

## **Polymath Regression tutorial on Polynomial fitting of data**

The following table shows the raw data for experimental tracer concentration from a reactor which you need to fit using Polymath (refer Example 16-1, Table E16-1.1, Elements of chemical reaction engineering, 5<sup>th</sup> edition)

Time (t)	0	0.5	1	2	3	4	5	6	7	8	9	10	12	14
C_tracer (C)	0	0.6	1.4	5	8	10	8	6	4	3	2.2	1.6	0.6	0

The polynomial fit is of the form:

$$C(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + \dots + a_n t^n$$

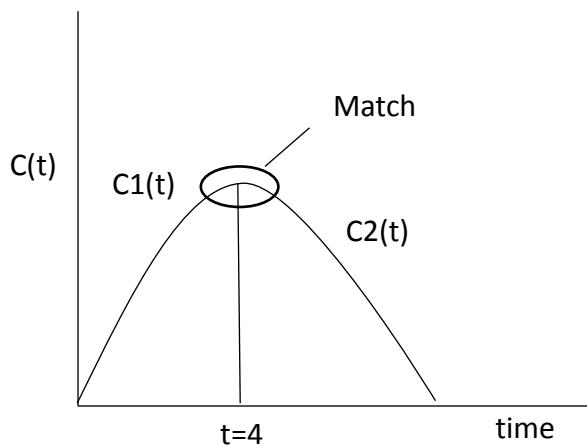
The given C(t) data is first increasing and then decreasing with time. So, we will use two polynomials to fit the C-curve, one for the ascending portion,  $C_1(t)$ , and another for the descending portion,  $C_2(t)$ . We will split our data into two parts, an increasing and a decreasing part, and regress both the data sets separately. Split the data at its maximum, and that happens at  $t = 4$ , when  $C(t)$  is 10. Our data now looks like this:

T1	0	0.5	1	2	3	4
C1	0	0.6	1.4	5	8	10

and

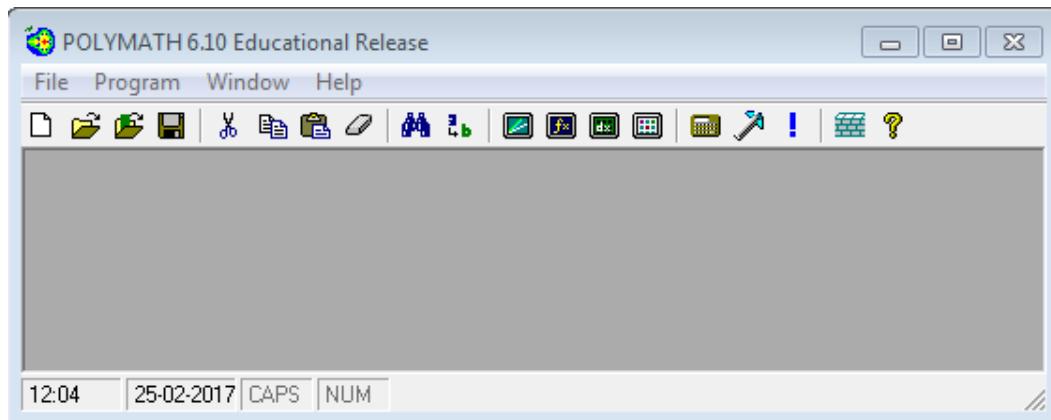
T2	4	5	6	7	8	9	10	12	14
C2	10	8	6	4	3	2.2	1.6	0.6	0

Both the polynomial must meet and give same value at  $t=4$  and should look like this

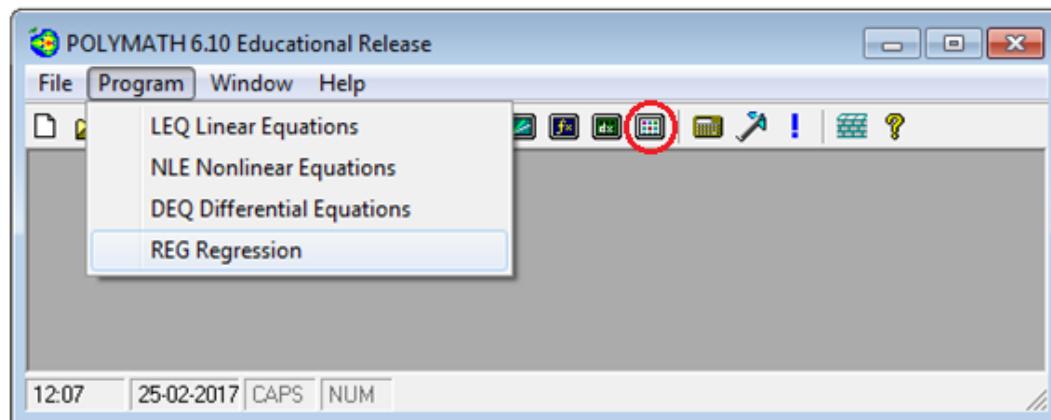


We will first regress the first portion of  $C(t)$  curve and then regress the second portion

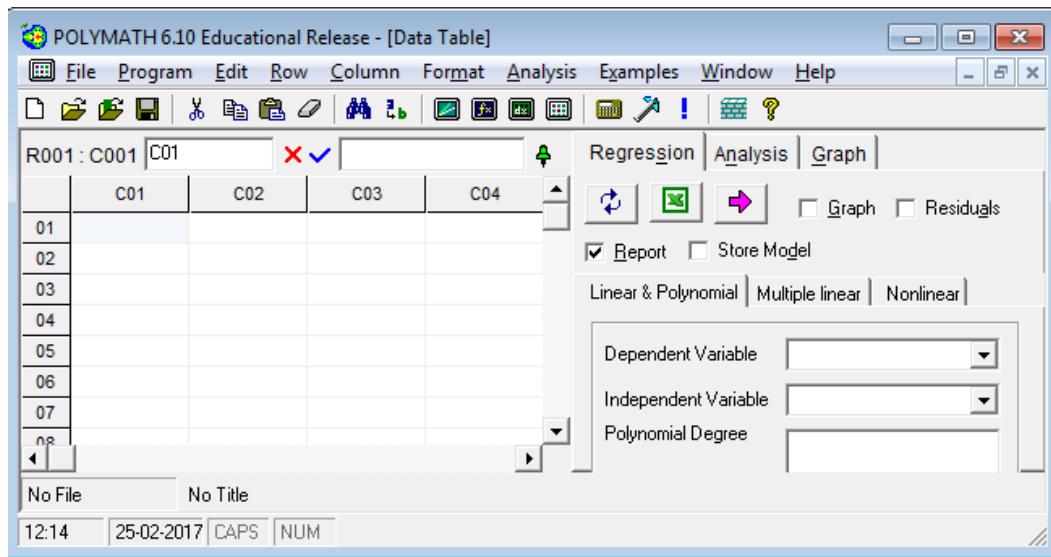
**Step 1:** First, launch Polymath which you can download from <http://www.polymath-software.com> You will see a window that looks like this.



