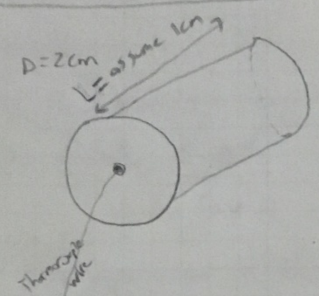
MET 490 | Frank Nguyen | Test 3

① Purpose

- Determine the convective heat transfer coefficient of the fluid for this process.
- Determine the temperature at the surface and at half the radius of the plastic rod at 1338 seconds.

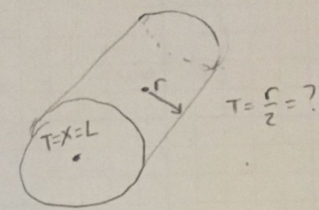
- Drawings and diagrams



$T_\infty = 25°C$

$T_i = 70°C$

$T_o = 30°C$



Sources

- Boyceitogl, Y. Ozgik, M, "A Textbook for Heat transfer Fundamentals", Begell House Inc, (2016)
- Blackboard Tables

Design considerations

- Constant properties
- Two dimensional
- Convective heat transfer coefficient is uniform.

Data and variables

Plastic properties: $\rho = 1190\ kg/m^3$, $C_p = 1465\ J/kg\cdot K$, $k = .19\ W/m\cdot K$

$T_\infty = 25°C$ $T_i = 70°C$ $T_o = 30°C$

$t = 1338$ seconds $D = 2cm$ $r = 1cm$

$$\alpha = \frac{k}{\rho C_p} = \frac{.19\ W/m\cdot K}{(1190\ kg/m^3)(1465\ J/kg\cdot K)}$$

$$\alpha = 1.09 \times 10^{-7} m^2/s$$

Procedure

For the multidimensional radial system we have to use the one-term approximation method for a long rod. with the equation we can iterate the RHS and LHS until we have a answer that's percent difference (%) on RHS and LHS that follows the (1%, 5%, 10% rule)

Calculation

we know Convective heat transfer coefficient for a cylinder is:

$$? \rightarrow h = \frac{k \cdot B_i}{r_o} \; ?$$

one-term approximation in long rod:

$$\Theta_o = \underbrace{C_1 \exp(-\lambda_1^2 \tau)}_{RHS} = \underbrace{\frac{T_o - T_\infty}{T_i - T_\infty}}_{LHS}$$

$$= \frac{30°C - 25°C}{70°C - 25C}$$

$$= .111 \; LHS$$

• Fourier number

$$\tau = \frac{\alpha t}{r_o^2} = \frac{kt}{\rho C_p r_o^2}$$

$$\tau = \frac{(.19\ W/m \cdot K)(1338\ sec)}{(1190\ kg/m^3)(.0465\ J/kg \cdot K)(.01\ m)^2}$$

$$\tau = 1{,}458$$

1) Assume B_i
2) Read tables C_1 and λ_1 from blackboard table 5.1 for cylinder
3) Compute RHS
4) Compare RHS to LHS → $\% \text{ diff} = \frac{RHS - LHS}{LHS} \times 100$

• 1st assumption: $B_i = .5$; $C_1 = 1.1143$ $\lambda_1 = .9408$

$$1.1143 e^{-(.9408^2)(1.458)} = .111$$

$$\underbrace{.306}_{RHS} = \underbrace{.111}_{LHS}$$

$$\% \text{ diff} = \frac{.111 - .306}{.306} \times 100$$

$\% \text{ diff} = 63.8\%$ too large of difference

Interpolate | $Bi = 1$ and $Bi = 2$

• 2nd assumption: $Bi = 1.5$: $C_1 = 1.27275$ $\lambda = 1.4276$

$$1.27275e^{-(1.4276)^2(1.458)} = .111$$

$$\underbrace{.0652}_{RHS} = \underbrace{.111}_{LHS}$$

$$\%\ diff = \frac{.111 - .0652}{.0652} \times 100$$

% diff = 70% : Extremly large differance

• 3rd assumption: $Bi = 1.0$: $C_1 = 1.2071$ $\lambda_1 = 1.2558$

$$1.2071e^{-(1.2558)^2(1.458)} = .111$$

$$\underbrace{.1211}_{RHS} = \underbrace{.111}_{LHS}$$

$$\%\ diff = \frac{.111 - .1211}{.1211} \times 100$$

% diff = 8.34 % diff

• Now we can plug in Bi into equation for heat transfer coefficient

$$h = \frac{K\,Bi}{r_o}$$

$$h = \frac{(.19\ W/m{\cdot}K)(1)}{.01m}$$

$$h = 19\ W/m^2{\cdot}K$$

Procedure

- For determining the temperature of the surface we have to consider the multidimensional, we have to solve by multiplying the solution of a plane wall / outer surface ($x = L$) and a cylinder ($r = 0$). First we find Biot number of plane wall and Fourier number of plane wall. We already have all the information of Biot number and Fourier number of cylinder from first part.
- For determining temperature at half of the radius we have to multiply the solution of a plane wall of thickness $2L = 1cm$ and half the radius of the cylinder. First find Biot and Fourier number of plane wall. Then find Biot and Fourier number of half the radius of the cylinder. Then we can calculate the temperature of half the cylinder.

