### *Unsteady-State Diffusion in a Slab*

This simple example is based on Cutlip and Shacham Problem 10.13: Unsteady-State Mass Transfer in a Slab. We will start with a simple problem in which the slab has no species A present at the start of the problem. Then we will move on to solve the Geankoplis/Cutlip and Shacham problem and compare the solutions between Comsol and Polymath. See the text for an explanation of the problem and the governing equations.

## PROBLEM DEFINITION

We start with the following PDE to solve:

$$\frac{\partial C_A}{\partial t} = D_{AB}\frac{\partial^2 C_A}{\partial x^2}$$

with a slight modification of the boundary and initial conditions from problem C&S10.13:

$$t = 0 \qquad C_A = 0 \text{ for all } x$$

$$C_A = 4\times10^{-3}\text{ kmol/m}^3 \qquad x = 0$$

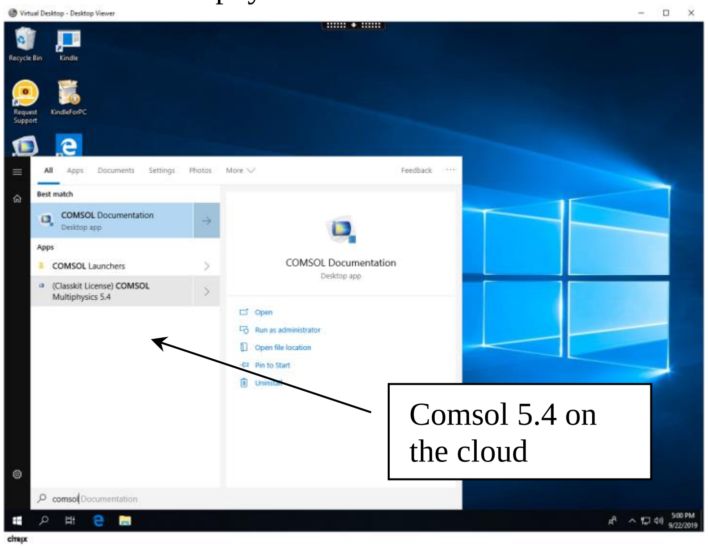
$$\text{Wall is insulated } \left(\left.\frac{\partial C_A}{dx}\right|_{x=0.004m} = 0\right) \text{at } x = 0.004m$$

Later we will examine the initial condition in which there is a concentration profile in the slab. We are now ready to model our system in COMSOL.

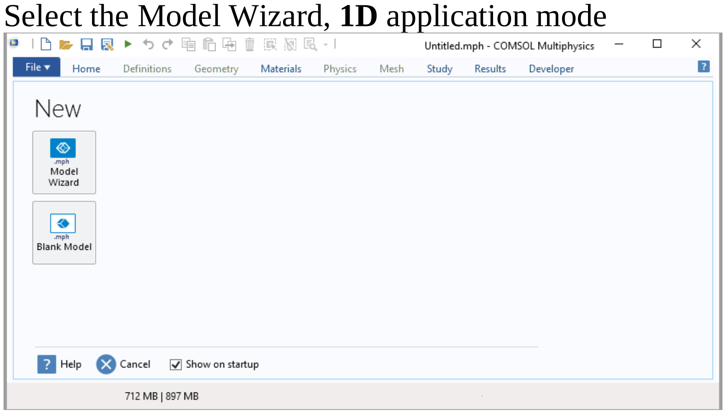
The analytical solution to the above equation is given by an infinite Fourier series in which the slab thickness is x=h. This problem is referred to in texts as transient diffusion in a finite-dimensional medium.

## Unsteady-State Diffusion through a slab

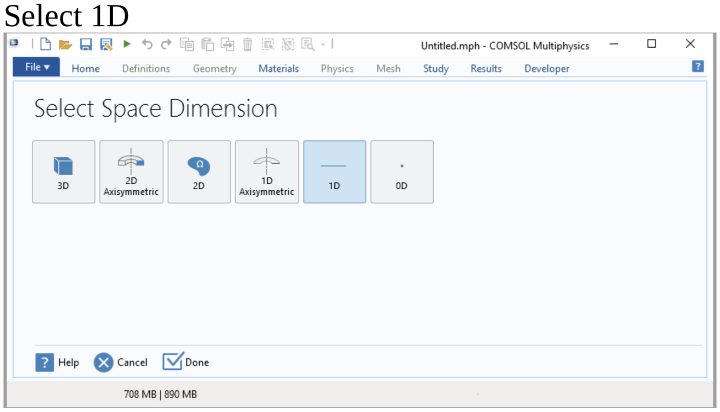
1. Use the Rowan Cloud by opening the Citrix Desktop and then open Comsol: Start COMSOL Multiphysics 5.4 Classkit License not the Documentation.



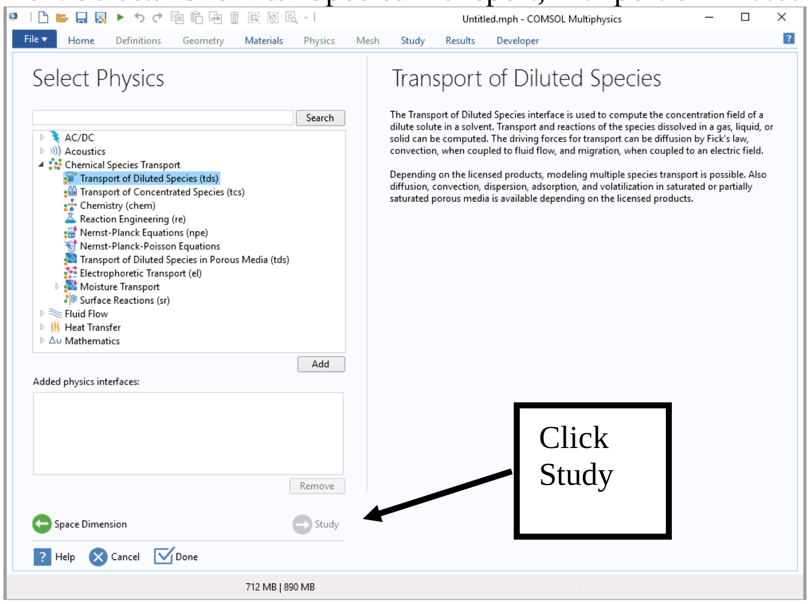

Select the Model Wizard, **1D** application mode



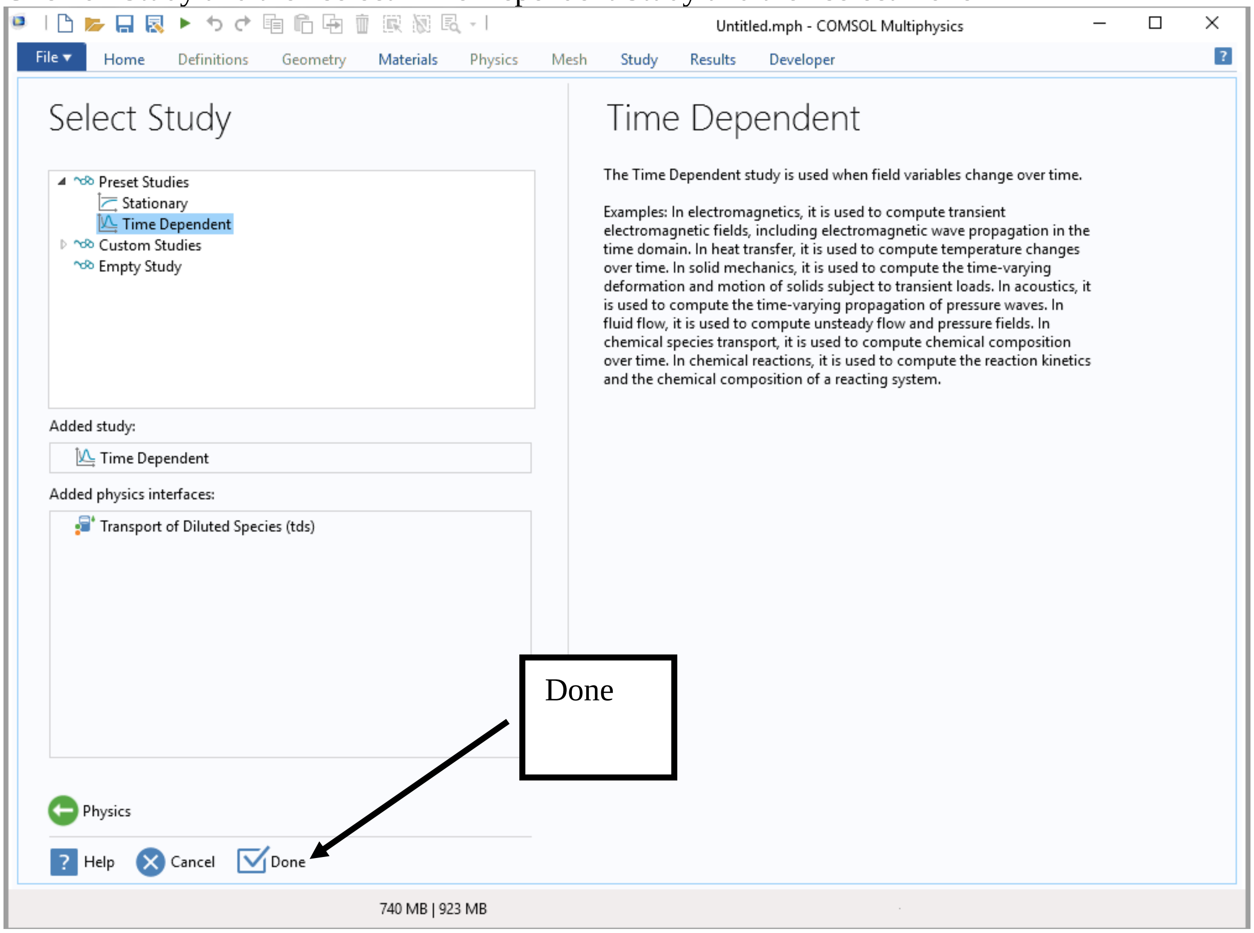

Select 1D



Next Select: Chemical Species Transport, Tranport of Diluted Species and press Add.

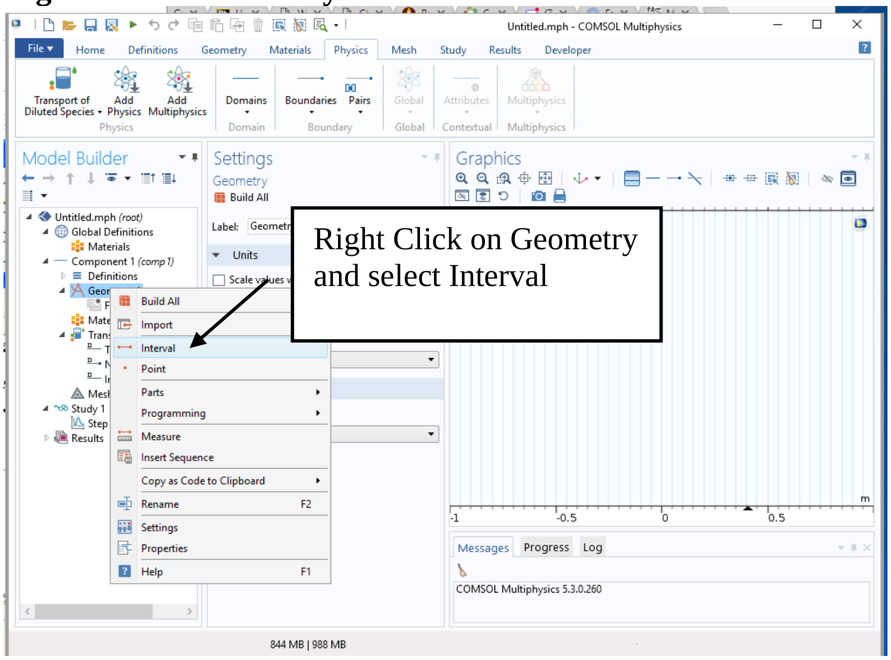


Click on Study and then select Time Dependent Study and then select Done

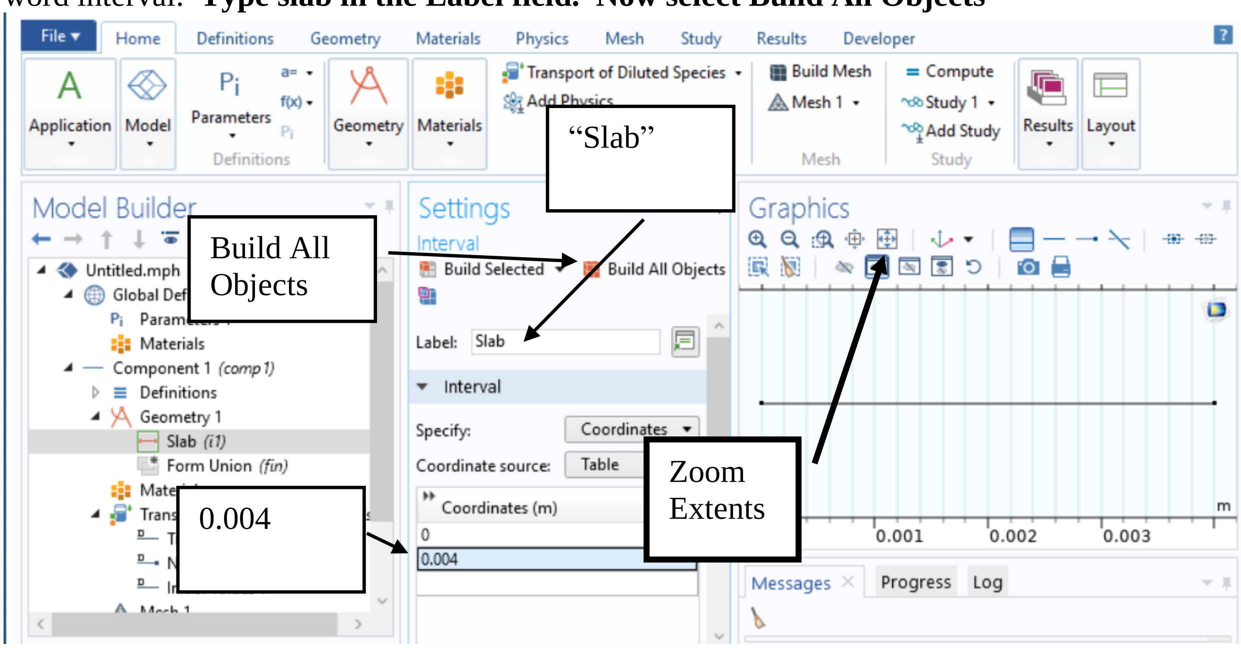


Geometry Modeling

**Right click on Geometry and select Interval**

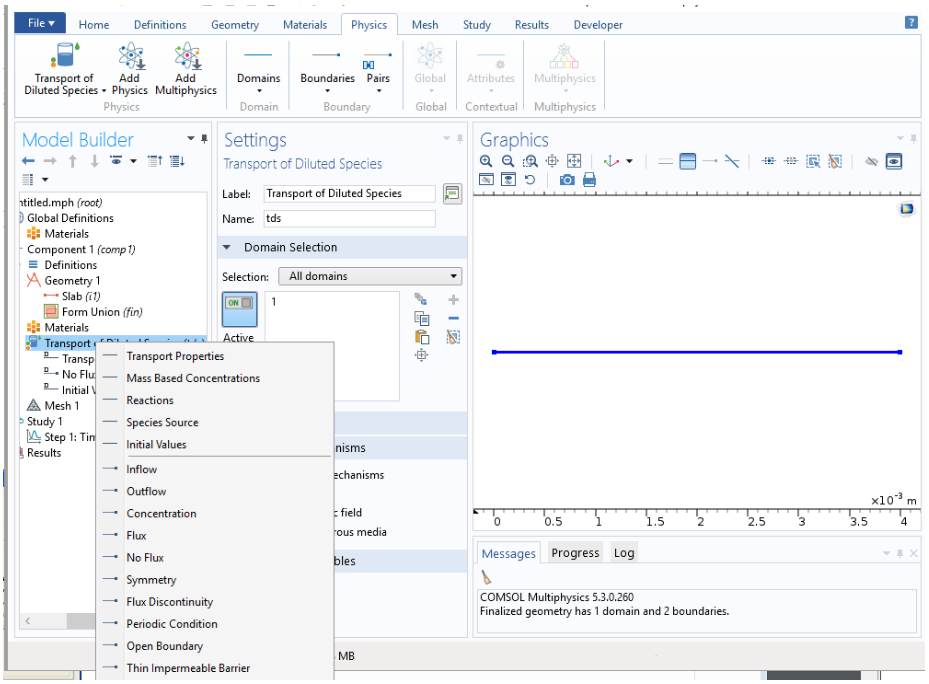



Specify 0 and 0.004 as **Coordinates of the line segment an**d type over the word slab over the word interval. **Type slab in the Label field. Now select Build All Objects**




Boundary Conditions

1. Right click on Transport of Diluted Species and select the Concentration boundary condition. Click on the left end of the interval to select the boundary and then specify the concentration as 4 mol/m$^3$ (Picture shown below)
2. Click on the second boundary point and check that this is the no Flux 1 boundary condition. This shows that the other boundary has no flux or is insulated.


