Be challenging, be smart: BE CAE & Test!

A COMSOL App to analyze bacteria lethality during sterilization processes

http://www.be-caetest.it/

Florence, 22-24/10/2024

COMSOL Certified Consultant

About us…

BE CAE & Test provides **consultancy services** to industrial partners by exploiting **CAE software** and developing **experimental testing**.

http://www.be-caetest.it/

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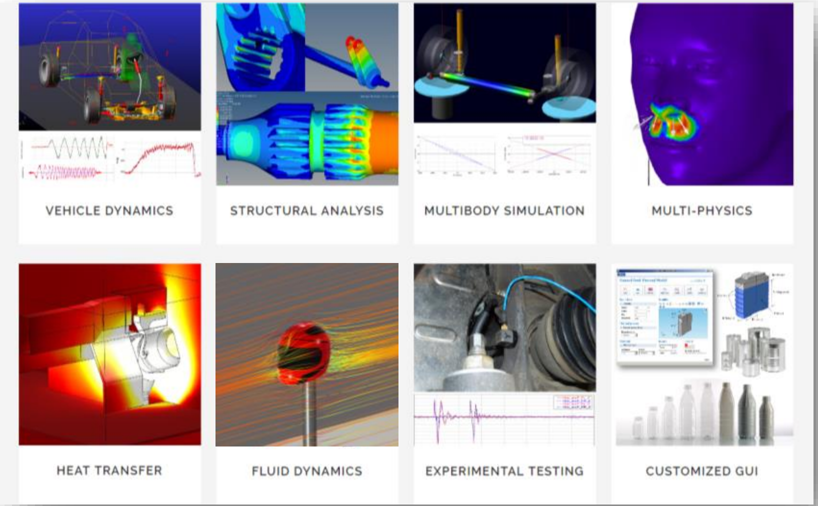

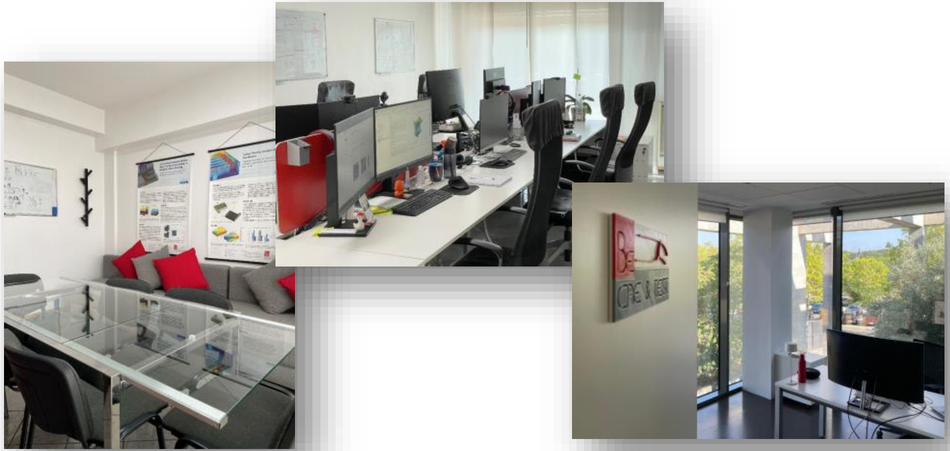

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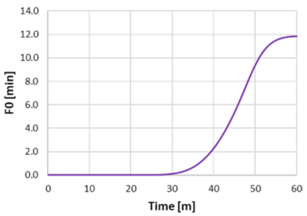
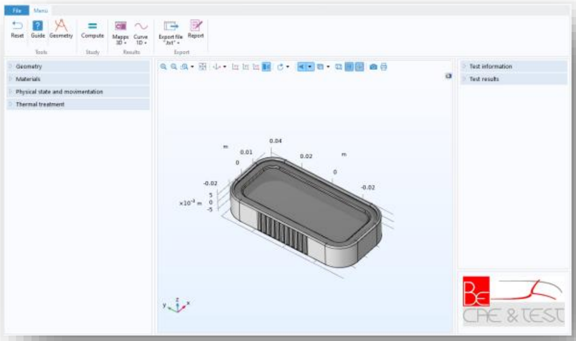
Introduction

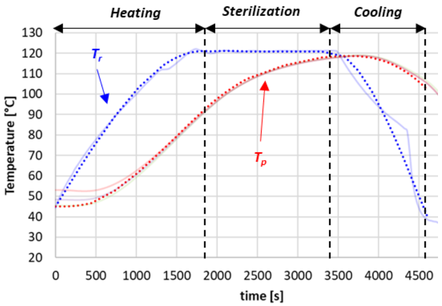
- About food safety
- Theoretical notes





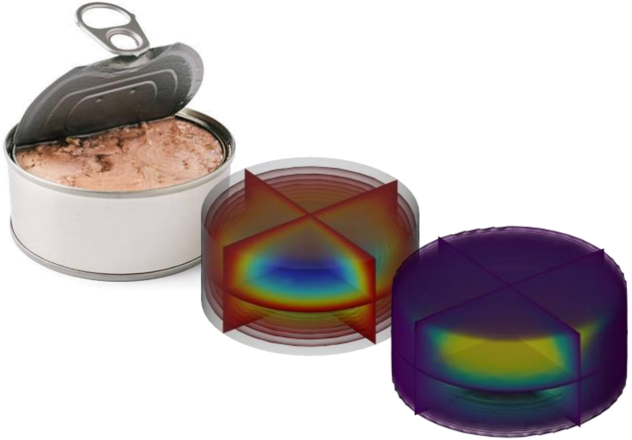
Method and validation

- Food safety parameters analysis
- Implementation: model nodes
- Num-exp validation
- Result



API construction

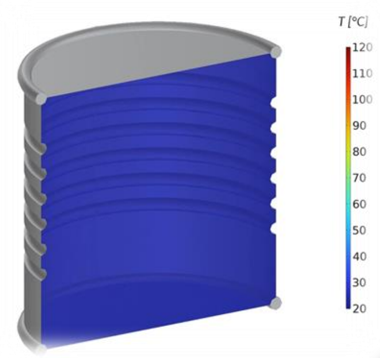
- Forms interface.
- How to choose geometry, materials and thermal cycle
- Results.



Remarks and conclusion

Food safety

- Historically, food safety is a very **critical aspect** in the field of the **food industry**. Making a product safe means **preserving the quality** for a certain period, so that it can be considered non-harmful for consumers and **be marketed**. At date, there are **specific protocols** and treatment useful to guarantee food quality.

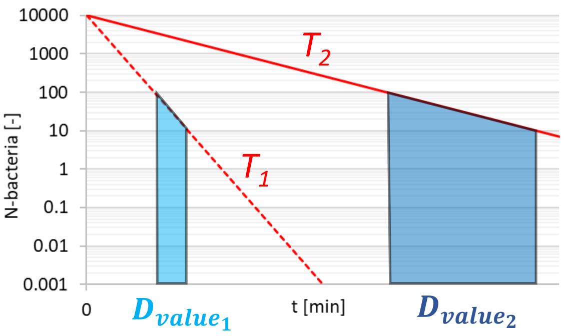


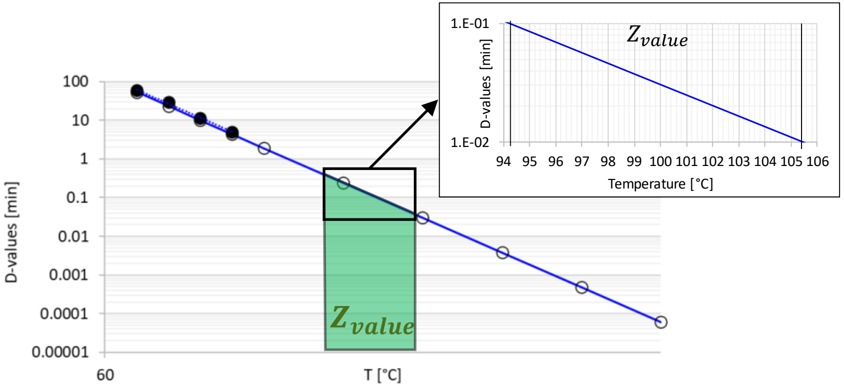
- **Degradation** of canned foods depends on the activity and **number of bacteria** inside.

- Our work with **COMSOL** was to create a **stand-alone application** that could **predict** bacteria reduction and **product safety** in **canned food**, related to specific treatments.

Bacteria heat sensitivity parameters

Bacteria are sensitive to **high temperatures**. During heat treatment, they **start reducing** and can be completely **neutralized** under specific **temperatures** and **time**.





Red lines = Number of surviving bacteria (N) as a function of the time (t) when a specific constant temperature (T_i) are applied.

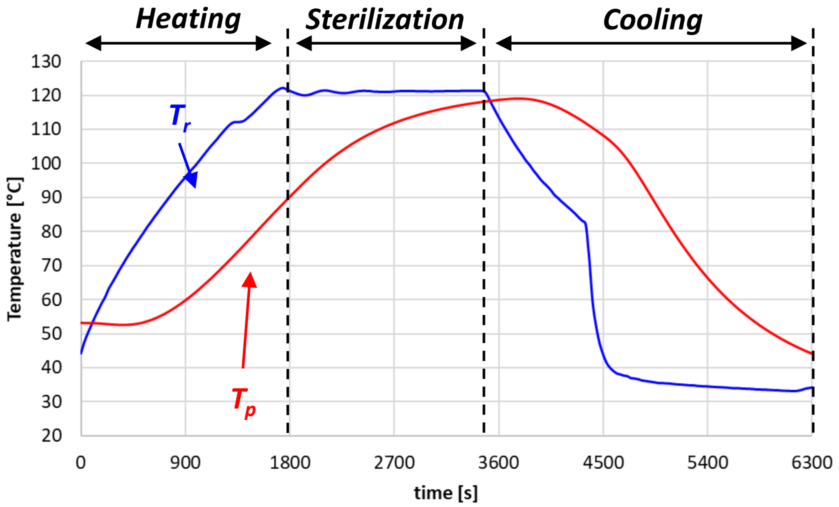
Blue line = Envelope of D-values as a function of the Temperature (T_i).

D_{value} = time required to reduce the number of bacteria by a logarithmic order

Z_{value} = temperature increase necessary to reduce the D_{value} by a logarithmic order

Heat penetration curve

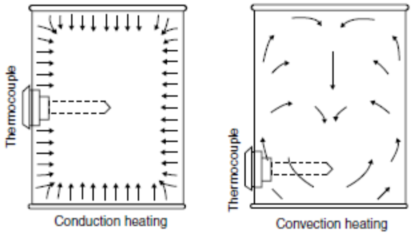
Typical heat treatment processes are made with **retort** and are usually composed by **3 steps** :



T_r = retort temperature.

