux\_cstx)\*ht3.unxmesh+up(ht3.thflux\_csty)\*ht3.unymesh+up(ht3.thflux\_cstz)\*ht3.unzmesh | W/m² | Internal normal total enthalpy flux, constant material properties, upside | Boundaries 1–12 |  |
| ht3.nthflux\_d | down(ht3.thfluxx)\*ht3.dnxmesh+down(ht3.thfluxy)\*ht3.dnymesh+down(ht3.thfluxz)\*ht3.dnzmesh | W/m² | Internal normal total enthalpy flux, downside | Boundaries 1–12 |  |
| ht3.nthflux\_cst\_d | down(ht3.thflux\_cstx)\*ht3.dnxmesh+down(ht3.thflux\_csty)\*ht3.dnymesh+down(ht3.thflux\_cstz)\*ht3.dnzmesh | W/m² | Internal normal total enthalpy flux, constant material properties, downside | Boundaries 1–12 |  |
| ht3.Qm | 0 | kg/(m³·s) | Mass source | Domains 1–2 |  |
| ht3.Q | 0 | W/m³ | Heat source | Domains 1–2 | + operation |
| ht3.Qoop | 0 | W/m³ | Out-of-plane heat source | Domains 1–2 | + operation |
| ht3.Qtot | 0 | W/m³ | Total heat source | Domains 1–2 | + operation |
| ht3.Qbtot | 0 | W/m² | Total boundary heat source | Boundaries 1–12 | + operation |
| ht3.ntflux\_contrib | 0 | W/m² | Boundary sources and fluxes contribution | Domains 1–2 | + operation |
| ht3.Qitot | 0 | W/m² | Total interface source | Domains 1–2 | + operation |
| ht3.qs | 0 | W/(m³·K) | Production/absorption coefficient | Domains 1–2 | + operation |
| ht3.qs\_oop | 0 | W/(m³·K) | Out-of-plane production/absorption coefficient | Domains 1–2 | + operation |
| ht3.Qltot | 0 | W/m | Total line heat source | Edges 1–24 | + operation |
| ht3.Qlrtot | 0 | W/m | Total line heat source with radius | Edges 1–24 | + operation |
| ht3.Qptot | 0 | W | Total point heat source | Points 1–16 | + operation |
| ht3.Qprtot | 0 | W | Total point heat source with radius | Points 1–16 | + operation |
| ht3.q0 | 0 | W/m² | Inward heat flux | Boundaries 1–5, 8–9, 12 | + operation |
| ht3.Tu | up(T3) | K | Temperature | Boundaries 6–7, 10–11 |  |
| ht3.Tu | T3 | K | Temperature | Boundaries 1–5, 8–9, 12 |  |
| ht3.Td | down(T3) | K | Temperature | Boundaries 6–7, 10–11 |  |
| ht3.Td | T3 | K | Temperature | Boundaries 1–5, 8–9, 12 |  |
| ht3.TuIsDown | 0 | 1 | Help variable | Boundaries 6–7, 10–11 |  |
| ht3.TuIsDown | 0 | 1 | Help variable | Boundaries 1–5, 8–9, 12 |  |
| ht3.TdIsUp | 0 | 1 | Help variable | Boundaries 6–7, 10–11 |  |
| ht3.TdIsUp | 0 | 1 | Help variable | Boundaries 1–5, 8–9, 12 |  |
| ht3.du | up(ht3.d) | 1 | Thickness | Boundaries 6–7, 10–11 |  |
| ht3.du | ht3.d | 1 | Thickness | Boundaries 1–5, 8–9, 12 |  |
| ht3.dd | down(ht3.d) | 1 | Thickness | Boundaries 6–7, 10–11 |  |
| ht3.dd | ht3.d | 1 | Thickness | Boundaries 1–5, 8–9, 12 |  |
| ht3.nx | nx | 1 | Normal vector, x-component | Boundaries 6–7, 10–11 |  |
| ht3.ny | ny | 1 | Normal vector, y-component | Boundaries 6–7, 10–11 |  |
| ht3.nz | nz | 1 | Normal vector, z-component | Boundaries 6–7, 10–11 |  |
| ht3.nx | dnx | 1 | Normal vector, x-component | Boundaries 1–5, 8–9, 12 |  |
| ht3.ny | dny | 1 | Normal vector, y-component | Boundaries 1–5, 8–9, 12 |  |
| ht3.nz | dnz | 1 | Normal vector, z-component | Boundaries 1–5, 8–9, 12 |  |
| ht3.nxmesh | nxmesh | 1 | Normal vector (mesh), x-component | Boundaries 6–7, 10–11 |  |
| ht3.nymesh | nymesh | 1 | Normal vector (mesh), y-component | Boundaries 6–7, 10–11 |  |
| ht3.nzmesh | nzmesh | 1 | Normal vector (mesh), z-component | Boundaries 6–7, 10–11 |  |
| ht3.nxmesh | dnxmesh | 1 | Normal vector (mesh), x-component | Boundaries 1–5, 8–9, 12 |  |
| ht3.nymesh | dnymesh | 1 | Normal vector (mesh), y-component | Boundaries 1–5, 8–9, 12 |  |
| ht3.nzmesh | dnzmesh | 1 | Normal vector (mesh), z-component | Boundaries 1–5, 8–9, 12 |  |
| ht3.dnx | dnx | 1 | Normal vector down direction, x-component | Boundaries 1–12 |  |
| ht3.dny | dny | 1 | Normal vector down direction, y-component | Boundaries 1–12 |  |
| ht3.dnz | dnz | 1 | Normal vector down direction, z-component | Boundaries 1–12 |  |
| ht3.dnxmesh | dnxmesh | 1 | Normal vector down direction (mesh), x-component | Boundaries 1–12 |  |
| ht3.dnymesh | dnymesh | 1 | Normal vector down direction (mesh), y-component | Boundaries 1–12 |  |
| ht3.dnzmesh | dnzmesh | 1 | Normal vector down direction (mesh), z-component | Boundaries 1–12 |  |
| ht3.unx | unx | 1 | Normal vector up direction, x-component | Boundaries 1–12 |  |
| ht3.uny | uny | 1 | Normal vector up direction, y-component | Boundaries 1–12 |  |
| ht3.unz | unz | 1 | Normal vector up direction, z-component | Boundaries 1–12 |  |
| ht3.unxmesh | unxmesh | 1 | Normal vector up direction (mesh), x-component | Boundaries 1–12 |  |
| ht3.unymesh | unymesh | 1 | Normal vector up direction (mesh), y-component | Boundaries 1–12 |  |
| ht3.unzmesh | unzmesh | 1 | Normal vector up direction (mesh), z-component | Boundaries 1–12 |  |
| ht3.dEiInt | 0 | W | Total accumulated heat rate | Global | + operation |
| ht3.dEiInt\_cst | 0 | W | Total accumulated heat rate, constant material properties | Global | + operation |
| ht3.dEi0Int | 0 | W | Total accumulated energy rate | Global | + operation |
| ht3.dEi0Int\_cst | 0 | W | Total accumulated energy rate, constant material properties | Global | + operation |
| ht3.ntfluxInt | ht3.intExtBnd(ht3.ntflux\*ht3.varIntSpa)+ht3.intIntBnd(ht3.ncflux\_u\*up(ht3.varIntSpa)+ht3.ncflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate | Global |  |
| ht3.ntfluxInt\_cst | ht3.intExtBnd(ht3.ntflux\_cst\*ht3.varIntSpa)+ht3.intIntBnd(ht3.ncflux\_u\*up(ht3.varIntSpa)+ht3.ncflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate, constant material properties | Global |  |
| ht3.ntefluxInt | ht3.intExtBnd(ht3.nteflux\*ht3.varIntSpa)+ht3.intIntBnd(ht3.nthflux\_u\*up(ht3.varIntSpa)+ht3.nthflux\_d\*down(ht3.varIntSpa)) | W | Total net energy rate | Global |  |
| ht3.ntefluxInt\_cst | ht3.intExtBnd(ht3.nteflux\_cst\*ht3.varIntSpa)+ht3.intIntBnd(ht3.nthflux\_cst\_u\*up(ht3.varIntSpa)+ht3.nthflux\_cst\_d\*down(ht3.varIntSpa)) | W | Total net energy rate, constant material properties | Global |  |
| ht3.QInt | ht3.intDom(ht3.Qtot\*ht3.varIntSpa)+ht3.intIntLine(ht3.Qltot\*ht3.varIntSpa)+ht3.intLine(ht3.Qlrtot\*ht3.varIntSpa)+ht3.intIntPnt(ht3.Qptot)+ht3.intPnt(ht3.Qprtot)-ht3.intIntBnd(ht3.ndflux\_u\*up(ht3.varIntSpa)+ht3.ndflux\_d\*down(ht3.varIntSpa)) | W | Total heat source | Global |  |
| ht3.QInt\_cst | ht3.intDom(ht3.Qtot\*ht3.varIntSpa)+ht3.intIntLine(ht3.Qltot\*ht3.varIntSpa)+ht3.intLine(ht3.Qlrtot\*ht3.varIntSpa)+ht3.intIntPnt(ht3.Qptot)+ht3.intPnt(ht3.Qprtot)-ht3.intIntBnd(ht3.ndflux\_u\*up(ht3.varIntSpa)+ht3.ndflux\_d\*down(ht3.varIntSpa)) | W | Total heat source, constant material properties | Global |  |
| ht3.Wstr | 0 | W/m³ | Total stress power | Domains 1–2 | + operation |
| ht3.WstrInt | 0 | W | Total stress power | Global | + operation |
| ht3.WstrInt\_cst | 0 | W | Total stress power, constant material properties | Global | + operation |
| ht3.Wtot | 0 | W/m³ | Total work source | Domains 1–2 | + operation |
| ht3.WBndTot\_u | 0 | W/m² | Total work source, upside | Boundaries 6–7, 10–11 | + operation |
| ht3.WBndTot\_d | 0 | W/m² | Total work source, downside | Boundaries 1–12 | + operation |
| ht3.WInt | 0 | W | Total work source | Global | + operation |
| ht3.WInt\_cst | 0 | W | Total work source, constant material properties | Global | + operation |
| ht3.heatBalance | ht3.dEiInt+ht3.ntfluxInt+ht3.WstrInt-ht3.QInt | W | Heat balance | Global |  |
| ht3.heatBalance\_cst | ht3.dEiInt\_cst+ht3.ntfluxInt\_cst+ht3.WstrInt\_cst-ht3.QInt\_cst | W | Heat balance, constant material properties | Global |  |
| ht3.energyBalance | ht3.dEi0Int+ht3.ntefluxInt-ht3.WInt-ht3.QInt | W | Energy balance | Global |  |
| ht3.energyBalance\_cst | ht3.dEi0Int\_cst+ht3.ntefluxInt\_cst-ht3.WInt\_cst-ht3.QInt\_cst | W | Energy balance, constant material properties | Global |  |
| ht3.id | 1 | 1 | Physics indicator | Domains 1–2 |  |
| ht3.varIntSpa | ht3.d | 1 | Intermediate variable | Domains 1–2 | Meta |