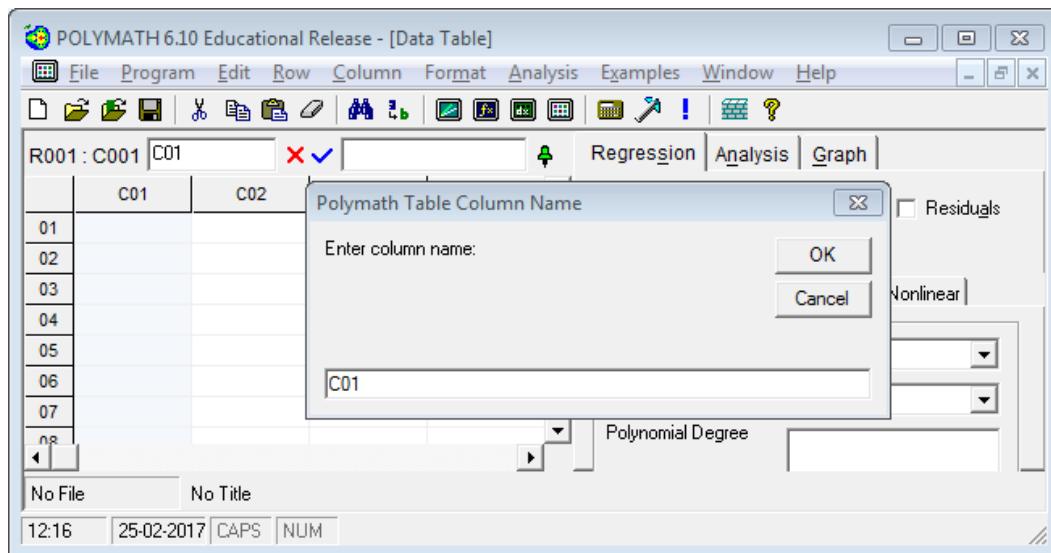
**Step 2:** To regress the data in Polymath, first click on the “Program” tab present on the toolbar. This will bring up a list of options from which you need to select. In this case we want to perform polynomial fitting, so select "REG Regression". The shortcut button for Regression solver is also present on the menu bar (  ) as shown by red circle in below screenshot



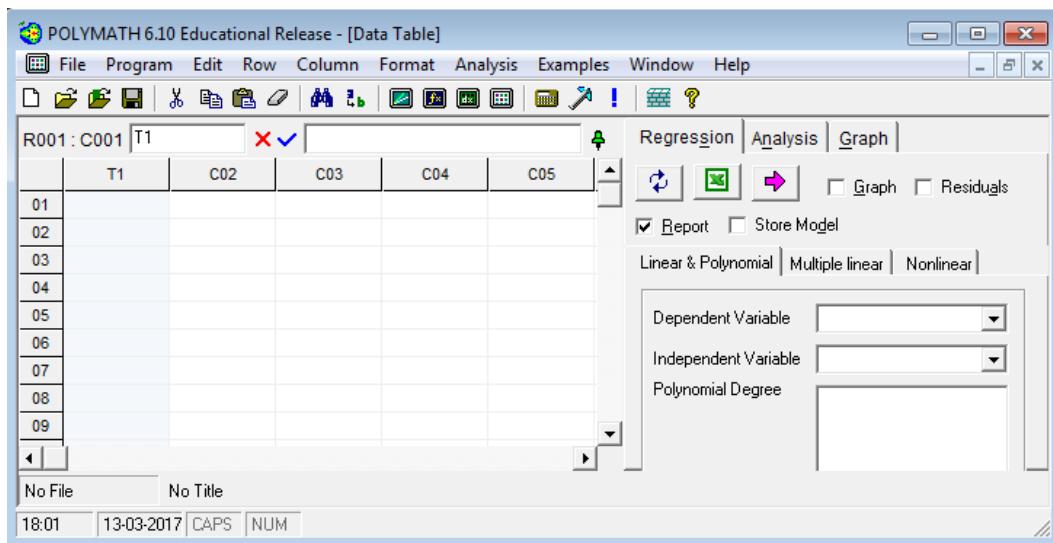
The following window will appear



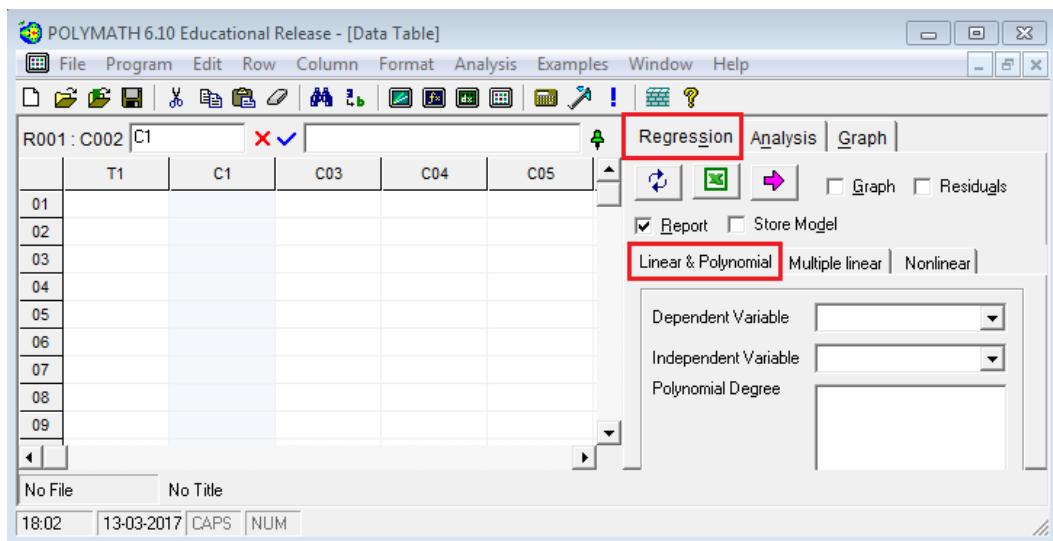
**Step 3:** Before inserting the data into the spreadsheet, it is recommended to change the column name with the name of the variable mentioned in the data table. This would make it easy to comprehend the polymath output. To change the column name of C01, double click on the column name "C01" or right click on C01 and select "Column Name...". A dialog box will appear where column name can be changed