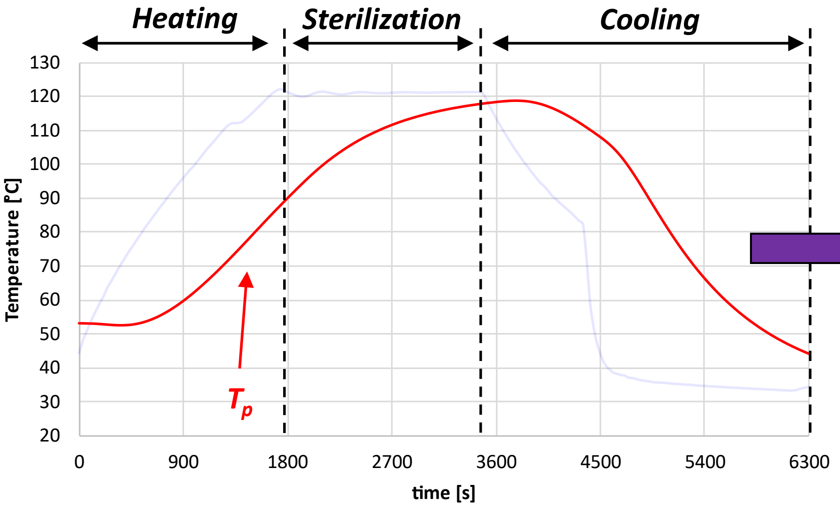
T_p = Coldest product point temperature

- The shape of the T_p curve can be significantly different as the location of the coldest point in the can, according to their physical state.



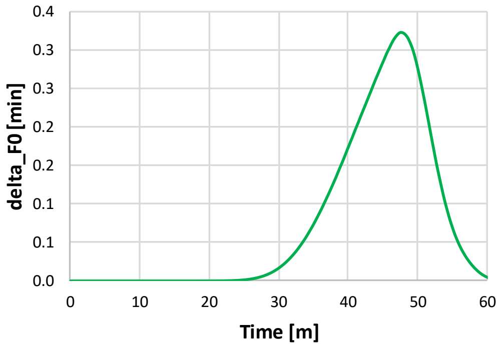
Letality factor

By integrating the heating curve of the product, we can obtain the **lethality factor** F_{value}, define as the time to neutralize all bacteria for a given temperature.

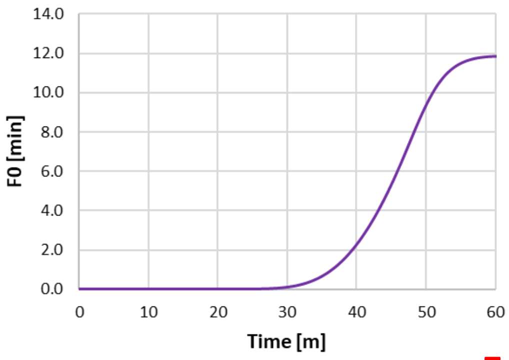


$$F_{value} = \int_0^t 10^{\left(\frac{T_p(t) - T_{ref}}{Z_{ref}}\right)} dt$$

$$F_0 = F_{value} \quad @\ T_{ref} = 121°C$$



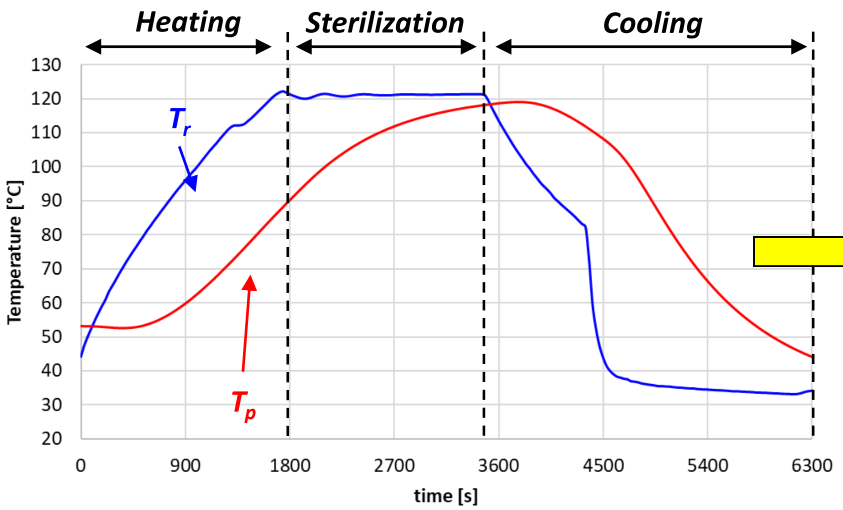
T_{ref} = Reference temperature
Z_{ref} = Z_{value} of the bacterium at T_{ref}
$T_p(t)$ = product temperature beavior
dt = heat treatment time

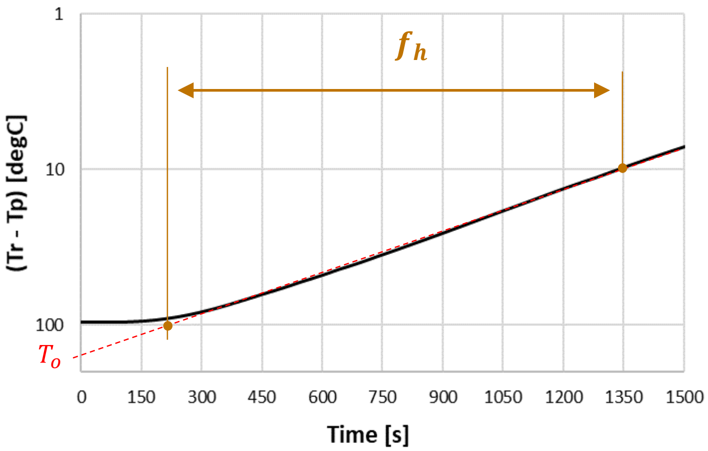


- F_{value} = equivalent time to neutralize the same number of bacteria of an ideal thermal cycle at temperature T_{ref}

Other process parameters

Furthermore, considering the function (Tr–Tp) in logarithmic scale, we obtain the plot in the right part.





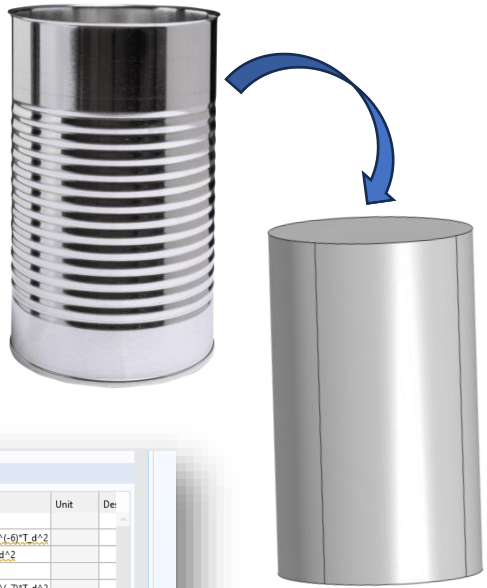
- **The penetration factor f_h** is the time necessary to reduce the difference between Tr and Tp by one logarithmic cycle.

- The **delay factor J_c** is the initial lag time before the internal temperature of a product begins to rise significantly during heating.

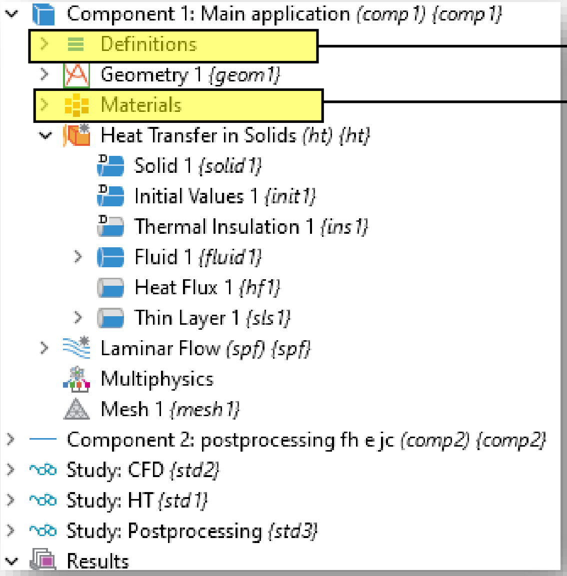
$$J_c = \frac{T_r - T_o}{T_r - T_{init}}$$

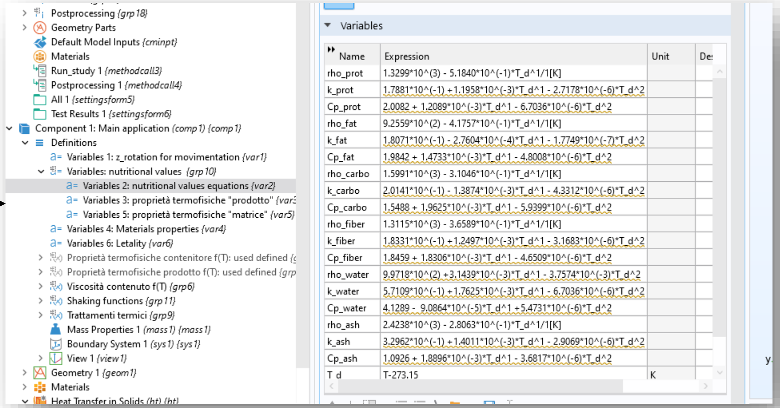
Model implementation

- A **thermo-fluid dynamic model** in COMSOL environment was built to analyze the **heat penetration** inside the box.



- **Thermal properties** of product are made of **analytical equation** refers to the **nutritional values**.

