Test 2

Report date	Oct 16, 2023 2:12:07 AM

Contents

1. Global Definitions

Date	Oct 13, 2023 5:19:43 PM

Global settings

Name	Test 2 - COMSOL (1).mph
Path	C:\Users\jadri002\Downloads\Test 2 - COMSOL (1).mph
COMSOL version	COMSOL 5.1 (Build: 145)

Used products

COMSOL Multiphysics
CAD Import Module

2. Component 1

Component settings

Unit system	SI

2.1. Definitions

2.1.1. Variables

Variables 1

Selection

Geometric entity level	Entire model

Name	Expression	Unit	Description
ko	10[W/m/K]	W/(m*K)	
h	200[W/m^2/K]	W/(m^2*K)	
a	2[cm]	m	
b	5[cm]	m	
Tinf	100[degC]	K	
go	10^6[W/m^3]	W/m^3	

2.1.2. Coordinate Systems

Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

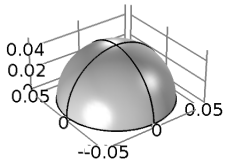
Coordinate names

First (t1)	Second (t2)	Third (n)
t1	t2	n

Settings

Description	Value
Create first tangent direction from	Global Cartesian

2.2. Geometry 1



Geometry 1

Units

Length unit	m
Angular unit	deg

Geometry statistics

Description	Value
Space dimension	3
Number of domains	1
Number of boundaries	9
Number of edges	16
Number of vertices	10

2.2.1. Sphere 1 (Sph1)

Position

Description	Value
Position	{0, 0, 0}

Axis

Description	Value
Axis type	z - axis
Layers	

Size

Description	Value
Radius	5[cm]

2.2.2. Sphere 2 (Sph2)

Position

Description	Value
Position	{0, 0, 0}

Axis

Description	Value
Axis type	z - axis
Layers	

Size

Description	Value
Radius	2[cm]

2.2.3. Block 1 (Blk1)

Position

Description	Value
Position	{0, 0, -0.025}
Base	Center

Axis

Description	Value
Axis type	z - axis

Size and shape

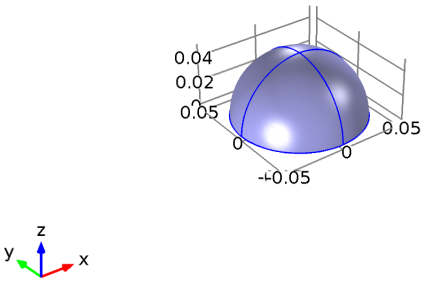
Description	Value
Width	0.1
Depth	0.1
Height	0.05

Layers

Description	Value
Layers	

2.3. Materials

2.3.1. Material 1



Material 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Material parameters

Name	Value	Unit
Density	1	kg/m^3
Heat capacity at constant pressure	1	J/(kg*K)
Thermal conductivity	ko*b/sqrt(x^2+y^2+z^2)	W/(m*K)

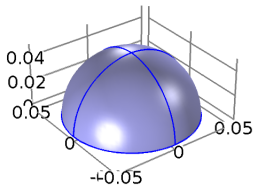
Basic Settings

Description	Value
Density	1
Heat capacity at constant pressure	1
Thermal conductivity	{{ko*b/sqrt(x^2 + y^2 + z^2), 0, 0}, {0, ko*b/sqrt(x^2 + y^2 + z^2), 0}, {0, 0, ko*b/sqrt(x^2 + y^2 + z^2)}}

2.4. Heat Transfer in Solids

Used products

COMSOL Multiphysics



Heat Transfer in Solids

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{ted}$$

$$\mathbf{q} = -k \nabla T$$

Settings

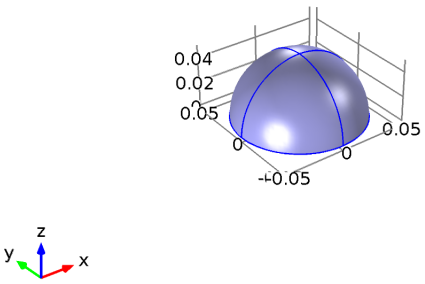
Description	Value
Temperature	Quadratic
Compute boundary fluxes	On
Apply smoothing to boundary fluxes	On
Value type when using splitting of complex variables	Real
Surface-to-surface radiation	Off
Radiation in participating media	Off
Heat transfer in biological tissue	Off
Isothermal domain	Off
Heat transfer in porous media	Off
Streamline diffusion	On
Crosswind diffusion	On
Isotropic diffusion	Off