### Fluid 1

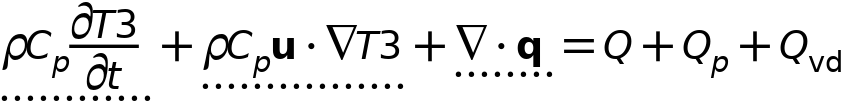


Fluid 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Equations





#### Heat Convection

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Velocity field | User defined |  |
| Velocity field | {0, 0, 0} | m/s |

#### Heat Conduction, Fluid

Settings

| **Description** | **Value** |
| --- | --- |
| Thermal conductivity | From material |

#### Thermodynamics, Fluid

Settings

| **Description** | **Value** |
| --- | --- |
| Fluid type | Gas/Liquid |
| Density | From material |
| Heat capacity at constant pressure | From material |
| Ratio of specific heats | From material |

#### Coordinate System Selection

Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Model Input

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Absolute pressure | User defined |  |
| Absolute pressure | 1.0133E5 | Pa |

Properties from material

| **Property** | **Material** | **Property group** |
| --- | --- | --- |
| Heat capacity at constant pressure | Battery block | Basic |
| Ratio of specific heats | Battery block | Basic |
| Density | Battery block | Basic |
| Thermal conductivity | Battery block | Basic |
| Heat capacity at constant pressure | PCM Layer | Basic |
| Ratio of specific heats | PCM Layer | Basic |
| Density | PCM Layer | Basic |
| Thermal conductivity | PCM Layer | Basic |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| domflux.T3x | ht3.dfluxx\*ht3.d | W/m² | Domain flux, x-component | Domains 1–2 |  |
| domflux.T3y | ht3.dfluxy\*ht3.d | W/m² | Domain flux, y-component | Domains 1–2 |  |
| domflux.T3z | ht3.dfluxz\*ht3.d | W/m² | Domain flux, z-component | Domains 1–2 |  |
| ht3.chiT | d(ht3.rho,ht3.prho)/max(ht3.rho,eps) | 1/Pa | Isothermal compressibility coefficient | Domains 1–2 |  |
| ht3.alphap | -d(ht3.rho,T3)/max(ht3.rho,eps) | 1/K | Isobaric compressibility coefficient | Domains 1–2 |  |
| ht3.DeltaH\_add | integrate(ht3.CpInt,ht3.TInt,ht3.DeltaH\_Tlow,T3)+integrate(ht3.dHdp,ht3.fluid1.minput\_pressure,ht3.DeltaH\_plow,ht3.pA) | J/kg | Sensible enthalpy | Domains 1–2 | + operation |
| ht3.DeltaH\_add\_cst | ht3.Cp\*(T3-ht3.DeltaH\_Tlow)+ht3.dHdp\*(ht3.pA-ht3.DeltaH\_plow) | J/kg | Sensible enthalpy, constant material properties | Domains 1–2 | + operation |
| ht3.H | ht3.HRef+ht3.DeltaH | J/kg | Enthalpy | Domains 1–2 | + operation |
| ht3.H\_cst | ht3.HRef+ht3.DeltaH\_cst | J/kg | Enthalpy, constant material properties | Domains 1–2 | + operation |
| ht3.Ei | ht3.H-ht3.pA/ht3.rho | J/kg | Internal energy | Domains 1–2 | + operation |
| ht3.Ei\_cst | ht3.H\_cst-ht3.pA/ht3.rho | J/kg | Internal energy, constant material properties | Domains 1–2 | + operation |
| ht3.Ek | 0.5\*(ht3.ux^2+ht3.uy^2+ht3.uz^2) | J/kg | Kinetic energy | Domains 1–2 | + operation |
| ht3.dfluxx | -ht3.k\_effxx\*T3x-ht3.k\_effxy\*T3y-ht3.k\_effxz\*T3z | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht3.dfluxy | -ht3.k\_effyx\*T3x-ht3.k\_effyy\*T3y-ht3.k\_effyz\*T3z | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht3.dfluxz | -ht3.k\_effzx\*T3x-ht3.k\_effzy\*T3y-ht3.k\_effzz\*T3z | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht3.dfluxtestx | -ht3.k\_effxx\*test(T3x)-ht3.k\_effxy\*test(T3y)-ht3.k\_effxz\*test(T3z) | W/m² | Conductive heat flux, x-component | Domains 1–2 | + operation |
| ht3.dfluxtesty | -ht3.k\_effyx\*test(T3x)-ht3.k\_effyy\*test(T3y)-ht3.k\_effyz\*test(T3z) | W/m² | Conductive heat flux, y-component | Domains 1–2 | + operation |
| ht3.dfluxtestz | -ht3.k\_effzx\*test(T3x)-ht3.k\_effzy\*test(T3y)-ht3.k\_effzz\*test(T3z) | W/m² | Conductive heat flux, z-component | Domains 1–2 | + operation |
| ht3.cfluxx | ht3.rho\*ht3.ux\*ht3.Ei | W/m² | Convective heat flux, x-component | Domains 1–2 | + operation |
| ht3.cfluxy | ht3.rho\*ht3.uy\*ht3.Ei | W/m² | Convective heat flux, y-component | Domains 1–2 | + operation |
| ht3.cfluxz | ht3.rho\*ht3.uz\*ht3.Ei | W/m² | Convective heat flux, z-component | Domains 1–2 | + operation |
| ht3.tefluxx | ht3.dfluxx+ht3.thfluxx | W/m² | Total energy flux, x-component | Domains 1–2 | + operation |
| ht3.tefluxy | ht3.dfluxy+ht3.thfluxy | W/m² | Total energy flux, y-component | Domains 1–2 | + operation |
| ht3.tefluxz | ht3.dfluxz+ht3.thfluxz | W/m² | Total energy flux, z-component | Domains 1–2 | + operation |
| ht3.teflux\_cstx | ht3.dfluxx+ht3.thflux\_cstx | W/m² | Total energy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht3.teflux\_csty | ht3.dfluxy+ht3.thflux\_csty | W/m² | Total energy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht3.teflux\_cstz | ht3.dfluxz+ht3.thflux\_cstz | W/m² | Total energy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht3.thfluxx | ht3.rho\*ht3.ux\*ht3.H0 | W/m² | Total enthalpy flux, x-component | Domains 1–2 | + operation |
| ht3.thfluxy | ht3.rho\*ht3.uy\*ht3.H0 | W/m² | Total enthalpy flux, y-component | Domains 1–2 | + operation |
| ht3.thfluxz | ht3.rho\*ht3.uz\*ht3.H0 | W/m² | Total enthalpy flux, z-component | Domains 1–2 | + operation |
| ht3.thflux\_cstx | ht3.rho\*ht3.ux\*ht3.H0\_cst | W/m² | Total enthalpy flux, constant material properties, x-component | Domains 1–2 | + operation |
| ht3.thflux\_csty | ht3.rho\*ht3.uy\*ht3.H0\_cst | W/m² | Total enthalpy flux, constant material properties, y-component | Domains 1–2 | + operation |
| ht3.thflux\_cstz | ht3.rho\*ht3.uz\*ht3.H0\_cst | W/m² | Total enthalpy flux, constant material properties, z-component | Domains 1–2 | + operation |
| ht3.ndflux\_u | -uflux\_spatial(T3)/up(ht3.varIntSpa) | W/m² | Internal normal conductive heat flux, upside | Boundaries 6–7, 10–11 | + operation |
| ht3.ndflux\_d | -dflux\_spatial(T3)/down(ht3.varIntSpa) | W/m² | Internal normal conductive heat flux, downside | Boundaries 6–7, 10–11 | + operation |
| ht3.ndflux\_d | -dflux\_spatial(T3)/down(ht3.varIntSpa) | W/m² | Internal normal conductive heat flux, downside | Boundaries 1–5, 8–9, 12 | + operation |
| ht3.dEiInt | ht3.fluid1.dEiInt | W | Total accumulated heat rate | Global | + operation |
| ht3.dEiInt\_cst | ht3.fluid1.dEiInt\_cst | W | Total accumulated heat rate, constant material properties | Global | + operation |
| ht3.dEi0Int | ht3.fluid1.dEi0Int | W | Total accumulated energy rate | Global | + operation |
| ht3.dEi0Int\_cst | ht3.fluid1.dEi0Int\_cst | W | Total accumulated energy rate, constant material properties | Global | + operation |
| ht3.Wstr | ht3.pA\*(d(ht3.ux,x)+d(ht3.uy,y)+d(ht3.uz,z)) | W/m³ | Total stress power | Domains 1–2 | + operation |
| ht3.WstrInt | ht3.fluid1.WstrInt | W | Total stress power | Global | + operation |
| ht3.WstrInt\_cst | ht3.fluid1.WstrInt\_cst | W | Total stress power, constant material properties | Global | + operation |
| ht3.WInt | ht3.fluid1.WInt | W | Total work source | Global | + operation |
| ht3.WInt\_cst | ht3.fluid1.WInt\_cst | W | Total work source, constant material properties | Global | + operation |
| ht3.fluid1.pref | model.input.pref | Pa | Reference pressure level | Domains 1–2 | Meta |
| ht3.u\_primex | if(isdefined(model.input.u\_prime1),model.input.u\_prime1,0) | m/s | Subgrid velocity component, x-component | Domains 1–2 | Meta |
| ht3.u\_primey | if(isdefined(model.input.u\_prime2),model.input.u\_prime2,0) | m/s | Subgrid velocity component, y-component | Domains 1–2 | Meta |
| ht3.u\_primez | if(isdefined(model.input.u\_prime3),model.input.u\_prime3,0) | m/s | Subgrid velocity component, z-component | Domains 1–2 | Meta |
| ht3.res\_T | ht3.timeDerivative\*ht3.C\_eff-ht3.k\_effxx\*T3xx-ht3.k\_effxy\*T3xy-ht3.k\_effxz\*T3xz-ht3.k\_effyx\*T3yx-ht3.k\_effyy\*T3yy-ht3.k\_effyz\*T3yz-ht3.k\_effzx\*T3zx-ht3.k\_effzy\*T3zy-ht3.k\_effzz\*T3zz-(ht3.qs+ht3.qs\_oop)\*T3+ht3.C\_eff\*(ht3.ux\*T3x+ht3.uy\*T3y+ht3.uz\*T3z)-ht3.D\_Hx\*T3x-ht3.D\_Hy\*T3y-ht3.D\_Hz\*T3z-ht3.Q-ht3.Qoop | W/m³ | Equation residual | Domains 1–2 | + operation |
| ht3.pA | ht3.fluid1.minput\_pressure | Pa | Absolute pressure | Domains 1–2 |  |
| ht3.C\_eff | ht3.rho\*ht3.Cp | J/(m³·K) | Effective volumetric heat capacity | Domains 1–2 |  |
| ht3.cellPe | 0.5\*ht3.rho\*ht3.Cp\*h\*sqrt(ht3.ux^2+ht3.uy^2+ht3.uz^2)/ht3.kmean | 1 | Cell Péclet number | Domains 1–2 |  |
| ht3.ux | ht3.u\_inputx | m/s | Velocity field, x-component | Domains 1–2 | + operation |
| ht3.uy | ht3.u\_inputy | m/s | Velocity field, y-component | Domains 1–2 | + operation |
| ht3.uz | ht3.u\_inputz | m/s | Velocity field, z-component | Domains 1–2 | + operation |
| ht3.Qmet | 0 | W/m³ | Metabolic heat source | Domains 1–2 | + operation |
| ht3.rhoInit | subst(ht3.rho,T3,ht3.Tinit,minput.pA,ht3.pref) | kg/m³ | Initial density | Domains 1–2 |  |
| ht3.rho\_eff | ht3.rho | kg/m³ | Effective density | Domains 1–2 |  |
| ht3.k\_effxx | ht3.kxx | W/(m·K) | Effective thermal conductivity, xx-component | Domains 1–2 |  |
| ht3.k\_effyx | ht3.kyx | W/(m·K) | Effective thermal conductivity, yx-component | Domains 1–2 |  |
| ht3.k\_effzx | ht3.kzx | W/(m·K) | Effective thermal conductivity, zx-component | Domains 1–2 |  |
| ht3.k\_effxy | ht3.kxy | W/(m·K) | Effective thermal conductivity, xy-component | Domains 1–2 |  |
| ht3.k\_effyy | ht3.kyy | W/(m·K) | Effective thermal conductivity, yy-component | Domains 1–2 |  |
| ht3.k\_effzy | ht3.kzy | W/(m·K) | Effective thermal conductivity, zy-component | Domains 1–2 |  |
| ht3.k\_effxz | ht3.kxz | W/(m·K) | Effective thermal conductivity, xz-component | Domains 1–2 |  |
| ht3.k\_effyz | ht3.kyz | W/(m·K) | Effective thermal conductivity, yz-component | Domains 1–2 |  |
| ht3.k\_effzz | ht3.kzz | W/(m·K) | Effective thermal conductivity, zz-component | Domains 1–2 |  |
| ht3.kappaTxx | 0 | W/(m·K) | Turbulent thermal conductivity, xx-component | Domains 1–2 |  |
| ht3.kappaTyx | 0 | W/(m·K) | Turbulent thermal conductivity, yx-component | Domains 1–2 |  |
| ht3.kappaTzx | 0 | W/(m·K) | Turbulent thermal conductivity, zx-component | Domains 1–2 |  |
| ht3.kappaTxy | 0 | W/(m·K) | Turbulent thermal conductivity, xy-component | Domains 1–2 |  |
| ht3.kappaTyy | 0 | W/(m·K) | Turbulent thermal conductivity, yy-component | Domains 1–2 |  |
| ht3.kappaTzy | 0 | W/(m·K) | Turbulent thermal conductivity, zy-component | Domains 1–2 |  |
| ht3.kappaTxz | 0 | W/(m·K) | Turbulent thermal conductivity, xz-component | Domains 1–2 |  |
| ht3.kappaTyz | 0 | W/(m·K) | Turbulent thermal conductivity, yz-component | Domains 1–2 |  |
| ht3.kappaTzz | 0 | W/(m·K) | Turbulent thermal conductivity, zz-component | Domains 1–2 |  |
| ht3.kmean | (ht3.k\_effxx+ht3.k\_effyy+ht3.k\_effzz)/3 | W/(m·K) | Mean effective thermal conductivity | Domains 1–2 |  |
| ht3.alphaTdxx | ht3.k\_effxx/ht3.C\_eff | m²/s | Thermal diffusivity, xx-component | Domains 1–2 |  |