Calculations

- For temperature at surface

- Plane wall / outer surface:

$$B_i = \frac{hL}{K} = \frac{(19\ W/m^2 \cdot K)\left(\frac{.01m}{2}\right)}{(.19\ W/m \cdot K)}$$ (L: half of thickness)

$$\tau = \frac{\alpha t}{L^2} = \frac{(1.09 \times 10^{-7} m^2/s)(1338\ sec)}{(.005 m^2)}$$

$B_i = .5$ from table 5.1 for plane wall

$\tau = 5.834$

$\lambda = .6533$

$C_1 = 1.0701$

$$\theta(L,t)_{wall} = \frac{T(x,t) - T_\infty}{T_i - T_\infty} = C_1 e^{-\lambda^2 \tau} \cos\left(\lambda \frac{L}{L}\right)$$

$$= 1.0701 e^{-(.6533^2)(5.834)} \cos(.6533)$$

$$\theta(L,t)_{wall} = .07046$$

- Temperature at surface:

$$\frac{T(L,0,t) - T_\infty}{T_i - T_\infty} = \theta(L,t)_{wall} \cdot \theta_{cylinder}$$ ($\theta_{cylinder}$ = .111 from first part of test.)

$$\frac{T_{(L,o,t)} - 25°C}{70°C - 25°C} = (.07046)(.111)$$

$$\frac{T_{(L,o,t)} - 25°C}{45°C} = .00782106$$

$$T_{(L,o,t)} - 25°C = .3519477$$
$$+25°C \quad +25°C$$

$$T_{(L,o,t)} = 25.3519°C$$

• For temperature at half the radius

• Plane wall: information from the wall for last part.

Table 5.1 for the

$Bi = .5$ $\quad \tau = 5.834$

$\lambda = .6533$

$C_1 = 1.0701$

$$\Theta_{0,\,plane} = \frac{T_0 - T_\infty}{T_i - T_\infty} = C_1 e^{-\lambda^2 \tau}$$
$$= 1.0701 e^{-(.6533^2)(5.834)}$$

$$\Theta_{0,\,plane} = .08873$$

• Cylinder (half radius):

$$Bi = \frac{h\left(\frac{r_o}{2}\right)}{K} = \frac{(19\,W/m^2K)(.005m)}{(.19\,W/m \cdot K)}$$

$$\tau = \frac{\alpha t}{\frac{r_o^2}{2}} = \frac{(1.09 \times 10^{-7} m^2/s)(1338)}{(.005 m^2)}$$

$$\tau = 5.834$$

table 5.1 for cylinder:

$Bi = .5$

$\lambda = .9408$

$C_1 = 1.1143$

$$\Theta_{\frac{r}{2},\,cylinder} = \frac{T_0 - T_\infty}{T_i - T_\infty} = C_1 e^{-\lambda^2 \tau}$$

$= .4143 e^{-(.9408^2)(5.834)}$

$\Theta_{\frac{r}{2}\,cylinder} = .006374344$

• Temperature at half radius:

$$\frac{T_{(\frac{r}{2},0,t)} - T_\infty}{T_i - T_\infty} = \Theta_{plane} \cdot \Theta_{\frac{r}{2}\,cylinder} = (.08873)(.006374344)$$

$$\frac{T_{(\frac{r}{2},0,t)} - 25°C}{70°C - 25°C} = .00056521$$

$$\frac{T_{(\frac{r}{2},0,t)} - 25°C}{45°C} = .00056521$$

$$T_{(\frac{r}{2},0,t)} - 25°C = .02543$$
$$+25°C \qquad +25°C$$

$$T_{(\frac{r}{2},0,t)} = 25.025°C$$

Summary

- for finding h

LHS	Bi	(H)	% diff
.111	.5	.306	63.8
.111	1.5	.0652	70%
.111	1.0	.121	8.34%

- The temperature at the surface is 25.35°C
- The temperature at half the radius is 25.025°C

Material)

- Plastic rod
- Thermo Couple
- Fluid to Cool

Analysis)

- For finding heat transfer coefficient (h) we could of used a spreadsheet to help solve RHS and LHS which could of gave a more accurate answer. The table 5.1 for Biot number could have more values so we can interpolate to get a more accurate answer than using $Bi = 1$. I could only interpolate for values $Bi = 1$ and $Bi = 2$ to get values for $Bi = 1.5$, but was still too inaccurate so I just used $Bi = 1$

- For the temperature at the surface (25.35°C) and temperature at half the radius (25.025°C) the temperatures are close in value because its the temperature for a cylinder (long and solid) and the plane wall.

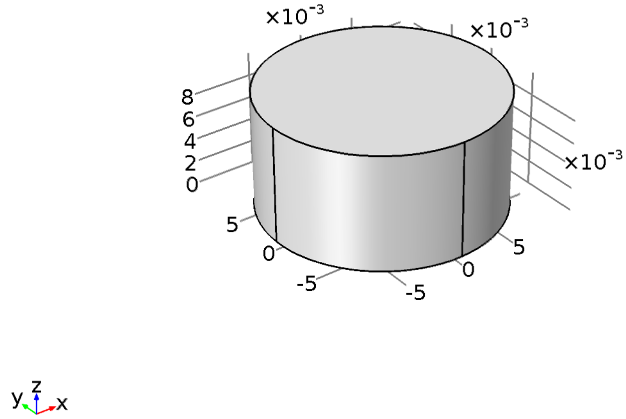
MET 440 3rd Test, 2nd Problem- Part A

Contents

1 Purpose

Determine the convective heat transfer coefficient of the fluid for this process.

2 Drawings and Diagrams



Geometry 1

Units

Length unit	m

Angular unit	deg

Size and shape

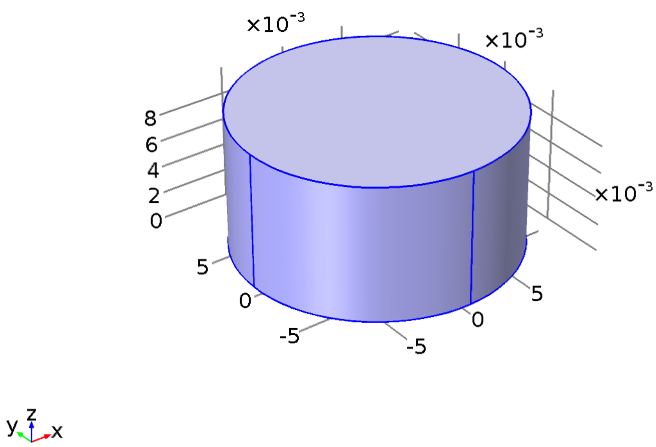
Description	Value
Radius	1[cm]
Height	1[cm]

