FEMCE - A 3D finite element simulation tool for magnetic refrigerants.
Tutorial

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This document serves as a tutorial to FEMCE, guiding the user on how to evaluate the performance of a magnetic refrigerant. The layout will be the same present here https://doi.org/10.1063/1.3487943.

Step 1 - Create the simulation volume

FEMCE user interface is now separated into 4 individual sections: `Load properties`, `Create model`, `Create mesh`, `Simulation`.

To simulate the magnetic field of the refrigerant, we also need to simulate the magnetic field in the space around it (the open boundary problem). So let's first create a container, at least 5 times larger than the refrigerant. **Start by pressing "Create model"**. Then, add the dimensions WDL as 8.25, 8.25, 0.2, keeping the "Units" rocker as "cm" (Figure 1) and then **press the "Add"** button.

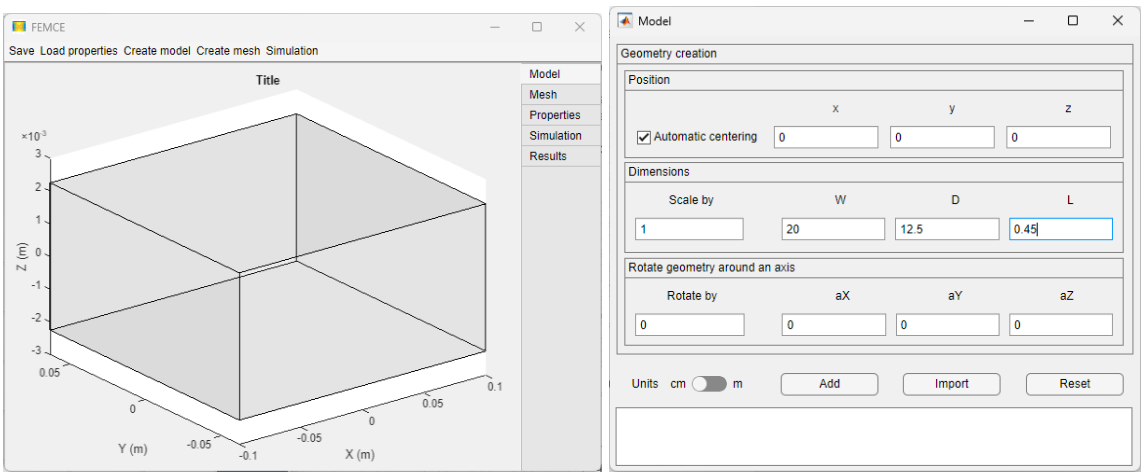

Figure 1: Model creation

Next, do the exact same to add the rectangular refrigerant, by placing the dimensions 1.65, 1.65, 0.04 (cm), and click "Add". You should now have a cuboid inside a container (Figure 2). If at any point you want to restart your model creation, click "Reset", which will empty the model. Once you are done, you may close the "Model" panel and proceed to the next step.

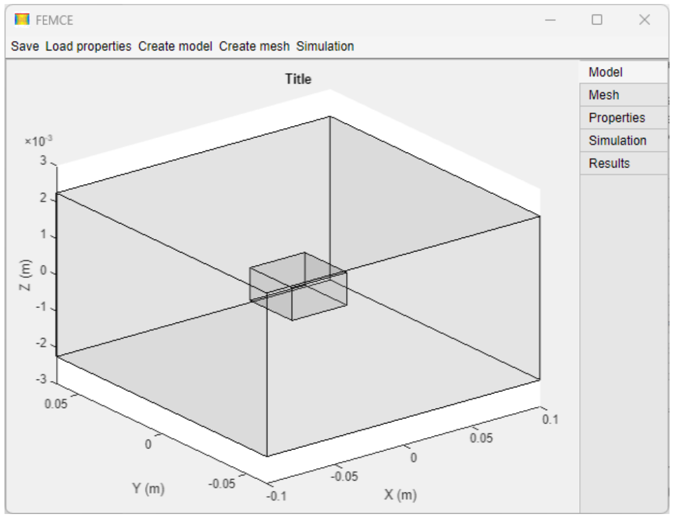

Figure 2: Adding the refrigerant.

Step 2 - Generate the finite element mesh

Now, we are going to create a mesh for the model. **Press the "Create mesh" tab**, next to the "Create model" tab. Users can set a target maximum and minimum element size of the mesh, or leave these values at 0 to let MATLAB choose the "best" parameters. The automatic mesh generation can fail, in which case the user should place target values for the mesh.

Set the maximum element size to 2 and the minimum to 0.1 and **press the "Create Mesh" button**. Now, on the message terminal you should see that the mesh generation was a success. You can view the mesh by selecting the "Mesh" tab, below the "Model" tab in FEMCE main panel (Figure 3). FEMCE mesh is a full tetrahedral mesh, but for visualization purposes only the surface triangles of the model are displayed. You can now close the "Create mesh" panel if desired.

For further flexibility with mesh generation, FEMCE allows user to input a list of edges of the model, on which they desire further increased resolution. Just add to the table the edge number and a "Local refinement size", set "Local refinement" to "on" and click "Create Mesh".