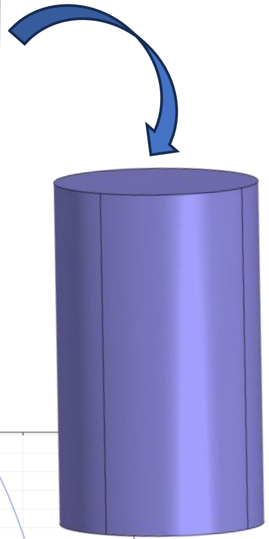




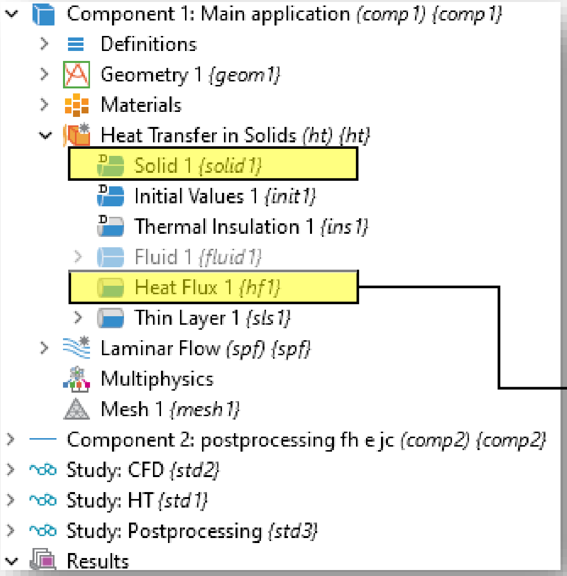
Name	Expression	Unit	Des
rho_prot	1.3299*10^(3) - 5.1840*10^(-1)*T_d^1/1[K]		
k_prot	1.7881*10^(-1) +1.1958*10^(-3)*T_d^1 - 2.7178*10^(-6)*T_d^2		
Cp_prot	2.0082 + 1.2089*10^(-3)*T_d^1 - 6.7036*10^(-6)*T_d^2		
rho_fat	9.2559*10^(2) - 4.1757*10^(-1)*T_d^1/1[K]		
k_fat	1.8071*10^(-1) - 2.7604*10^(-4)*T_d^1 - 1.7749*10^(-7)*T_d^2		
Cp_fat	1.9842 + 1.4733*10^(-3)*T_d^1 - 4.8008*10^(-6)*T_d^2		
rho_carbo	1.5991*10^(3) - 3.1046*10^(-1)*T_d^1/1[K]		
k_carbo	2.0141*10^(-1) - 1.3874*10^(-3)*T_d^1 - 4.3312*10^(-6)*T_d^2		
Cp_carbo	1.5488 + 1.9625*10^(-3)*T_d^1 - 5.9399*10^(-6)*T_d^2		
rho_fiber	1.3115*10^(3) - 3.6589*10^(-1)*T_d^1/1[K]		
k_fiber	1.8331*10^(-1) +1.2497*10^(-3)*T_d^1 - 3.1683*10^(-6)*T_d^2		
Cp_fiber	1.8459 + 1.8306*10^(-3)*T_d^1 - 4.6509*10^(-6)*T_d^2		
rho_water	9.9718*10^(2) +3.1439*10^(-3)*T_d^1 - 3.7574*10^(-3)*T_d^2		
k_water	5.7109*10^(-1) +1.7625*10^(-3)*T_d^1 - 6.7036*10^(-6)*T_d^2		
Cp_water	4.1289 - 9.0864*10^(-5)*T_d^1 +5.4731*10^(-6)*T_d^2		
rho_ash	2.4238*10^(3) - 2.8063*10^(-1)*T_d^1/1[K]		
k_ash	3.2962*10^(-1) +1.4011*10^(-3)*T_d^1 - 2.9069*10^(-6)*T_d^2		
Cp_ash	1.0926 + 1.8896*10^(-3)*T_d^1 - 3.6817*10^(-6)*T_d^2		
T_d	T-273.15	K	

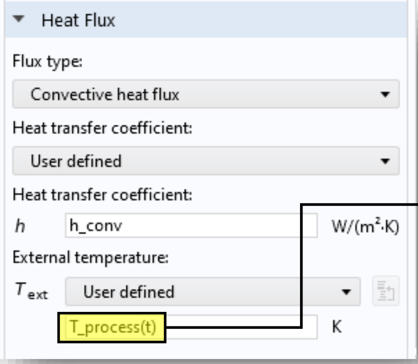
Model implementation

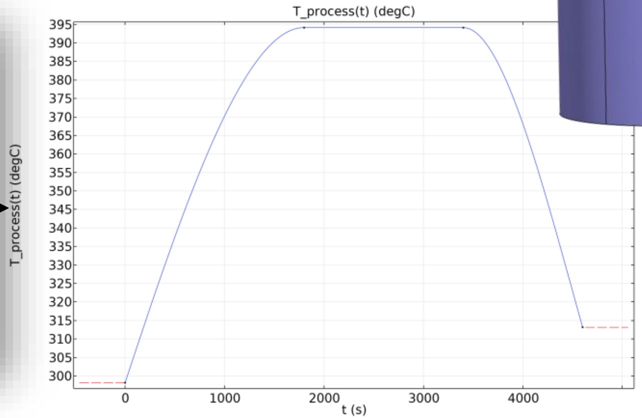
- **Conductive heat exchange** was **solved inside** the can (but also natural or forced heat exchange can be simulated, according to the physical states of the product and the specific treatment).



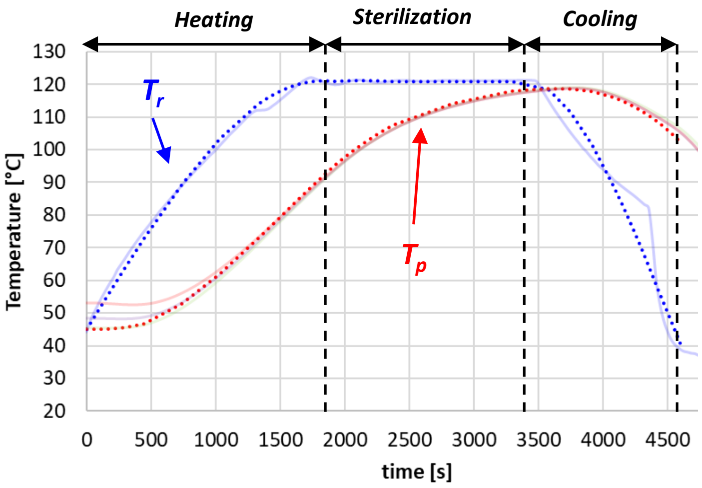
- **Convective heat flux** was imposed **along** the wall of **the can**, according to process temperature





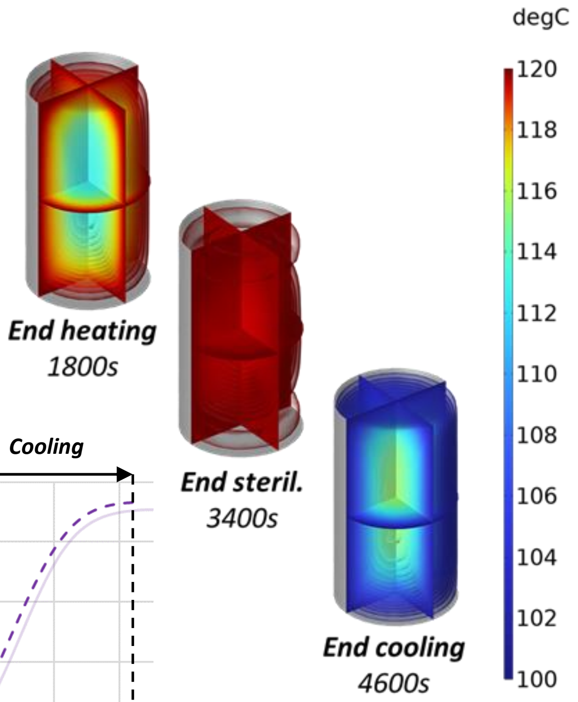


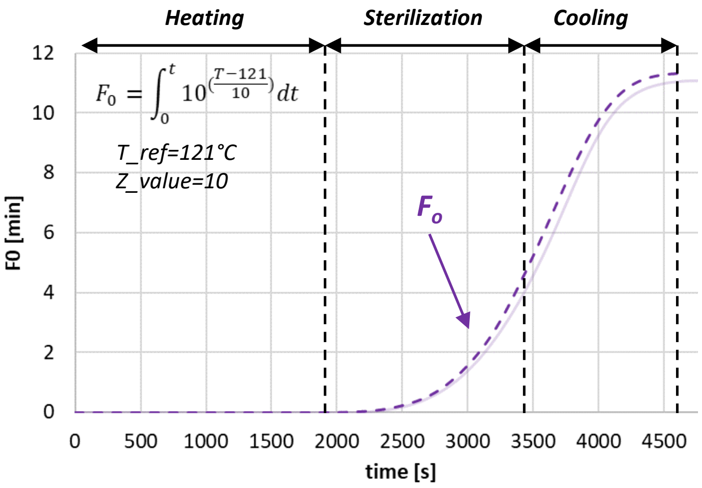
NUM-EXP Validation



- <u>Container = Tinplate</u>
- <u>Content = Meat sauce</u>
- <u>Thermal cycle = Standard</u>

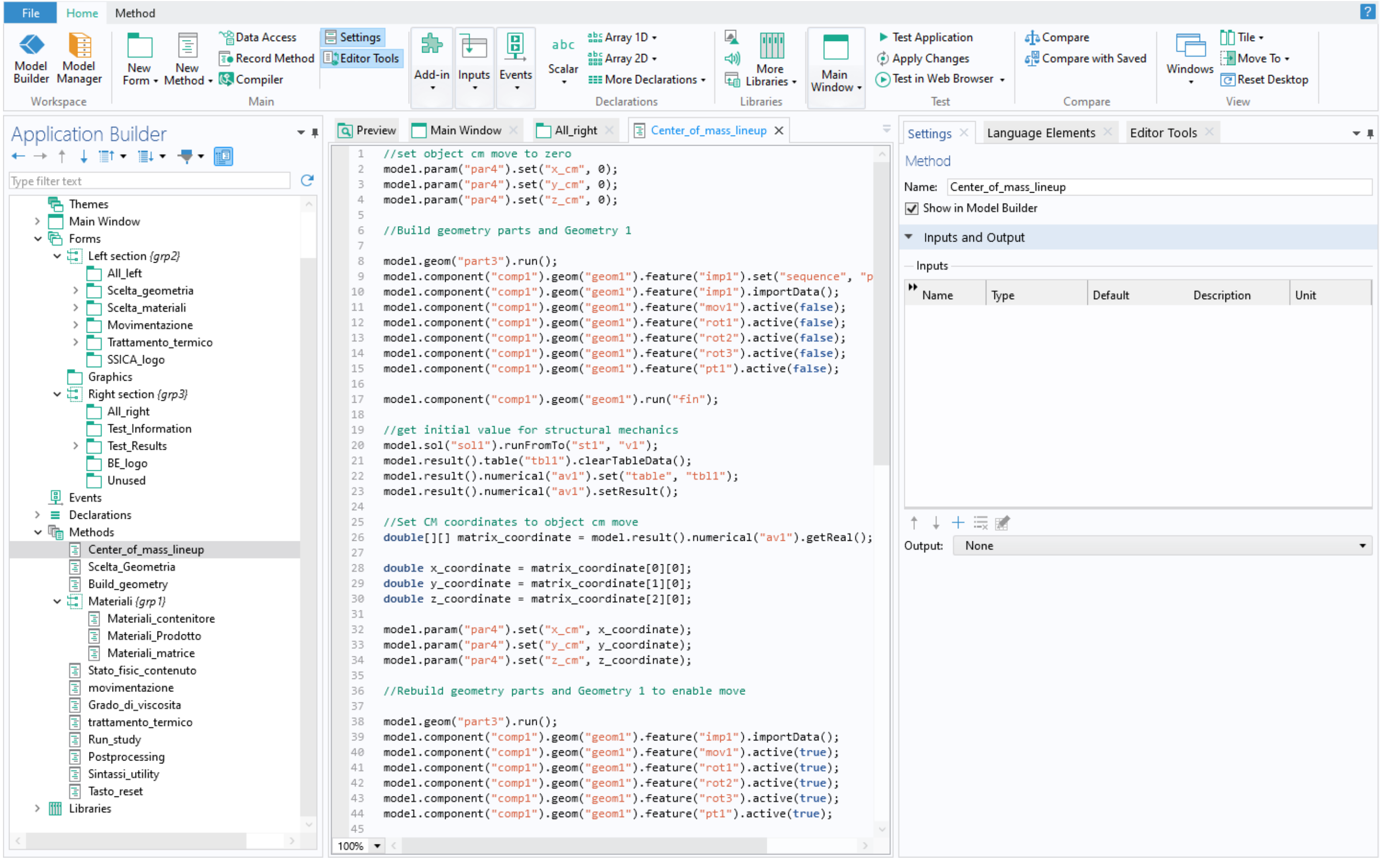
(heating/sterilization/cooling).