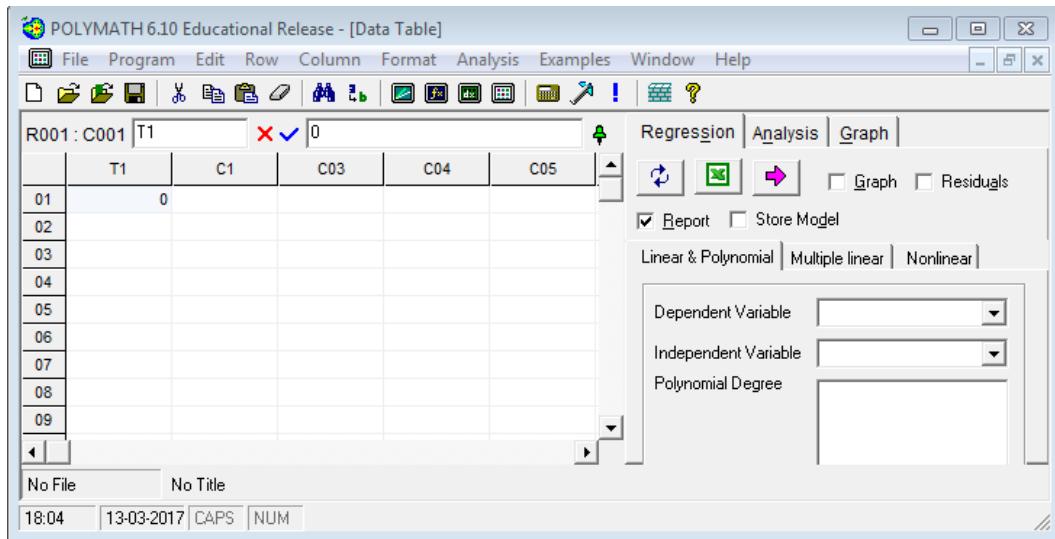
Change the column name from C01 to T1 and press OK. You will find that column name is changed to T1



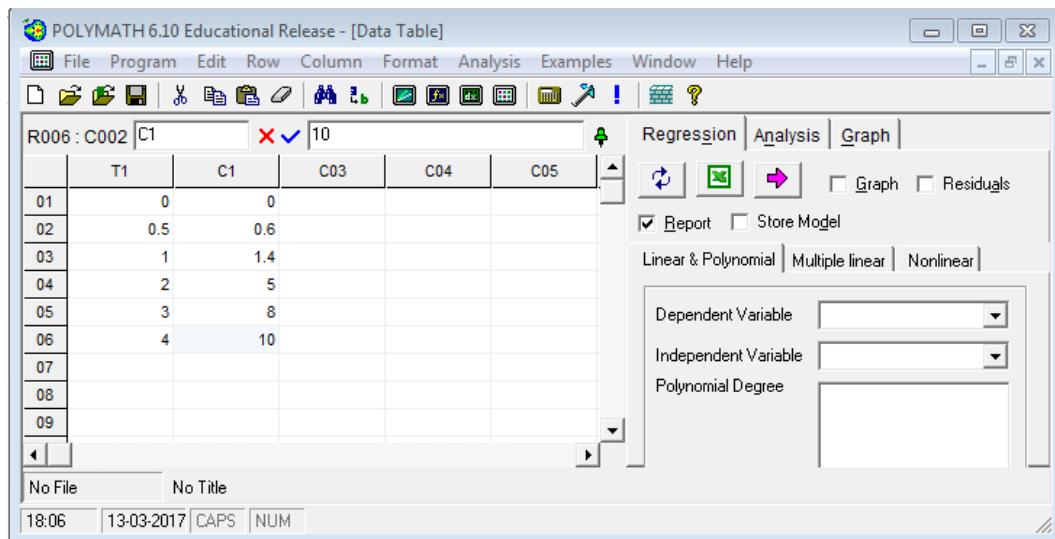
Similarly, rename C02 to C1 as shown below. By default Polymath select Regression method as “Linear and Polynomial”. If it is not so, then, click on the Regression tab on the right side of the window, and select the "Nonlinear" regression tab under the "Report" and "Store Model" check boxes (shown by red rectangle) The window should look like this:



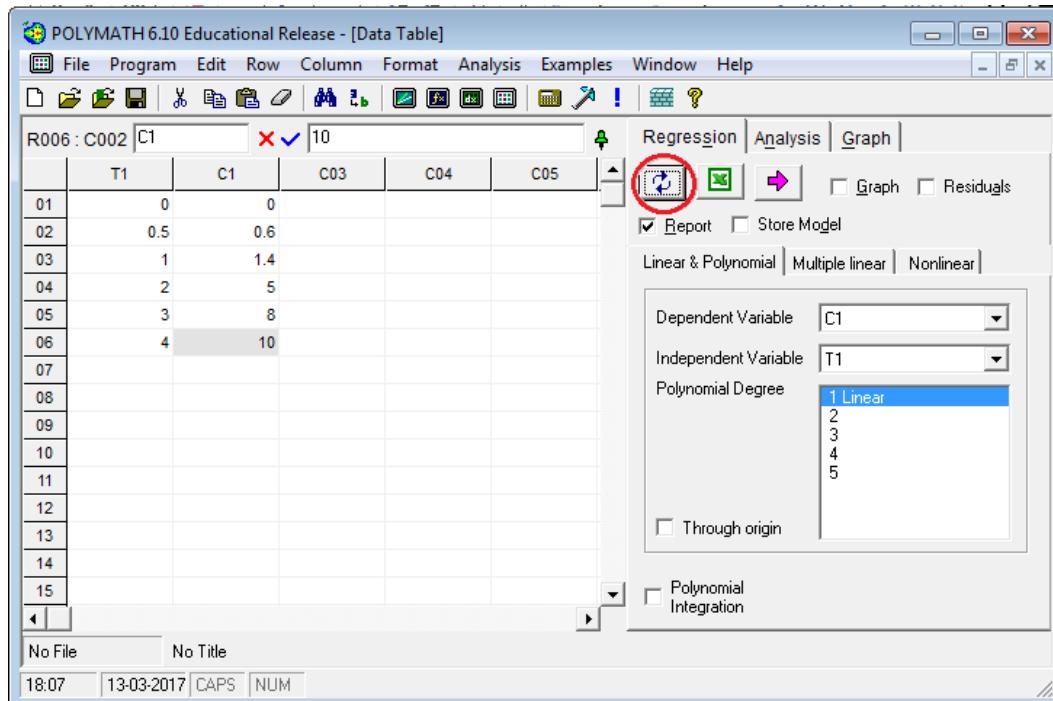
**Step 4:** To input the data for T1, select the first cell (row 01, column time) and enter the first data as shown below:



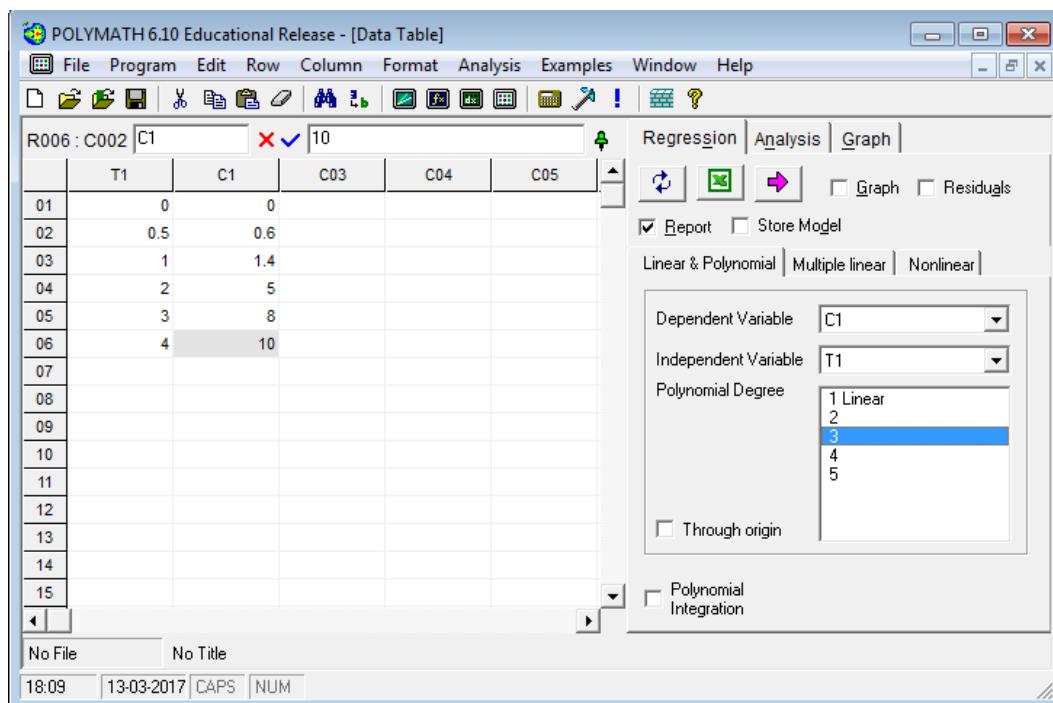
Similarly, enter the remaining data of T1 in subsequent rows. Repeat this procedure to input the data for C1. After entering the data, the spreadsheet would look like this