File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
Transport of Diluted Species
Add Physics
Add Multiphysics
Domains
Boundaries
Pairs
Global
Attributes
Multiphysics
Model Builder
Settings
Transport of Diluted Species
Label: Transport of Diluted Species
Name: tds
Domain Selection
Selection: All domains
Active
Graphics
Transport Properties
Mass Based Concentrations
Reactions
Species Source
Initial Values
Inflow
Outflow
Concentration
Flux
No Flux
Symmetry
Flux Discontinuity
Periodic Condition
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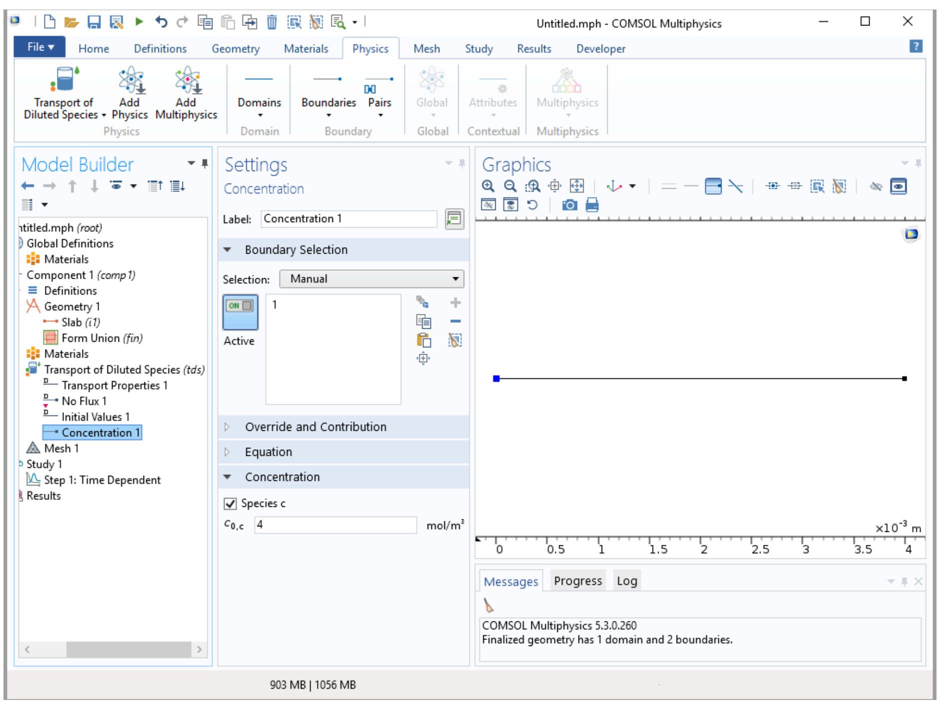
Thin Impermeable Barrier
Messages
Progress
Log
COMSOL Multiphysics 5.3.0.260
Finalized geometry has 1 domain and 2 boundaries.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Study
Results
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Model Builder
Global Definitions
Materials
Component 1 (comp1)
Definitions
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Slab (i1)
Form Union (fin)
Materials
Transport of Diluted Species (tds)
Transport Properties 1
No Flux 1
Initial Values 1
Concentration 1
Mesh 1
Study 1
Step 1: Time Dependent
Results
Settings
Concentration
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COMSOL Multiphysics 5.3.0.260
Finalized geometry has 1 domain and 2 boundaries.
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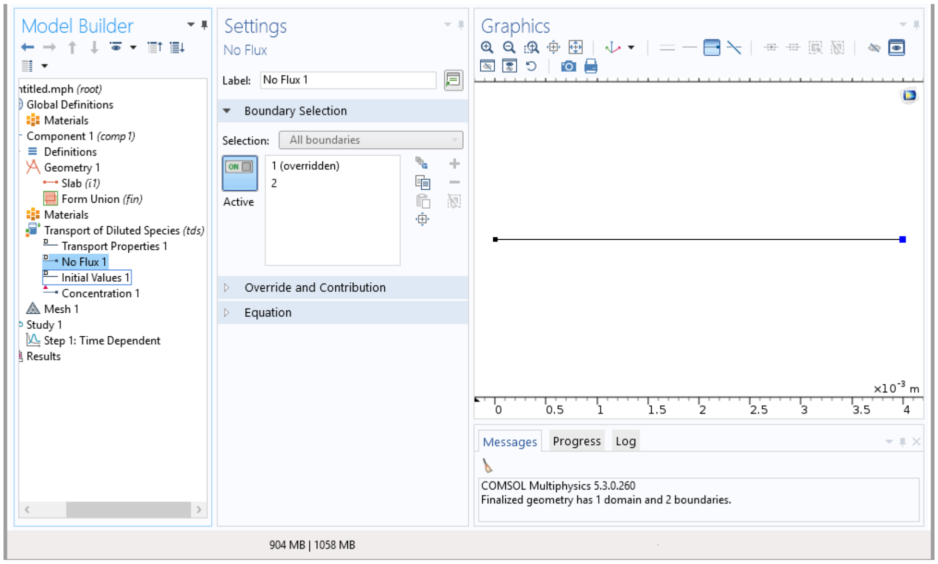
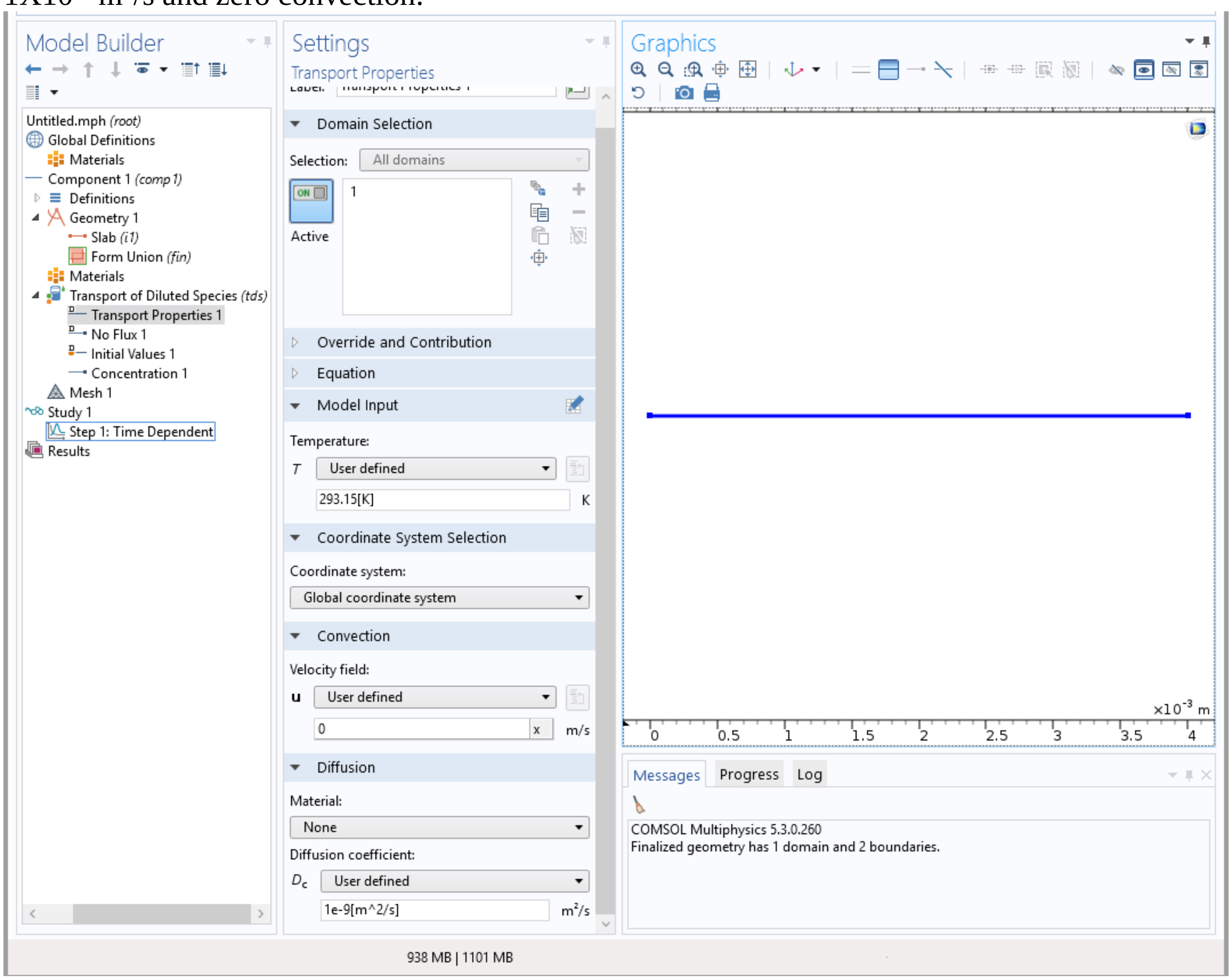
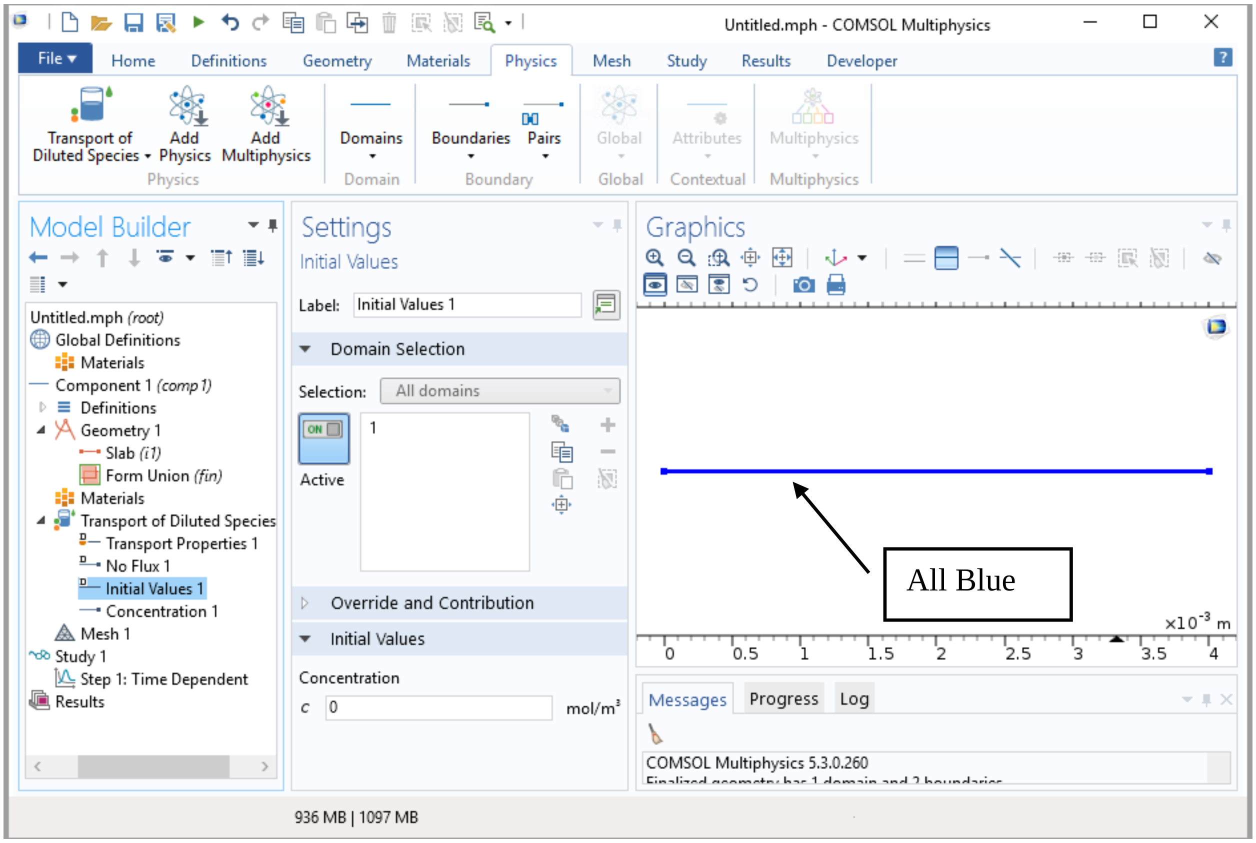


3. Select Transport Properties 1 and use the default values of the Diffusion coefficient of $1X10^{-9}$ $m^2/s$ and zero convection.