3 Sources

Bayazitoglu, Y., Ozisik, N., "A textbook for Heat Transfer Fundamentals",

Begell House Inc. (2012)

4 Materials



Material 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Material parameters

Name	Value	Unit
Thermal conductivity	.19	W/(m*K)
Density	1190	kg/m^3
Heat capacity at constant pressure	1465	J/(kg*K)

Basic Settings

Description	Value
Thermal conductivity	{{.19, 0, 0}, {0, .19, 0}, {0, 0, .19}}
Density	1190
Heat capacity at constant pressure	1465

5 Data and Variables

Material parameters

Name	Value	Unit
Thermal conductivity	.19	W/(m*K)
Density	1190	kg/m^3
Heat capacity at constant pressure	1465	J/(kg*K)

Initial Values

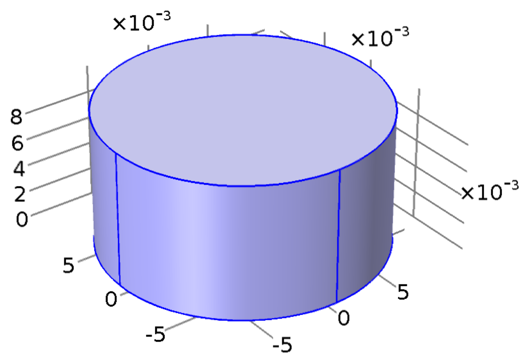
Description	Value
Temperature	343.15[K]

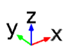
Settings

Description	Value
Heat flux	Convective heat flux
Heat transfer coefficient	**Variable to Determine**
External temperature	298.15[K]

Name	Expression	Unit	Description	Selection
ht.Tinit	343.15[K]	K	Temperature	Domain 1

6 Design Considerations





Selection

Geometric entity level	Boundary
Selection	Domain 1

Equations

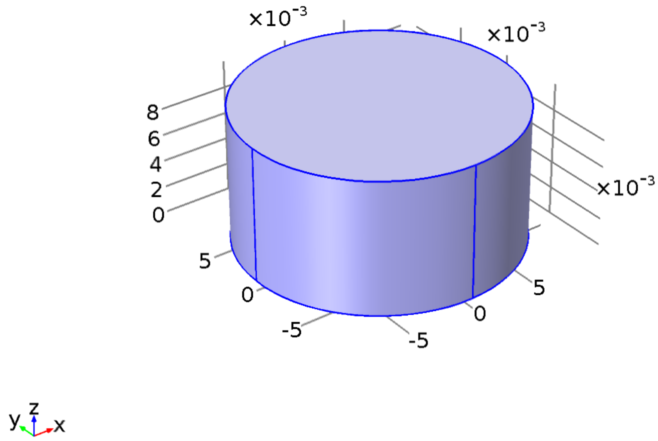
$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\mathrm{ted}}$$

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

Settings

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

Initial Values



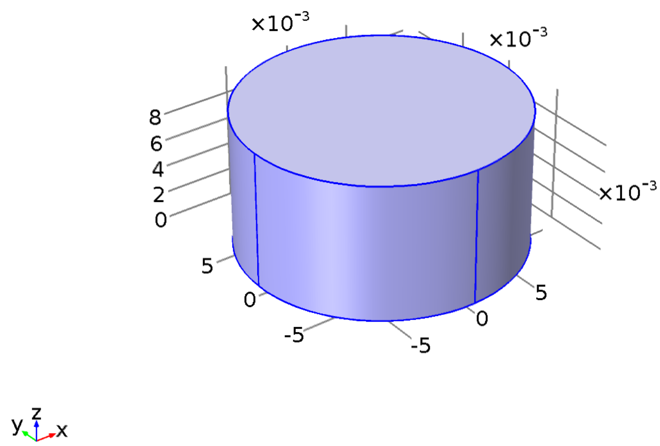
Settings

Description	Value
Temperature	343.15[K]

Variables

Name	Expression	Unit	Description	Selection
ht.Tinit	343.15[K]	K	Temperature	Domain 1

Heat Flux 1



Heat Flux 1

Equations

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

Settings

Description	Value
Heat flux	Convective heat flux
Heat transfer coefficient	User defined
Heat transfer coefficient	**Variable to Determine**
External temperature	298.15[K]

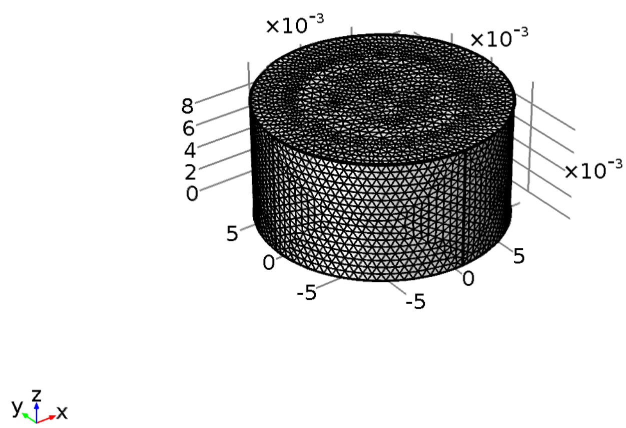
7 Procedure

The COMSOL program will be ran several times with different values of convective hear transfer coefficient, until it is noticed that the center of the rod reaches 30 C in 1338 seconds.