**Step 5:** Clicking the refresh button (shown below by red circle) on the left of the green excel sign updates the file. Now, you will find that Dependent variable, Independent variable and Polynomial degree is updated (shown by blue rectangle). By default, Polymath select the first column as independent variable, second column as dependent variable, and Polynomial degree as “1 Linear”. The window should look like this:

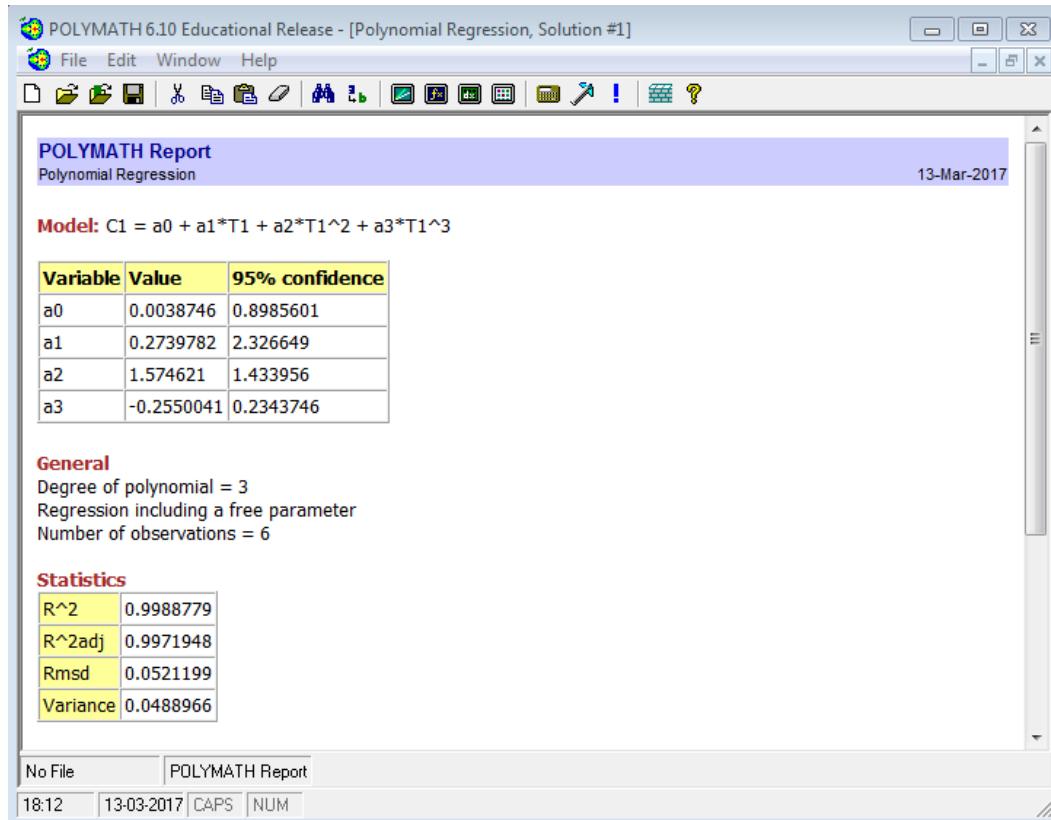


**Step 6:** You can also change the dependent variable, independent variable by selecting from the drop down menu next to variable name. In this case we want to change the polynomial degree only. Let's try to fit the data by Polynomial degree 3. Select the Polynomial degree as 3 as shown below



**Step 7:** Now select what you want polymath to output by checking the boxes on the right side of the window. The options are Graph, Residuals, Report, and Store Model. Click on the pink arrow  to have Polymath perform the regression.

If you selected "Report" you will see a screen that details the results from the regression analysis. The report includes the model, the values of the model parameters, the statistical confidence of the parameters, and several other statistics.



POLYMATHE 6.10 Educational Release - [Polynomial Regression, Solution #1]

File Edit Window Help

POLYMATHE Report  
Polynomial Regression 13-Mar-2017

**Model:**  $C1 = a0 + a1*T1 + a2*T1^2 + a3*T1^3$

Variable	Value	95% confidence
a0	0.0038746	0.8985601
a1	0.2739782	2.326649
a2	1.574621	1.433956
a3	-0.2550041	0.2343746