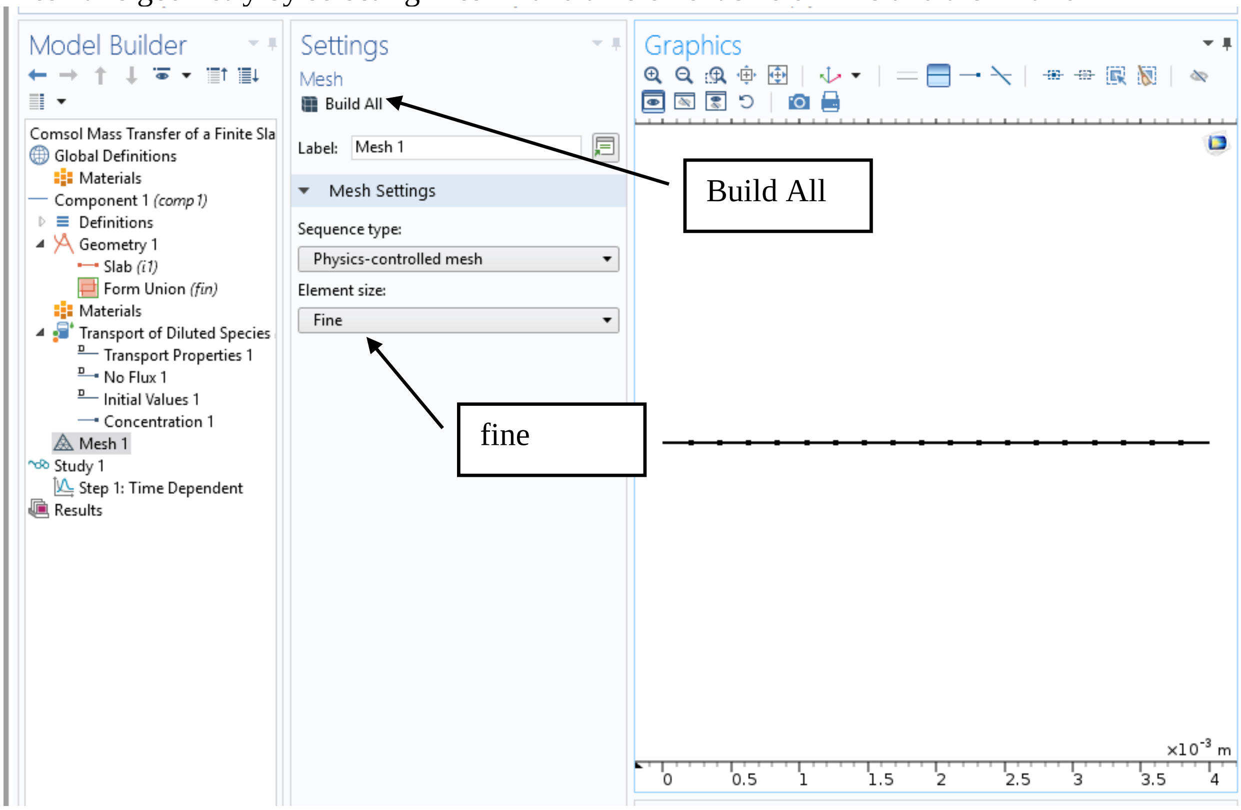


4. Also Click on Initial Values 1 to see that they are zero concentration for the entire interval. The line is now blue.



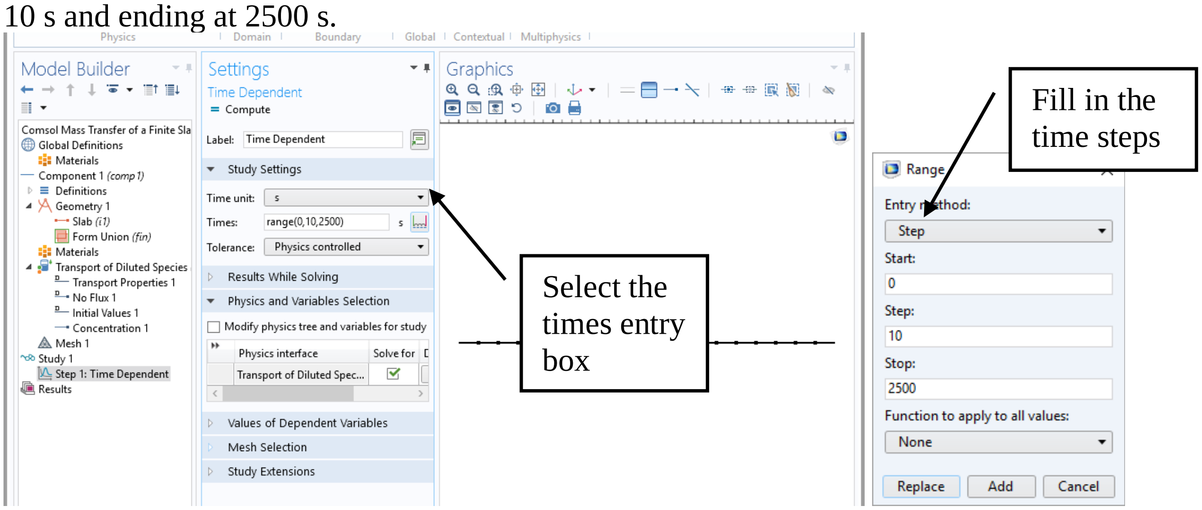

5. Perhaps now is a good time to save your file

6. Mesh this geometry by selecting Mesh 1 and an element size of Fine and then Build All

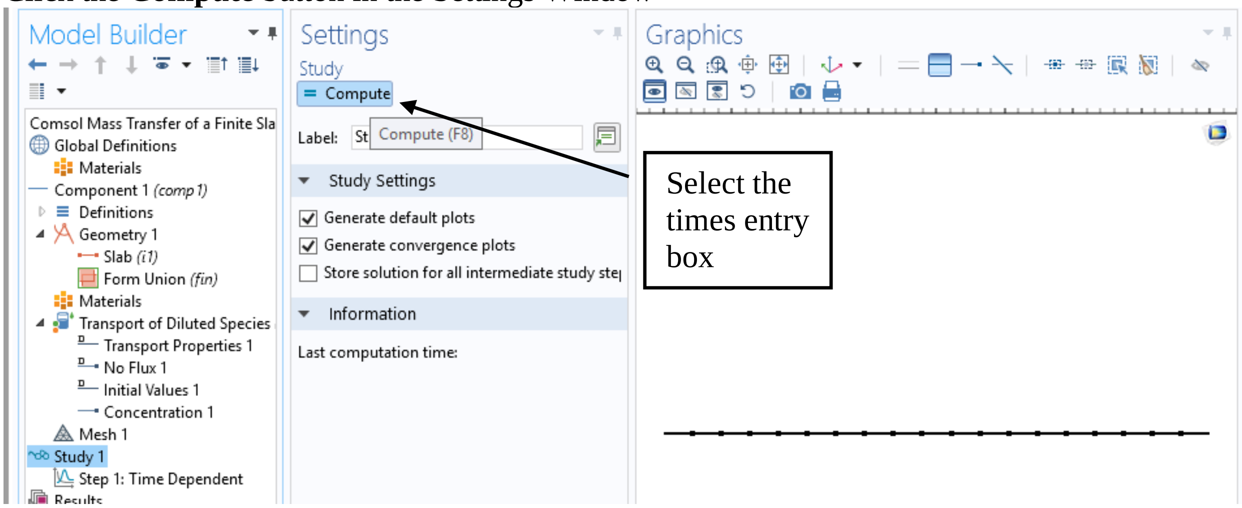



## *Computing the Solution*

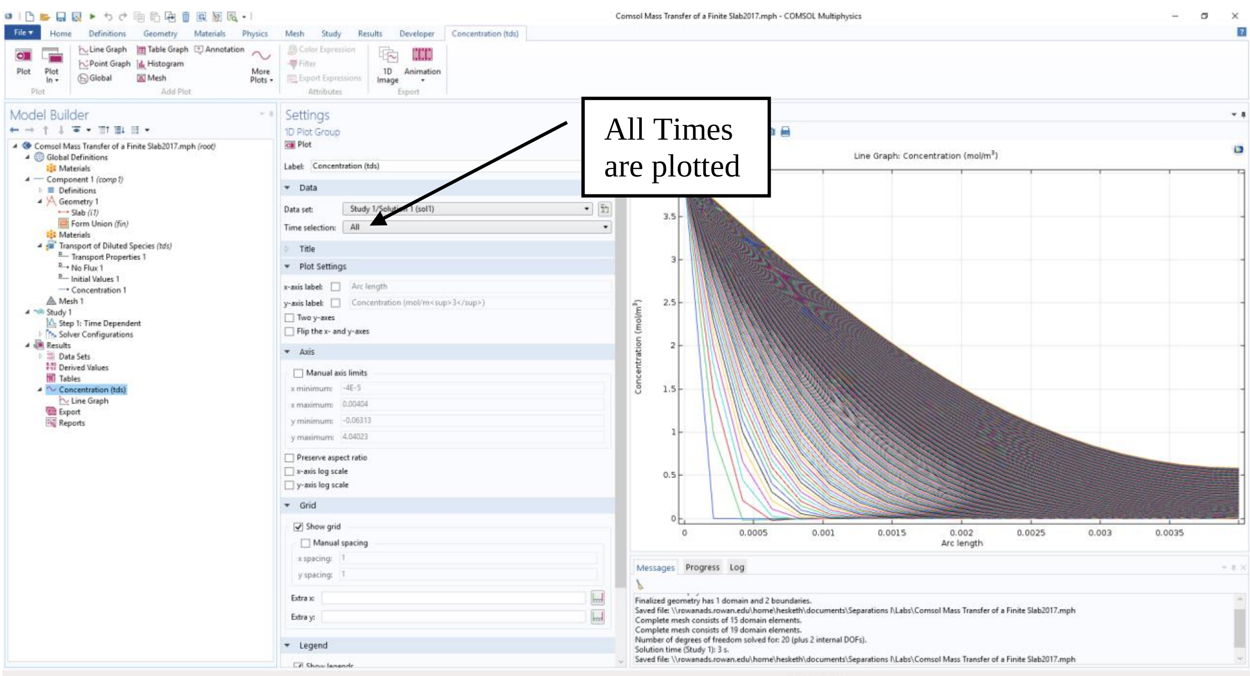
1. Select **Step 1: Time Dependent under** Study 1.
2. Select the times entry box and start at 0 s, Step 10 s and end at 2500 s and then select Replace. or you can type 0:10:2500 directly in the box. This stands for how you would like the output reported. This will report results starting at time t=0, stepping at intervals of 10 s and ending at 2500 s.



3. Click the **Compute** button in the Settings Window




4. WOW it plotted all of the times!




5. Now compare this to a polymath solution: Pull up problem C&S10.13a from Blackboard and change the initial conditions to be zero. You may also want to change the initial concentration of CA0 to 4 mol/m$^3$ instead of kmol/m$^3$. This is not necessary but will aid in making a comparison plot.
6. And then make a plot as shown in the following page of Concentration vs distance at 2500s. So for this plot you only need the final concentrations at t=2500s. Don't use Markers for simulated data!!

**POLYMATH Report** 10.13 modified Unsteady-state Mass Transfer in a Slab (zero initial concentration)

Ordinary Differential Equations

## Calculated values of DEQ variables

| | Variable | Initial value | Minimal value | Maximal value | Final value |
|---|---|---|---|---|---|
| 1 | t | 0 | 0 | 2500. | 2500. |
| 2 | CA2 | 0 | 0 | 0.0032935 | 0.0032935 |
| 3 | CA3 | 0 | 0 | 0.0026235 | 0.0026235 |
| 4 | CA4 | 0 | 0 | 0.0020219 | 0.0020219 |
| 5 | CA5 | 0 | 0 | 0.0015126 | 0.0015126 |
| 6 | CA6 | 0 | 0 | 0.0011105 | 0.0011105 |
| 7 | CA7 | 0 | 0 | 0.0008223 | 0.0008223 |
| 8 | CA8 | 0 | 0 | 0.0006498 | 0.0006498 |
| 9 | DAB | 1.0E-09 | 1.0E-09 | 1.0E-09 | 1.0E-09 |
| 10 | deltax | 0.0005 | 0.0005 | 0.0005 | 0.0005 |
| 11 | CA9 | 0 | -8.627E-07 | 0.0005922 | 0.0005922 |
| 12 | CA0 | 0.006 | 0.006 | 0.006 | 0.006 |
| 13 | K | 1.5 | 1.5 | 1.5 | 1.5 |
| 14 | CA1 | 0 | 0 | 0.004 | 0.004 |

## Differential equations

1 d(CA2)/d(t) = DAB * (CA3 - 2 * CA2 + CA1) / deltax ^ 2

2 d(CA3)/d(t) = DAB * (CA4 - 2 * CA3 + CA2) / deltax ^ 2

3 d(CA4)/d(t) = DAB * (CA5 - 2 * CA4 + CA3) / deltax ^ 2

4 d(CA5)/d(t) = DAB * (CA6 - 2 * CA5 + CA4) / deltax ^ 2

5 d(CA6)/d(t) = DAB * (CA7 - 2 * CA6 + CA5) / deltax ^ 2

6 d(CA7)/d(t) = DAB * (CA8 - 2 * CA7 + CA6) / deltax ^ 2

7 d(CA8)/d(t) = DAB * (CA9 - 2 * CA8 + CA7) / deltax ^ 2

## Explicit equations

1 DAB = 1.0e-9

2 deltax = 0.0005

3 CA9 = If (t == 0) Then (0) Else ((4 * CA8 - CA7) / 3)

4 CA0 = 6.0e-3

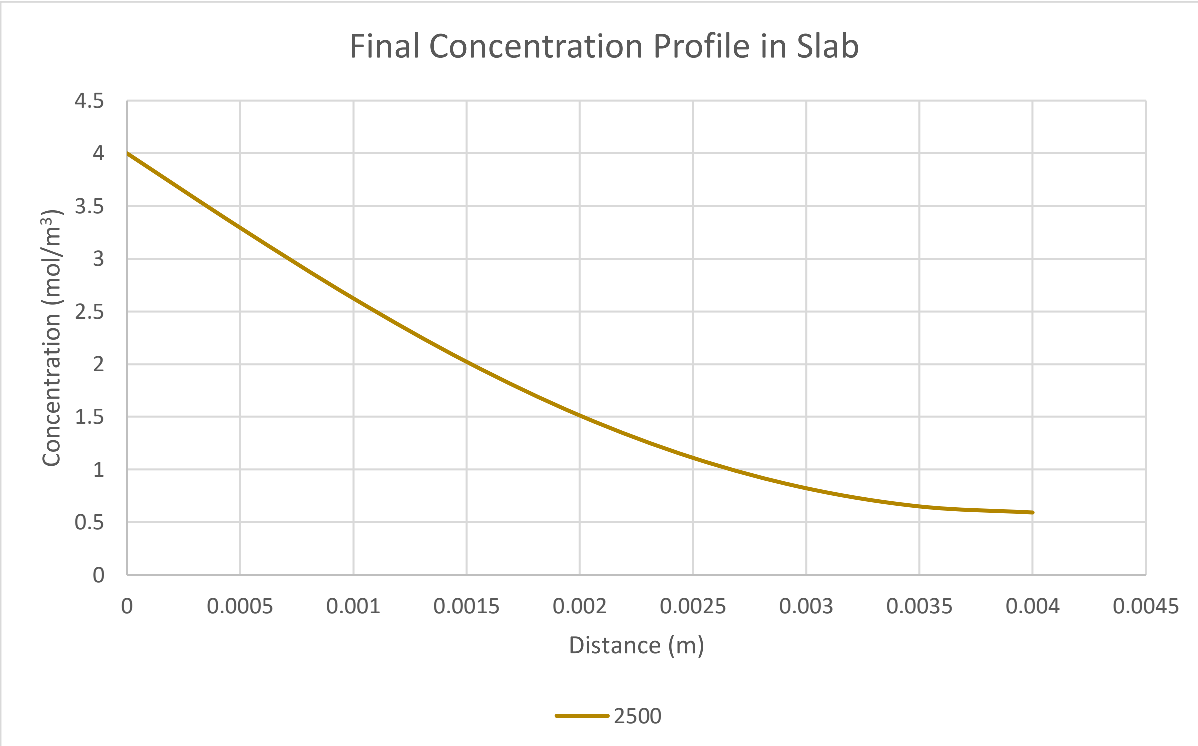
5 K = 1.5

6 CA1 = If (t == 0) Then (0) Else (CA0 / K)

## General

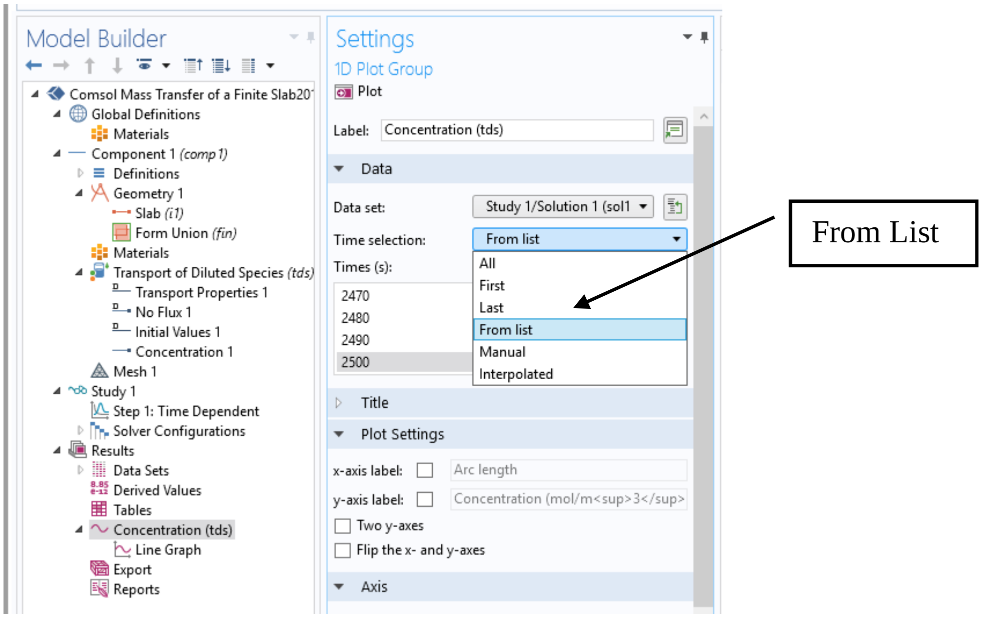
| | |
|---|---|
| Total number of equations | 13 |
| Number of differential equations | 7 |
| Number of explicit equations | 6 |
| Elapsed time | 0.000 sec |
| Solution method | RKF_45 |
| Step size guess. h | 0.000001 |
| Truncation error tolerance. eps | 0.000001 |