| ht3.alphaTdyx | ht3.k\_effyx/ht3.C\_eff | m²/s | Thermal diffusivity, yx-component | Domains 1–2 |  |
| ht3.alphaTdzx | ht3.k\_effzx/ht3.C\_eff | m²/s | Thermal diffusivity, zx-component | Domains 1–2 |  |
| ht3.alphaTdxy | ht3.k\_effxy/ht3.C\_eff | m²/s | Thermal diffusivity, xy-component | Domains 1–2 |  |
| ht3.alphaTdyy | ht3.k\_effyy/ht3.C\_eff | m²/s | Thermal diffusivity, yy-component | Domains 1–2 |  |
| ht3.alphaTdzy | ht3.k\_effzy/ht3.C\_eff | m²/s | Thermal diffusivity, zy-component | Domains 1–2 |  |
| ht3.alphaTdxz | ht3.k\_effxz/ht3.C\_eff | m²/s | Thermal diffusivity, xz-component | Domains 1–2 |  |
| ht3.alphaTdyz | ht3.k\_effyz/ht3.C\_eff | m²/s | Thermal diffusivity, yz-component | Domains 1–2 |  |
| ht3.alphaTdzz | ht3.k\_effzz/ht3.C\_eff | m²/s | Thermal diffusivity, zz-component | Domains 1–2 |  |
| ht3.alphaTdMean | ht3.kmean/ht3.C\_eff | m²/s | Mean thermal diffusivity | Domains 1–2 |  |
| ht3.gradTx | T3x | K/m | Temperature gradient, x-component | Domains 1–2 |  |
| ht3.gradTy | T3y | K/m | Temperature gradient, y-component | Domains 1–2 |  |
| ht3.gradTz | T3z | K/m | Temperature gradient, z-component | Domains 1–2 |  |
| ht3.gradTmag | sqrt(ht3.gradTx^2+ht3.gradTy^2+ht3.gradTz^2) | K/m | Temperature gradient magnitude | Domains 1–2 |  |
| ht3.pref | ht3.fluid1.pref | Pa | Reference pressure level | Domains 1–2 |  |
| ht3.DeltaH\_Tlow | ht3.Tref | K | Temperature lower bound for enthalpy evaluation | Domains 1–2 |  |
| ht3.DeltaH\_plow | ht3.pref | Pa | Pressure lower bound for enthalpy evaluation | Domains 1–2 |  |
| ht3.dHdp | (1-ht3.alphap\*T3)/max(ht3.rho,eps) | m³/kg | Intermediate variable | Domains 1–2 |  |
| ht3.chiT\_ref | d(ht3.rhoref,ht3.pref)/max(ht3.rhoref,eps) | 1/Pa | Reference isothermal compressibility coefficient | Domains 1–2 |  |
| ht3.mujtT | -ht3.dHdp/ht3.Cp | K/Pa | Isothermal Joule-Thomson coefficient | Domains 1–2 |  |
| ht3.alphap\_ref | -d(ht3.rhoref,ht3.Tref)/max(ht3.rhoref,eps) | 1/K | Reference isobaric compressibility coefficient | Domains 1–2 |  |
| ht3.alphapT | ht3.alphap\*T3 | 1 | Help variable | Domains 1–2 |  |
| ht3.dEi | material.dt(ht3.rho\*ht3.Ei) | W/m³ | Total accumulated heat rate density | Domains 1–2 |  |
| ht3.dEi\_cst | material.dt(ht3.rho\*ht3.Ei\_cst) | W/m³ | Total accumulated heat rate density, constant material properties | Domains 1–2 |  |
| ht3.dEi0 | material.dt(ht3.rho\*ht3.Ei0) | W/m³ | Total accumulated energy rate density | Domains 1–2 |  |
| ht3.dEi0\_cst | material.dt(ht3.rho\*ht3.Ei0\_cst) | W/m³ | Total accumulated energy rate density, constant material properties | Domains 1–2 |  |
| ht3.fluid1.dEiInt | ht3.fluid1.intDom((ht3.dEi-ht3.Qm\*ht3.Ei)\*ht3.varIntSpa) | W | Total accumulated heat rate | Global |  |
| ht3.fluid1.dEiInt\_cst | ht3.fluid1.intDom((ht3.dEi\_cst-ht3.Qm\*ht3.Ei\_cst)\*ht3.varIntSpa) | W | Total accumulated heat rate, constant material properties | Global |  |
| ht3.fluid1.dEi0Int | ht3.fluid1.intDom((ht3.dEi0-ht3.Qm\*ht3.H)\*ht3.varIntSpa) | W | Total accumulated energy rate | Global |  |
| ht3.fluid1.dEi0Int\_cst | ht3.fluid1.intDom((ht3.dEi0\_cst-ht3.Qm\*ht3.H\_cst)\*ht3.varIntSpa) | W | Total accumulated energy rate, constant material properties | Global |  |
| ht3.fluid1.QInt | ht3.fluid1.intDom(ht3.Qtot\*ht3.varIntSpa)+ht3.fluid1.intIntLine(ht3.Qltot\*ht3.varIntSpa)+ht3.intLine(subst(ht3.Qlrtot,ht3.id,isdefined(ht3.fluid1.id))\*ht3.varIntSpa)+ht3.fluid1.intIntPnt(ht3.Qptot)+ht3.intPnt(subst(ht3.Qprtot,ht3.id,isdefined(ht3.fluid1.id)))-ht3.fluid1.intIntBnd(ht3.ndflux\_u\*up(ht3.varIntSpa)+ht3.ndflux\_d\*down(ht3.varIntSpa)) | W | Total heat source | Global |  |
| ht3.fluid1.QInt\_cst | ht3.fluid1.intDom(ht3.Qtot\*ht3.varIntSpa)+ht3.fluid1.intIntLine(ht3.Qltot\*ht3.varIntSpa)+ht3.intLine(subst(ht3.Qlrtot,ht3.id,isdefined(ht3.fluid1.id))\*ht3.varIntSpa)+ht3.fluid1.intIntPnt(ht3.Qptot)+ht3.intPnt(subst(ht3.Qprtot,ht3.id,isdefined(ht3.fluid1.id)))-ht3.fluid1.intIntBnd(ht3.ndflux\_u\*up(ht3.varIntSpa)+ht3.ndflux\_d\*down(ht3.varIntSpa)) | W | Total heat source, constant material properties | Global |  |
| ht3.fluid1.WstrInt | ht3.fluid1.intDom(ht3.Wstr\*ht3.varIntSpa) | W | Total stress power | Global |  |
| ht3.fluid1.WstrInt\_cst | ht3.fluid1.intDom(ht3.Wstr\*ht3.varIntSpa) | W | Total stress power, constant material properties | Global |  |
| ht3.fluid1.WInt | ht3.fluid1.intDom(ht3.Wtot\*ht3.varIntSpa)+ht3.fluid1.intBndUp(ht3.WBndTot\_u\*up(ht3.varIntSpa))+ht3.fluid1.intBndDown(ht3.WBndTot\_d\*down(ht3.varIntSpa)) | W | Total work source | Global |  |
| ht3.fluid1.WInt\_cst | ht3.fluid1.intDom(ht3.Wtot\*ht3.varIntSpa)+ht3.fluid1.intBndUp(ht3.WBndTot\_u\*up(ht3.varIntSpa))+ht3.fluid1.intBndDown(ht3.WBndTot\_d\*down(ht3.varIntSpa)) | W | Total work source, constant material properties | Global |  |
| ht3.fluid1.ntfluxInt | ht3.fluid1.intExtBnd(ht3.ntflux\*ht3.varIntSpa)+ht3.fluid1.intExtBndUp(ht3.ntflux\_u\*up(ht3.varIntSpa))+ht3.fluid1.intExtBndDown(ht3.ntflux\_d\*down(ht3.varIntSpa))+ht3.fluid1.intIntBnd(ht3.ncflux\_u\*up(ht3.varIntSpa)+ht3.ncflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate | Global |  |
| ht3.fluid1.ntfluxInt\_cst | ht3.fluid1.intExtBnd(ht3.ntflux\_cst\*ht3.varIntSpa)+ht3.fluid1.intExtBndUp(ht3.ntflux\_cst\_u\*up(ht3.varIntSpa))+ht3.fluid1.intExtBndDown(ht3.ntflux\_cst\_d\*down(ht3.varIntSpa))+ht3.fluid1.intIntBnd(ht3.ncflux\_u\*up(ht3.varIntSpa)+ht3.ncflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate, constant material properties | Global |  |
| ht3.fluid1.ntefluxInt | ht3.fluid1.intExtBnd(ht3.nteflux\*ht3.varIntSpa)+ht3.fluid1.intExtBndUp(ht3.nteflux\_u\*up(ht3.varIntSpa))+ht3.fluid1.intExtBndDown(ht3.nteflux\_d\*down(ht3.varIntSpa))+ht3.fluid1.intIntBnd(ht3.nthflux\_u\*up(ht3.varIntSpa)+ht3.nthflux\_d\*down(ht3.varIntSpa)) | W | Total net energy rate | Global |  |
| ht3.fluid1.ntefluxInt\_cst | ht3.fluid1.intExtBnd(ht3.nteflux\_cst\*ht3.varIntSpa)+ht3.fluid1.intExtBndUp(ht3.nteflux\_cst\_u\*up(ht3.varIntSpa))+ht3.fluid1.intExtBndDown(ht3.nteflux\_cst\_d\*down(ht3.varIntSpa))+ht3.fluid1.intIntBnd(ht3.nthflux\_cst\_u\*up(ht3.varIntSpa)+ht3.nthflux\_cst\_d\*down(ht3.varIntSpa)) | W | Total net energy rate, constant material properties | Global |  |
| ht3.fluid1.heatBalance | ht3.fluid1.dEiInt+ht3.fluid1.ntfluxInt+ht3.fluid1.WstrInt-ht3.fluid1.QInt | W | Heat balance | Global |  |
| ht3.fluid1.heatBalance\_cst | ht3.fluid1.dEiInt\_cst+ht3.fluid1.ntfluxInt\_cst+ht3.fluid1.WstrInt\_cst-ht3.fluid1.QInt\_cst | W | Heat balance, constant material properties | Global |  |
| ht3.fluid1.energyBalance | ht3.fluid1.dEi0Int+ht3.fluid1.ntefluxInt-ht3.fluid1.WInt-ht3.fluid1.QInt | W | Energy balance | Global |  |
| ht3.fluid1.energyBalance\_cst | ht3.fluid1.dEi0Int\_cst+ht3.fluid1.ntefluxInt\_cst-ht3.fluid1.WInt\_cst-ht3.fluid1.QInt\_cst | W | Energy balance, constant material properties | Global |  |
| ht3.Tradu | ht3.Tu | K | Upside temperature | Domains 1–2 |  |
| ht3.Tradu | ht3.Tu | K | Upside temperature | Boundaries 1–12 |  |
| ht3.Tradd | ht3.Td | K | Downside temperature | Domains 1–2 |  |
| ht3.Tradd | ht3.Td | K | Downside temperature | Boundaries 1–12 |  |
| ht3.kxx | ht3.kmatxx | W/(m·K) | Thermal conductivity, xx-component | Domains 1–2 |  |
| ht3.kyx | ht3.kmatyx | W/(m·K) | Thermal conductivity, yx-component | Domains 1–2 |  |
| ht3.kzx | ht3.kmatzx | W/(m·K) | Thermal conductivity, zx-component | Domains 1–2 |  |
| ht3.kxy | ht3.kmatxy | W/(m·K) | Thermal conductivity, xy-component | Domains 1–2 |  |
| ht3.kyy | ht3.kmatyy | W/(m·K) | Thermal conductivity, yy-component | Domains 1–2 |  |
| ht3.kzy | ht3.kmatzy | W/(m·K) | Thermal conductivity, zy-component | Domains 1–2 |  |
| ht3.kxz | ht3.kmatxz | W/(m·K) | Thermal conductivity, xz-component | Domains 1–2 |  |
| ht3.kyz | ht3.kmatyz | W/(m·K) | Thermal conductivity, yz-component | Domains 1–2 |  |
| ht3.kzz | ht3.kmatzz | W/(m·K) | Thermal conductivity, zz-component | Domains 1–2 |  |
| ht3.kmatxx | material.k11 | W/(m·K) | Thermal conductivity, xx-component | Domains 1–2 | Meta |
| ht3.kmatyx | material.k21 | W/(m·K) | Thermal conductivity, yx-component | Domains 1–2 | Meta |
| ht3.kmatzx | material.k31 | W/(m·K) | Thermal conductivity, zx-component | Domains 1–2 | Meta |
| ht3.kmatxy | material.k12 | W/(m·K) | Thermal conductivity, xy-component | Domains 1–2 | Meta |
| ht3.kmatyy | material.k22 | W/(m·K) | Thermal conductivity, yy-component | Domains 1–2 | Meta |
| ht3.kmatzy | material.k32 | W/(m·K) | Thermal conductivity, zy-component | Domains 1–2 | Meta |
| ht3.kmatxz | material.k13 | W/(m·K) | Thermal conductivity, xz-component | Domains 1–2 | Meta |
| ht3.kmatyz | material.k23 | W/(m·K) | Thermal conductivity, yz-component | Domains 1–2 | Meta |
| ht3.kmatzz | material.k33 | W/(m·K) | Thermal conductivity, zz-component | Domains 1–2 | Meta |
| ht3.rho | ht3.rhomat | kg/m³ | Density | Domains 1–2 |  |
| ht3.rhomat | subst(material.rho,ht3.fluid1.minput\_pressure,ht3.prho) | kg/m³ | Density | Domains 1–2 | Meta |
| ht3.rhoref | subst(material.rho,ht3.fluid1.minput\_pressure,ht3.pref,ht3.fluid1.minput\_temperature,ht3.Tref) | kg/m³ | Reference density | Domains 1–2 | Meta |
| ht3.Cp | ht3.Cpmat | J/(kg·K) | Heat capacity at constant pressure | Domains 1–2 |  |
| ht3.CpInt | subst(material.Cp,ht3.fluid1.minput\_pressure,ht3.pref,ht3.fluid1.minput\_temperature,ht3.TInt) | J/(kg·K) | Specific heat capacity for integration | Domains 1–2 | Meta |
| ht3.Cp\_ref | subst(material.Cp,ht3.fluid1.minput\_pressure,ht3.pref,ht3.fluid1.minput\_temperature,ht3.Tref) | J/(kg·K) | Reference heat capacity | Domains 1–2 | Meta |
| ht3.Cpmat | material.Cp | J/(kg·K) | Heat capacity at constant pressure | Domains 1–2 | Meta |
| ht3.gamma | material.gamma\_not\_IG | 1 | Ratio of specific heats | Domains 1–2 | Meta |
| ht3.gamma\_ref | subst(material.gamma\_not\_IG,ht3.fluid1.minput\_pressure,ht3.pref,ht3.fluid1.minput\_temperature,ht3.Tref) | 1 | Reference ratio of specific heats | Domains 1–2 | Meta |
| ht3.c\_s | sqrt((-1+ht3.gamma)\*ht3.Cp/(ht3.Trho\*ht3.alphap^2)) | m/s | Speed of sound | Domains 1–2 |  |
| ht3.Ma | sqrt(model.input.u1^2+model.input.u2^2+model.input.u3^2)/ht3.c\_s | 1 | Mach number | Domains 1–2 | Meta |
| ht3.prho | ht3.fluid1.minput\_pressure | Pa | Pressure for the evaluation of density | Domains 1–2 |  |
| ht3.T | ht3.fluid1.minput\_temperature | K | Temperature | Domains 1–2 |  |
| ht3.Trho | ht3.fluid1.minput\_temperature | K | Temperature for density evaluation | Domains 1–2 |  |
| ht3.timeDerivative | material.dt(T3) | K/s | Temperature, first time derivative | Domains 1–2 |  |
| ht3.helem | h\_spatial | m | Element size | Domains 1–2 |  |