**General**  
Degree of polynomial = 3  
Regression including a free parameter  
Number of observations = 6

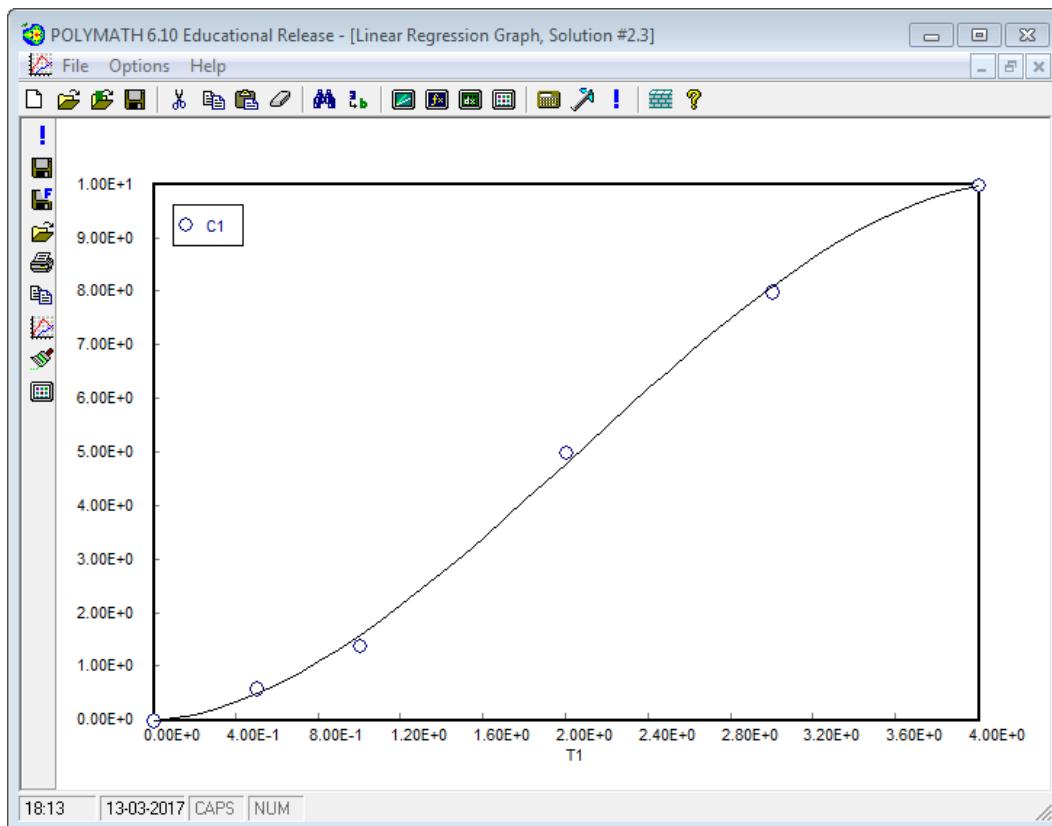
**Statistics**

R <sup>2</sup>	0.9988779
R <sup>2</sup> adj	0.9971948
Rmsd	0.0521199
Variance	0.0488966

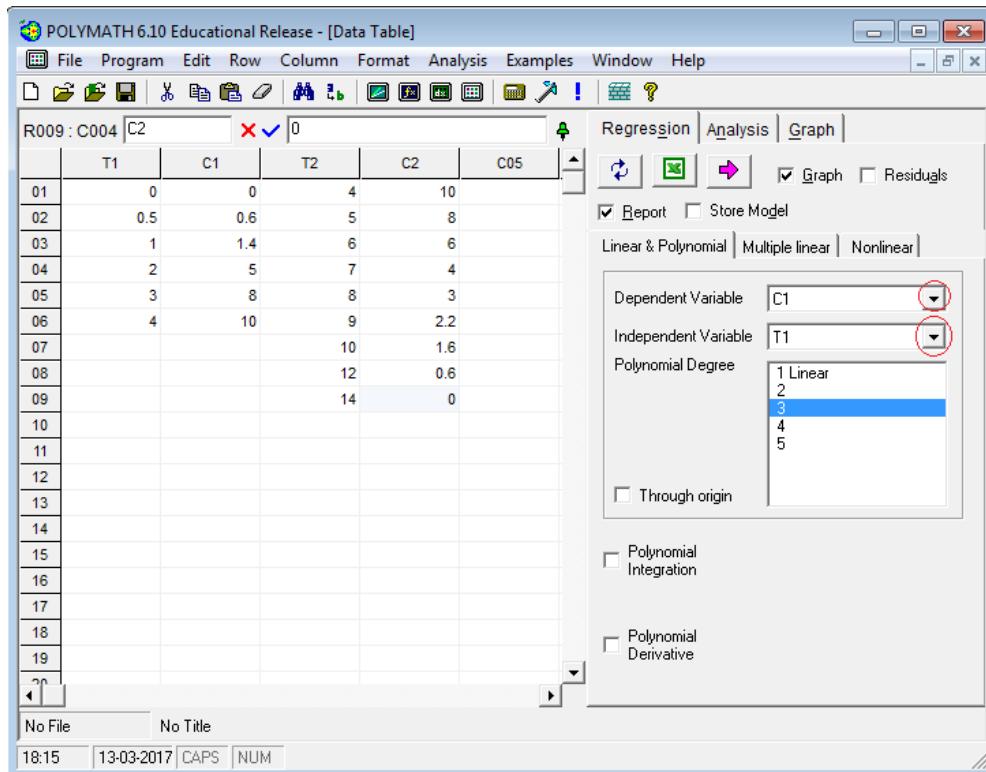
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The above report shows that 3 degree polynomial fits well to the 1<sup>st</sup> set of data as is evident from  $R^2 = 0.999$

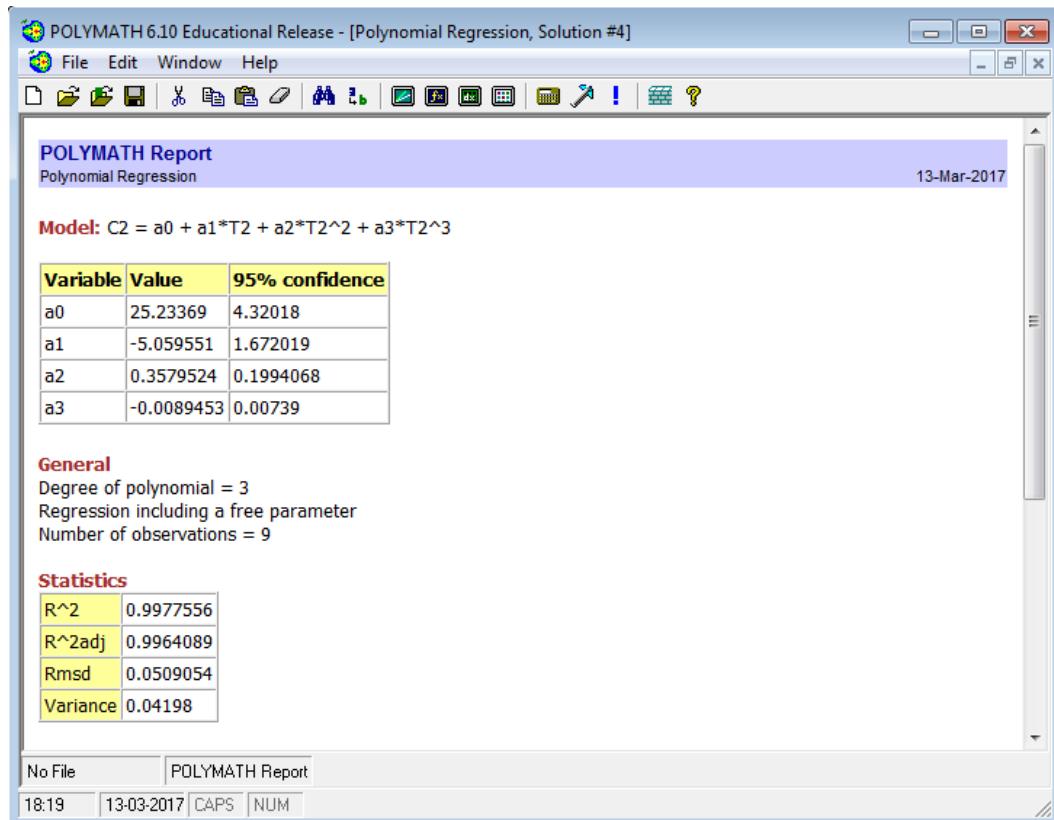
If you checked the graph option, a new window will appear like this. The graph shows the model that we fit to the data.