- Checking out our numerical temperature profile with some experimental curves, we achieve a **very good agreement** also in the lethality factor behavior.

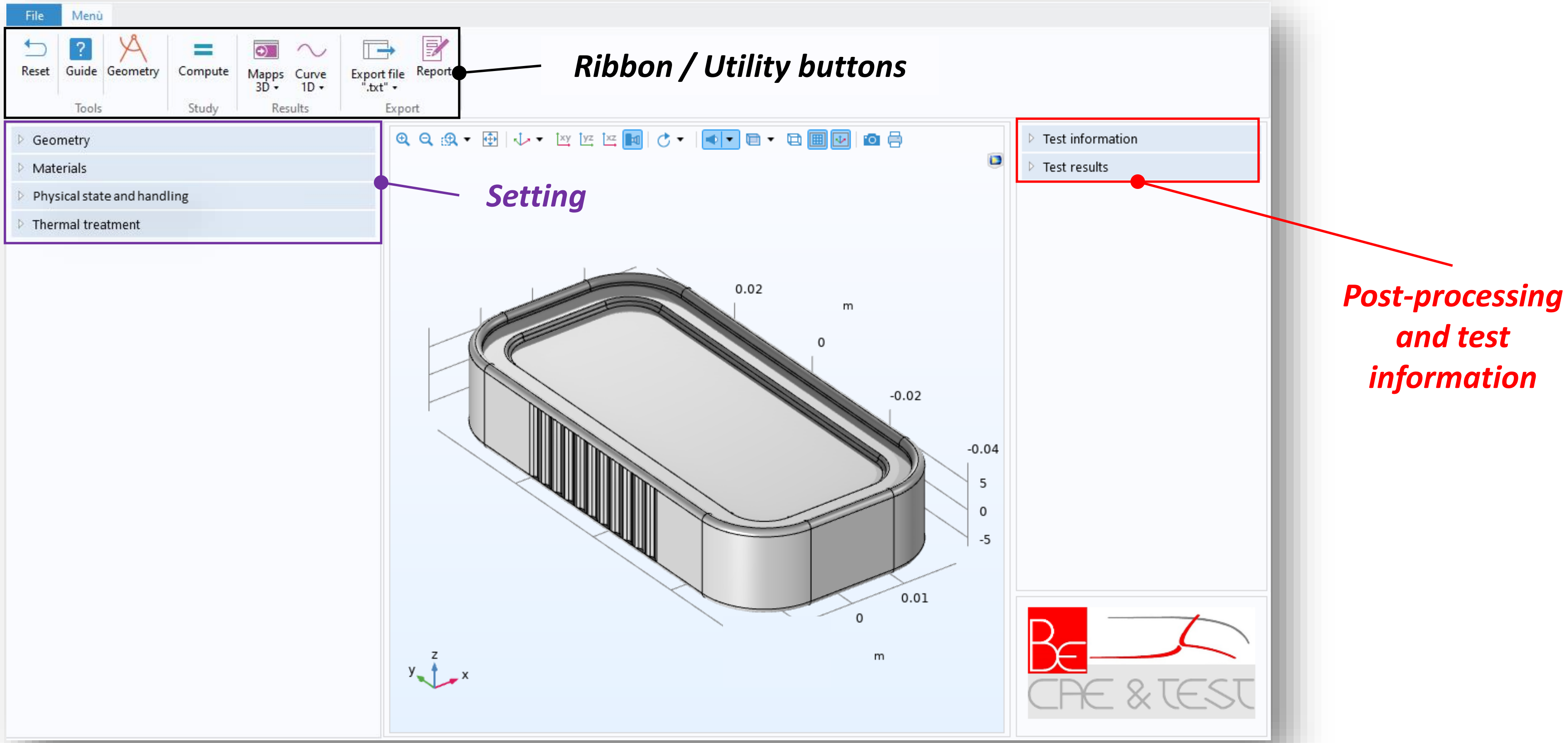
Forms and methods: to make the model user-friendly



- **Application builder** interface was used to design a **simplified graphics** interface for all customers, from data entry to the result.
- Several **methods** and **form** have been implemented to **manage** the various **features** of the application.

Let's take a closer look at how the app works in the next slides.

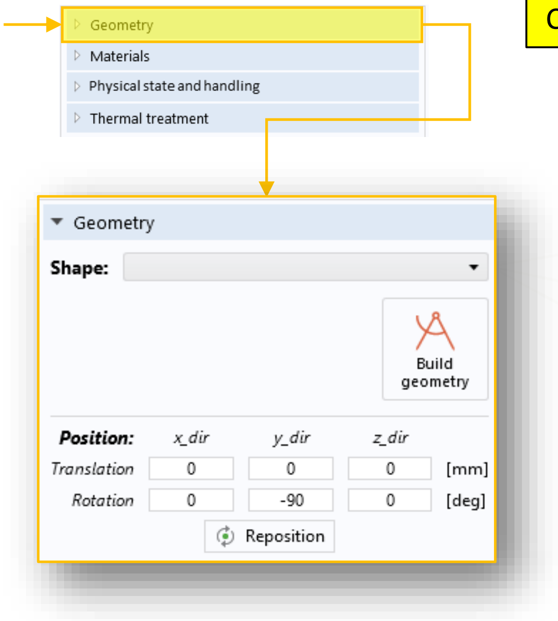
App UI



File
Menù
Reset
Guide
Geometry
Compute
Mapps 3D
Curve 1D
Export file ".txt"
Report
Tools
Study
Results
Export
Ribbon / Utility buttons
Geometry
Materials
Physical state and handling
Thermal treatment
Setting
Test information
Test results
Post-processing and test information
0.02
m
0
-0.02
-0.04
5
0
-5
0.01
0
m
z
y
x

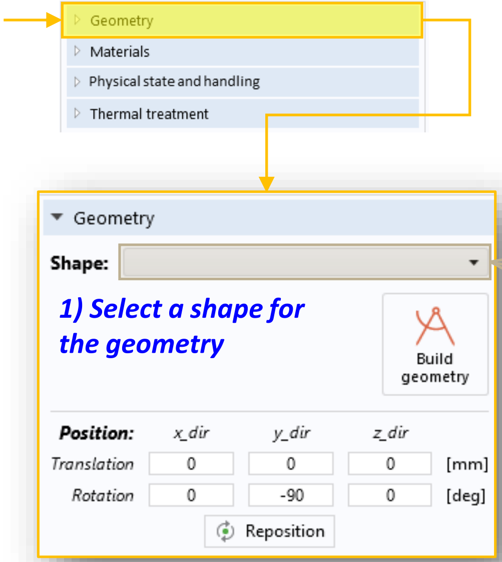
App UI: Geometry

Choose the **shape** of the **container** and the main **dimensions**.

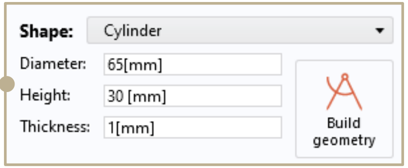


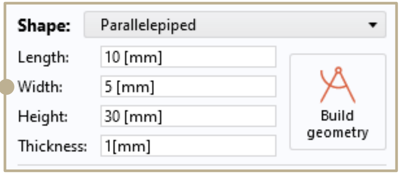
App UI: Geometry

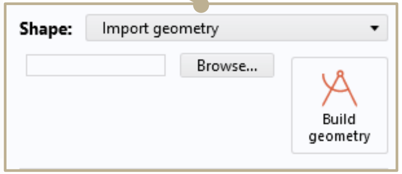
Choose the **shape** of the **container** and the main **dimensions**.

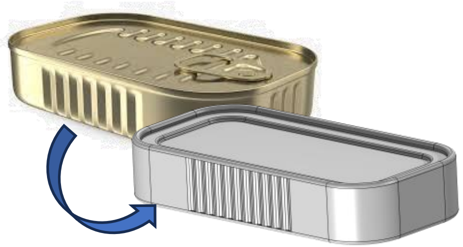


2) Positioning and orientation





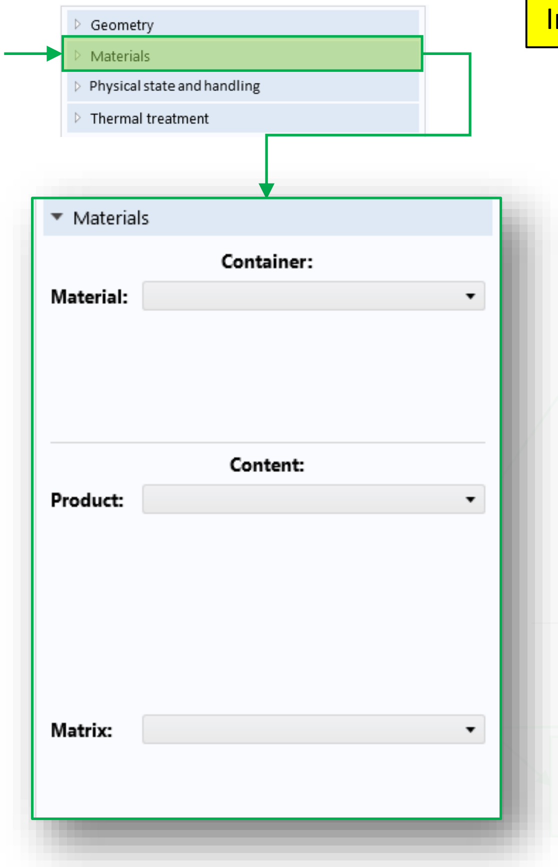




- **Rotate** the container if is necessary

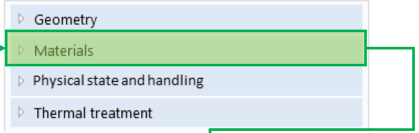
App UI: Materials

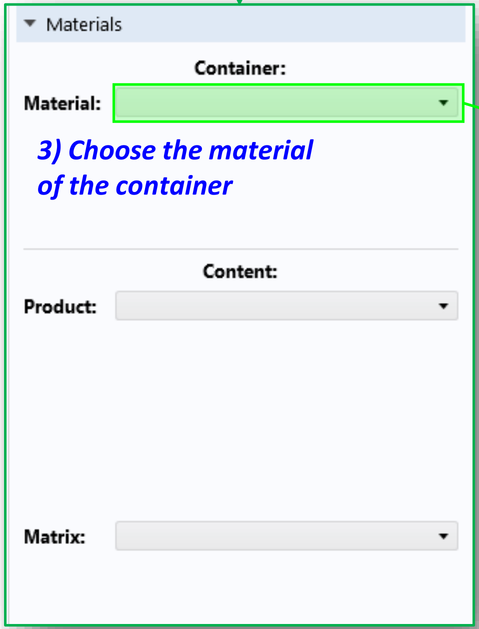
Insert **thermal properties** throw a pre-implemented materials library or a “user defined” settings.