Variables

Name	Expression	Unit	Description	Selection
ht.q0	0	W/m^2	Inward heat flux	Boundaries 1–9
ht.Tu	T	K	Temperature	Boundaries 1–9
ht.Td	T	K	Temperature	Boundaries 1–9
ht.opaqueLayer	1		Thin layer opacity	Boundaries 1–9
ht.Tvar	T	K	Temperature	Domain 1
ht.Tvar	T	K	Temperature	Boundaries 1–9
ht.Tvar	T	K	Temperature	Edges 1–16
ht.Tvar	T	K	Temperature	Points 1–10
ht.addContinuityWeak	1		Boolean	Boundaries 1–9
ht.isConductiveLayer	1		Boolean	Domain 1
ht.d	1	1	Thickness	Domain 1
ht.nx	dnx	1	Normal vector, x component	Boundaries 1–9
ht.ny	dny	1	Normal vector, y component	Boundaries 1–9

ht.nz	dnz	1	Normal vector, z component	Boundaries 1–9
ht.nxmesh	root.dnxmesh	1	Normal vector (mesh), x component	Boundaries 1–9
ht.nymesh	root.dnymesh	1	Normal vector (mesh), y component	Boundaries 1–9
ht.nzmesh	root.dnzmesh	1	Normal vector (mesh), z component	Boundaries 1–9
ht.dnx	dnx	1	Normal vector down direction, x component	Boundaries 1–9
ht.dny	dny	1	Normal vector down direction, y component	Boundaries 1–9
ht.dnz	dnz	1	Normal vector down direction, z component	Boundaries 1–9
ht.unx	unx	1	Normal vector up direction, x component	Boundaries 1–9
ht.uny	uny	1	Normal vector up direction, y component	Boundaries 1–9
ht.unz	unz	1	Normal vector up direction, z component	Boundaries 1–9
ht.dEiInt	ht.intDom(d(ht.rho*ht.Ei,t)*ht.varIntSpa)	W	Total accumulated heat rate	Global
ht.dEi0Int	ht.intDom(d(ht.rho*ht.Ei0,t)*ht.varIntSpa)	W	Total accumulated energy rate	Global
ht.ntfluxInt	ht.intExtBnd(ht.ntflux*ht.varIntSpa)	W	Total net heat rate	Global
ht.ntefluxInt	ht.intExtBnd(ht.nteflux*ht.varIntSpa)	W	Total net energy rate	Global
ht.QInt	ht.intDom(ht.Qtot*ht.varIntSpa)-ht.intIntBnd((ht.ndflux_u+ht.ndflux_d)*ht.varIntSpa)	W	Total heat source	Global
ht.WnsInt	0	W	Total work source	Global
ht.WInt	0	W	Total work source	Global

2.4.1. Heat Transfer in Solids 1



Heat Transfer in Solids 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{ted}$$

$$\mathbf{q} = -k \nabla T$$

Settings

Description	Value
Thermal conductivity	From material
Density	From material
Heat capacity at constant pressure	From material