***Save your polymath solution in a word document to be submitted at the end of the tutorial.***

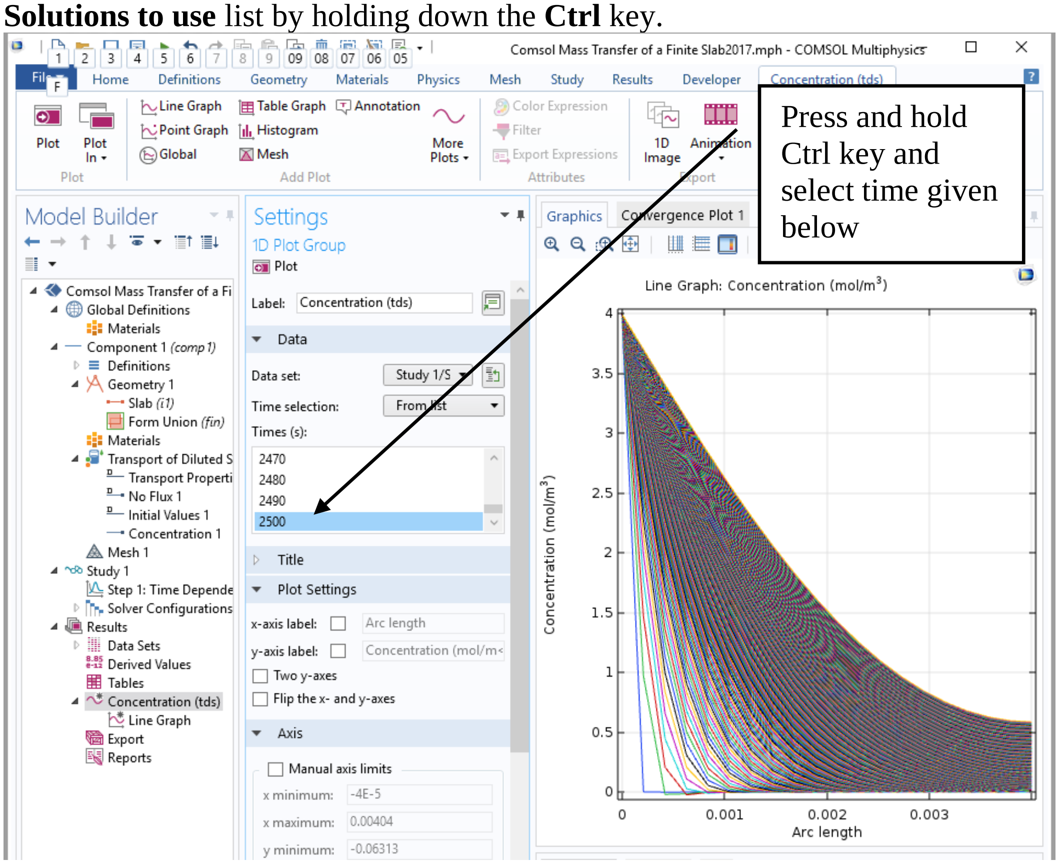


## *Post Mode*

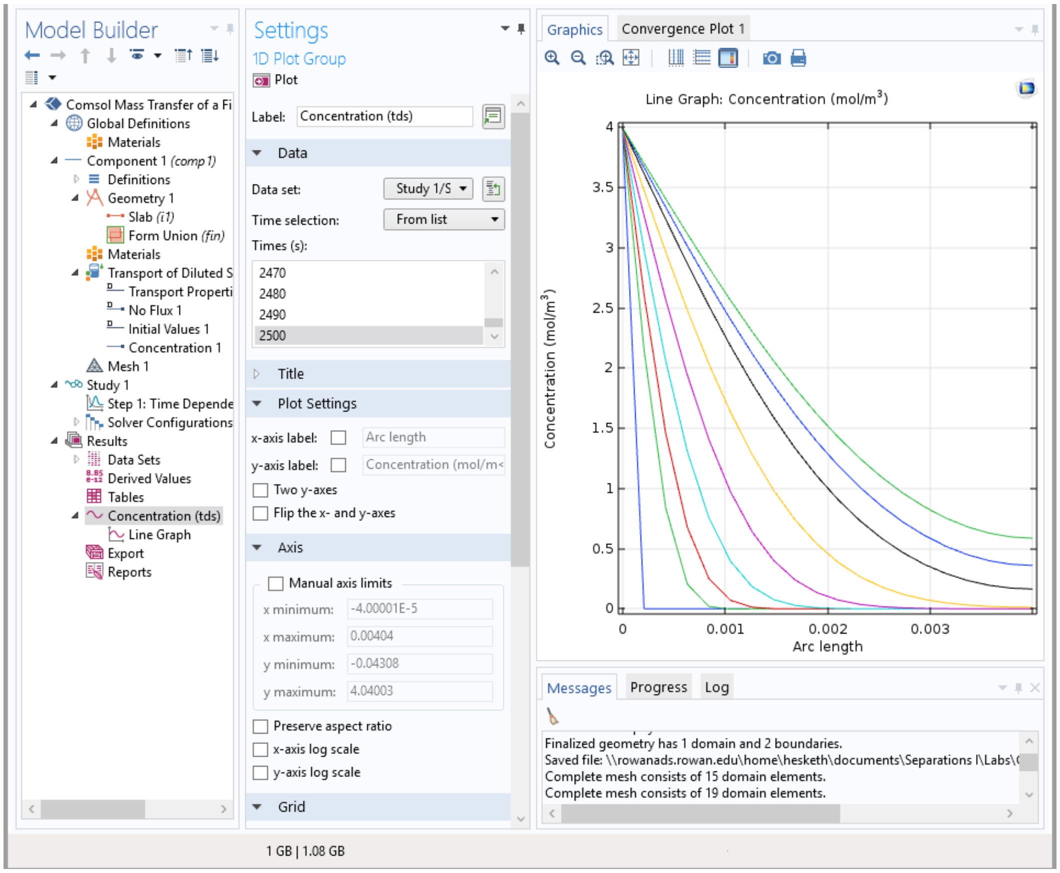
1. Select the Concentration Plot and then in the Time Selection choose **From list**.



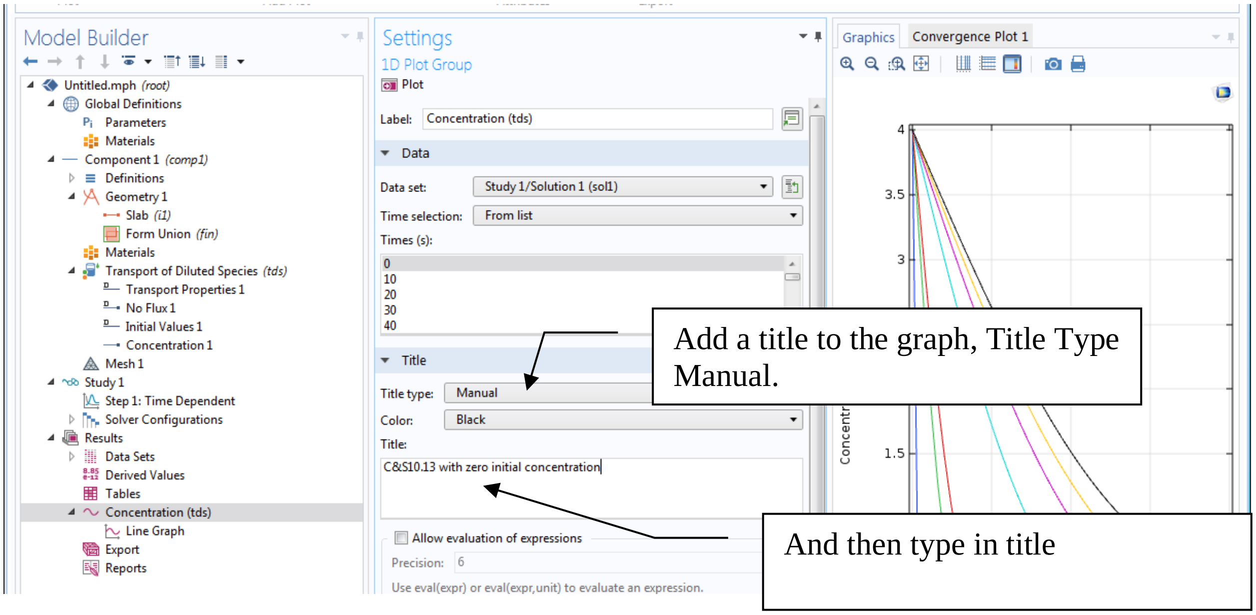

2. Select the following time-steps, 0, 50, 100, 200, 400, 800, 1500, 2000, 2500 from the **Solutions to use** list by holding down the **Ctrl** key.



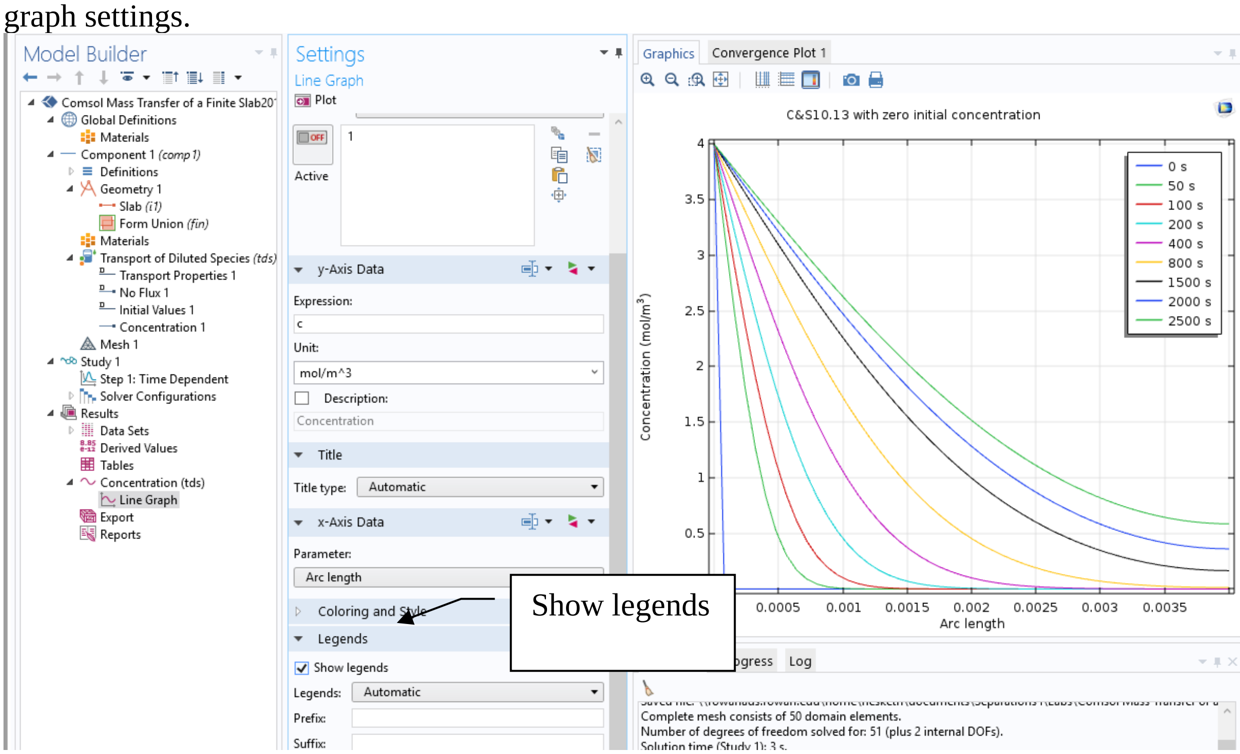
3. Click **on the plot button**.




4. Notice the kinks in the green, red and blue lines. Go back and create a finer mesh and resolve the problem. (but not too fine or you will have too many points in your graph you will make later!
5. Add a title to the graph by pressing the Title/Axis button: C&S10.13 with zero initial concentration.

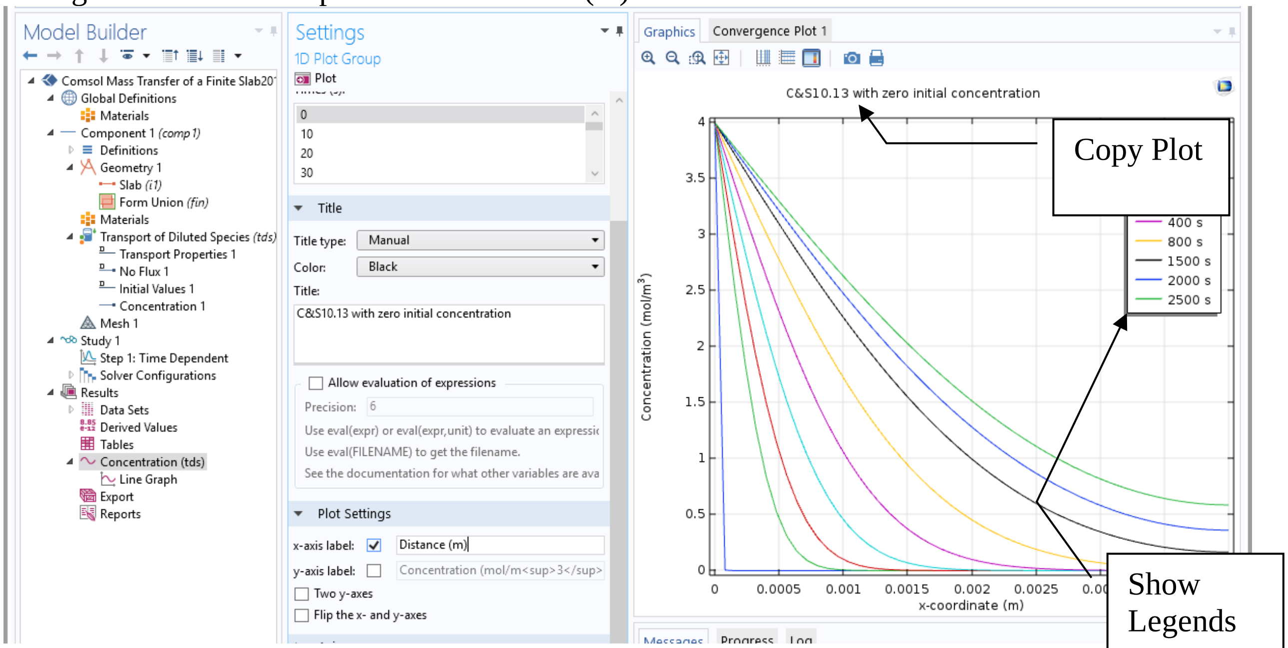



6. Select Line Graph, and then Legends to give a legend by choosing Show legends in the line graph settings.




7. You should now have a plot with a title as shown above.

8. Change the x-axis description of this plot by selecting the painters pad to edit the plot. Change the x-axis description to be Distance (m).




9. Paste a copy of this plot into your word document by using the copy button. (See the location of this button in the figure on above.)