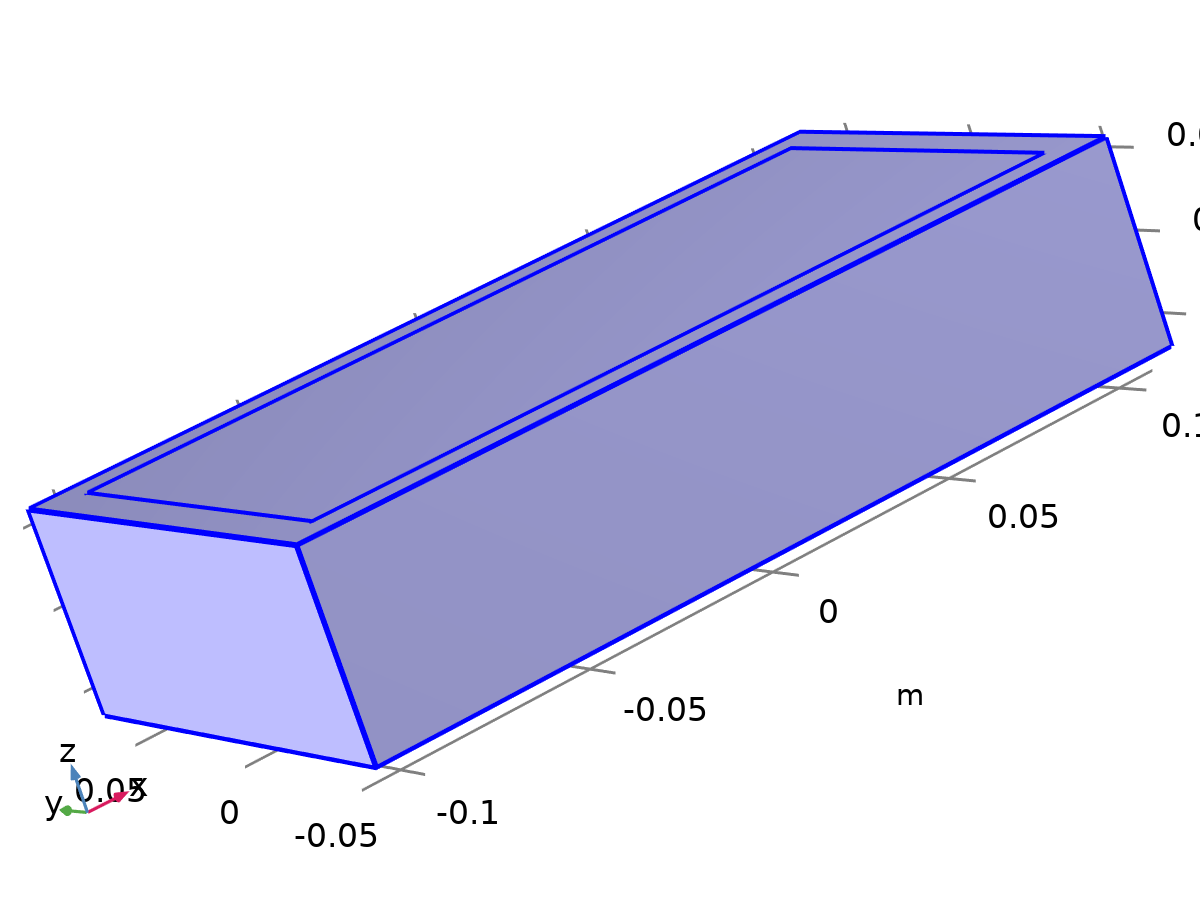
#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| T3 | Lagrange (Linear) | K | Temperature | Spatial | Domains 1–2 |
| T3 | Lagrange (Linear) | K | Temperature | Material | Domains 1–2 |
| T3 | Lagrange (Linear) | K | Temperature | Geometry | Domains 1–2 |
| T3 | Lagrange (Linear) | K | Temperature | Mesh | Domains 1–2 |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| ht3.crosswind | 2 | Spatial | Domains 1–2 |
| ht3.streamline | 2 | Spatial | Domains 1–2 |
| (ht3.dfluxx\*test(T3x)+ht3.dfluxy\*test(T3y)+ht3.dfluxz\*test(T3z))\*ht3.d | 2 | Spatial | Domains 1–2 |
| -ht3.C\_eff\*ht3.timeDerivative\*test(T3)\*ht3.d | 2 | Spatial | Domains 1–2 |
| -ht3.C\_eff\*(ht3.ux\*T3x+ht3.uy\*T3y+ht3.uz\*T3z)\*test(T3)\*ht3.d | 2 | Spatial | Domains 1–2 |