**Step 8:** To enter the second set of data in the spreadsheet, change C03 to T2 and C04 to C2, enter the data in corresponding column and then you need to select the dependent and independent variable as C2 and T2 from the drop down menu (shown by red circle in the screenshot). Select the polynomial degree as 3 as was done earlier. Your window will appear like this

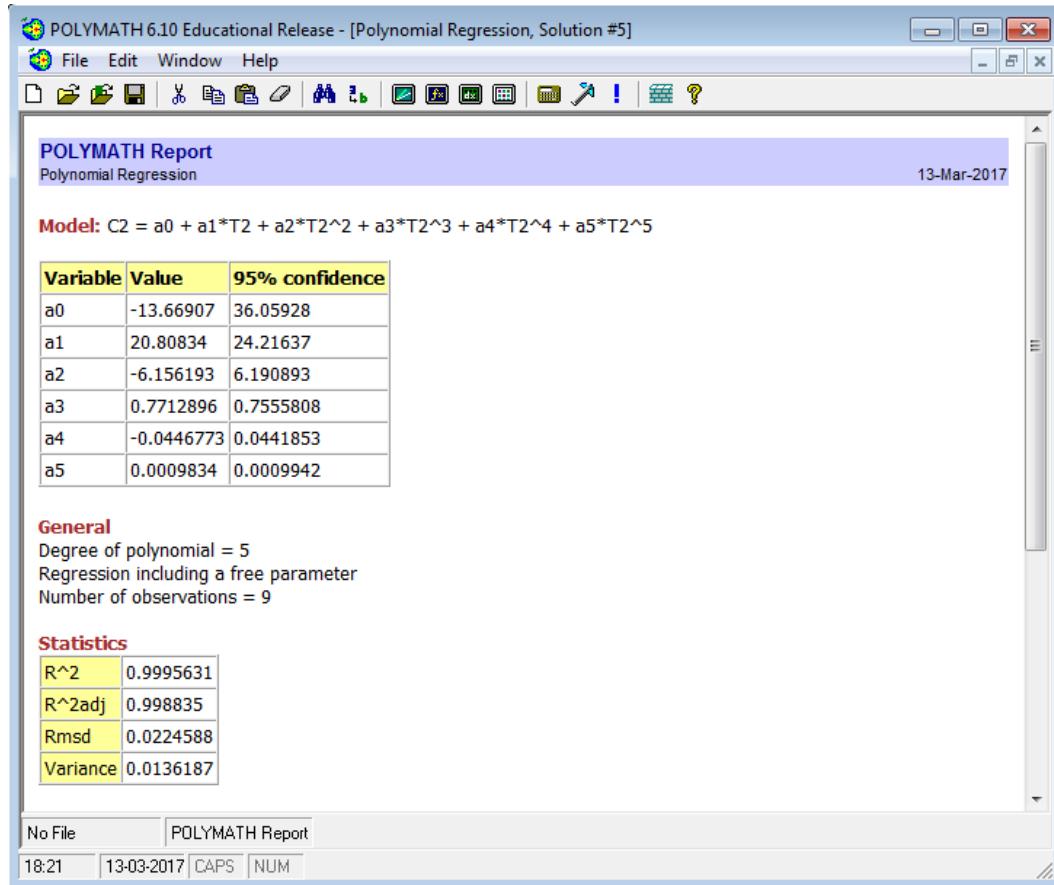


Run the model by clicking the pink arrow and generate the report. The report shows R^2 value to be 0.998 which is a good fit



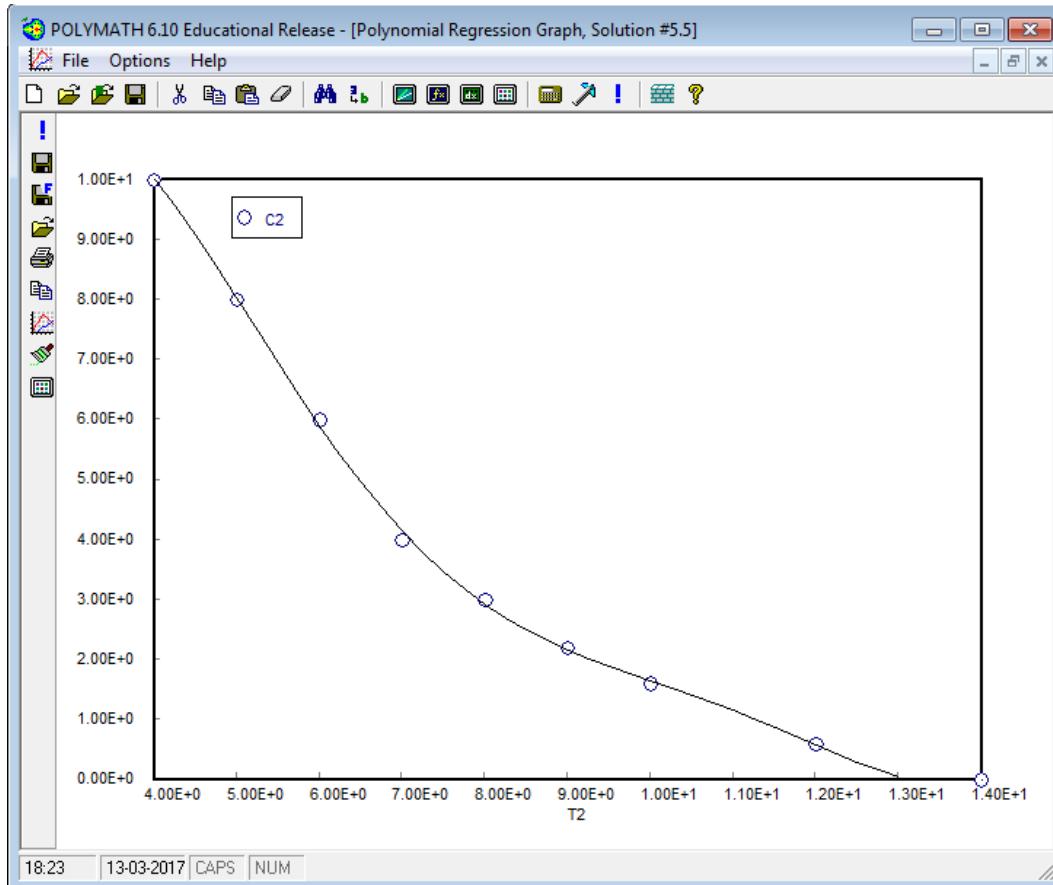
To improve the accuracy of the fitting of the second data set, we can use higher order polynomial. Let's regress using a 5th Order polynomial, which is the maximum polynomial degree one can use in Polymath under "Linear and Polynomial Tab"

**Step 9:** Go back to the main window and change the polynomial degree to 5 and run the program to generate the report



From the above report you can see that  $R^2$  has improved to 0.999 from 0.998. So, 5<sup>th</sup> order polynomial fits better for the decreasing portion of the C(t) curve.