7.1 Mesh 1

Mesh statistics

Description	Value
Minimum element quality	0.213
Average element quality	0.7724
Tetrahedral elements	155785
Triangular elements	6980
Edge elements	244
Vertex elements	8



Mesh 1

7.1.1 Size (size)

Settings

Description	Value
Maximum element size	7.0E-4

Description	Value
Minimum element size	3.0E-5
Curvature factor	0.3
Resolution of narrow regions	0.85
Maximum element growth rate	1.35
Predefined size	Extra fine

Computation information

Computation time	2 min 18 s
CPU	Intel(R) Xeon(R) CPU E5-2670 0 @ 2.60GHz, 3 cores
Operating system	Windows 7

7.2 Time Dependent

Study settings

Description	Value
Include geometric nonlinearity	Off

Times	Unit
range(0,20,1340)	s

Physics and variables selection

Physics interface	Discretization
Heat Transfer in Solids (ht)	physics

Mesh selection

Geometry	Mesh
Geometry 1 (geom1)	mesh1

7.2.1 Free Tetrahedral 1 (ftet1)

Selection

Geometric entity level	Remaining

Compile Equations: Time Dependent (st1)

Study and step

Description	Value
Use study	Study 1

Description	Value
Use study step	Time Dependent

Dependent Variables 1 (v1)

General

Description	Value
Defined by study step	Time Dependent

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

Time-Dependent Solver 1 (t1)

General

Description	Value
Defined by study step	Time Dependent
Time	{0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, 360, 380, 400, 420, 440, 460, 480, 500, 520, 540, 560, 580, 600, 620, 640, 660, 680, 700, 720, 740, 760, 780, 800, 820, 840, 860, 880, 900, 920, 940, 960, 980, 1000, 1020, 1040, 1060, 1080, 1100, 1120, 1140, 1160, 1180, 1200, 1220, 1240, 1260, 1280, 1300, 1320, 1340}

Time stepping

Description	Value
Maximum BDF order	2
Error estimation	Exclude algebraic

Log

Fully Coupled 1 (fc1)

General

Description	Value
Linear solver	Iterative 1

Method and termination

Description	Value
Damping factor	0.9
Jacobian update	Once per time step
Maximum number of iterations	5

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

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

8 Calculations

The COMSOL program will be ran several times with different values of convective hear transfer coefficient, until it is noticed that the center of the rod reaches 30 C in 1338 seconds

The different values used were :

9 W/m2 .K

10 W/m2 .K

15 W/m2 .K

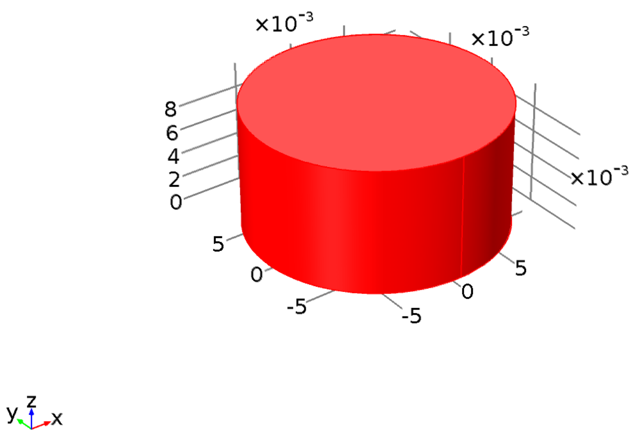
19 W/m2 .K

8.1 Data Sets

8.1.1 Study 1/Solution 1

Solution

Description	Value
Solution	Solution 1
Component	Save Point Geometry 1



Data set: Study 1/Solution 1

8.1.2 Cut Point 3D 1

Data

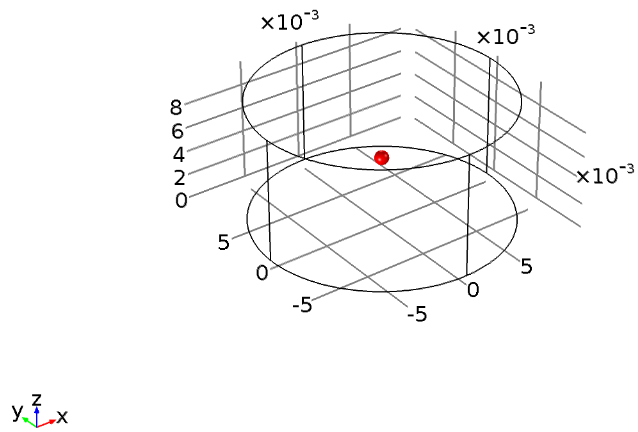
Description	Value
Data set	Study 1/Solution 1

Point data

Description	Value
Entry method	Coordinates

Settings

Description	Value
x	0
y	0
z	0.005



Data set: Cut Point 3D 1

8.2 Derived Values

8.2.1 Point Evaluation 1

Data

Description	Value
Data set	Cut Point 3D 1

Expression

Description	Value
Expression	T
Unit	degC
Description	Temperature

8.3 Tables

8.3.1 Table 1

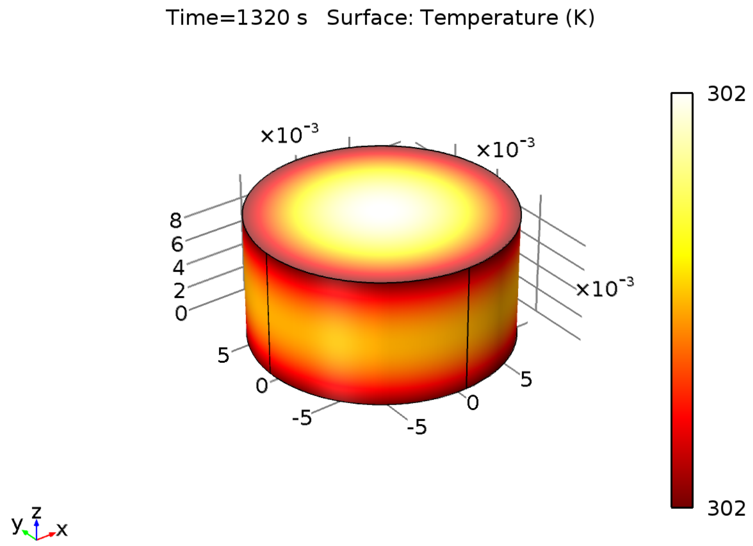
Point Evaluation 1 (T)

Table 1

Time (s)	Temperature (degC), Point: (0, 0, 0.005)	Temperature (degC), Point: (0, 0, 0.005)
1340.0	29.148	29.633