Properties from material

Property	Material	Property group
Thermal conductivity	Material 1	Basic

Density	Material 1	Basic
Heat capacity at constant pressure	Material 1	Basic

Variables

Name	Expression
domflux.Tx	-ht.k_effxx*Tx-ht.k_effxy*Ty-ht.k_effxz*Tz
domflux.Ty	-ht.k_effyx*Tx-ht.k_effyy*Ty-ht.k_effyz*Tz
domflux.Tz	-ht.k_effzx*Tx-ht.k_effzy*Ty-ht.k_effzz*Tz
ht.WnsInt	ht.solid1.intDom(ht.pA*(d(ht.ux,x)+d(ht.uy,y)+d(ht.uz,z))*ht.solid1.varIntSpa)
ht.Q	0
ht.Qtot	0
ht.kxx	material.k11
ht.kyx	material.k21
ht.kzx	material.k31
ht.kxy	material.k12
ht.kyy	material.k22
ht.kzy	material.k32
ht.kxz	material.k13
ht.kyz	material.k23
ht.kzz	material.k33
ht.rho	material.rho
ht.Cp	material.Cp
ht.solid1.pRef	model.input.pRef
ht.alphap	-d(ht.rho,T)/(ht.rho+eps)
ht.pA	model.input.minput_pressure
ht.gradTmag	sqrt(ht.gradTx^2+ht.gradTy^2+ht.gradTz^2)
ht.kmean	(ht.k_effxx+ht.k_effyy+ht.k_effzz)/3
ht.qs	0
ht.Qmet	0
ht.rhoInt	subst(ht.rho,root.comp1.ht.solid1.minput_pressure,ht.pA)
ht.CpInt	subst(ht.Cp,root.comp1.ht.solid1.minput_pressure,ht.pA)
ht.gammaInt	subst(ht.gamma,root.comp1.ht.solid1.minput_pressure,ht.pA)
ht.TRef	298.15[K]
ht.pRef	ht.solid1.pRef
ht.HRef	0
ht.DeltaH	integrate(subst(ht.CpInt,ht.pA,ht.pRef),T,ht.TRef,T)
ht.H	ht.HRef+ht.DeltaH
ht.H0	ht.H
ht.Ei	ht.H
ht.Ei0	ht.Ei
ht.Qbtot	0

ht.k_effxx	ht.kxx
ht.k_effyx	ht.kyx
ht.k_effzx	ht.kzx
ht.k_effxy	ht.kxy
ht.k_effyy	ht.kyy
ht.k_effzy	ht.kzy
ht.k_effxz	ht.kxz
ht.k_effyz	ht.kyz
ht.k_effzz	ht.kzz
ht.C_eff	ht.rho*ht.Cp
ht.ux	0
ht.uy	0
ht.uz	0
ht.gradTx	Tx
ht.gradTy	Ty
ht.gradTz	Tz
ht.Qltot	0
ht.Qptot	0
ht.alphaTdxx	ht.k_effxx/ht.C_eff
ht.alphaTdyx	ht.k_effyx/ht.C_eff
ht.alphaTdzx	ht.k_effzx/ht.C_eff
ht.alphaTdxy	ht.k_effxy/ht.C_eff
ht.alphaTdyy	ht.k_effyy/ht.C_eff
ht.alphaTdzy	ht.k_effzy/ht.C_eff
ht.alphaTdxz	ht.k_effxz/ht.C_eff
ht.alphaTdyz	ht.k_effyz/ht.C_eff
ht.alphaTdzz	ht.k_effzz/ht.C_eff
ht.alphaTdMean	ht.kmean/ht.C_eff
ht.dfluxx	-ht.k_effxx*Tx-ht.k_effxy*Ty-ht.k_effxz*Tz
ht.dfluxy	-ht.k_effyx*Tx-ht.k_effyy*Ty-ht.k_effyz*Tz
ht.dfluxz	-ht.k_effzx*Tx-ht.k_effzy*Ty-ht.k_effzz*Tz