### Initial Values 1



Initial Values 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

#### Initial Values

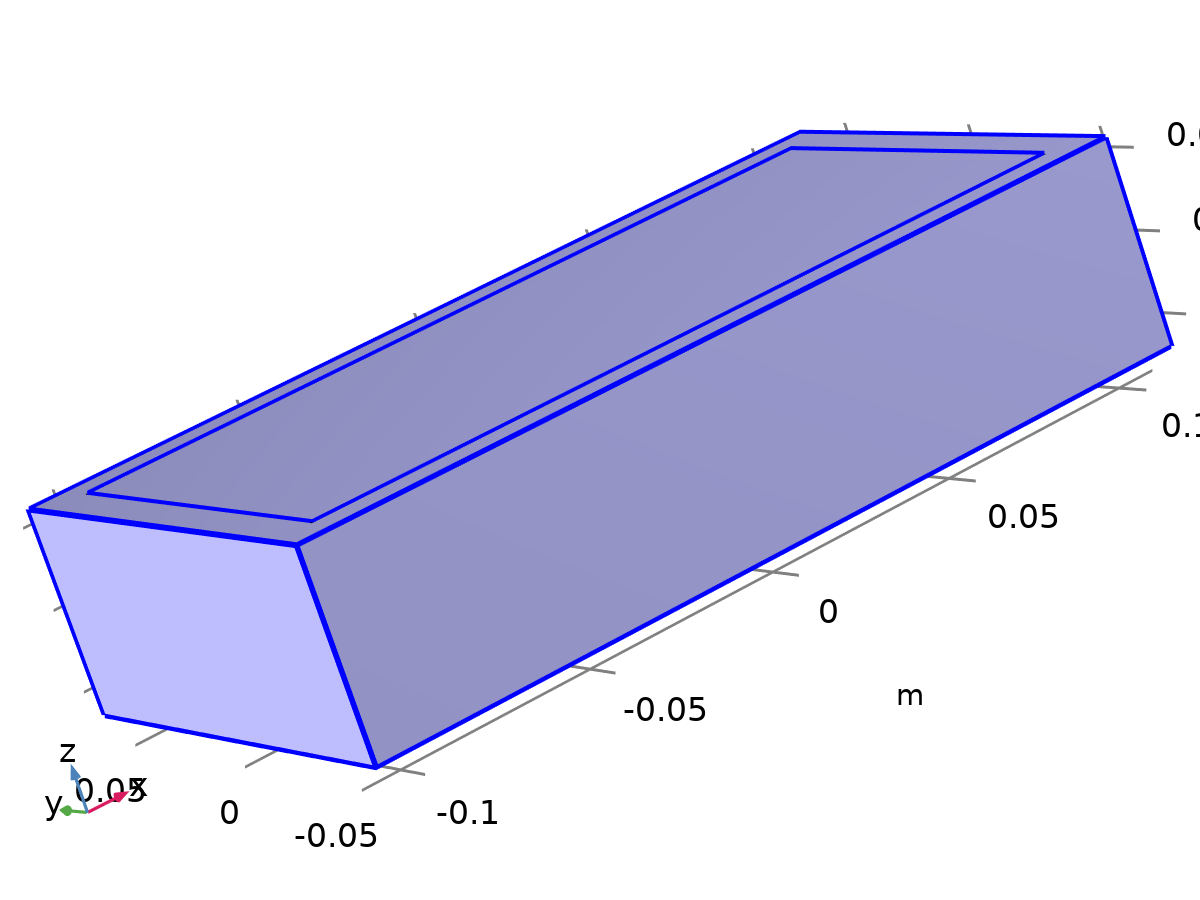
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Temperature | User defined |  |
| Temperature | 333.15 | K |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| ht3.Tinit | 333.15[K] | K | Initial temperature | Domains 1–2 |

### Thermal Insulation 1



Thermal Insulation 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: All boundaries |

Equations



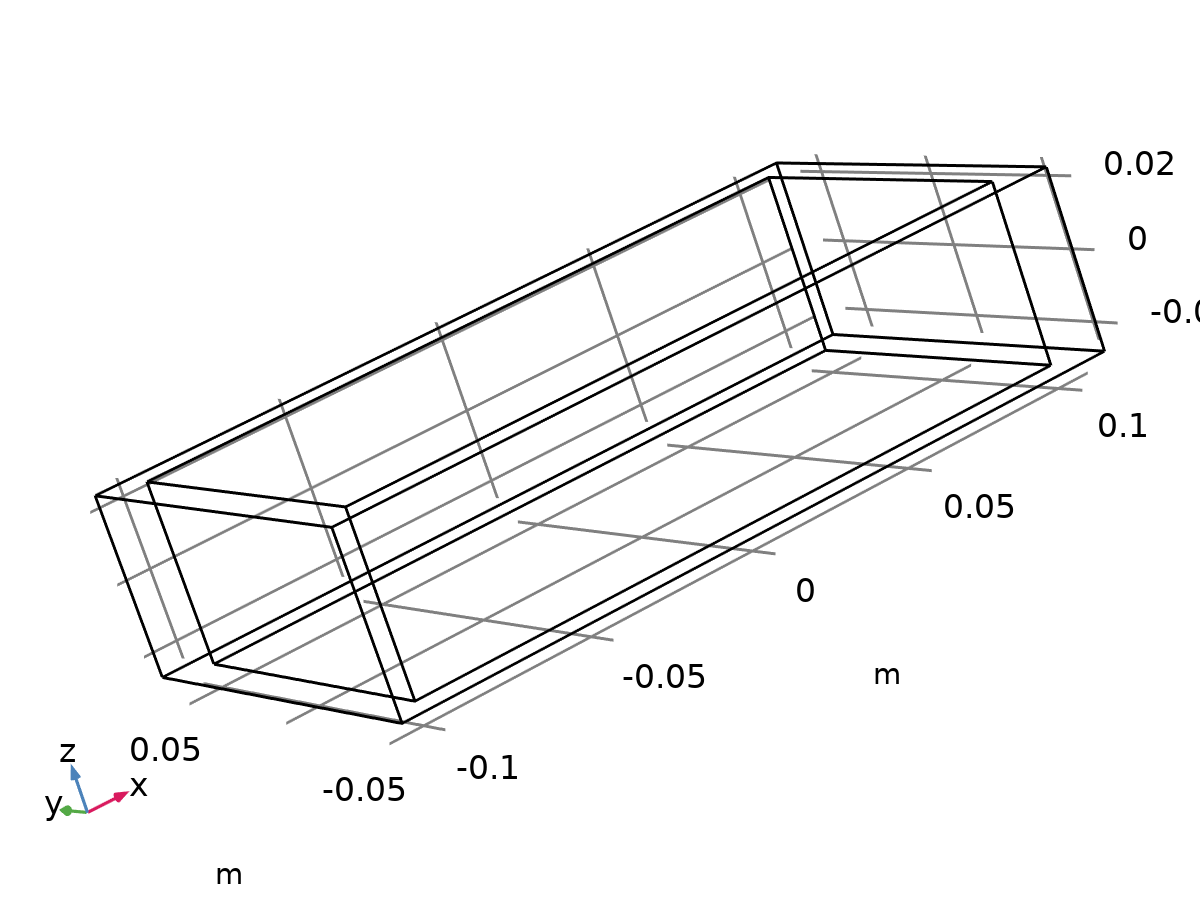
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| ht3.ins1.ntfluxInt | ht3.ins1.intExtBnd(ht3.ntflux\*ht3.varIntSpa)+ht3.ins1.intIntBnd(ht3.ncflux\_u\*up(ht3.varIntSpa)+ht3.ncflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate | Global |
| ht3.ins1.ntfluxInt\_cst | ht3.ins1.intExtBnd(ht3.ntflux\*ht3.varIntSpa)+ht3.ins1.intIntBnd(ht3.ncflux\_u\*up(ht3.varIntSpa)+ht3.ncflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate, constant material properties | Global |
| ht3.ins1.ntefluxInt | ht3.ins1.intExtBnd(ht3.nteflux\*ht3.varIntSpa)+ht3.ins1.intIntBnd(ht3.nthflux\_u\*up(ht3.varIntSpa)+ht3.nthflux\_d\*down(ht3.varIntSpa)) | W | Total net energy rate | Global |
| ht3.ins1.ntefluxInt\_cst | ht3.ins1.intExtBnd(ht3.nteflux\_cst\*ht3.varIntSpa)+ht3.ins1.intIntBnd(ht3.nthflux\_cst\_u\*up(ht3.varIntSpa)+ht3.nthflux\_cst\_d\*down(ht3.varIntSpa)) | W | Total net energy rate, constant material properties | Global |
| ht3.ins1.ntfluxInt\_u | ht3.ins1.intIntBnd(ht3.ntflux\_u\*up(ht3.varIntSpa)) | W | Total net heat rate, upside | Global |
| ht3.ins1.ntfluxInt\_cst\_u | ht3.ins1.intIntBnd(ht3.ntflux\_u\*up(ht3.varIntSpa)) | W | Total net heat rate, constant material properties, upside | Global |
| ht3.ins1.ntefluxInt\_u | ht3.ins1.intIntBnd(ht3.nteflux\_u\*up(ht3.varIntSpa)) | W | Total net energy rate, upside | Global |
| ht3.ins1.ntefluxInt\_cst\_u | ht3.ins1.intIntBnd(ht3.nteflux\_cst\_u\*up(ht3.varIntSpa)) | W | Total net energy rate, constant material properties, upside | Global |
| ht3.ins1.ntfluxInt\_d | ht3.ins1.intIntBnd(ht3.ntflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate, downside | Global |
| ht3.ins1.ntfluxInt\_cst\_d | ht3.ins1.intIntBnd(ht3.ntflux\_d\*down(ht3.varIntSpa)) | W | Total net heat rate, constant material properties, downside | Global |
| ht3.ins1.ntefluxInt\_d | ht3.ins1.intIntBnd(ht3.nteflux\_d\*down(ht3.varIntSpa)) | W | Total net energy rate, downside | Global |
| ht3.ins1.ntefluxInt\_cst\_d | ht3.ins1.intIntBnd(ht3.nteflux\_cst\_d\*down(ht3.varIntSpa)) | W | Total net energy rate, constant material properties, downside | Global |
| ht3.ins1.Tave | nojac(ht3.ins1.intBnd(ht3.varIntSpa\*ht3.rho\*ht3.Cp\*T3\*max(abs(ht3.ux\*ht3.nxmesh+ht3.uy\*ht3.nymesh+ht3.uz\*ht3.nzmesh),eps)))/nojac(ht3.ins1.intBnd(ht3.varIntSpa\*ht3.rho\*ht3.Cp\*max(abs(ht3.ux\*ht3.nxmesh+ht3.uy\*ht3.nymesh+ht3.uz\*ht3.nzmesh),eps))) | K | Weighted average temperature | Global |