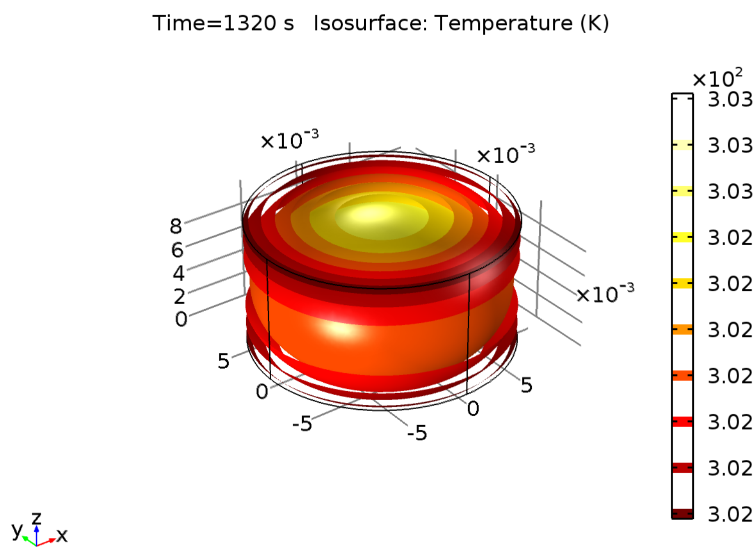
8.4 Plot Groups

8.4.1 Temperature (ht)



Time=1320 s Surface: Temperature (K)

8.4.2 Isothermal Contours (ht)



Time=1320 s Isosurface: Temperature (K)

9 Summary

We changed the Values of convective heat transfer until we reached 30 C at the center of the cylinder in 1338 seconds. Here are the results:

h (W/m2 .K)	Temperature(C)
9	29.633
10	28.731
15	26.280
19	25.475

For this numerical result process when h= 9 (W/m2 .K) is when the temperature in the center of the rod is 29.633 C. The percentage difference is between the numerical and analytical results is 111%.

10 Analysis

COMSOL's answer for convective heat transfer coefficient is h= 9 (W/m2 .K) and the analytical method is h= 19 (W/m2 .K). I believe the answer is far off because of the interpolation for Biot number during the analytical process. COMSOL doesn't understand interpolation of Biot number which is why when solving for convective heat transfer coefficient it is not that accurate,

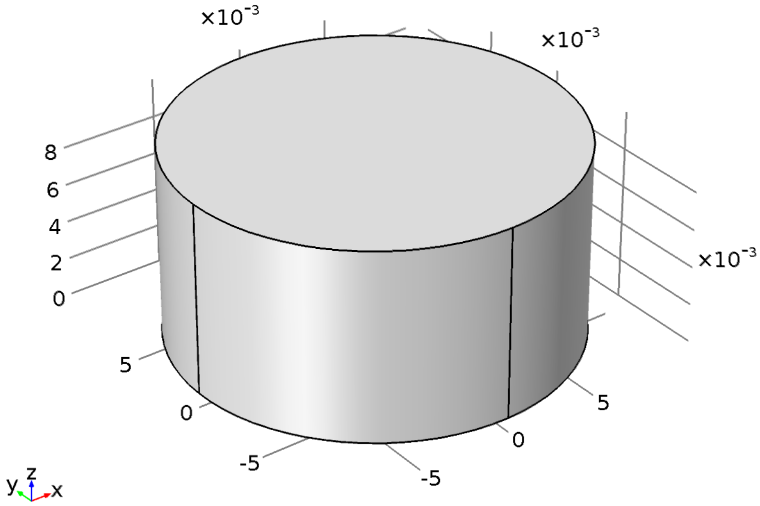
MET 440 3rd Test 2nd Problem- Part B

Contents

1 Purpose

Determine the temperature at the surface and at half the radius of the plastic rod at 1338 seconds with the COMSOL program.

2 Drawings and Diagrams



Geometry 1

Units

Length unit	m
Angular unit	deg

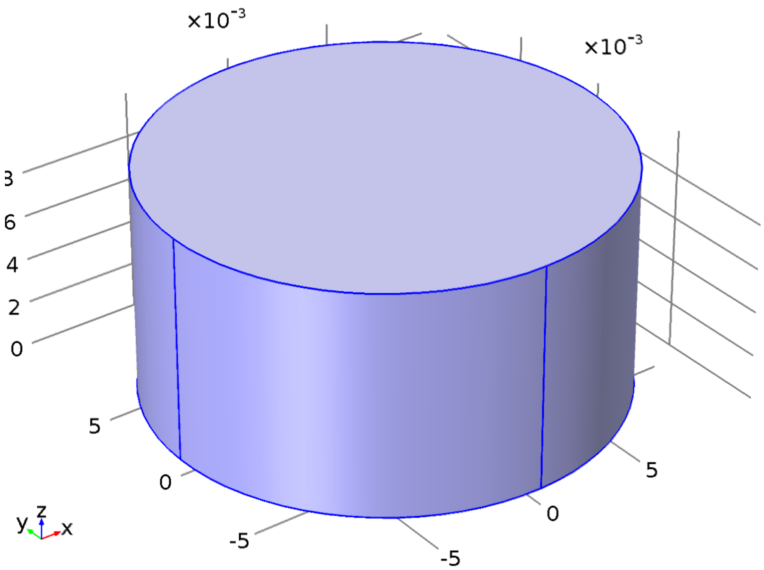
Size and shape

Description	Value
Radius	1[cm]
Height	1[cm]

3 Sources

Bayazitoglu, Y., Ozisik, N., "A textbook for Heat Transfer Fundamentals", Begell House Inc. (2012)

4 Materials



Material 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Material parameters

Name	Value	Unit
Thermal conductivity	.19	W/(m*K)
Density	1190	kg/m^3
Heat capacity at constant pressure	1465	J/(kg*K)

Basic Settings

Description	Value
Thermal conductivity	{{.19, 0, 0}, {0, .19, 0}, {0, 0, .19}}
Density	1190
Heat capacity at constant pressure	1465