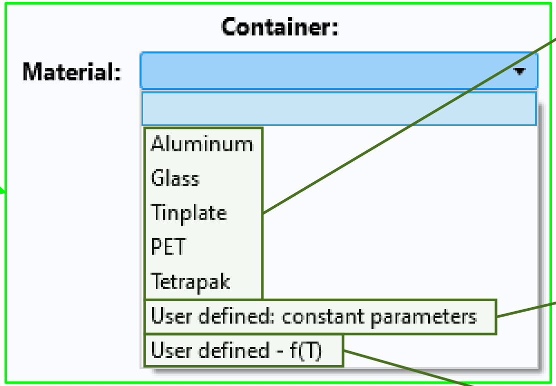
App UI: Materials / Container

Allocate **thermal properties** throw a pre-implemented materials library or a "user defined" settings.



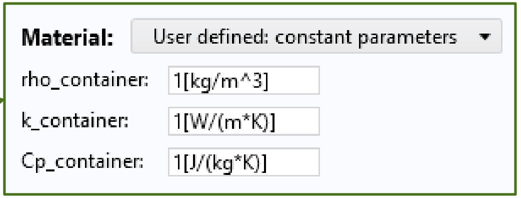


3) Choose the material of the container

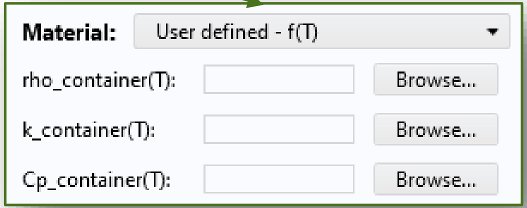


Pre-implemented materials library

- *In the "costant parameters" setting, user must **import** thermal properties value as a **single value**.*

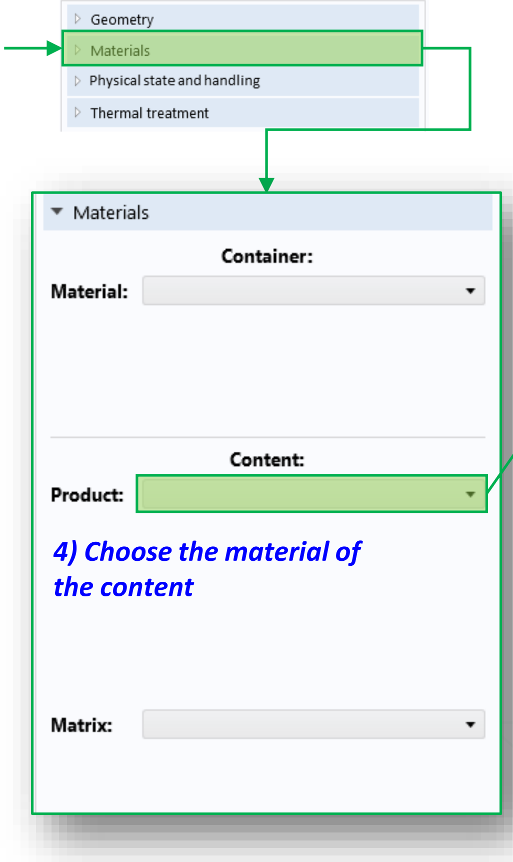


- *In the "f(T)" parameters setting, user must **import** thermal properties as **curves functions of temperature**.*

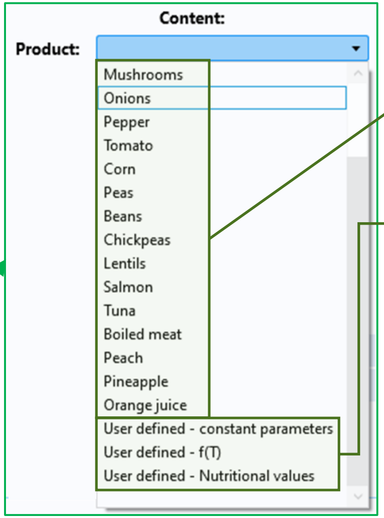


App UI: Materials / Content

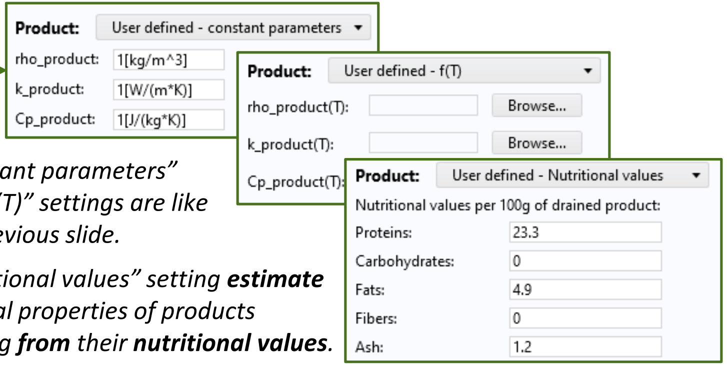
Insert **thermal properties** throw a pre-implemented materials library or a “user defined” settings.



4) Choose the material of the content



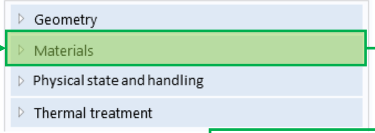
Pre-implemented materials library

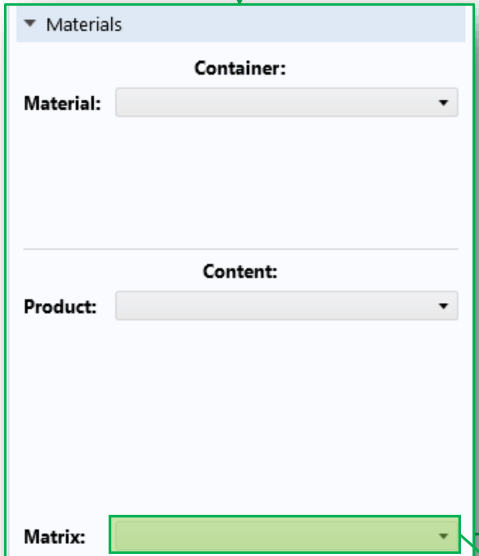


- *“Constant parameters” and “f(T)” settings are like the previous slide.*
- *“Nutritional values” setting **estimate** thermal properties of products starting **from** their **nutritional values.***

- *If **product is packed in a fluid matrix** (such as oil or Brine), it is necessary to specify the **total weight** and the **net weight** of the can; the app will calculate **averages** thermal properties between matrix and product as a function of the specified weights.*

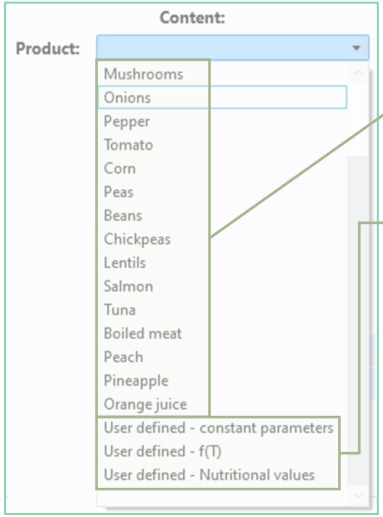
App UI: Materials / Content



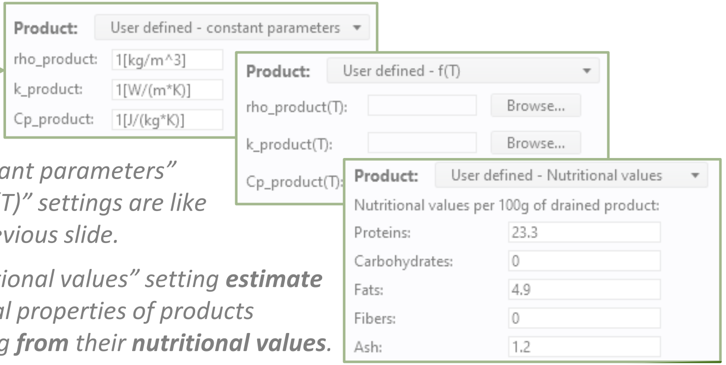


5) Specify if the content has biphasic states

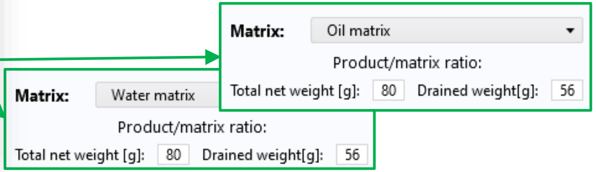
Insert **thermal properties** throw a pre-implemented materials library or a "user defined" settings.