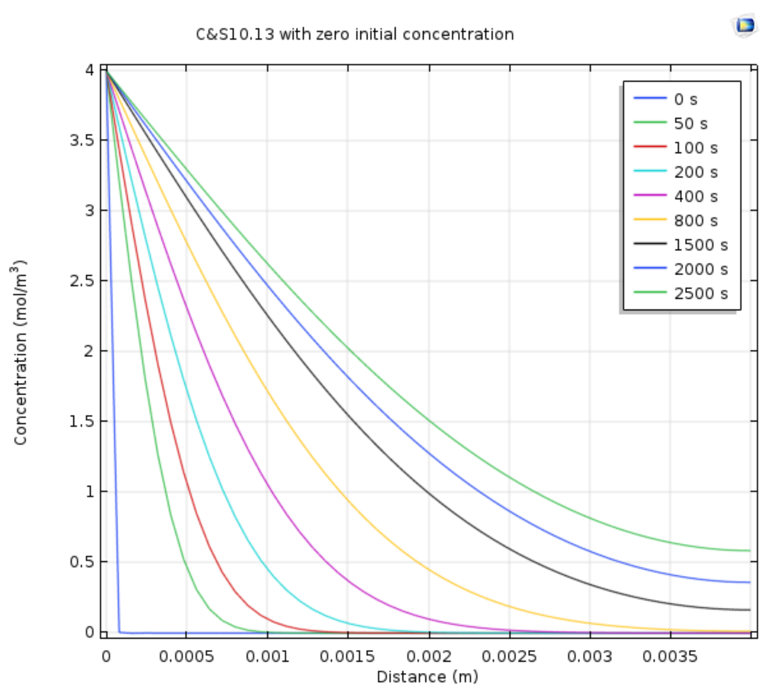
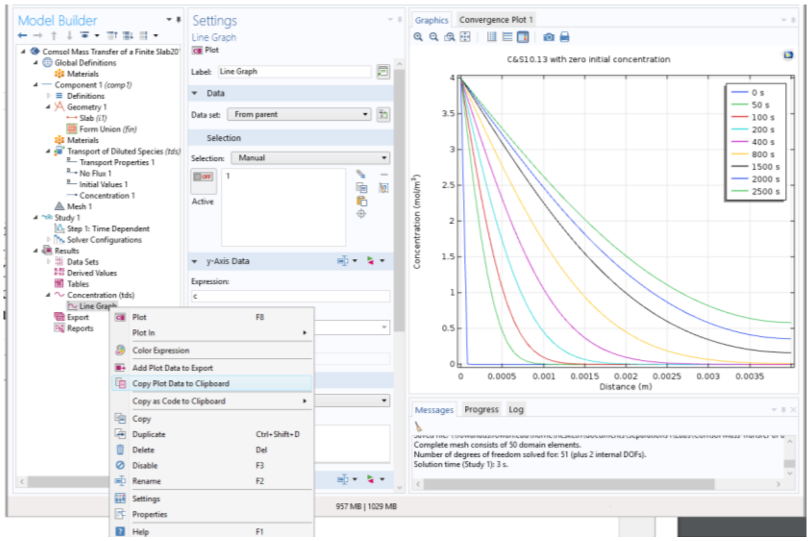


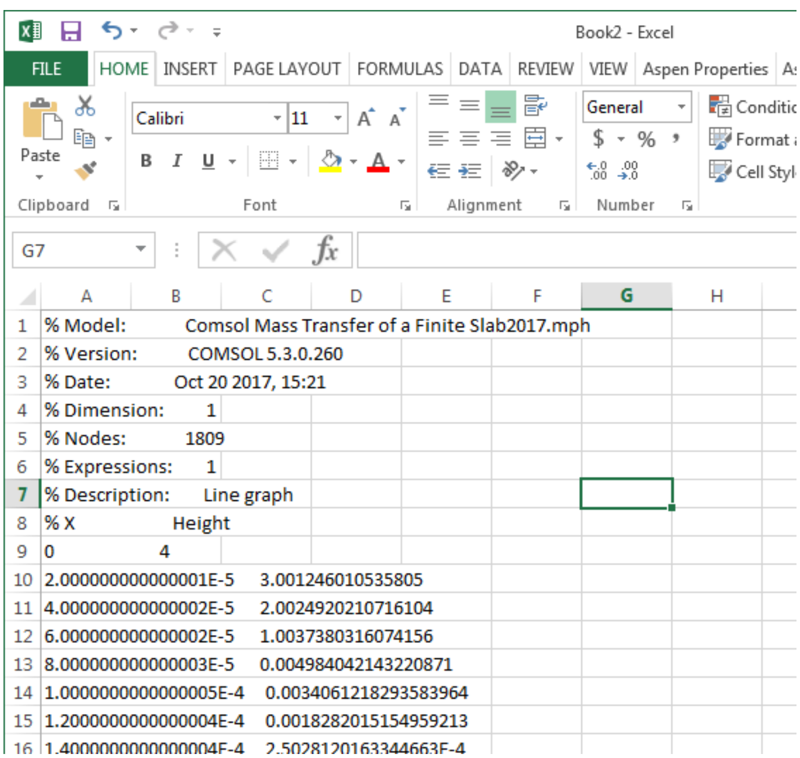

**Figure 1: Problem C&S10.13 with initial concentrations of zero**

10. You will now compare this plot to a plot of the polymath output. You will first make the Polymath plot and then copy this and make an additional plot in excel comparing the two

solutions. In this figure you will plot data from Polymath and Comsol on the same figure. To do this follow the instructions given below.

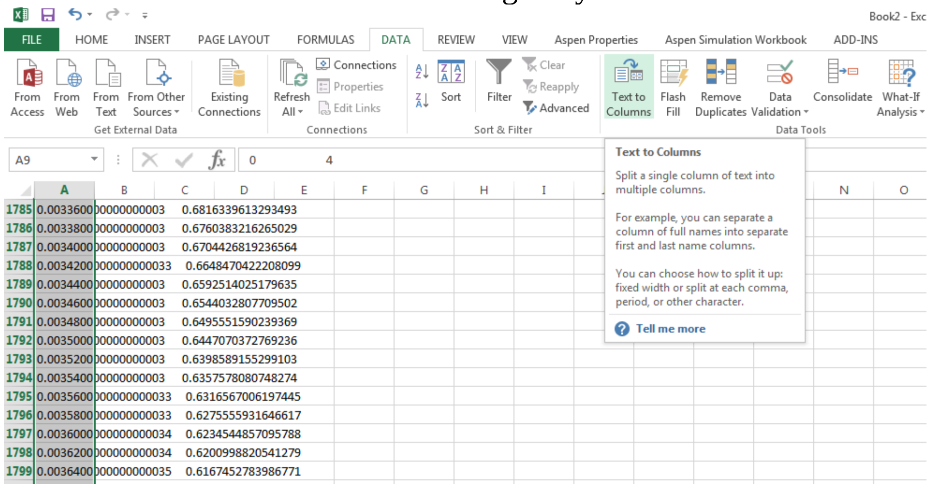
11. ***Exporting the Current COMSOL Plot to your excel File***
    There are several methods to export the data to excel by either copying to the windows clipboard or a text file that can be imported into a spreadsheet. I recommend using the copy data to the clip board. Paste this into your spreadsheet with your POLYMATH plot.



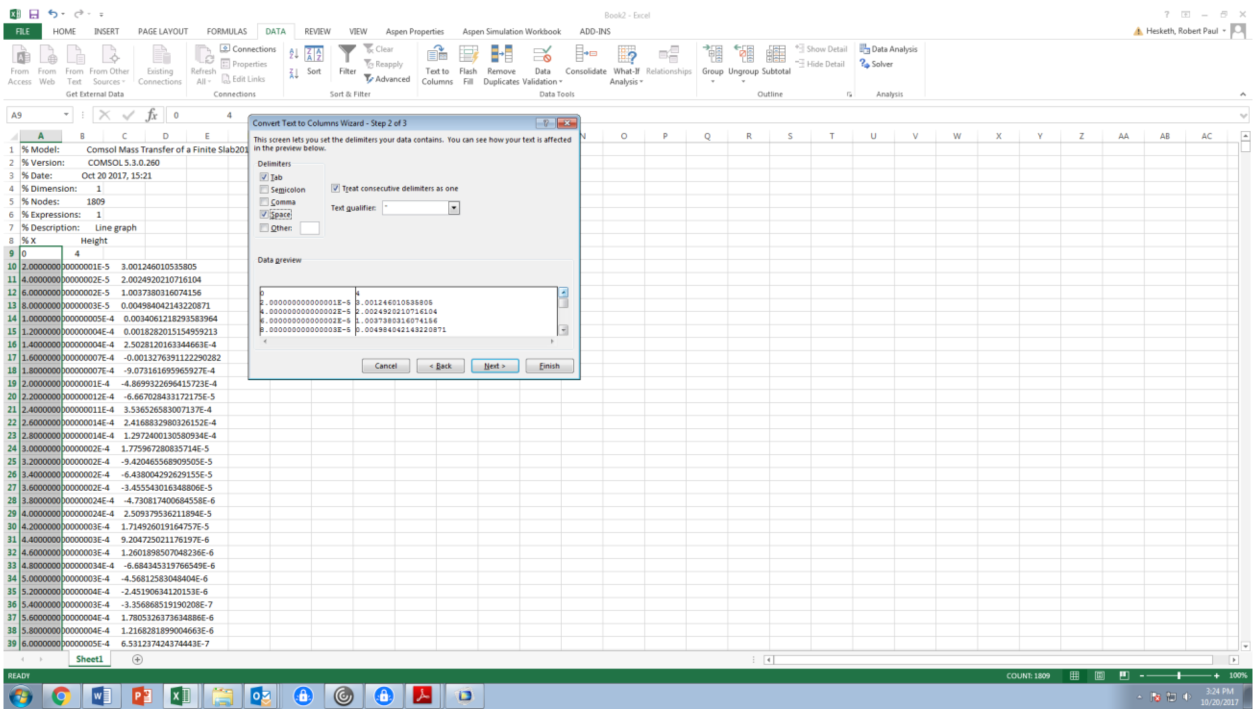




| | A | B | C |
|---|---|---|---|
| 1 | % Model: | Comsol Mass Transfer of a Finite Slab2017.mph | |
| 2 | % Version: | COMSOL 5.3.0.260 | |
| 3 | % Date: | Oct 20 2017, 15:21 | |
| 4 | % Dimension: | 1 | |
| 5 | % Nodes: | 1809 | |
| 6 | % Expressions: | 1 | |
| 7 | % Description: | Line graph | |
| 8 | % X | Height | |
| 9 | 0 | 4 | |
| 10 | 2.000000000000001E-5 | | 3.001246010535805 |
| 11 | 4.000000000000002E-5 | | 2.0024920210716104 |
| 12 | 6.000000000000002E-5 | | 1.0037380316074156 |
| 13 | 8.000000000000003E-5 | | 0.004984042143220871 |
| 14 | 1.0000000000000005E-4 | | 0.0034061218293583964 |
| 15 | 1.2000000000000004E-4 | | 0.0018282015154959213 |
| 16 | 1.4000000000000004E-4 | | 2.5028120163344663E-4 |

12. Select your column of data in Column A.  Next a go to your data tab and choose Text to Columns.

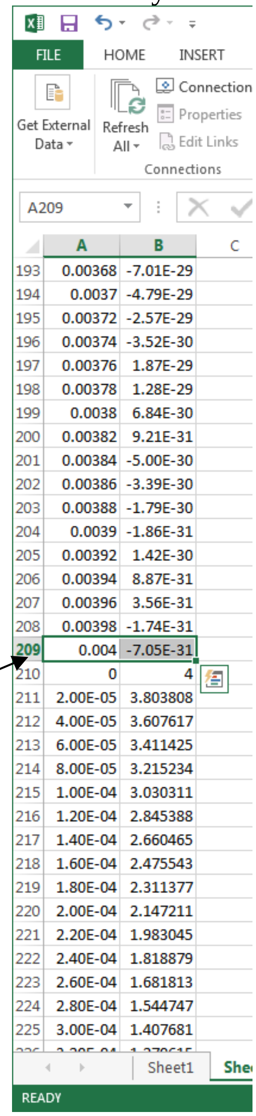


13. Now select appropriate options to separate the data in to the first column containing the position and the second column containing the concentration.



14. You will now have sets of data corresponding to the times given in your legend.  The first set of data will be at time zero followed by 50, 100, 200, 400, 800, 1500, 2000 and 2500s.  The

problem is that all of the data is in these 2 columns! To locate each set you could search for

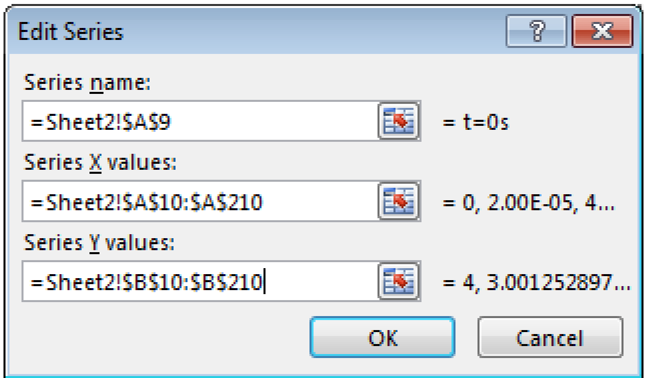


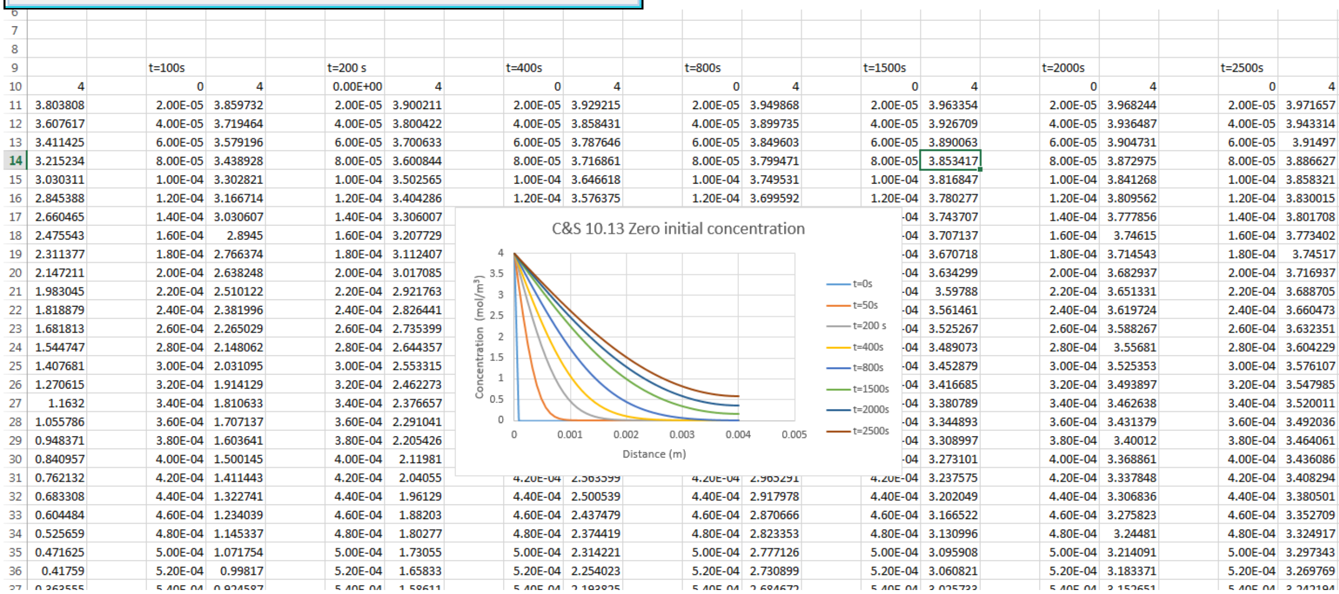

Depending on high fine your meshing is will determine how many data points you have for the first time step.

0.004 that will appear as the last data point of each data set.

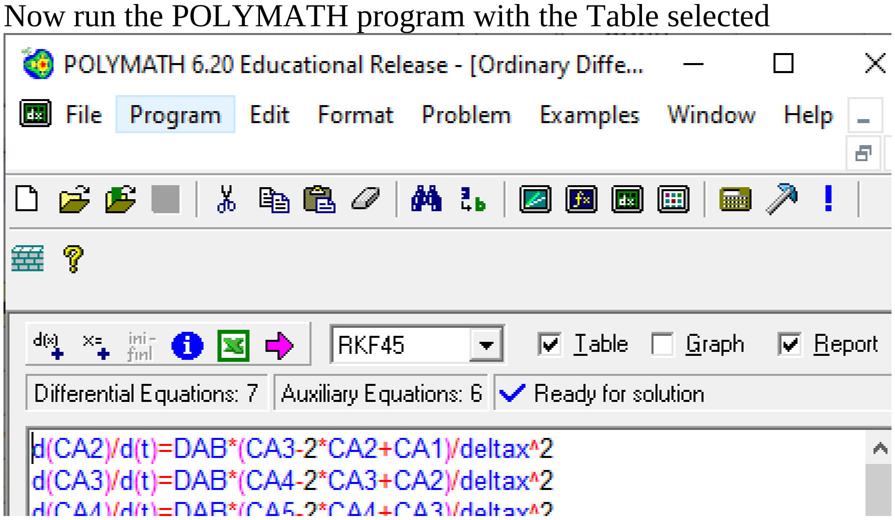
15. Its now that you wish that you didn't make the mesh so fine! I use the End key and the arrow buttons to quickly navigate through excel.