#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- | --- |
| T3 | Lagrange (Linear) | K | Temperature | Spatial | No boundaries | Slit |
| T3 | Lagrange (Linear) | K | Temperature | Material | No boundaries | Slit |
| T3 | Lagrange (Linear) | K | Temperature | Geometry | No boundaries | Slit |
| T3 | Lagrange (Linear) | K | Temperature | Mesh | No boundaries | Slit |

### Temperature 1



Temperature 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: No boundaries |

Equations

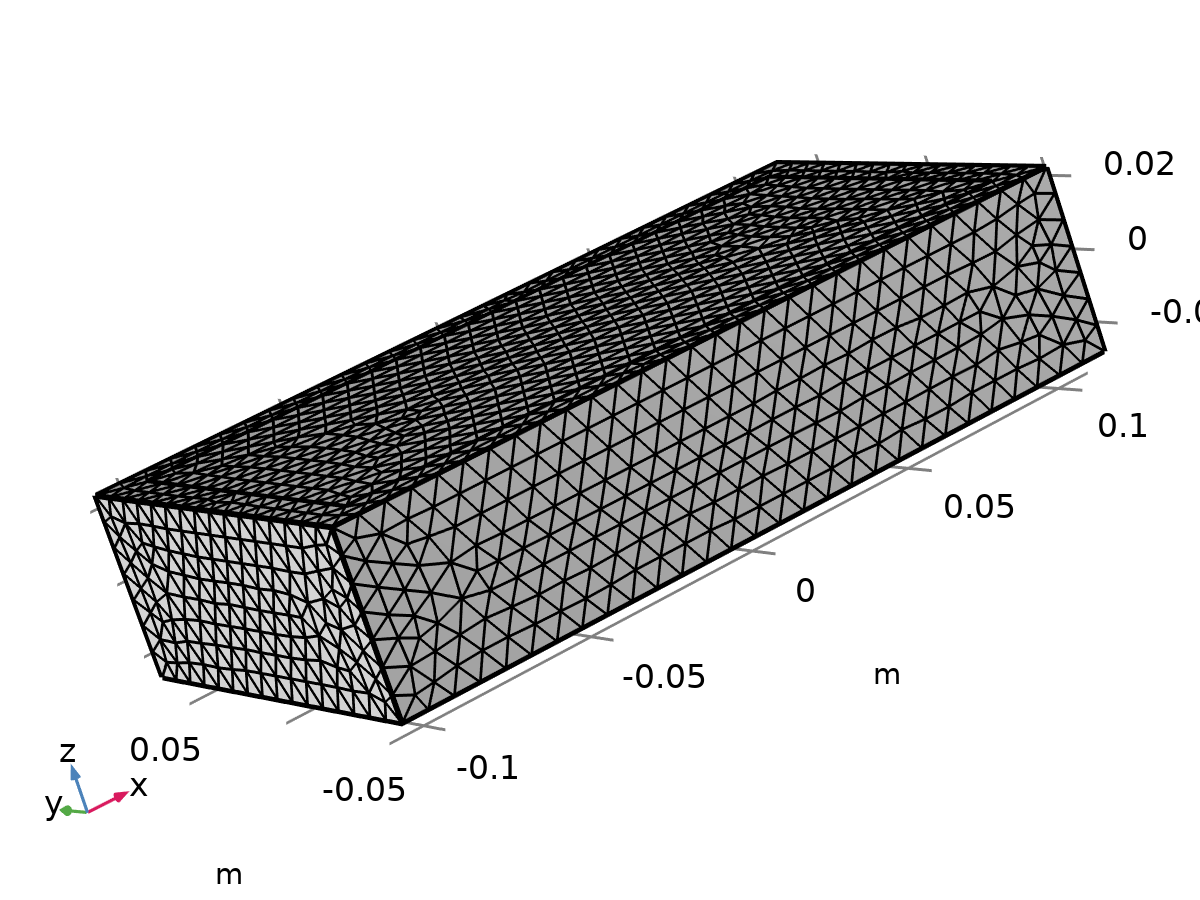


#### Temperature

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Temperature | User defined |  |
| Temperature | 293.15 | K |

## Mesh 1



Mesh 1

Mesh statistics

| **Description** | **Value** |
| --- | --- |
| Status | Complete mesh |
| Mesh vertices | 8343 |
| Tetrahedra | 44131 |
| Triangles | 5064 |
| Edge elements | 392 |
| Vertex elements | 16 |
| Number of elements | 44131 |
| Minimum element quality | 0.2314 |
| Average element quality | 0.6733 |
| Element volume ratio | 0.076257 |
| Mesh volume | 0.00132 m³ |

### Size (size)

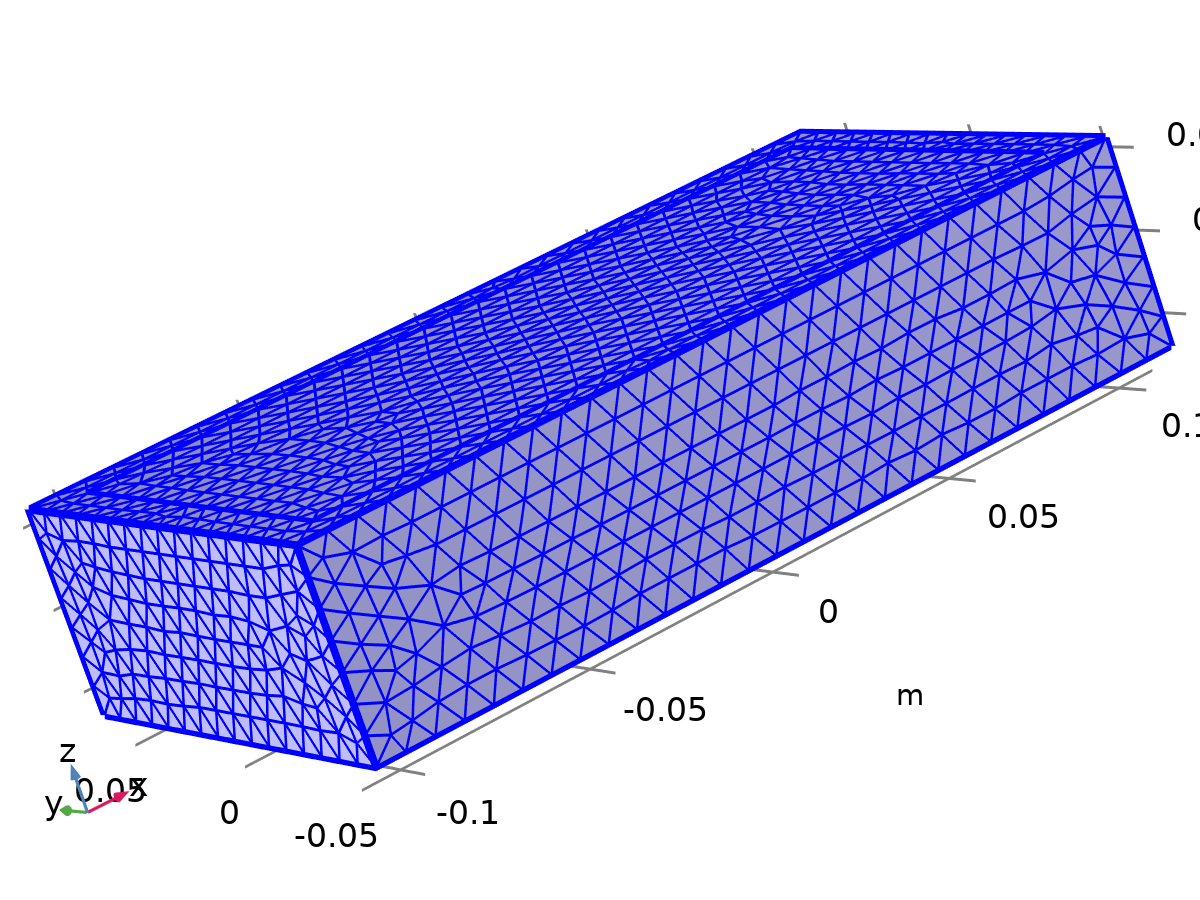
Settings

| **Description** | **Value** |
| --- | --- |
| Calibrate for | Fluid dynamics |
| Maximum element size | 0.00775 |
| Minimum element size | 0.00232 |
| Curvature factor | 0.7 |
| Resolution of narrow regions | 0.6 |
| Maximum element growth rate | 1.2 |
| Predefined size | Coarse |

### Free Tetrahedral 1 (ftet1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Remaining |



Free Tetrahedral 1

Settings

| **Description** | **Value** |
| --- | --- |
| Avoid inverted curved elements | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.3.0.335 (win64), Apr 29, 2025, 6:05:04 AM |

# Study 1

Computation information

|  |  |
| --- | --- |
| Computation time | 2 min 33 s |

## Time Dependent

| **Times** | **Unit** |
| --- | --- |
| 0 300 | s |

Study settings

| **Description** | **Value** |
| --- | --- |
| Include geometric nonlinearity | Off |

Study settings

| **Description** | **Value** |
| --- | --- |
| Output times | {0, 300} |

Physics and variables selection

| **Key** | **Solve for** |
| --- | --- |
| Laminar Flow (spf) | On |
| Heat Transfer in Solids 2 (ht2) | On |
| Heat Transfer in Fluids 3 (ht3) | On |

Store in output

| **Interface** | **Output** | **Selection** |
| --- | --- | --- |
| Laminar Flow (spf) | Physics controlled |  |
| Heat Transfer in Solids 2 (ht2) | Physics controlled |  |
| Heat Transfer in Fluids 3 (ht3) | Physics controlled |  |

Mesh selection

| **Component** | **Mesh** |
| --- | --- |
| Component 1 | Mesh 1 |

## Solver Configurations

### Solution 1

#### Compile Equations: Time Dependent (st1)

Study and step

| **Description** | **Value** |
| --- | --- |
| Use study | [Study 1](#cs1637428) |
| Use study step | Time Dependent |

Log

<---- Compile Equations: Time Dependent in Study 1/Solution 1 (sol1) -----------

Started at Apr 29, 2025, 6:04:47 AM.