5 Data and Variables

Material parameters

Name	Value	Unit
Thermal conductivity	.19	W/(m*K)
Density	1190	kg/m^3
Heat capacity at constant pressure	1465	J/(kg*K)

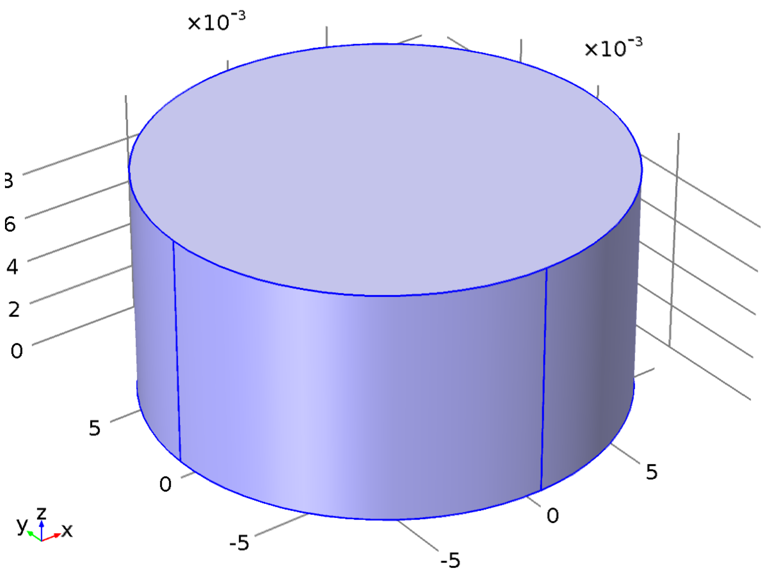
Initial Values

Description	Value
Temperature	343.15[K]

Heat Flux Settings

Description	Value
Heat transfer coefficient	19
External temperature	298.15[K]

6 Design Considerations



Heat Transfer in Solids 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

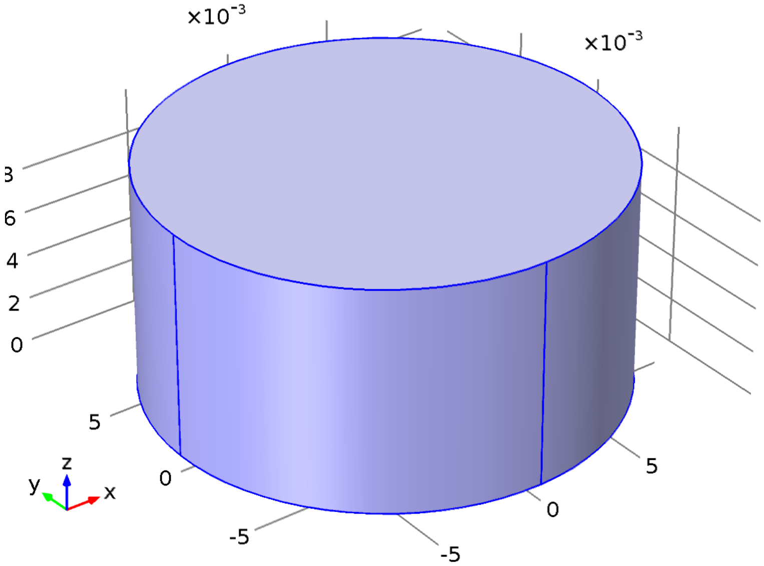
$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q + Q_{\mathrm{ted}}$$

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

Settings

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

6.1.1 Initial Values 1



Initial Values 1

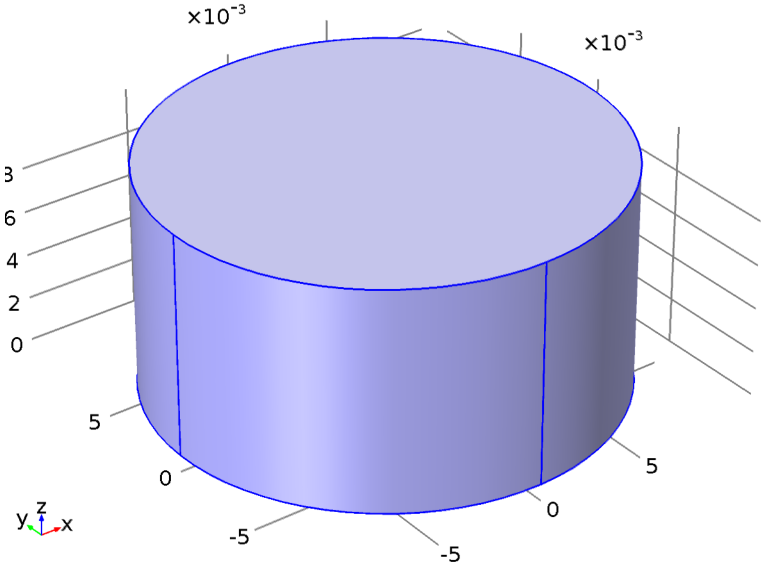
Settings

Description	Value
Temperature	343.15[K]

Variables

Name	Expression	Unit	Description	Selection
ht.Tinit	343.15[K]	K	Temperature	Domain 1

6.1.2 Heat Flux 1



Heat Flux 1

Equations

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

Settings

Description	Value
Heat flux	Convective heat flux
Heat transfer coefficient	User defined
Heat transfer coefficient	19
External temperature	298.15[K]