Pre-implemented materials library

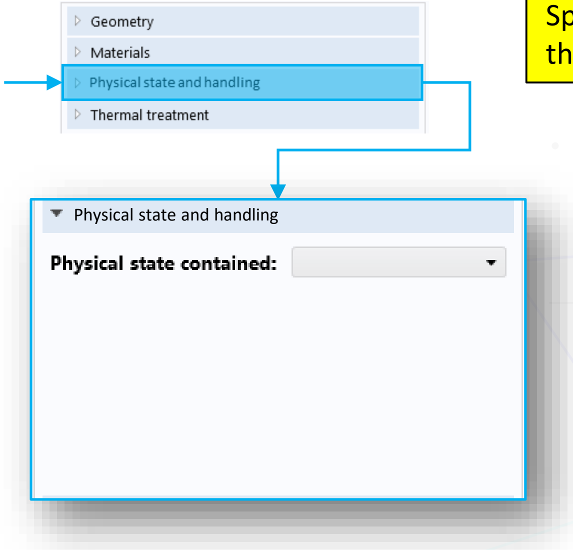


- *"Constant parameters" and "f(T)" settings are like the previous slide.*
- *"Nutritional values" setting **estimate** thermal properties of products starting **from** their **nutritional values**.*



- ***If product is packed in a fluid matrix** (such as oil or Brine), it is necessary to **specify** the **total weight** and the **net weight** of the can; the app will calculate **averages** thermal properties between matrix and product as a function of the specified weights.*

App UI: Physical state



Specify the **physical state** of the content. This will identify the **numerical model** for the **heat penetration**.

- "Solid" state simulate only a conductive heat exchange inside the can.
- "Liquid" state simulate both convective and conductive heat exchange inside the can.

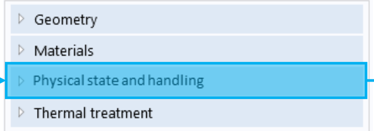
- *Since we are solving fluid dynamics, we must specify the degree of viscosity of the product*

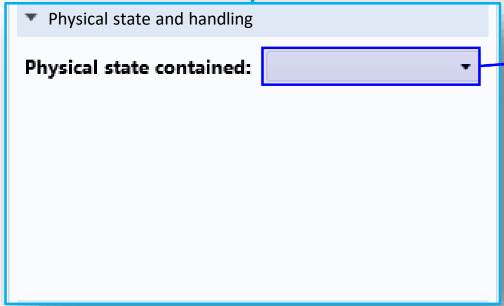
Water
Fruit juice 40%
Fruit juice 50%
Fruit juice 60%
Oil
User defined(T)

- *Specify the type of handling to change the convection model:*
  - *Static=natural convection flow;*
  - *Rotation=forced rotated flow;*

Static
Continous rotation
Oscillating rotation

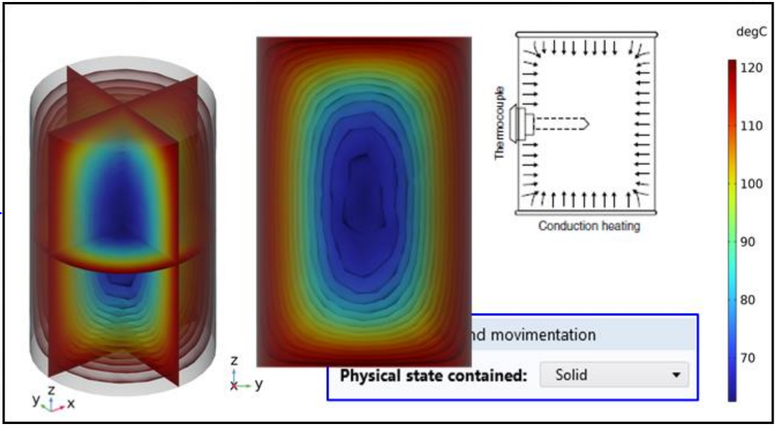
App UI: Physical state





Specify the **physical state** of the content. This will identify the **numerical model** for the **heat penetration**.

- "Solid" state simulate conductive heat exchange inside the can.



App UI: Physical state

- Geometry
- Materials
- Physical state and handling
- Thermal treatment

Physical state and handling

Physical state contained:

6) Choose an appropriate numerical approach

- "Liquid" state simulate convective heat exchange inside the can.

Physical states and handling

Content physical state: Liquid

Grade of viscosity:

Handling:

- Static
- Continous rotation
- Oscillating rotation

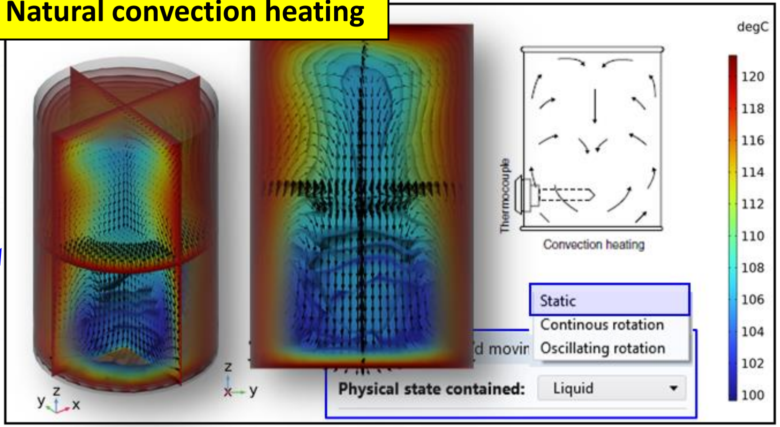
- *Since we are solving fluid dynamics, we must specify the degree of viscosity of the product*

- Water
- Fruit juice 40%
- Fruit juice 50%
- Fruit juice 60%
- Oli
- User defined(T)

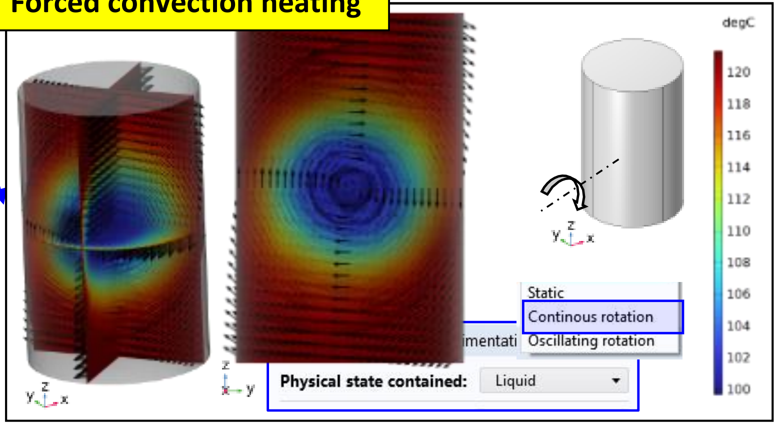
Specify the type of handling to change the convection model:

- ❑ *Static=natural convection fluid flow;*
- ❑ *Rotation=forced rotated fluid flow;*

Natural convection heating

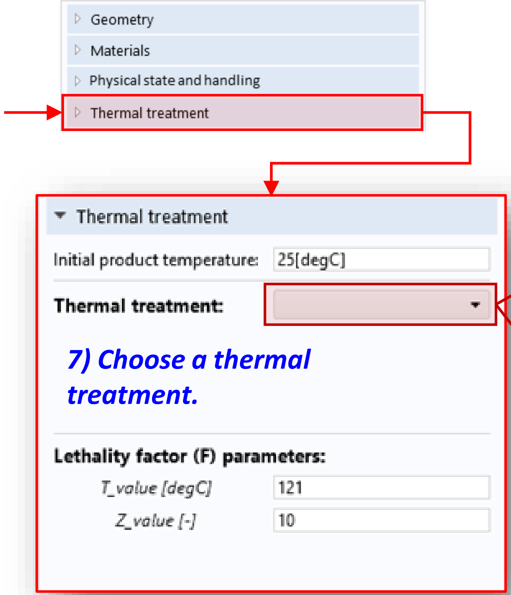


Forced convection heating



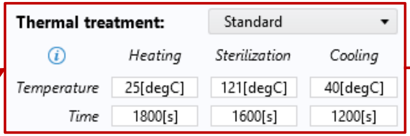
App UI: Thermal treatment

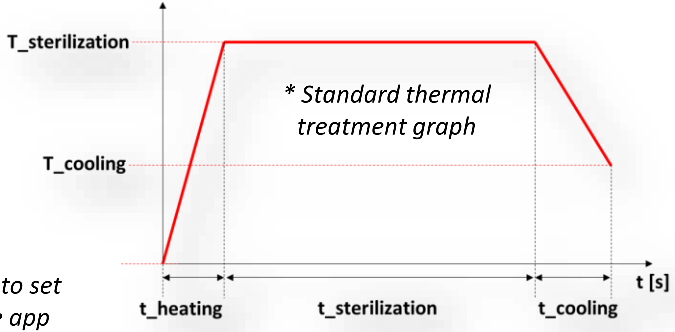
Specify the **thermal cycle**. Choose between "standard" or "user defined" mode.



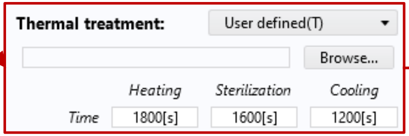
7) Choose a thermal treatment.

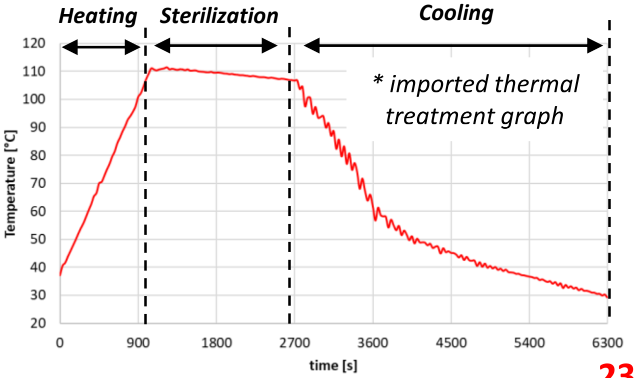
8) Specify the characteristics of the bacterium we want to neutralize.