16. Now make the same plot as Figure 1 using excel. (In excel add a scatter plot and bring in each set of data. Remember to use the End key and arrow to avoid scrolling for long times!)

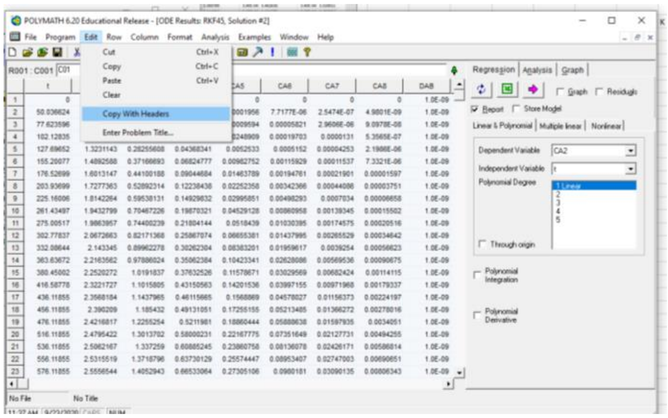


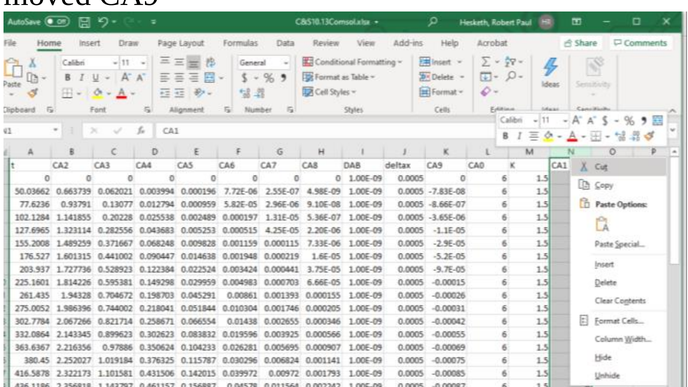

17. Now run the POLYMATH program with the Table selected

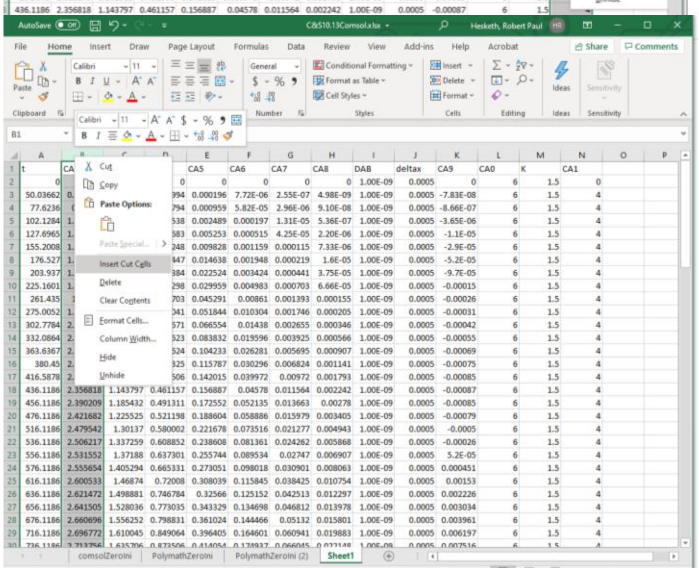


18. Copy the data using Edit, Copy with Headers



19. Now transform your Polymath output to match what is given in comsol. In other words make a plot of concentration as a function of distance at various times. First put all the concentrations in order( CA1, CA2 etc). To do this select the entire column and Cut and then click on the column letter and insert Cut Cells. I had to move CA1 before CA2. Then I moved CA9



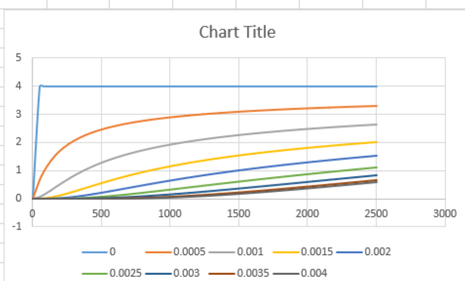


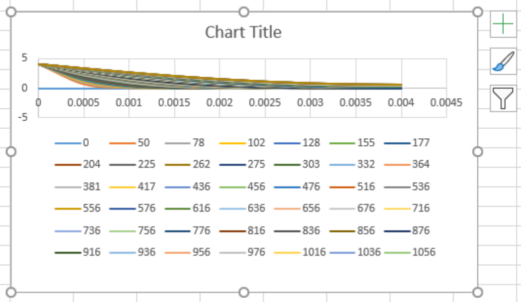
| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | t | CA1 | CA2 | CA3 | CA4 | CA5 | CA6 | CA7 | CA8 | CA9 | DAB |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.00E-09 |
| 3 | 50.03662 | 4 | 0.663739 | 0.062021 | 0.003994 | 0.000196 | 7.72E-06 | 2.55E-07 | 4.98E-09 | -7.83E-08 | 1.00E-09 |
| 4 | 77.6236 | 4 | 0.93791 | 0.13077 | 0.012794 | 0.000959 | 5.82E-05 | 2.96E-06 | 9.10E-08 | -8.66E-07 | 1.00E-09 |
| 5 | 102.1284 | 4 | 1.141855 | 0.20228 | 0.025538 | 0.002489 | 0.000197 | 1.31E-05 | 5.36E-07 | -3.65E-06 | 1.00E-09 |
| 6 | 127.6965 | 4 | 1.323114 | 0.282556 | 0.043683 | 0.005253 | 0.000515 | 4.25E-05 | 2.20E-06 | -1.1E-05 | 1.00E-09 |
| 7 | 155.2008 | 4 | 1.489259 | 0.371667 | 0.068248 | 0.009828 | 0.001159 | 0.000115 | 7.33E-06 | -2.9E-05 | 1.00E-09 |
| 8 | 176.527 | 4 | 1.601315 | 0.441002 | 0.090447 | 0.014638 | 0.001948 | 0.000219 | 1.6E-05 | -5.2E-05 | 1.00E-09 |
| 9 | 203.937 | 4 | 1.727736 | 0.528923 | 0.122384 | 0.022524 | 0.003424 | 0.000441 | 3.75E-05 | -9.7E-05 | 1.00E-09 |
| 10 | 225.1601 | 4 | 1.814226 | 0.595381 | 0.149298 | 0.029959 | 0.004983 | 0.000703 | 6.66E-05 | -0.00015 | 1.00E-09 |

20. Next add a row that gives distances since these are hidden in the use of the lines for CA1, CA2 etc.

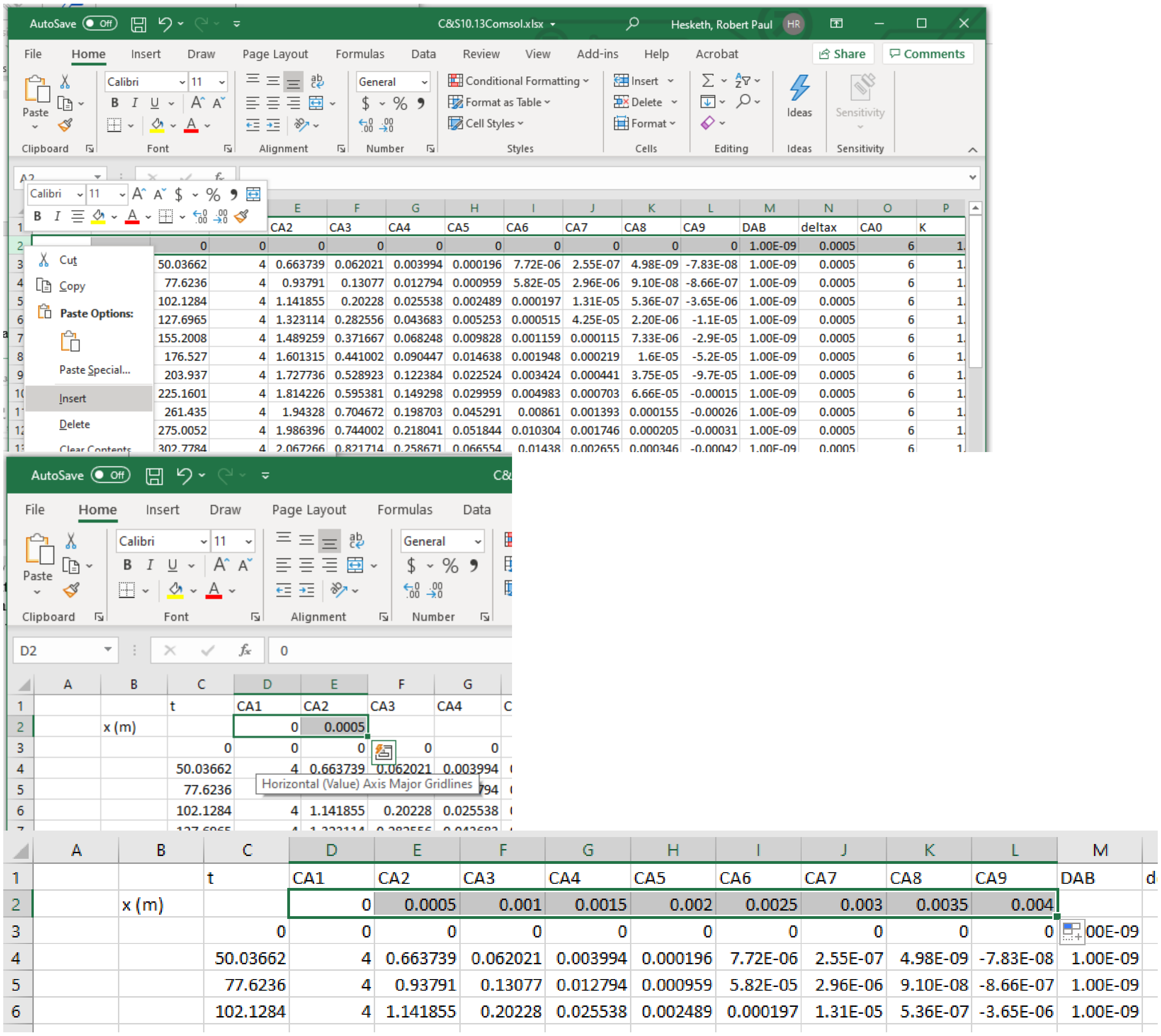
| R | S | T | U | V | W | X | Y | Z | AA |
|---|---|---|---|---|---|---|---|---|---|
| t | | 0 | 50 | 78 | 102 | 128 | 155 | 177 | 204 |
| CA1 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| CA2 | 0.0005 | 0 | 0.664082 | 0.938295 | 1.142203 | 1.323461 | 1.489654 | 1.601753 | 1.72822 |
| CA3 | 0.001 | 0 | 0.062089 | 0.130887 | 0.202418 | 0.282726 | 0.371898 | 0.441289 | 0.52928 |
| CA4 | 0.0015 | 0 | 0.004001 | 0.012812 | 0.025566 | 0.043726 | 0.068317 | 0.090544 | 0.122523 |
| CA5 | 0.002 | 0 | 0.000196 | 0.000961 | 0.002493 | 0.00526 | 0.009842 | 0.01466 | 0.02256 |
| CA6 | 0.0025 | 0 | 7.74E-06 | 5.84E-05 | 0.000197 | 0.000516 | 0.001162 | 0.001952 | 0.003431 |
| CA7 | 0.003 | 0 | 2.56E-07 | 2.97E-06 | 1.31E-05 | 4.26E-05 | 0.000116 | 0.00022 | 0.000442 |
| CA8 | 0.0035 | 0 | 5.00E-09 | 9.13E-08 | 5.37E-07 | 2.20E-06 | 7.35E-06 | 1.60E-05 | 3.76E-05 |
| CA9 | 0.004 | 0 | -7.86E-08 | -8.68E-07 | -3.66E-06 | -1.13E-05 | -2.87E-05 | -5.18E-05 | -9.72E-05 |

| R | AB | AC | AD | AE | AF | AG | AH | AI | AJ |
|---|---|---|---|---|---|---|---|---|---|
| t | 225 | 262 | 275 | 303 | 332 | 364 | 381 | 417 | 4 |
| CA1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |
| CA2 | 1.814706 | 1.943759 | 1.986877 | 2.067713 | 2.143771 | 2.216767 | 2.252433 | 2.322571 | 2.3572 |
| CA3 | 0.595765 | 0.705102 | 0.744449 | 0.822158 | 0.900072 | 0.979319 | 1.019648 | 1.10206 | 1.1442 |
| CA4 | 0.149461 | 0.19891 | 0.218266 | 0.258912 | 0.302886 | 0.350911 | 0.376627 | 0.431837 | 0.4615 |
| CA5 | 0.030005 | 0.04536 | 0.051922 | 0.066645 | 0.083939 | 0.10436 | 0.115925 | 0.142179 | 0.1570 |
| CA6 | 0.004993 | 0.008627 | 0.010325 | 0.014406 | 0.01963 | 0.026324 | 0.030345 | 0.040034 | 0.0458 |
| CA7 | 0.000705 | 0.001397 | 0.00175 | 0.002661 | 0.003934 | 0.005707 | 0.006838 | 0.009739 | 0.0115 |
| CA8 | 6.68E-05 | 0.000156 | 0.000206 | 0.000347 | 0.000568 | 0.000909 | 0.001144 | 0.001798 | 0.0022 |
| CA9 | -0.00015 | -0.00026 | -0.00031 | -0.00042 | -0.00055 | -0.00069 | -0.00075 | -0.00085 | -0.000 |



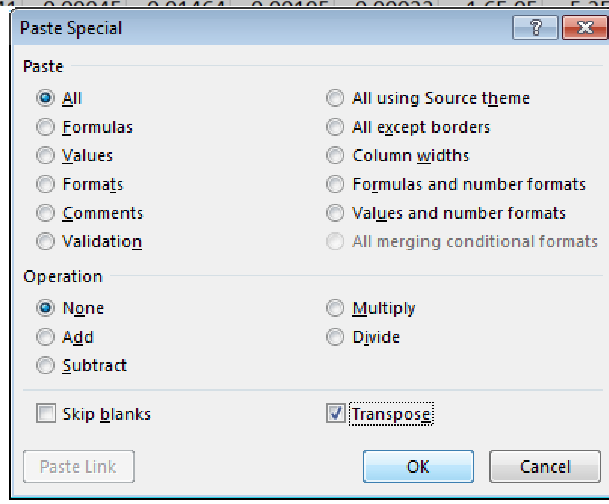
21. Next add a row for the distance. I inserted two columns and then a new row under row 2. In this way I can add a label in cell B3. Next I typed in D2 a zero and in E2 0.0005. Next I selected these two cells and moved my mouse to the solid green square (the cursor turns to a black + sign when it is over the green square) to repeat this series to get values starting at 0 and ending at 0.004m with increment of 0.0005m.