10.1

10.2

10.3

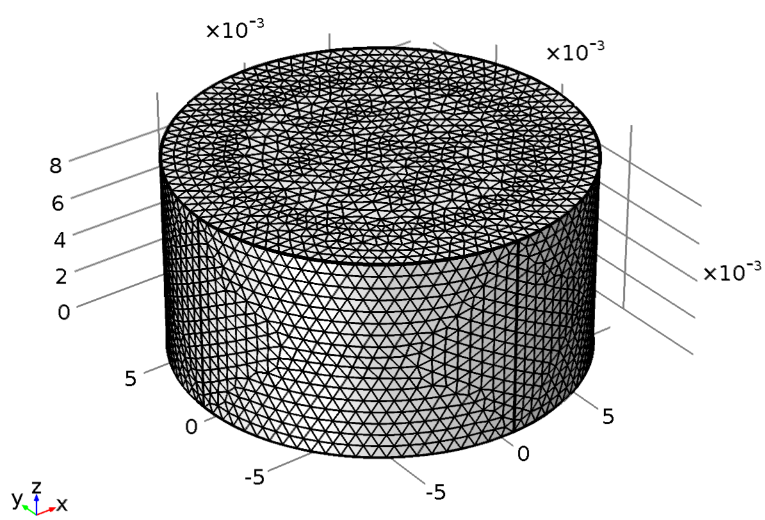
10.4

10.5

7 Procedure

Mesh statistics

Description	Value
Minimum element quality	0.213
Average element quality	0.7724
Tetrahedral elements	155785
Triangular elements	6980
Edge elements	244
Vertex elements	8



Mesh 1

7.1.1 Size (size)

Settings

Description	Value
Maximum element size	7.0E-4
Minimum element size	3.0E-5
Curvature factor	0.3
Resolution of narrow regions	0.85
Maximum element growth rate	1.35
Predefined size	Extra fine

Computation information

Computation time	2 min 0 s
CPU	Intel(R) Xeon(R) CPU E5-2670 0 @ 2.60GHz, 3 cores
Operating system	Windows 7

10.6Time Dependent

Study settings

Description	Value
Include geometric nonlinearity	Off

Times	Unit
range(0,20,1338)	s

Physics and variables selection

Physics interface	Discretization
Heat Transfer in Solids (ht)	physics

Mesh selection

Geometry	Mesh
Geometry 1 (geom1)	mesh1

10.7Solver Configurations

7.1.2 Solution 1

Compile Equations: Time Dependent (st1)

Study and step

Description	Value

Description	Value
Use study	Study 1
Use study step	Time Dependent

Time-Dependent Solver 1 (t1)

General

Description	Value
Defined by study step	Time Dependent
Time	{0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, 360, 380, 400, 420, 440, 460, 480, 500, 520, 540, 560, 580, 600, 620, 640, 660, 680, 700, 720, 740, 760, 780, 800, 820, 840, 860, 880, 900, 920, 940, 960, 980, 1000, 1020, 1040, 1060, 1080, 1100, 1120, 1140, 1160, 1180, 1200, 1220, 1240, 1260, 1280, 1300, 1320}

Time stepping

Description	Value
Maximum BDF order	2
Error estimation	Exclude algebraic

General

Description	Value
Linear solver	Iterative 1

Method and termination

Description	Value
Damping factor	0.9
Jacobian update	Once per time step
Maximum number of iterations	5

Iterative 1 (i1)

General

Description	Value
Factor in error estimate	20

Multigrid 1 (mg1)