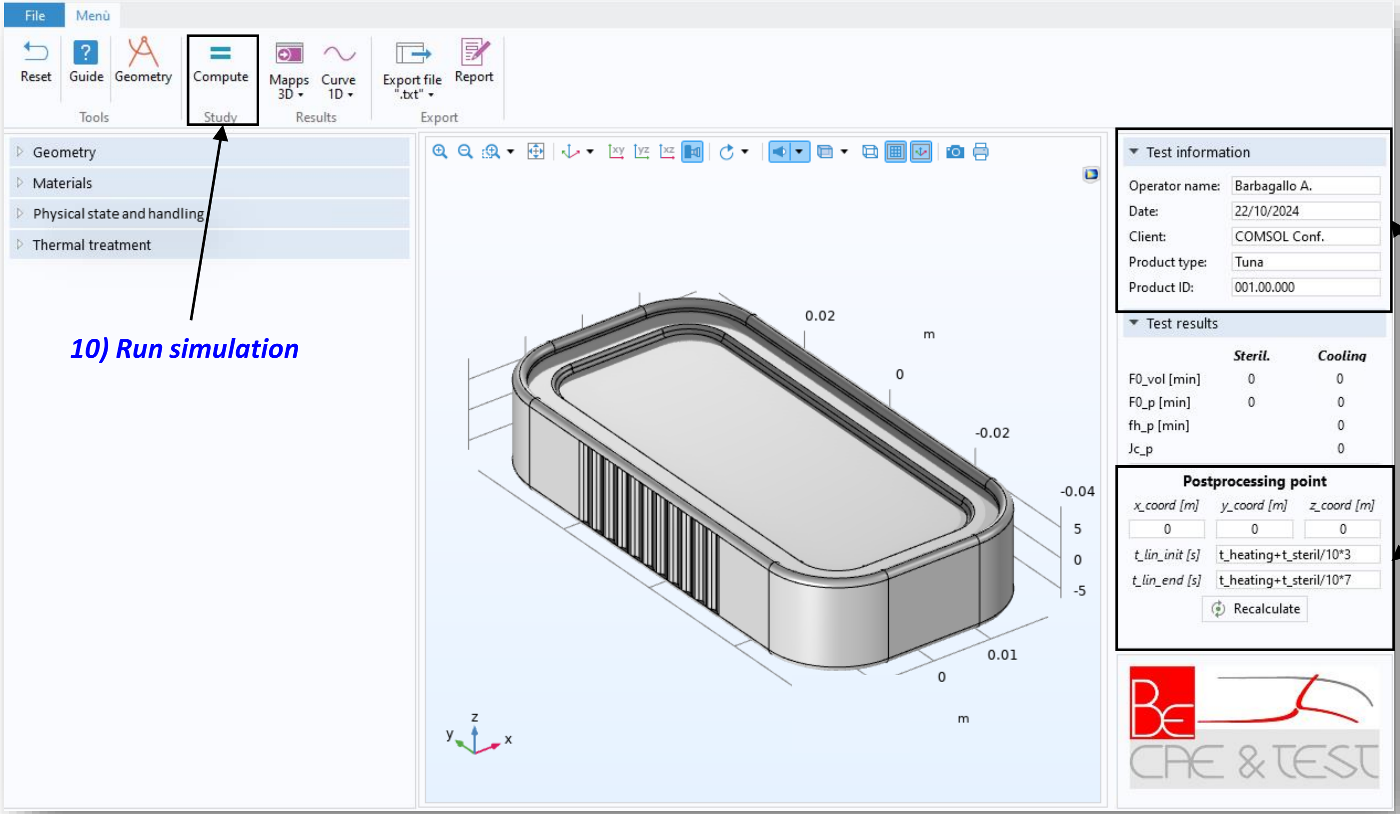
- *In the "standard" treatment setting, we need to set the limit values of the thermal profile, and the app will create the curve as in the plot above.*





- *Use the "user defined" setting to import a particular thermal curve. In this case, we need only specify the duration time of the three step of the treatment.*

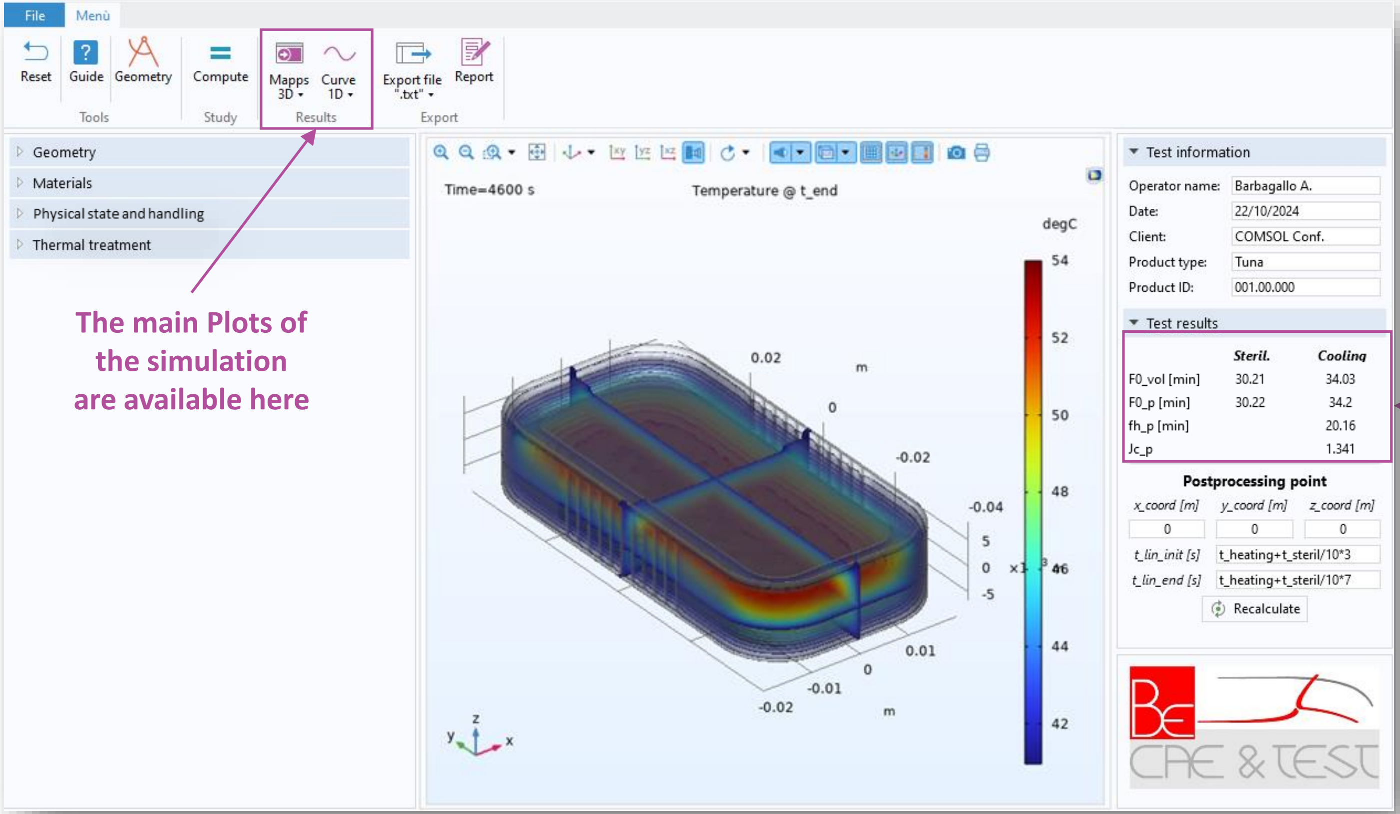
App UI: start simulation



10) Run simulation

9) Fill the test information section and enter the coordinates of the point you want to analyse (by default the origin).

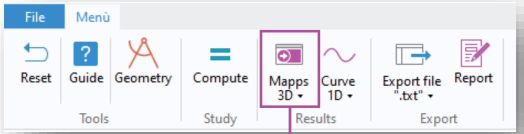
App UI: Results

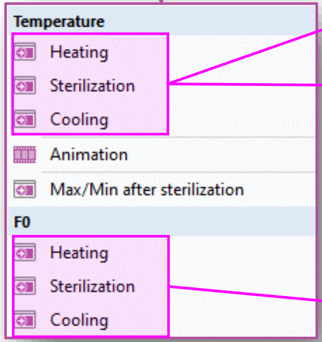


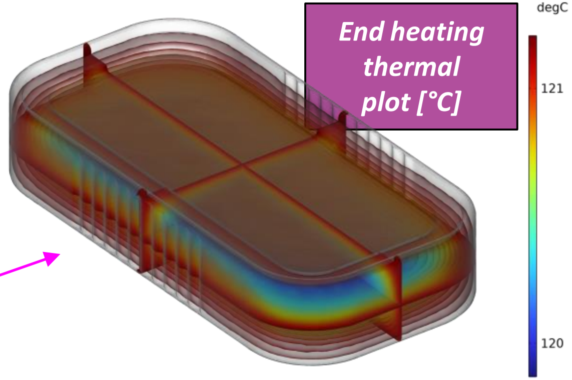
The main Plots of the simulation are available here

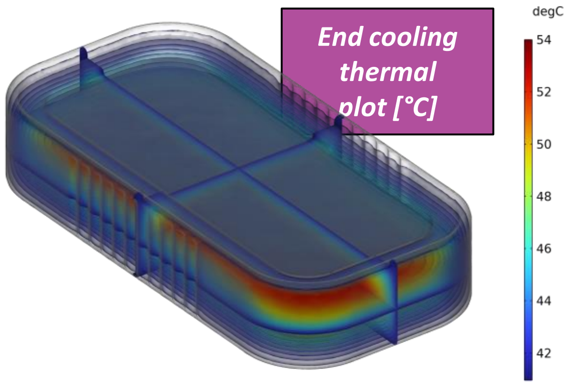
The main results of the simulation are shown here