ht.dfluxMag	sqrt(ht.dfluxx^2+ht.dfluxy^2+ht.dfluxz^2)
ht.trlfluxx	0
ht.trlfluxy	0
ht.trlfluxz	0
ht.trlfluxMag	sqrt(ht.trlfluxx^2+ht.trlfluxy^2+ht.trlfluxz^2)
ht.cfluxx	0
ht.cfluxy	0
ht.cfluxz	0
ht.cfluxMag	sqrt(ht.cfluxx^2+ht.cfluxy^2+ht.cfluxz^2)
ht.tfluxx	ht.dfluxx+ht.trlfluxx+ht.cfluxx
ht.tfluxy	ht.dfluxy+ht.trlfluxy+ht.cfluxy
ht.tfluxz	ht.dfluxz+ht.trlfluxz+ht.cfluxz
ht.tfluxMag	sqrt(ht.tfluxx^2+ht.tfluxy^2+ht.tfluxz^2)
ht.tefluxx	ht.dfluxx
ht.tefluxy	ht.dfluxy
ht.tefluxz	ht.dfluxz
ht.tefluxMag	sqrt(ht.tefluxx^2+ht.tefluxy^2+ht.tefluxz^2)
ht.rflux	0
ht.chflux	0
ht.ntrlflux	mean(ht.trlfluxx)*ht.nx+mean(ht.trlfluxy)*ht.ny+mean(ht.trlfluxz)*ht.nz
ht.ncflux	mean(ht.cfluxx)*ht.nx+mean(ht.cfluxy)*ht.ny+mean(ht.cfluxz)*ht.nz
ht.ndflux	-dflux_spatial(T)/ht.d
ht.ntflux	ht.ndflux+ht.ntrlflux+ht.ncflux
ht.nteflux	mean(ht.tefluxx)*ht.nx+mean(ht.tefluxy)*ht.ny+mean(ht.tefluxz)*ht.nz-mean(ht.dfluxx)*ht.nx-mean(ht.dfluxy)*ht.ny-mean(ht.dfluxz)*ht.nz+ht.ndflux
ht.solid1.dEiInt	ht.solid1.intDom(d(ht.rho*ht.Ei,t)*ht.solid1.varIntSpa)
ht.solid1.dEi0Int	ht.solid1.intDom(d(ht.rho*ht.Ei0,t)*ht.solid1.varIntSpa)
ht.solid1.ntfluxInt	ht.solid1.intExtBnd(ht.ntflux*ht.solid1.varIntSpa)+ht.solid1.intExtBndUp(ht.ntflux_u*ht.solid1.varIntSpa)+ht.solid1.intExtBndDown(ht.ntflux_d*ht.sc
ht.solid1.ntefluxInt	ht.solid1.intExtBnd(ht.nteflux*ht.solid1.varIntSpa)+ht.solid1.intExtBndUp(ht.nteflux_u*ht.solid1.varIntSpa)+ht.solid1.intExtBndDown(ht.nteflux_d*h
ht.solid1.QInt	ht.solid1.intDom(ht.Qtot*ht.solid1.varIntSpa)-ht.solid1.intIntBnd((ht.ndflux_u+ht.ndflux_d)*ht.solid1.varIntSpa)
ht.solid1.WnsInt	ht.solid1.intDom(ht.pA*(d(ht.ux,x)+d(ht.uy,y)+d(ht.uz,z))*ht.solid1.varIntSpa)
ht.solid1.WInt	0
ht.gamma	1
ht.helem	h
ht.res_T	-ht.k_effxx*Txx-ht.k_effxy*Txy-ht.k_effxz*Txz-ht.k_effyx*Tyx-ht.k_effyy*Tyy-ht.k_effyz*Tyz-ht.k_effzx*Tzx-ht.k_effzy*Tzy-ht.k_effzz*Tzz-(ht.qs+ht.qs_oop)*T+ht.rho*ht.Cp*(ht.ux*Tx+ht.uy*Ty+ht.uz*Tz)-ht.Q-ht.Qoop

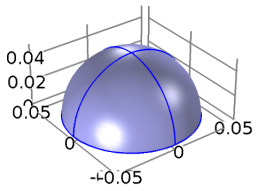
Shape Functions

Name	Shape function	Unit	Description	Shape frame	Selection
T	Lagrange (Quadratic)	K	Temperature	Material	Domain 1

Weak Expressions

Weak expression	Integration frame	Selection
(-(ht.k_effxx*Tx+ht.k_effxy*Ty+ht.k_effxz*Tz)*test(Tx)-(ht.k_effyx*Tx+ht.k_effyy*Ty+ht.k_effyz*Tz)*test(Ty)-(ht.k_effzx*Tx+ht.k_effzy*Ty+ht.k_effzz*Tz)*test(Tz))*ht.d	Material	Domain 1
-ht.rho*ht.Cp*(ht.ux*Tx+ht.uy*Ty+ht.uz*Tz)*test(T)*ht.d	Material	Domain 1
ht.streamline	Material	Domain 1