If you checked the graph option, your graph will appear like this



Thus, by splitting data in to two parts, you can obtain a fit with  $R^2=0.999$

**The polynomial equation is given by**

For 1<sup>st</sup> data set , $t \leq 4 \text{ min}$ ,  $C1(t)= 0.0039 + 0.274t + 1.57t^2 - 0.255t^3$

For 2<sup>nd</sup> data set ,  $t \geq 4 \text{ min and } t \leq 14 \text{ min}$ ,

$$C2(t)= -13.669 + 20.808t - 6.156t^2 + 0.771t^3 - 0.0446t^4 + 0.00098t^5$$

The complete equation for  $C(t)$  curve can be written as

$$C(t) = If(t \leq 4 \text{ and } t \geq 0) \text{then } C1 \text{ else if } (t \geq 4 \text{ and } t \leq 14) \text{then } C2 \text{ else } 0$$

**Step 10:** Now you have obtained equation for both increasing and decreasing part of C(t) curve. Let's combine both part and obtain a complete and continuous graph. We will do this using Polymath DEQ solver.

We will fool Polymath by defining a dummy dependent variable (A) varying with t and then enter the C1(t), C2(t) and C(t) equation to get the desired curve

So,

$$\frac{dA}{dt} = 1$$

With A(0) = 0

$$C1 = 0.0038746 + 0.2739782*t + 1.574621*t^2 - 0.2550041*t^3$$

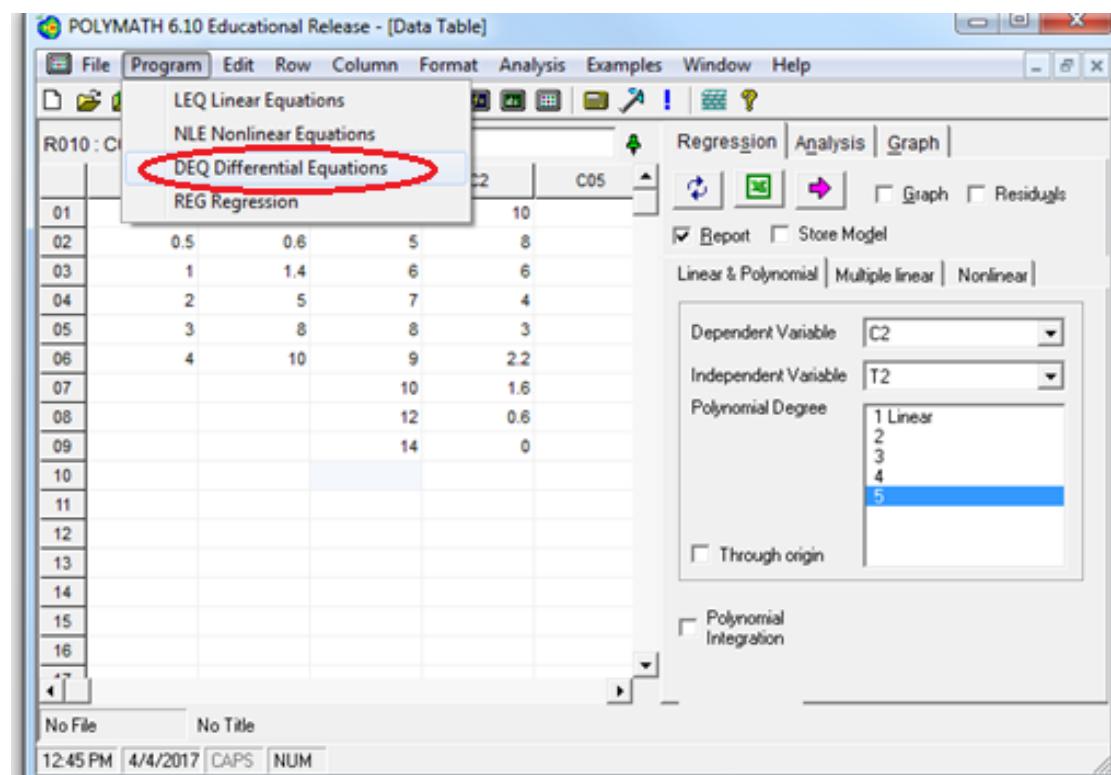
$$C2 = -13.66907 + 20.80834*t - 6.156193*t^2 + 0.7712896*t^3 - 0.0446773*t^4 + 0.0009834*t^5$$

C = If (t<=4 and t>=0) then C1 else if (t>=4 and t<=14) then C2 else 0

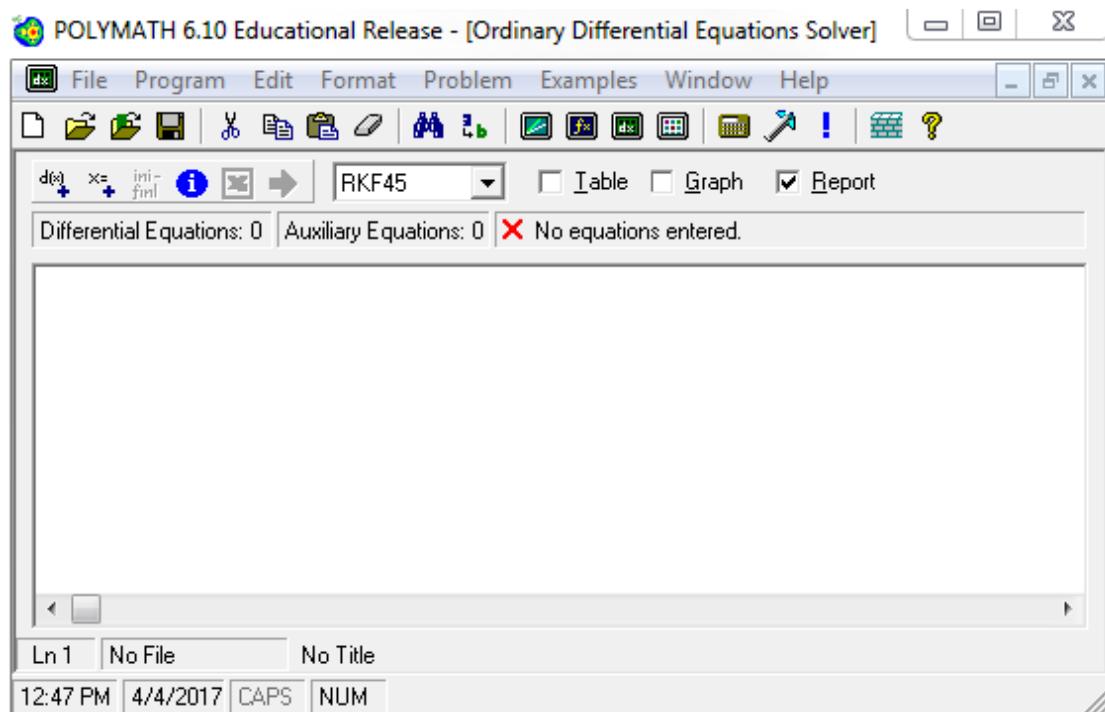
$$t(0) = 0$$

$$t(f) = 14$$

Click on Program tab and select “DEQ Differential Equations”