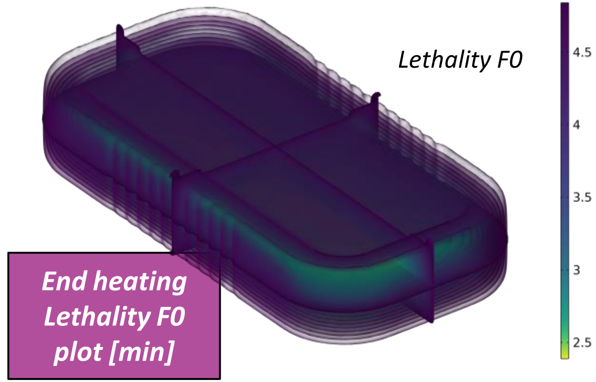
App UI: 3D Results



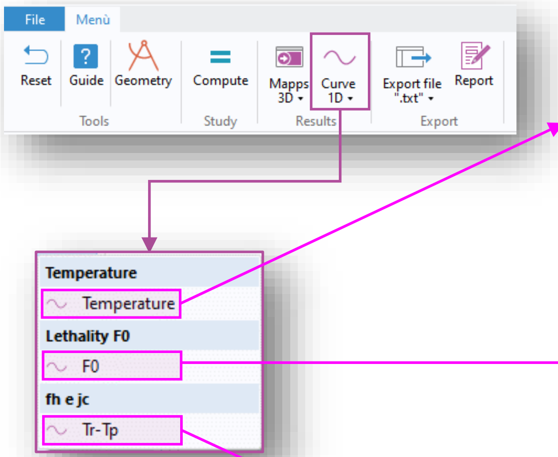


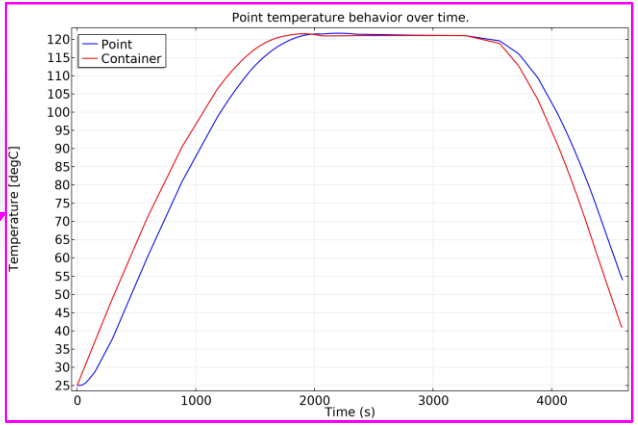


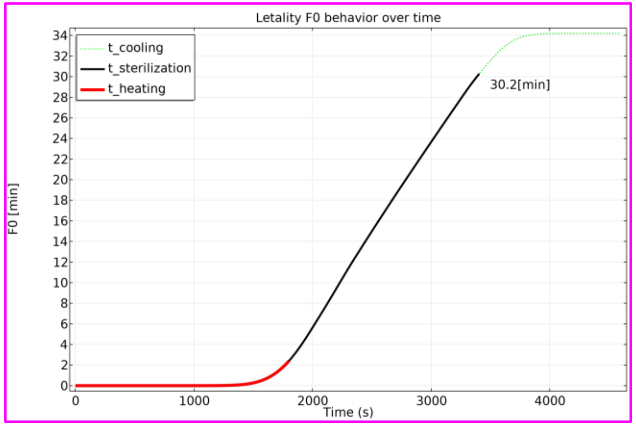


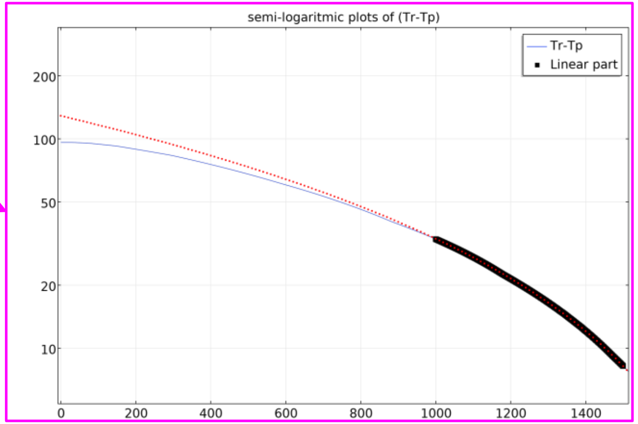


App UI: 1D results

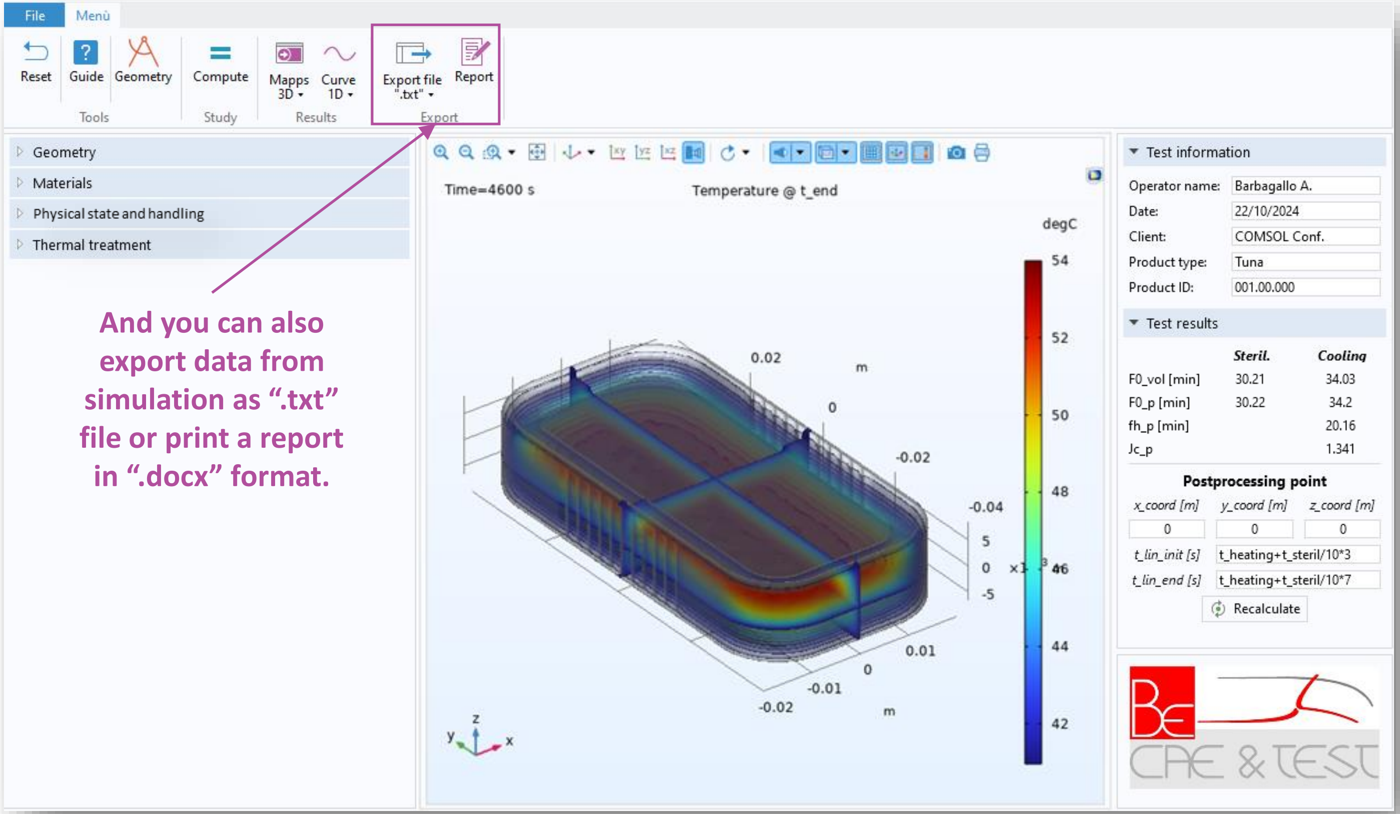








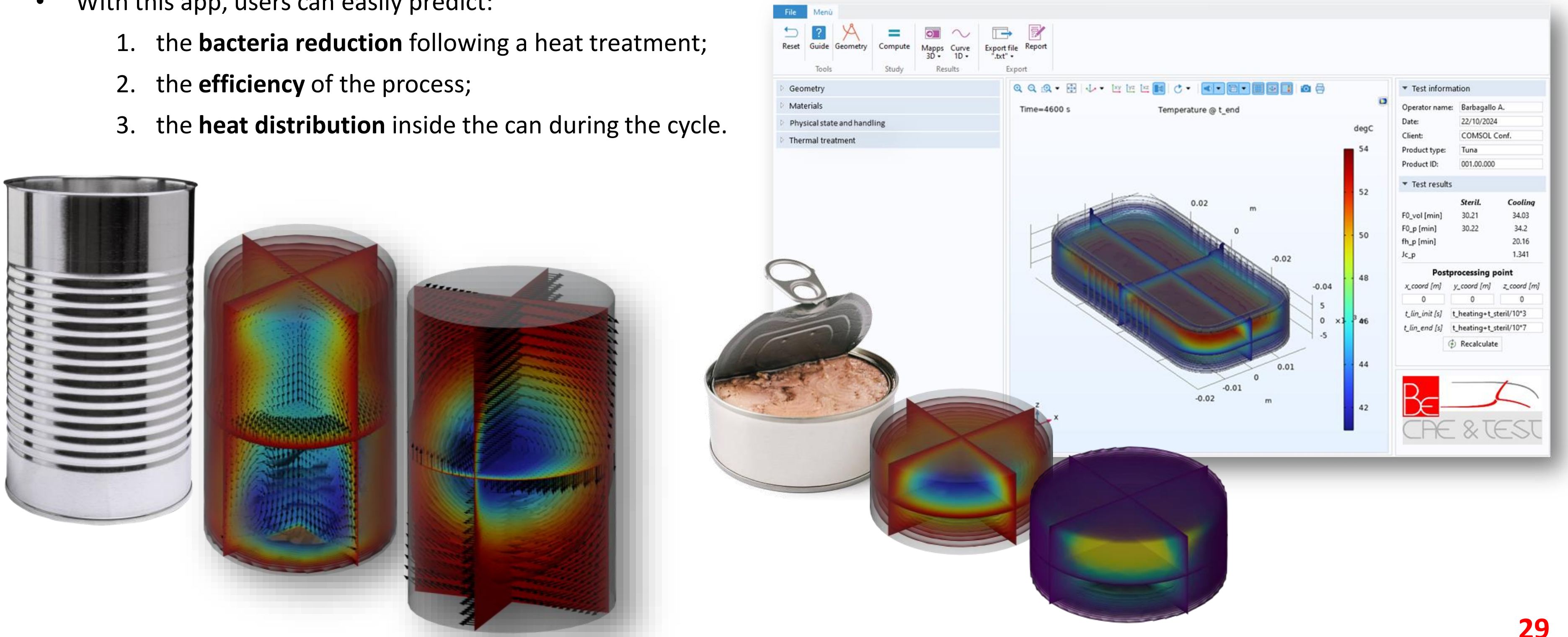
App UI: Export



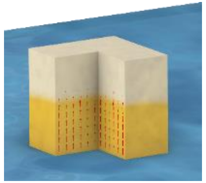
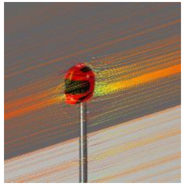
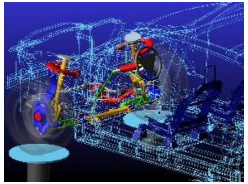
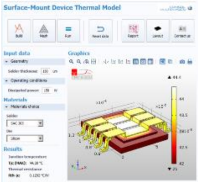
And you can also export data from simulation as ".txt" file or print a report in ".docx" format.

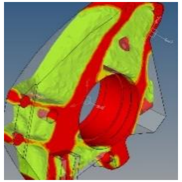
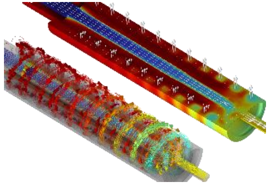
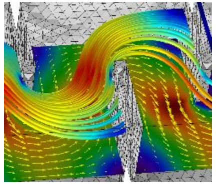
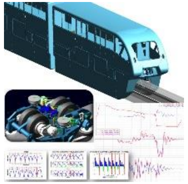
To summarize…

- Several protocols and industrial treatment are made up to **guarantee food safety** and preserve its quality.
- With this app, users can easily predict:
    1. the **bacteria reduction** following a heat treatment;
    2. the **efficiency** of the process;
    3. the **heat distribution** inside the can during the cycle.



Thank you all for your attention!

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