2.4.2. Initial Values 1



Initial Values 1

Selection

Geometric entity level	Domain
Selection	Domain 1

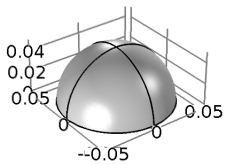
Settings

Description	Value
Temperature	293.15[K]

Variables

Name	Expression	Unit	Description	Selection
ht.Tinit	293.15[K]	K	Temperature	Domain 1

2.4.3. Thermal Insulation 1



Thermal Insulation 1

Selection

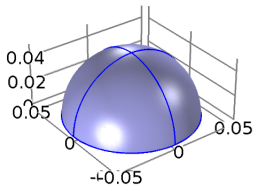
Geometric entity level	Boundary

Selection	No boundaries

Equations

$$-\mathbf{n}\cdot\mathbf{q}=0$$

2.4.4. Heat Source 1



Heat Source 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$Q=Q_0$$

Settings

Description	Value
Heat source	General source
Heat source	User defined
Heat source	go*b/sqrt(x^2 + y^2 + z^2)

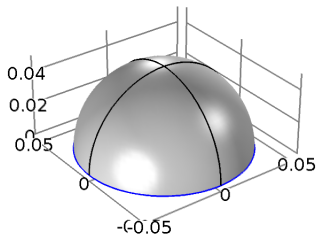
Variables

Name	Expression	Unit	Description	Selection
ht.Q	ht.hs1.Q	W/m^3	Heat source	Domain 1
ht.Qtot	ht.hs1.Q	W/m^3	Total heat source	Domain 1
ht.hs1.Q	go*b/sqrt(x^2+y^2+z^2)	W/m^3	Heat source	Domain 1

Weak Expressions

Weak expression	Integration frame	Selection
ht.hs1.Q*test(T)*ht.d	Material	Domain 1

2.4.5. Thermal Insulation 2



Thermal Insulation 2

Selection

Geometric entity level	Boundary
Selection	Boundaries 2, 4–5, 7–8

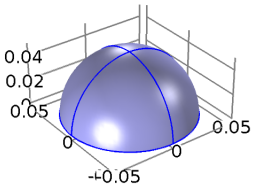
Equations

$$-\mathbf{n}\cdot\mathbf{q}=0$$

Variables

Name	Expression
ht.ins2.ntfluxInt	ht.ins2.intExtBnd(ht.ntflux*ht.ins2.varIntSpa)
ht.ins2.ntefluxInt	ht.ins2.intExtBnd(ht.nteflux*ht.ins2.varIntSpa)
ht.ins2.ntfluxInt_u	ht.ins2.intIntBnd(ht.ntflux_u*ht.ins2.varIntSpa)
ht.ins2.ntefluxInt_u	ht.ins2.intIntBnd(ht.nteflux_u*ht.ins2.varIntSpa)
ht.ins2.ntfluxInt_d	ht.ins2.intIntBnd(ht.ntflux_d*ht.ins2.varIntSpa)
ht.ins2.ntefluxInt_d	ht.ins2.intIntBnd(ht.nteflux_d*ht.ins2.varIntSpa)
ht.ins2.Tave	if(ht.ins2.intBnd(ht.ins2.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))==0,ht.ins2.intBnd(ht.ins2.varIntSpa*T)/ht.ins2.intBnd(ht.ins2.varIntSpa),ht.ins2.intBnd(ht.ins2.varIntSpa*ht.rh(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))/ht.ins2.intBnd(ht.ins2.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz)))

2.4.6. Heat Flux 1



Heat Flux 1

Selection

Geometric entity level	Boundary
Selection	Boundaries 1, 3, 6, 9

Equations

$$-\mathbf{n} \cdot \mathbf{q} = q_0$$

Settings

Description	Value
Heat flux	Convective heat flux
Heat transfer coefficient	User defined
Heat transfer coefficient	h
External temperature	Tinf