General

Description	Value

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

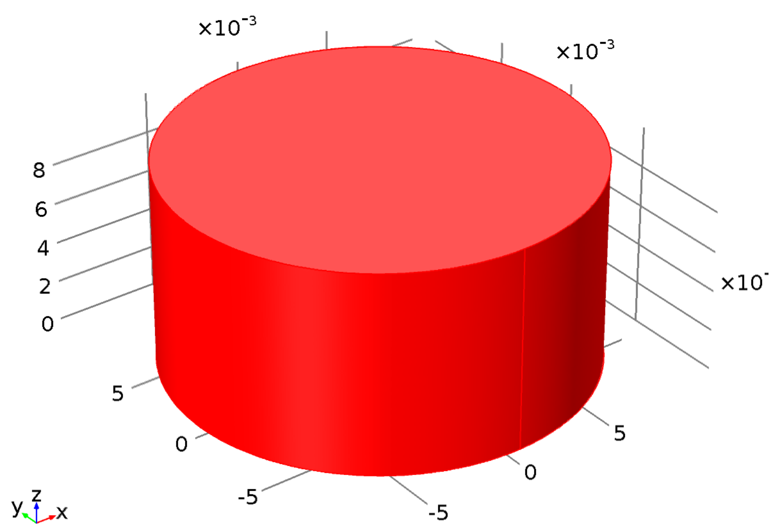
8 Calculations

10.8Data Sets

8.1.1 Study 1/Solution 1

Solution

Description	Value
Solution	Solution 1
Component	Save Point Geometry 1



Data set: Study 1/Solution 1

8.1.2 Cut Point 3D 1

Data

Description	Value
Data set	Study 1/Solution 1

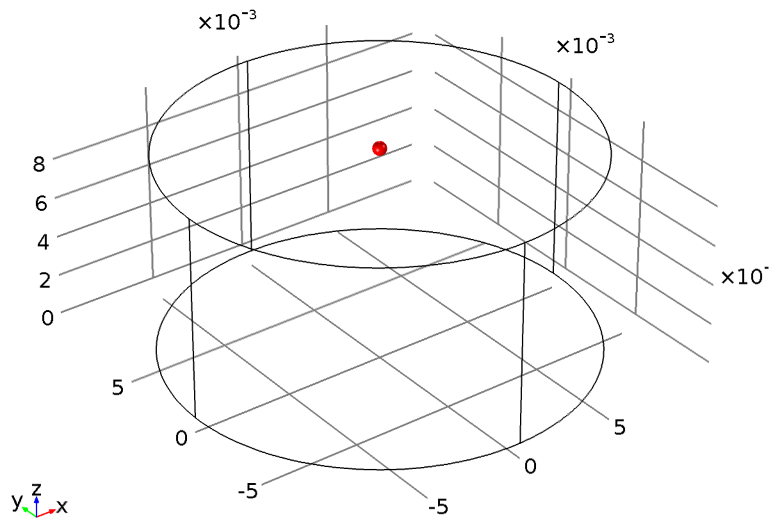
Point data

Description	Value
Entry method	Coordinates

Settings

Description	Value
x	0

Description	Value
y	0
z	0.01



Data set: Cut Point 3D 1

8.1.3 Cut Point 3D 2

Data

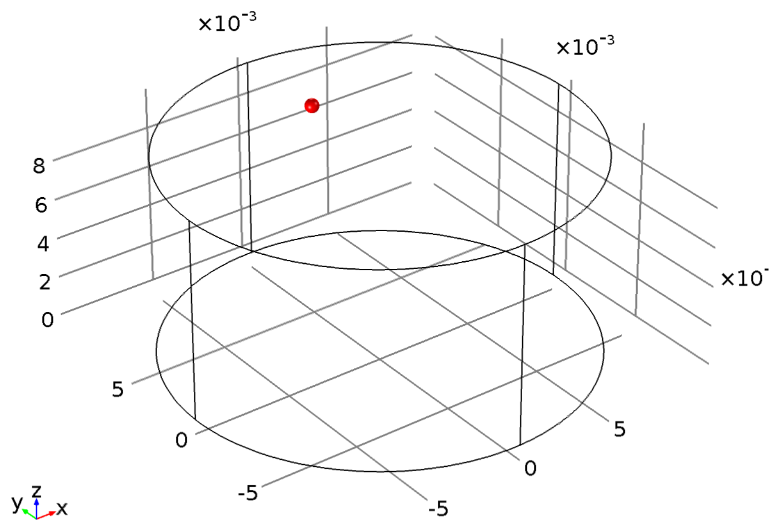
Description	Value
Data set	Study 1/Solution 1

Point data

Description	Value
Entry method	Coordinates

Settings

Description	Value
x	0
y	0.005
z	0.01



Data set: Cut Point 3D 2

10.9Derived Values

8.1.4 Point Evaluation 1

Data

Description	Value
Data set	Cut Point 3D 1

Expression

Description	Value
Expression	T
Unit	K
Description	Temperature

8.1.5 Point Evaluation 2

Data

Description	Value
Data set	Cut Point 3D 2

Expression

Description	Value
Expression	T
Unit	K

Description	Value
Description	Temperature

10.10Tables

8.1.6 Table 1

Point Evaluation 1 (T)

Table 1

Time (s)	Temperature (K), Point: (0, 0, 0.01)
1320.0	298.56

8.1.7 Table 2

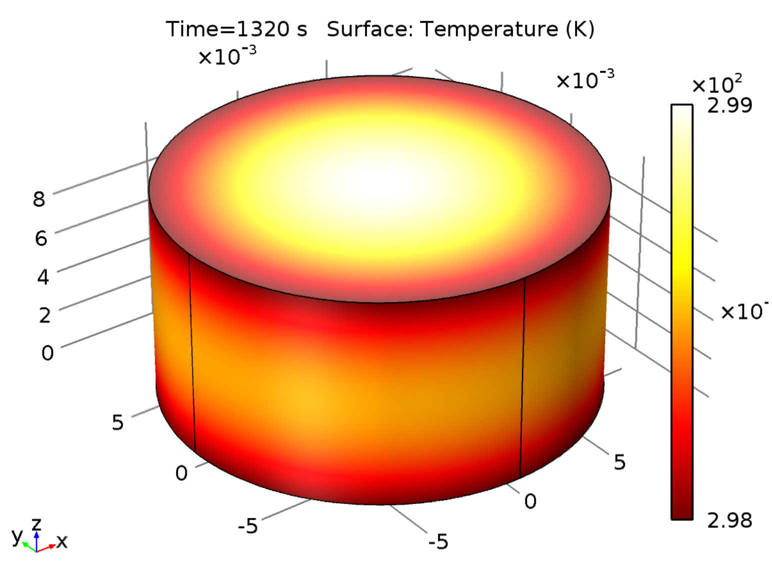
Point Evaluation 2 (T)

Table 2

Time (s)	Temperature (K), Point: (0, 0.005, 0.01)
1320.0	298.52

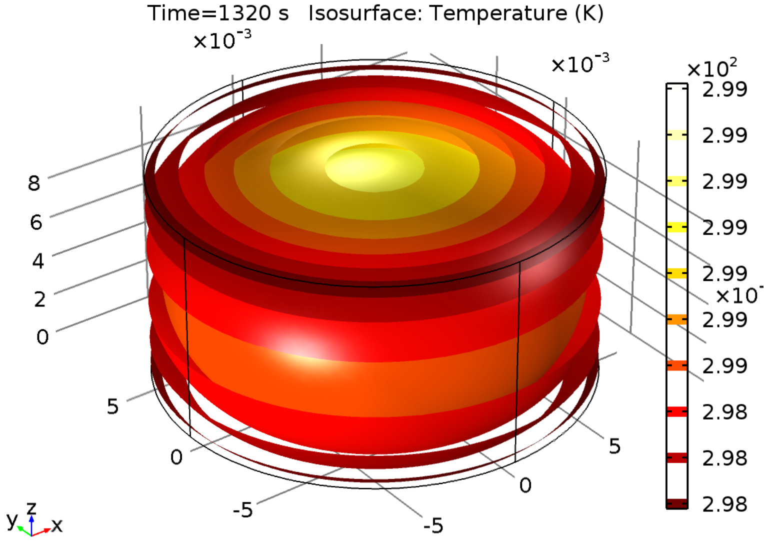
10.11Plot Groups

8.1.8 Temperature (ht)



Time=1320 s Surface: Temperature (K)

8.1.9 Isothermal Contours (ht)



Time=1320 s Isosurface: Temperature (K)

9 Summary

Using COMCOL and solving for temperatures at the surface and temperature at half the radius at 1338 seconds we get these results:

	Numerical/COMSOL	Analytical	% Difference
Surface	298.56 K = 25.41 C	25.35 C	0.24%
Half Radius	298.52 K = 25.37 C	25.025 C	0.014%

10 Analysis

Our results for COMSOL and analytical results are very accurate and under 1% difference. COMSOL could have been used to find temperatures at all different points in the plastic rod. In this case the results for COMSOL are more accurate because in the analytical method we had to iterate Biot number for the one term approximation method which leaves room for user error because of linear interpolation.