22. Select the data and copy (put mouse on the t, then press and hold Shift and then the down arrow twice (or until you reach the end of the column) and then similarly to get all of the C's.

| B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | t | CA1 | CA2 | CA3 | CA4 | CA5 | CA6 | CA7 | CA8 | CA9 | DAB |
| x (m) | | 0 | 0.0005 | 0.001 | 0.0015 | 0.002 | 0.0025 | 0.003 | 0.0035 | 0.004 | |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.00E-09 |
| | 50.0366 | 4 | 0.66374 | 0.06202 | 0.00399 | 0.0002 | 7.72E-06 | 2.55E-07 | 4.98E-09 | -7.83E-08 | 1.00E-09 |
| | 77.6236 | 4 | 0.93791 | 0.13077 | 0.01279 | 0.00096 | 5.8E-05 | 2.96E-06 | 9.10E-08 | -8.66E-07 | 1.00E-09 |
| | 102.128 | 4 | 1.14186 | 0.20228 | 0.02554 | 0.00249 | 0.0002 | 1.3E-05 | 5.36E-07 | -3.65E-06 | 1.00E-09 |
| | 127.697 | 4 | 1.32311 | 0.28256 | 0.04368 | 0.00525 | 0.00052 | 4.3E-05 | 2.20E-06 | -1.1E-05 | 1.00E-09 |
| | 155.201 | 4 | 1.48926 | 0.37167 | 0.06825 | 0.00983 | 0.00116 | 0.00012 | 7.33E-06 | -2.9E-05 | 1.00E-09 |

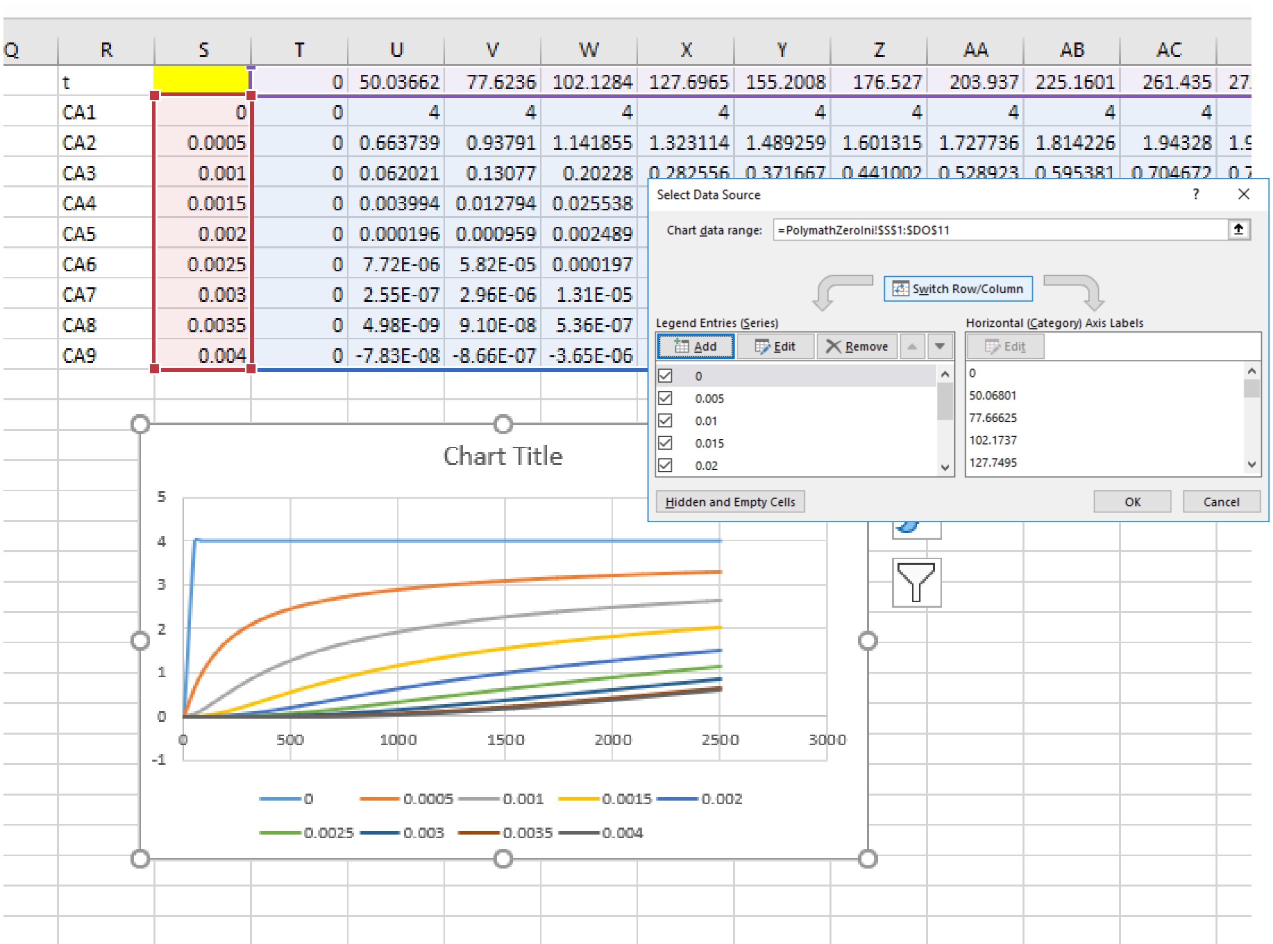
23. Then Paste Special, Transpose

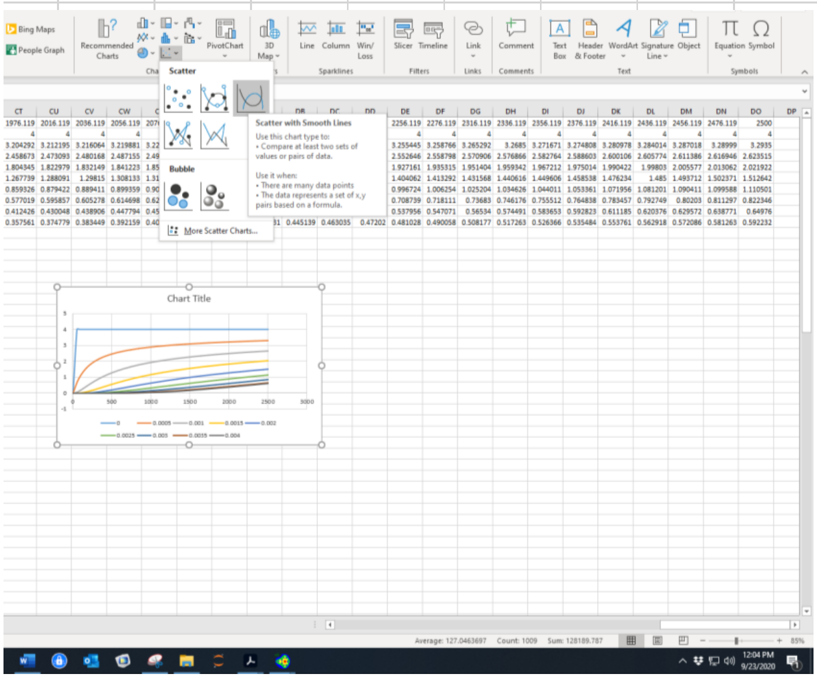


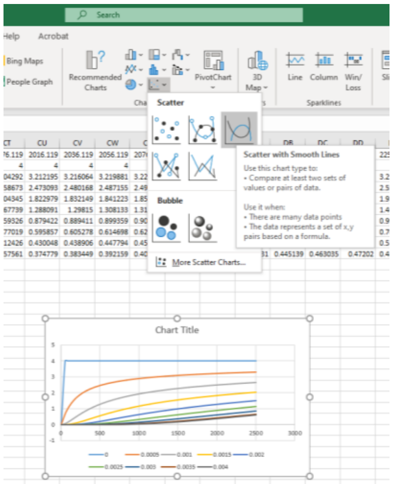

The result of the Transpose is that column S (In the image below) contains the distance entries. Row 1 contains the time entries. And the rest are concentrations in mol/$m^3$

| R | S | T | U | V | W | X |
|---|---|---|---|---|---|---|
| t | | 0 | 50.03662 | 77.6236 | 102.1284 | 127.69 |
| CA1 | 0 | 0 | 4 | 4 | 4 | |
| CA2 | 0.0005 | 0 | 0.663739 | 0.93791 | 1.141855 | 1.3231 |
| CA3 | 0.001 | 0 | 0.062021 | 0.13077 | 0.20228 | 0.2825 |
| CA4 | 0.0015 | 0 | 0.003994 | 0.012794 | 0.025538 | 0.0436 |
| CA5 | 0.002 | 0 | 0.000196 | 0.000959 | 0.002489 | 0.0052 |
| CA6 | 0.0025 | 0 | 7.72E-06 | 5.82E-05 | 0.000197 | 0.0005 |
| CA7 | 0.003 | 0 | 2.55E-07 | 2.96E-06 | 1.31E-05 | 4.25E- |
| CA8 | 0.0035 | 0 | 4.98E-09 | 9.10E-08 | 5.36E-07 | 2.20E- |
| CA9 | 0.004 | 0 | -7.83E-08 | -8.66E-07 | -3.65E-06 | -1.1E- |

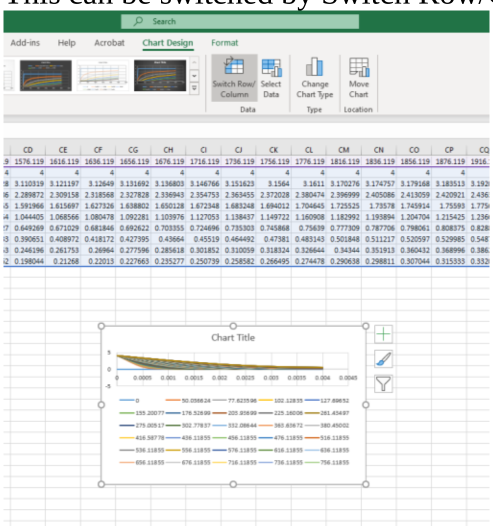
24. Highlighting all the simulation results and time labels (In the above figure it was from S1 to DO10. Then inserting a scatter graph with smoothed lines results in a backward graph with time on the x-axis and distance as the labels.



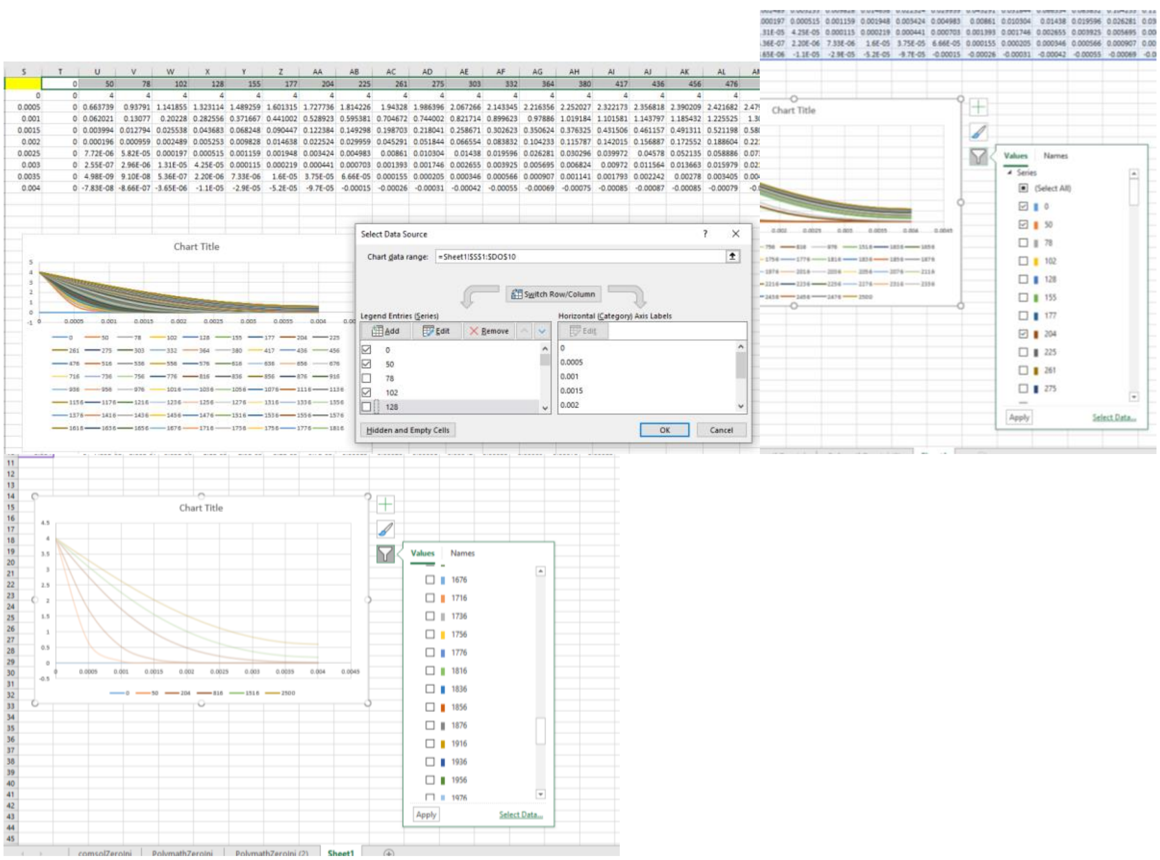





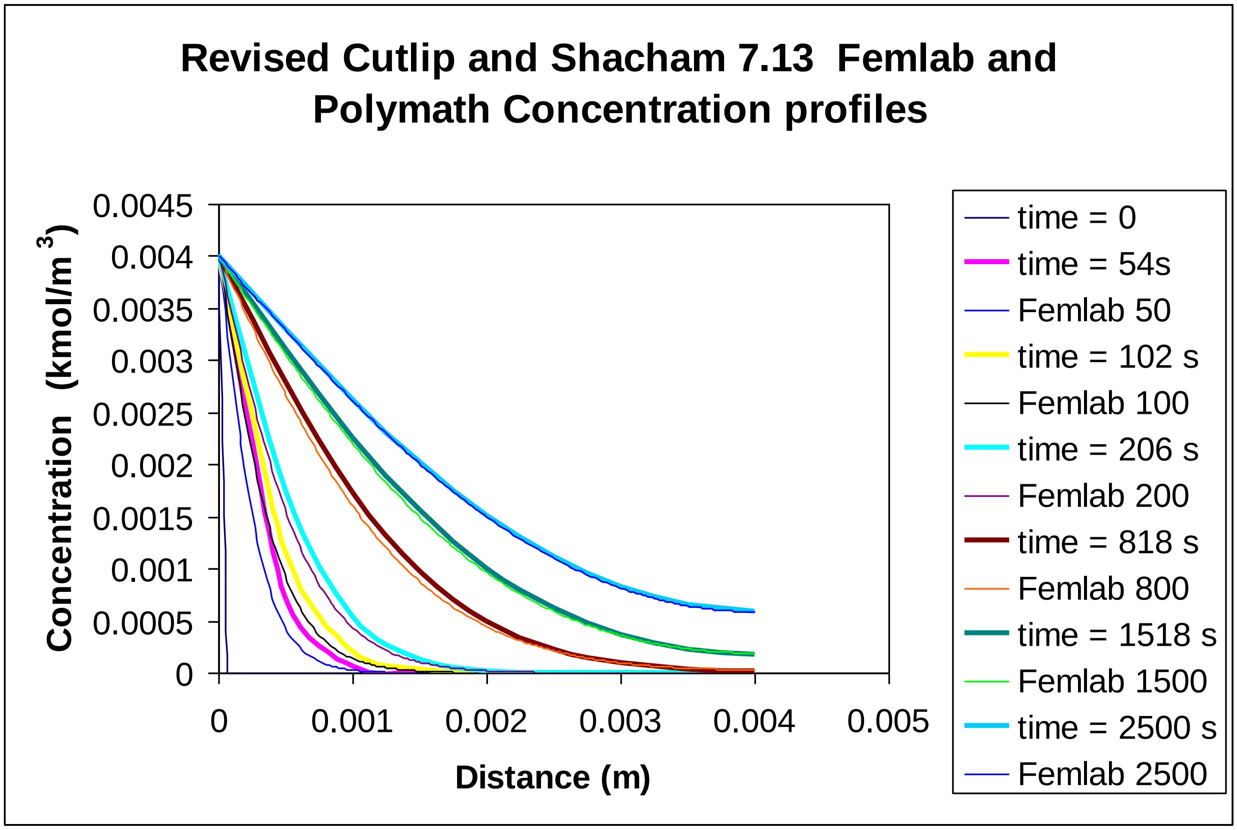
25. This can be switched by Switch Row/Column