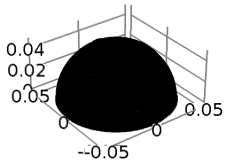
Variables

Name	Expression
ht.q0	ht.hf1.q0
ht.hf1.h	h
ht.hf1.Text	Tinf
ht.hf1.q0	ht.hf1.h*(ht.hf1.Text-ht.hf1.Tvar)
ht.hf1.Tvar	ht.Tu
ht.hf1.ntfluxInt	ht.hf1.intExtBnd(ht.ntflux*ht.hf1.varIntSpa)
ht.hf1.ntefluxInt	ht.hf1.intExtBnd(ht.nteflux*ht.hf1.varIntSpa)
ht.hf1.ntfluxInt_u	ht.hf1.intIntBnd(ht.ntflux_u*ht.hf1.varIntSpa)
ht.hf1.ntefluxInt_u	ht.hf1.intIntBnd(ht.nteflux_u*ht.hf1.varIntSpa)
ht.hf1.ntfluxInt_d	ht.hf1.intIntBnd(ht.ntflux_d*ht.hf1.varIntSpa)
ht.hf1.ntefluxInt_d	ht.hf1.intIntBnd(ht.nteflux_d*ht.hf1.varIntSpa)
ht.hf1.Tave	if(ht.hf1.intBnd(ht.hf1.varIntSpa*ht.rho*ht.Cp* (ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))==0,ht.hf1.intBnd(ht.hf1.varIntSpa*T)/ht.hf1.intBnd(ht.hf1.varIntSpa),ht.hf1.intBnd(ht.hf1.varIntSpa*ht.rho*ht. (ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz))/ht.hf1.intBnd(ht.hf1.varIntSpa*ht.rho*ht.Cp*(ht.ux*ht.nx+ht.uy*ht.ny+ht.uz*ht.nz)))

Weak Expressions

Weak expression	Integration frame	Selection
ht.hf1.q0*test(ht.hf1.Tvar)*ht.d	Material	Boundaries 1, 3, 6, 9

2.5. Mesh 1



Mesh 1

2.5.1. Size (Size)

Settings

Description	Value
Maximum element size	0.002
Minimum element size	2.0E-5
Curvature factor	0.2
Maximum element growth rate	1.3
Predefined size	Extremely fine

2.5.2. Free Tetrahedral 1 (Ftet1)

Selection

Geometric entity level	Remaining

3. Study 1

Computation information

Computation time	23 s
CPU	Intel(R) Xeon(R) Platinum 8370C CPU @ 2.80GHz, 4 cores
Operating system	Windows Server 2012

3.1. Stationary

Study settings

Description	Value
Include geometric nonlinearity	Off

Physics and variables selection

Physics interface	Discretization
Heat Transfer in Solids (ht)	physics

Mesh selection

Geometry	Mesh
Geometry 1 (geom1)	mesh1

3.2. Solver Configurations

3.2.1. Solution 1

Compile Equations: Stationary (St1)

Study and step

Description	Value
Use study	Study 1
Use study step	Stationary

Dependent Variables 1 (V1)

General

Description	Value
Defined by study step	Stationary

Initial values of variables solved for

Description	Value
Solution	Zero

Values of variables not solved for

Description	Value
Solution	Zero

Temperature (Comp1.T) (Comp1_T)

General

Description	Value
Field components	comp1.T

Stationary Solver 1 (S1)

General

Description	Value
Defined by study step	Stationary

Fully Coupled 1 (Fc1)

General

Description	Value
Linear solver	Iterative 1

Method and termination

Description	Value
Initial damping factor	0.01
Minimum damping factor	1.0E-6
Maximum number of iterations	50

Iterative 1 (I1)

General

Description	Value
Factor in error estimate	20

Multigrid 1 (Mg1)

General

Description	Value
Use hierarchy in geometries	Geometry 1

Presmoother (Pr)

SOR Line 1 (Sl1)

Main

Description	Value
Relaxation factor	0.2

Secondary

Description	Value
Number of secondary iterations	2
Relaxation factor	0.5

Postsmoother (Po)

SOR Line 1 (Sl1)

Main

Description	Value
Relaxation factor	0.2

Secondary

Description	Value
Number of secondary iterations	2
Relaxation factor	0.5

Coarse Solver (Cs)

Direct 1 (D1)

General

Description	Value
Solver	PARDISO

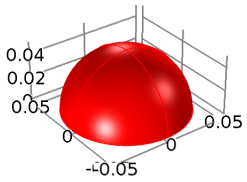
4. Results

4.1. Data Sets

4.1.1. Study 1/Solution 1

Solution

Description	Value
Solution	Solution 1
Component	Save Point Geometry 1
Frame	Mesh (x, y, z)