Running on Intel64 Family 6 Model 140 Stepping 1, GenuineIntel.

Using 1 socket with 4 cores in total on DESKTOP-J7DCJNQ.

Available memory: 7.87 GB.

Geometry shape function: Linear Lagrange

Number of vertex elements: 16

Number of edge elements: 392

Number of boundary elements: 5064

Number of elements: 44131

Minimum element quality: 0.2314

Time: 21 s.

Physical memory: 728 MB

Virtual memory: 1246 MB

Ended at Apr 29, 2025, 6:05:08 AM.

----- Compile Equations: Time Dependent in Study 1/Solution 1 (sol1) ---------->

#### Dependent Variables 1 (v1)

General

| **Description** | **Value** |
| --- | --- |
| Defined by study step | [Step 1: Time Dependent](#cs5558883) |

Residual scaling

| **Description** | **Value** |
| --- | --- |
| Method | Manual |

Initial value calculation constants

| **Constant name** | **Initial-value source** |
| --- | --- |
| t | {0, 300}[s} |
| timestep | 0.1[s] |

Log

<---- Dependent Variables 1 in Study 1/Solution 1 (sol1) -----------------------

Started at Apr 29, 2025, 6:05:08 AM.

Solution time: 0 s.

Physical memory: 666 MB

Virtual memory: 1223 MB

Ended at Apr 29, 2025, 6:05:08 AM.

----- Dependent Variables 1 in Study 1/Solution 1 (sol1) ---------------------->

##### Pressure (comp1.p) (comp1\_p)

General

| **Description** | **Value** |
| --- | --- |
| Field components | comp1.p |

##### Temperature (comp1.T2) (comp1\_T2)

General

| **Description** | **Value** |
| --- | --- |
| Field components | comp1.T2 |
| Internal variables | {comp1.ht2.dt2Inv\_T, comp1.uflux.T2, comp1.dflux.T2} |

##### Temperature (comp1.T3) (comp1\_T3)

General

| **Description** | **Value** |
| --- | --- |
| Field components | comp1.T3 |
| Internal variables | {comp1.uflux.T3, comp1.dflux.T3, comp1.ht3.dt2Inv\_T} |

##### Velocity Field (comp1.u) (comp1\_u)

General

| **Description** | **Value** |
| --- | --- |
| Field components | {comp1.u, comp1.v, comp1.w} |
| Internal variables | {comp1.spf.dt2Inv\_u, comp1.spf.isFluidHasBeenSolved} |

#### Time-Dependent Solver 1 (t1)

General

| **Description** | **Value** |
| --- | --- |
| Output times | {0, 300} |
| Relative tolerance | 0.005 |

Absolute tolerance

| **Description** | **Value** |
| --- | --- |
| Tolerance factor | 0.05 |

Absolute tolerance

| **Field** | **Method** | **Tolerance method** | **Tolerance factor** | **Derivative tolerance method** | **Time derivative factor** | **Tolerance** | **Tolerance for time derivatives** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Pressure (comp1.p) | Scaled | Factor | 1 | Automatic | 1 | 0.001 | 0.001 |
| Temperature (comp1.T2) | Use global | Factor | 0.1 | Automatic | 1 | 0.001 | 0.001 |
| Temperature (comp1.T3) | Use global | Factor | 0.1 | Automatic | 1 | 0.001 | 0.001 |
| Velocity Field (comp1.u) | Use global | Factor | 0.1 | Automatic | 1 | 0.001 | 0.001 |

Time stepping

| **Description** | **Value** |
| --- | --- |
| Initial step | 0.1 |
| Initial step | On |
| Maximum BDF order | 2 |
| Nonlinear controller | On |
| Fraction of initial step for Backward Euler | 0.01 |
| Error estimation | Exclude algebraic |

Log

<---- Time-Dependent Solver 1 in Study 1/Solution 1 (sol1) ---------------------

Started at Apr 29, 2025, 6:05:10 AM.

Time-dependent solver (BDF)

Number of degrees of freedom solved for: 104417 (plus 105909 internal DOFs).

Symmetric matrices found.

Scales for dependent variables:

Temperature (comp1.T2): 2.9e+02

Orthonormal null-space function used.

Symmetric matrices found.

Scales for dependent variables:

Temperature (comp1.T3): 3.3e+02

Orthonormal null-space function used.

Nonsymmetric matrix found.

Scales for dependent variables:

Pressure (comp1.p): 0.014

Velocity Field (comp1.u): 1

Orthonormal null-space function used.

Nonsymmetric matrix found.

Step        Time    Stepsize      Res  Jac  Sol Order Tfail NLfail   LinErr   LinRes

   0           0           - out    6    9    6                  0

                   Group #1:        2    3    2                     1.2e-15  2.7e-16

                   Group #2:        2    3    2                     4.2e-16  4.6e-16

                   Group #3:        2    3    2                           0        0

   1       0.102         0.1        9   12    9     1     0      0

                   Group #1:        3    4    3                     1.1e-15  2.8e-16

                   Group #2:        3    4    3                     4.1e-16  4.5e-16

                   Group #3:        3    4    3                           0        0

   2       0.202         0.1       12   15   12     1     0      0

                   Group #1:        4    5    4                     9.5e-16  3.2e-16

                   Group #2:        4    5    4                     4.7e-16  3.7e-16

                   Group #3:        4    5    4                           0        0

   3       0.402         0.2       15   18   15     2     0      0

                   Group #1:        5    6    5                     1.1e-15  2.9e-16

                   Group #2:        5    6    5                     4.7e-16  3.7e-16

                   Group #3:        5    6    5                           0        0

   4       0.802         0.4       18   21   18     2     0      0

                   Group #1:        6    7    6                     8.7e-16  3.3e-16

                   Group #2:        6    7    6                       5e-16  4.1e-16

                   Group #3:        6    7    6                           0        0

   5       1.602         0.8       21   24   21     2     0      0

                   Group #1:        7    8    7                     7.1e-16  5.6e-16

                   Group #2:        7    8    7                     5.1e-16  4.3e-16

                   Group #3:        7    8    7                           0        0

   6       3.202         1.6       24   27   24     2     0      0

                   Group #1:        8    9    8                     7.2e-16  4.9e-16

                   Group #2:        8    9    8                     4.8e-16  4.3e-16

                   Group #3:        8    9    8                           0        0

   7       6.402         3.2       27   30   27     2     0      0

                   Group #1:        9   10    9                     6.7e-16  4.3e-16

                   Group #2:        9   10    9                     4.4e-16  4.1e-16

                   Group #3:        9   10    9                           0        0

   8      12.802         6.4       30   33   30     2     0      0

                   Group #1:       10   11   10                     6.7e-16  4.2e-16

                   Group #2:       10   11   10                     3.9e-16  3.7e-16

                   Group #3:       10   11   10                           0        0

   9      25.602        12.8       33   36   33     2     0      0

                   Group #1:       11   12   11                     6.6e-16  4.6e-16

                   Group #2:       11   12   11                     4.1e-16  3.6e-16

                   Group #3:       11   12   11                           0        0

  10      51.202        25.6       36   39   36     2     0      0

                   Group #1:       12   13   12                     6.9e-16    5e-16

                   Group #2:       12   13   12                     4.4e-16  3.8e-16

                   Group #3:       12   13   12                           0        0

  11      81.202          30       39   42   39     2     0      0

                   Group #1:       13   14   13                       7e-16  5.3e-16

                   Group #2:       13   14   13                     4.4e-16  3.4e-16

                   Group #3:       13   14   13                           0        0

  12       111.2          30       42   45   42     2     0      0

                   Group #1:       14   15   14                     6.8e-16  5.7e-16

                   Group #2:       14   15   14                     4.6e-16  3.5e-16

                   Group #3:       14   15   14                           0        0

  13       141.2          30       45   48   45     2     0      0

                   Group #1:       15   16   15                     6.9e-16  6.8e-16

                   Group #2:       15   16   15                     4.2e-16  3.3e-16

                   Group #3:       15   16   15                           0        0

  14       171.2          30       48   51   48     2     0      0

                   Group #1:       16   17   16                     7.1e-16    7e-16

                   Group #2:       16   17   16                     4.6e-16  3.4e-16

                   Group #3:       16   17   16                           0        0

  15       201.2          30       51   54   51     2     0      0

                   Group #1:       17   18   17                     7.5e-16    6e-16

                   Group #2:       17   18   17                     4.5e-16  3.6e-16

                   Group #3:       17   18   17                           0        0

  16       231.2          30       54   57   54     2     0      0

                   Group #1:       18   19   18                       7e-16  6.1e-16

                   Group #2:       18   19   18                     4.5e-16  3.5e-16

                   Group #3:       18   19   18                           0        0

  17       261.2          30       57   60   57     2     0      0

                   Group #1:       19   20   19                     6.9e-16  6.3e-16

                   Group #2:       19   20   19                     4.3e-16  3.5e-16

                   Group #3:       19   20   19                           0        0

  18       291.2          30       60   63   60     2     0      0

                   Group #1:       20   21   20                     6.9e-16  8.2e-16

                   Group #2:       20   21   20                     4.6e-16  3.7e-16

                   Group #3:       20   21   20                           0        0

   -         300           - out

  19       321.2          30       63   66   63     2     0      0

                   Group #1:       21   22   21                     7.1e-16  7.1e-16

                   Group #2:       21   22   21                     4.5e-16  3.7e-16

                   Group #3:       21   22   21                           0        0

Time-stepping completed.

Solution time: 129 s. (2 minutes, 9 seconds)

Physical memory: 1.45 GB

Virtual memory: 2.52 GB

Ended at Apr 29, 2025, 6:07:18 AM.