26. This is too many lines and the labels for the lines have too many digits.  Format the times to show no decimal places and use then use the Format Select Data or the Funnel to the Right of the chart to only show a limited number of times on the plot

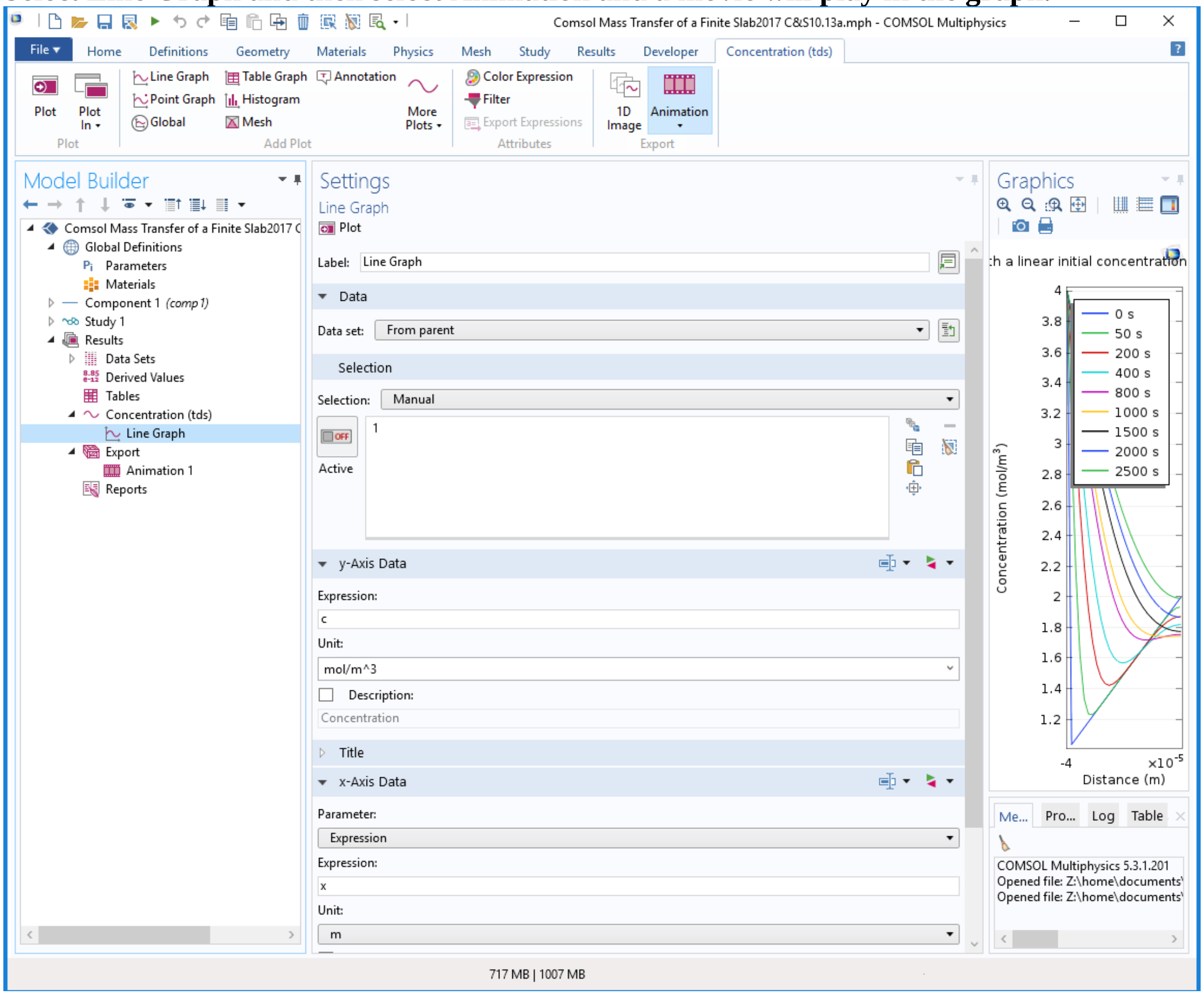



27. Next add axis labels, adjust axis limits (don’t need negative numbers) and show the legend to the right of the graph.
28. Paste all 3 of the above plots into a word file.

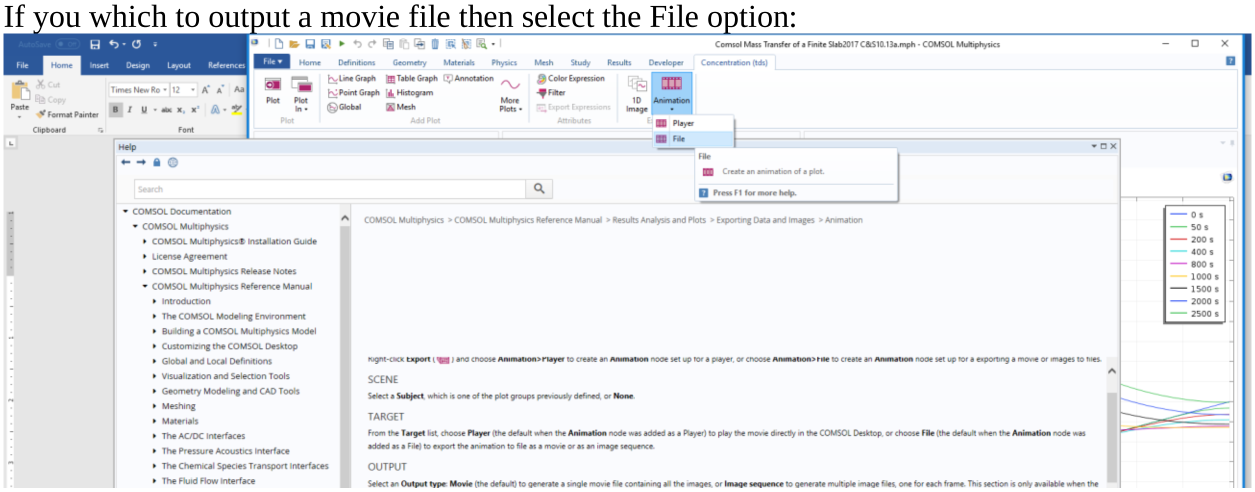

Revised Cutlip and Shacham 7.13 Femlab and Polymath Concentration profiles
Concentration (kmol/m3)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
0.001
0.002
0.003
0.004
0.005
Distance (m)
time = 0
time = 54s
Femlab 50
time = 102 s
Femlab 100
time = 206 s
Femlab 200
time = 818 s
Femlab 800
time = 1518 s
Femlab 1500
time = 2500 s
Femlab 2500

## Create a Movie

29. Select **Line Graph and then select Animation and a movie will play in the graph.**

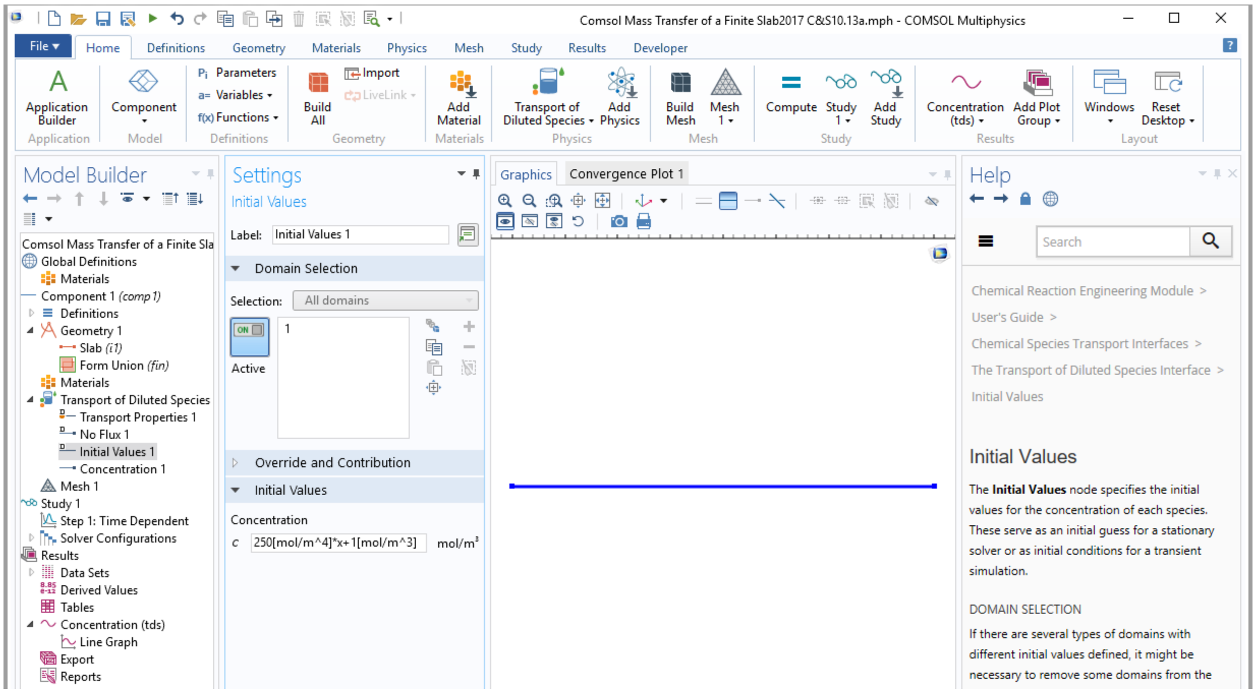



30. If you which to output a movie file then select the File option:

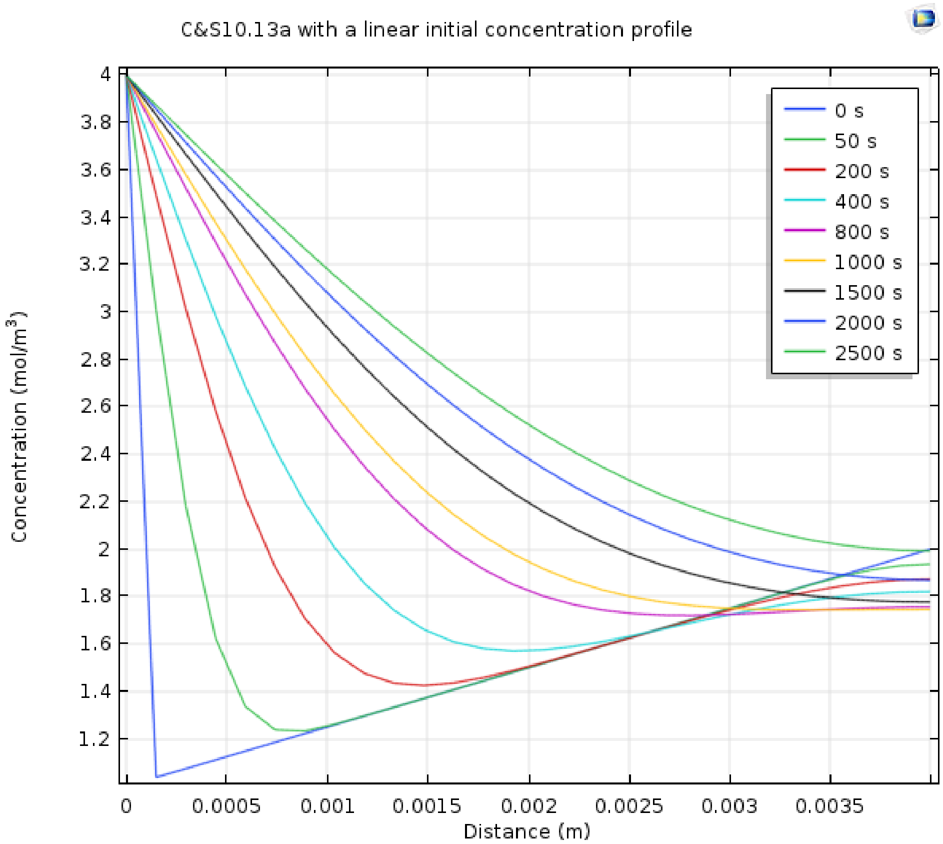


## Cutlip and Shacham Problem 10.13a

31. Now we will solve the original problem 10.13a (Given originally as Geankoplis Example 7.7-1) Go to the initial condition specifications of the slab and change them to have a linear variation from $1\times10^{-3}$ to $2\times10^{-3}$ kmol/m$^3$ over the distance of 0.004 m. This is done by entering the following equation in the Physics, Subdomain Settings,




32. Now you will obtain the following result after specifying the times to be plotted and request a legend (choose the Line/Extrusion tab and select the Line Settings button).



C&S10.13a with a linear initial concentration profile
Concentration (mol/m3)
Distance (m)
0 s
50 s
200 s
400 s
800 s
1000 s
1500 s
2000 s
2500 s
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035

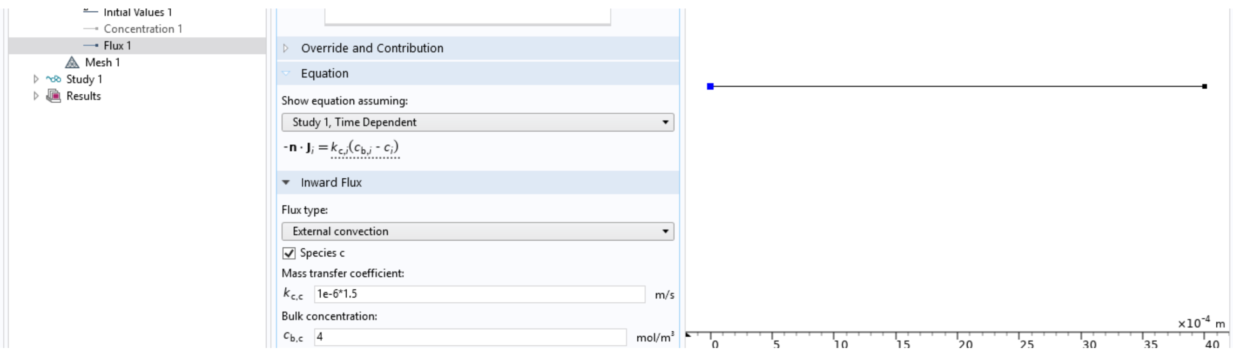
**Cutlip & Shacham 10.13e – Flux boundary condition**

33. In this part of the problem you need to use the flux boundary condition instead of the concentration boundary condition. The flux boundary condition uses a mass transfer coefficient. The boundary condition that you are using is based on the liquid phase concentrations:

$$N_A = k_c\left(C_A^{liq\ bulk} - C_A^{liq}\big|_{x=0}\right) = k_c\left(C_{A0}^{liq} - C_A^{liq}\big|_{x=0}\right)$$

34. The comsol boundary condition is based on the solid concentration so you will need to modify the above equation as follows:

$$N_A = k_c\left(C_{A0}^{liq} - C_A^{liq}\big|_{x=0}\right) = k_c\left(C_{A0}^{liq} - KC_{A1}^{solid}\right) = k_cK\left(C_{A0}^{liq}/K - C_{A1}^{solid}\right)$$




**Submit files for Polymath and Comsol of parts 2 and 3**
**Submit after completing this Tutorial in a pdf document containing the following. .**

1. Modified 10.13 (Initial condition of zero concentration of A in slab)
   a. Polymath solution
   b. Plot of concentration as a function of distance with the parameter of time.
      i. Polymath
      ii. COMSOL
      iii. Both COMSOL and Polymath results on same plot
   c. Comment on the comparison between COMSOL and Polymath results
2. Cutlip & Shacham Problem 10.13a
   a. Polymath Solution
   b. COMSOL Plot of concentration as a function of distance with the parameter of time (default plot)
   c. A comparison plot of POLYMATH and COMSOL in which Concentration is a function of distance with parameter of time.
   d. Comment on the difference between the initial conditions of the solid (subdomain) as zero concentration and linear concentration.

3. (We will do this later!) Cutlip & Shacham Problem 10.13e
    a. Polymath Solution
    b. COMSOL Plot of concentration as a function of distance with the parameter of time (default plot)
    c. A comparison plot of POLYMATH and COMSOL in which Concentration is a function of distance with parameter of time.
    d. Comment on the difference between the initial conditions of the solid (subdomain) as zero concentration and linear concentration.