

Tutorial Lesson 1 — Pre-tutorial

Course: Fundamentals of Modelling in Process Engineering | Chem.E_M2

— Practical example 1: Modelling a heated water tank

A student wants to model the heating of water using a simple mathematical model implemented in Microsoft Excel.

A quantity of water is heated in a tank using an electrical heater. The water temperature increases with time. For this introductory exercise, assume that the heating power is constant and no heat is lost to the surroundings.

The temperature of the water can be calculated using the following equation:

$$T(t) = T_0 + \frac{P \cdot t}{m \cdot C_p}$$

Where

Parameter	Description	Value
T_0	Initial water temperature	20 °C
P	Heater power	1 000 W
m	Mass of water	2 kg
C_p	Specific heat capacity of water	4 180 J/(kg·°C)
t	Heating time	Variable (s)
$T(t)$	Water temperature at time t	To calculate (°C)

Your task is to implement this mathematical model in Excel and observe how the water temperature changes with time.

Questions and tasks

1. Open Microsoft Excel and create a table with two columns: heating time (s) and water temperature (°C).
2. Enter the model parameters (T_0 , P , m , and C_p) into separate cells.
3. Enter heating times from 0 to 600 s, using intervals of 60 s.
4. Write an Excel formula to calculate the water temperature at each time step.
5. Use Excel's fill handle to apply the formula to all time values.
6. Plot the water temperature as a function of heating time using an XY scatter chart.
7. Answer the following questions:
 - What is the initial water temperature?
 - What is the calculated temperature after 300 s?
 - What is the calculated temperature after 600 s?
 - Does the temperature increase linearly with time? Explain your answer.

— Practical example 2: Newton's law of cooling

A hot liquid is placed in a tank and allowed to cool naturally in a room. The liquid temperature decreases over time until it approaches the ambient temperature.

A process engineer wants to predict the liquid temperature at different times using Microsoft Excel.

For this exercise, assume that the cooling process follows **Newton's law of cooling**, expressed by the following mathematical model:

$$T(t) = T_a + (T_0 - T_a)e^{-kt}$$

Where

Parameter	Description	Value
T_0	Initial liquid temperature	90 °C
T_a	Ambient temperature	25 °C
k	Cooling constant	0.08 min ⁻¹
t	Cooling time	Variable (min)
$T(t)$	Liquid temperature at time t	To calculate (°C)

The objective is to implement the model in Excel, calculate the temperature over time, and analyze the cooling behavior.

Questions and tasks

Part 1 — Construct the Excel model

1. Open a new Excel worksheet.
2. Enter the model parameters in separate cells.
3. Create a table with two columns:
 - Cooling time (**min**)
 - Liquid temperature (°C)
4. Enter time values from **0 to 60 minutes** using intervals of **5 minutes**.
5. Enter the mathematical model as an Excel formula to calculate the temperature at each time.
6. Use the fill handle to calculate the temperature for all time values.

Part 2 — Analyze the results

7. Calculate the liquid temperature after **10, 30, and 60 minutes**.
8. Determine the time required for the liquid temperature to reach **40 °C**. Use the calculated table to estimate the time, then improve the estimate using Excel's Goal Seek feature if available.
9. Plot liquid temperature versus cooling time using an XY scatter chart with a smooth line.
10. Identify the trend observed in the temperature curve.

Part 3 — Investigate the influence of a model parameter

The engineer wants to understand how the cooling constant affects the cooling process.

11. Repeat the calculations for the following values of k :

- Case A: $k = 0.04 \text{ min}^{-1}$
- Case B: $k = 0.08 \text{ min}^{-1}$
- Case C: $k = 0.12 \text{ min}^{-1}$

12.Plot all three temperature curves on the same graph.

13.Compare the results and answer these questions:

- Which case cools the liquid most rapidly?
- Which case reaches ambient temperature most quickly in practical terms?
- What happens to the temperature when time becomes very large?
- Why is it useful to investigate the influence of a model parameter?