----- Time-Dependent Solver 1 in Study 1/Solution 1 (sol1) -------------------->

##### Advanced (aDef)

Assembly settings

| **Description** | **Value** |
| --- | --- |
| Reuse sparsity pattern | On |

##### Segregated 1 (se1)

General

| **Description** | **Value** |
| --- | --- |
| Tolerance factor | 0.5 |
| Stabilization and acceleration | Anderson acceleration |
| Dimension of iteration space | 5 |
| Mixing parameter | 0.9 |
| Iteration delay | 1 |

###### Heat transfer T2 (ss1)

General

| **Description** | **Value** |
| --- | --- |
| Variables | Temperature (comp1.T2) |
| Linear solver | [PARDISO (ht2)](#cs2276916) |

Method and termination

| **Description** | **Value** |
| --- | --- |
| Damping factor | 0.8 |
| Jacobian update | Once per time step |

###### Heat transfer T3 (ss2)

General

| **Description** | **Value** |
| --- | --- |
| Variables | Temperature (comp1.T3) |
| Linear solver | [PARDISO (ht3)](#cs3935636) |

Method and termination

| **Description** | **Value** |
| --- | --- |
| Damping factor | 0.8 |
| Jacobian update | Once per time step |

###### Velocity u, Pressure p (ss3)

General

| **Description** | **Value** |
| --- | --- |
| Variables | {Velocity Field (comp1.u), Pressure (comp1.p)} |
| Linear solver | [Direct 3](#cs5970473) |

Method and termination

| **Description** | **Value** |
| --- | --- |
| Damping factor | 0.9 |
| Jacobian update | Once per time step |

###### Lower Limit 1 (ll1)

Lower limit

| **Description** | **Value** |
| --- | --- |
| Lower limits (field variables) | comp1.T3 0 comp1.T2 0 |

##### PARDISO (ht2) (d1)

General

| **Description** | **Value** |
| --- | --- |
| Solver | PARDISO |
| Pivoting perturbation | 1E-13 |

##### PARDISO (ht3) (d2)

General

| **Description** | **Value** |
| --- | --- |
| Solver | PARDISO |
| Pivoting perturbation | 1E-13 |

##### Direct 3 (d3)

General

| **Description** | **Value** |
| --- | --- |
| Solver | PARDISO |
| Pivoting perturbation | 1E-13 |

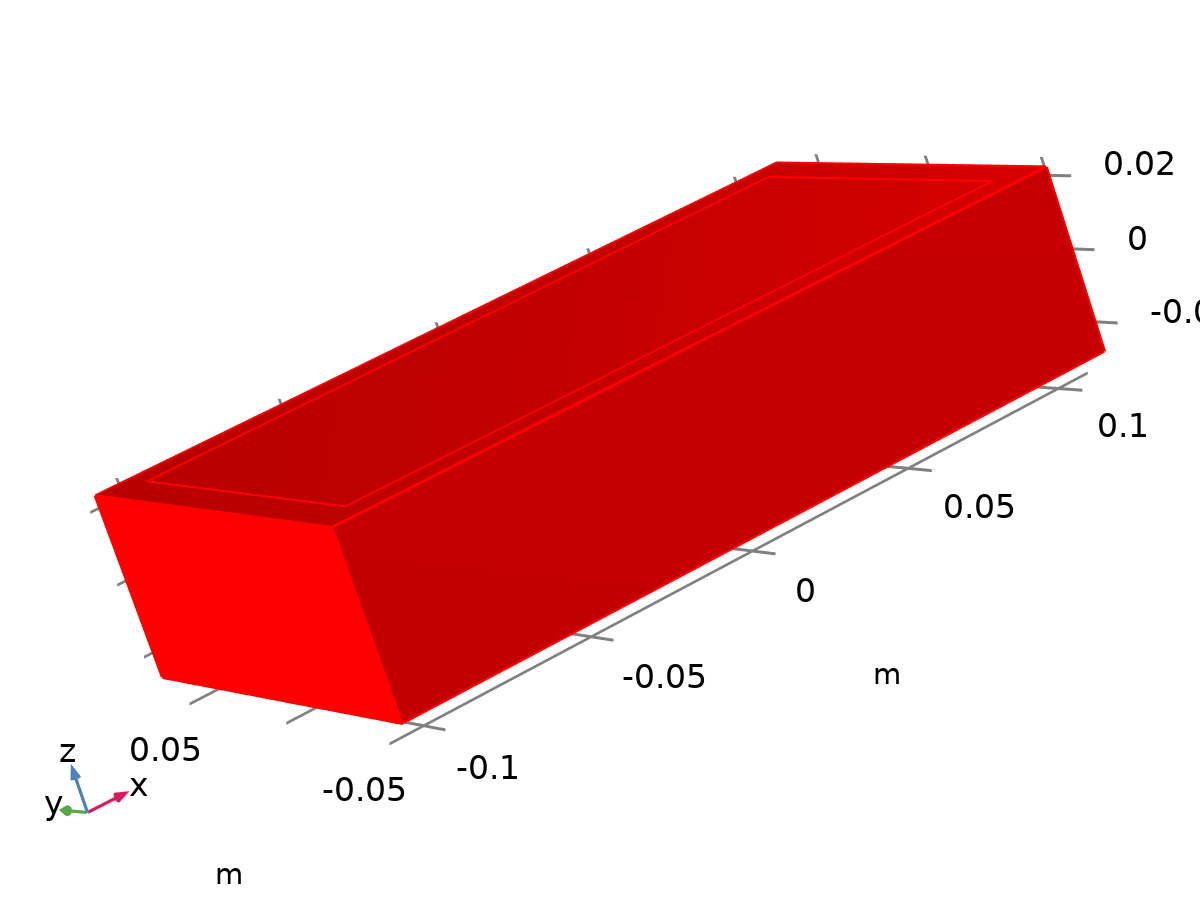
# Results

## Data Sets

### Study 1/Solution 1

Solution

| **Description** | **Value** |
| --- | --- |
| Solution | [Solution 1 (sol1)](#cs5515079) |
| Component | Component 1 (comp1) |



Dataset: Study 1/Solution 1

### Exterior Walls

Data

| **Description** | **Value** |
| --- | --- |
| Dataset | [Study 1/Solution 1 (sol1)](#cs2734867) |

Parameterization

| **Description** | **Value** |
| --- | --- |
| x- and y-axes | Surface parameters |

## Derived Values

### Surface Integration 1

Data

| **Description** | **Value** |
| --- | --- |
| Dataset | [Study 1/Solution 1 (sol1)](#cs2734867) |

Expressions

| **Expression** | **Unit** | **Description** |
| --- | --- | --- |
| T2 | m^2\*K | Temperature |
| T3 | m^2\*K | Temperature |

Integration settings

| **Description** | **Value** |
| --- | --- |
| Integration order | 4 |

## Plot Groups

### Velocity (spf)

[COMSOLlink[]]

Slice: Velocity magnitude (m/s)

### Pressure (spf)

[COMSOLlink[]]

Contour: Pressure (Pa)

### Temperature (ht2)

[COMSOLlink[]]

Surface: Temperature (K)

### Isothermal Contours (ht2)

[COMSOLlink[]]

Isosurface: Temperature (K)

### Temperature (ht3)

[COMSOLlink[]]

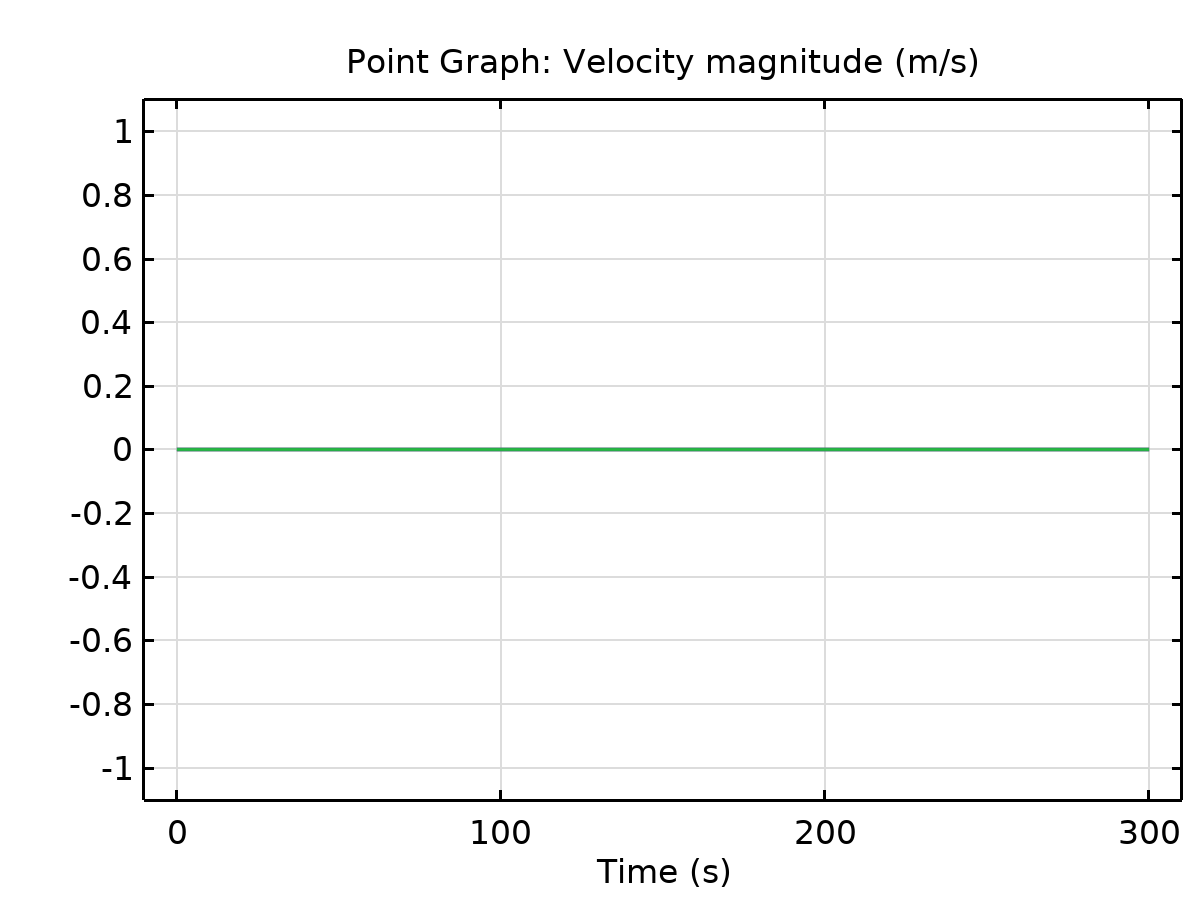
Surface: Temperature (K)

### Isothermal Contours (ht3)

[COMSOLlink[]]

Isosurface: Temperature (K)

### 1D Plot Group 7



Point Graph: Velocity magnitude (m/s) Global: Average 1

### Cooling Power vs Time