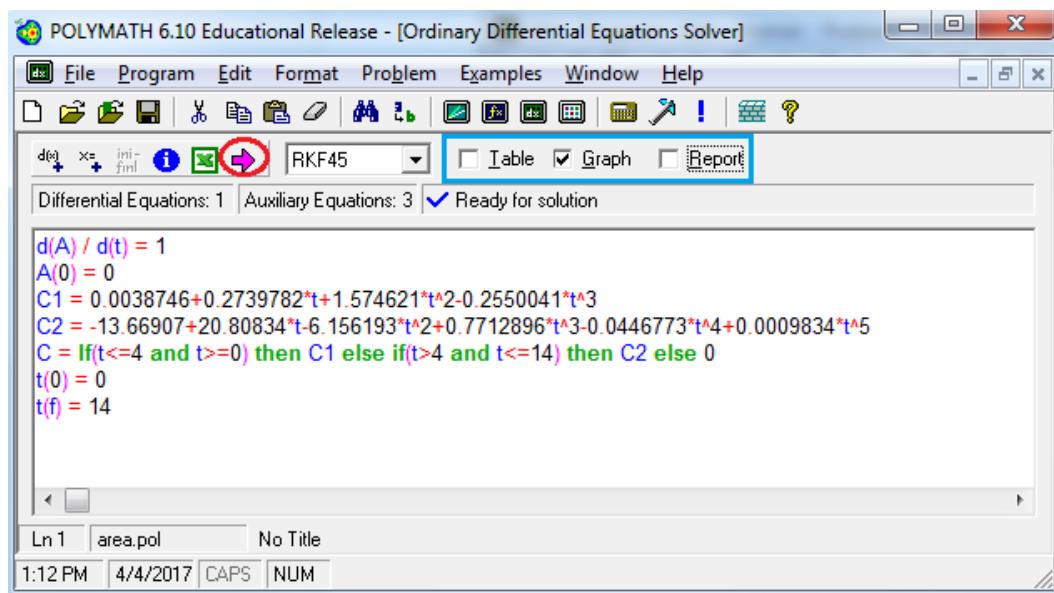


This will open up a blank window as shown below

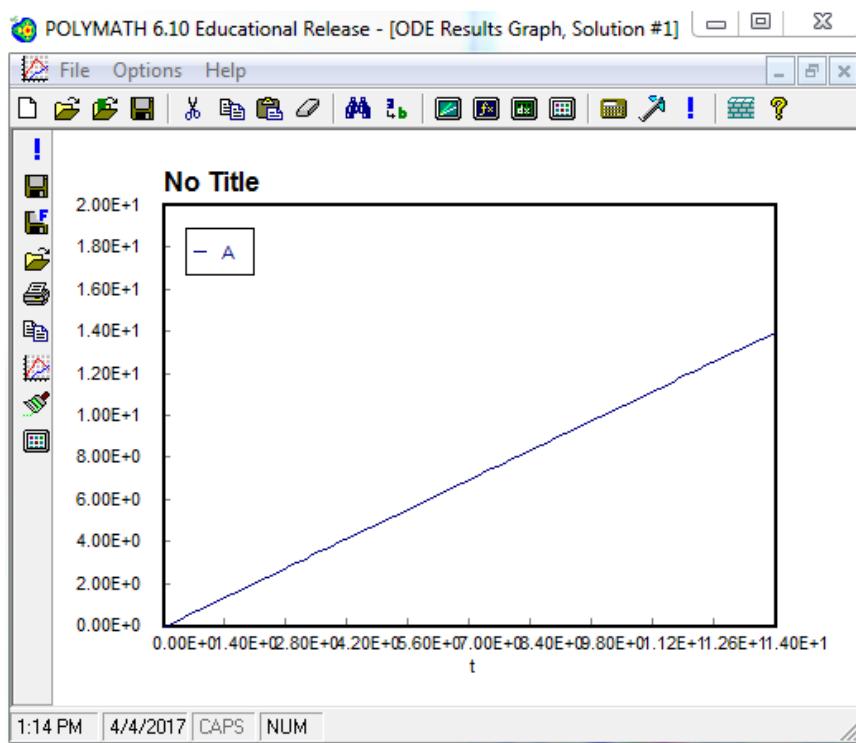


**Step 11:** Enter the differential equation and explicit equation in the window. For more details on how to enter equations and initial values, refer to Polymath ODE tutorial at <http://umich.edu/~elements/5e/software/polymath.html>

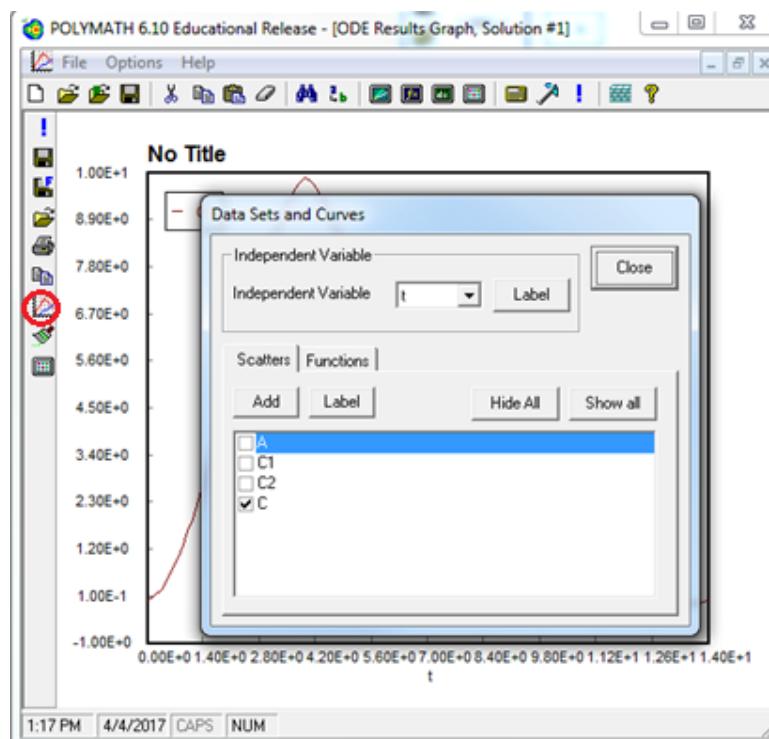
After you have entered all your equations, check the box corresponding to Graph option and uncheck the box corresponding to Report (as we want only graph) . Click on the pink arrow to run Polymath program.



You will obtain the following graph



**Step 12:** To select the variable you want to plot, double click on the graph or click on graph button present on left panel (shown below). This will open up a dialogue box. You can select independent variable from drop-down menu and dependent variable by checking/unchecking the boxes next to the variables. So uncheck the box for A and check the box for C. After you are done, hit Close button



**Step 13:** To edit graph properties right click on graph and select “Format” or click on brush button present on the left panel. This will open up a dialogue box with different tabs such as Curves, Titles, Fonts, axis format, margin etc. In this tutorial we will edit some of the graph properties.

In the “**Titles**” tab, enter the graph title as C(t) curve

In the “**X,Y axis**” tab select 0 for X axis and 0.0 for Y axis using drop down menu

In the “**Scale and Margins**” tab, put 0 as min value of Y axis.

Apply the changes and close the dialogue box. You will obtain the following graph