Data set: Study 1/Solution 1

4.1.2. Cut Line 3D 1

Data

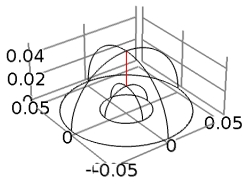
Description	Value
Data set	Study 1/Solution 1

Line data

Description	Value
Line entry method	Two points
Points	{{0, 0, 2[cm]}, {0, 0, 5[cm]}}

Advanced

Description	Value
Space variable	cln1x



Data set: Cut Line 3D 1

4.2. Derived Values

4.2.1. Surface Integration 1

Selection

Geometric entity level	Boundary
Selection	Boundaries 1, 3, 6, 9

Data

Description	Value
Data set	Study 1/Solution 1

Expression

Description	Value
Expression	ht.ndflux
Unit	W
Description	Normal conductive heat flux

4.3. Tables

4.3.1. Table 2

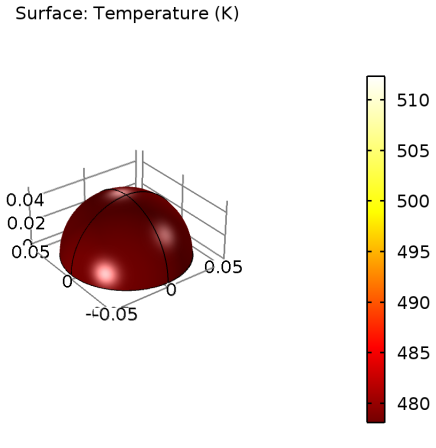
Surface Integration 1 (ht.ndflux)

Table 2

Normal conductive heat flux (W)	Normal conductive heat flux (W)
330.14	330.14

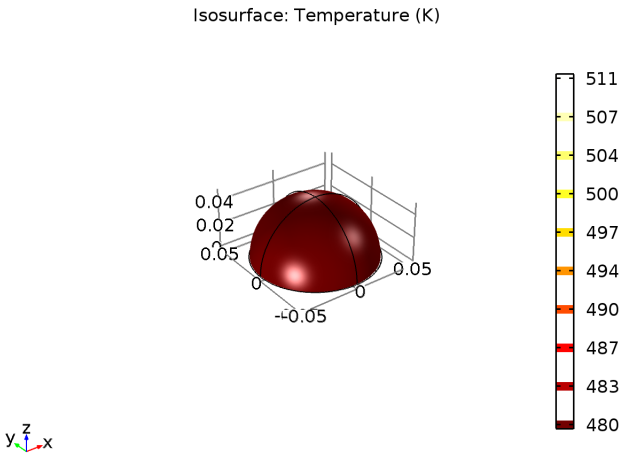
4.4. Plot Groups

4.4.1. Temperature (Ht)



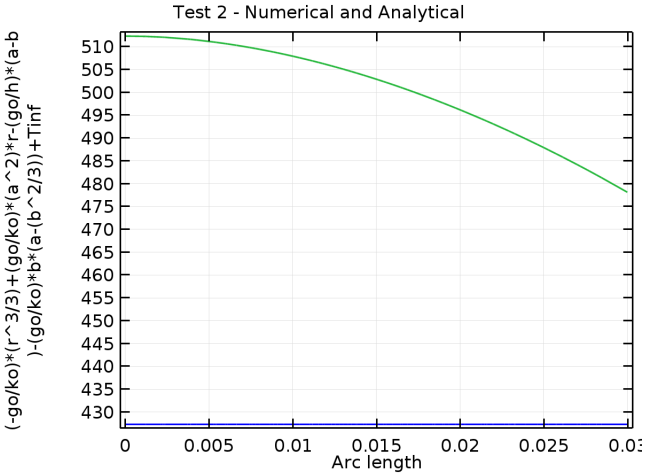
Surface: Temperature (K)

4.4.2. Isothermal Contours (Ht)



Isosurface: Temperature (K)

4.4.3. 1D Plot Group 3



Test 2 - Numerical and Analytical