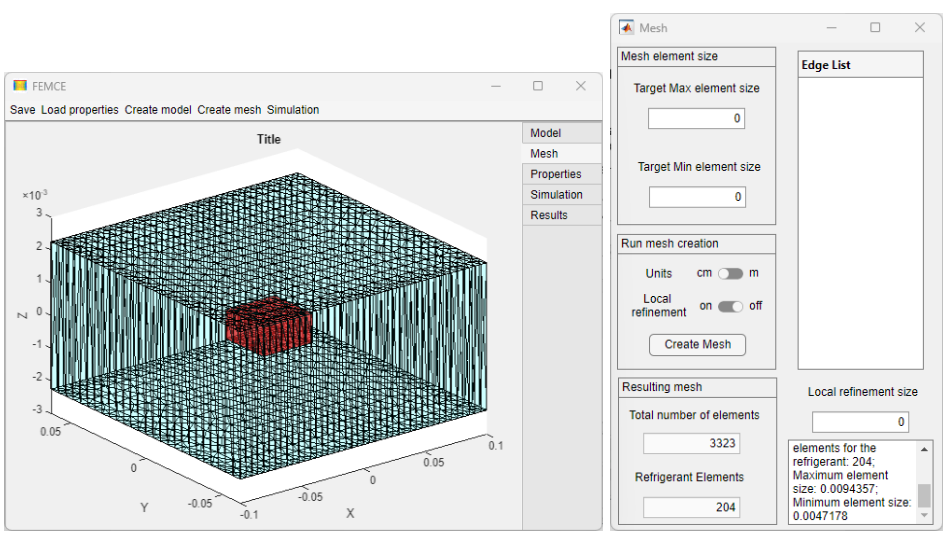

Figure 3: Mesh generation.

Step 3 - Adding the refrigerant properties

The refrigerant is described by its thermomagnetic properties: M, C_p, ΔT. To facilitate users, FEMCE github https://github.com/rkiefe/femce provides a complete data set that reasonably replicates Gadolinium, from mean field theory (MFT). **Download the `MFT_Gd` folder**. These properties must be in the following units:

M emu/g

Cp J/g/K

dT K

H Oe

T K

Next, open the "Load properties" panel, next to the "Save" tab. Now, you can either paste the folder directory in the "Root Folder" (for example `C:/Users/rkiefe/Documents`) and click "Load", or press the "Load" button immediately, which will open a file explorer for you to select the target folder. Once loaded, each property successfully loaded will be shown in the message panel. Now, you can press "Update Graphics" to plot the data in the FEMCE main panel on the "Properties" tab (4).

Magnetization M data must be a matrix where each column corresponds to M at a different magnetic field values and a constant temperature, and each row corresponds to M at a different temperatures but at a constant magnetic field. You must also provide the H and T arrays of that data. You can load files individually, with any name desired, but for "Load All" the files must be named "Cp", "M", "TofCp", "TofM", "HofCp", "HofM" accordingly. You can also load the temperature change ($\Delta T(H, T)$) data just like you would the magnetization and specific heat, if you want the program to interpolate that information instead. C_p can be provided as solely temperature dependent, or you can select "Use constant Specific Heat?" and provide the value in J/g/K.

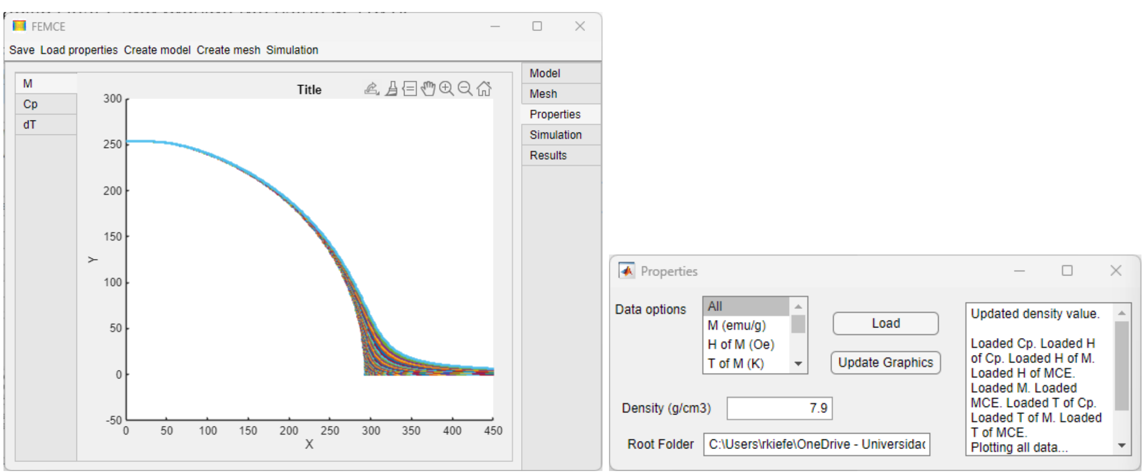

Figure 4: Loading material properties.

Step 3 - Run a simulation

Now, the user is ready to run a simulation. Press the "Simulation" tab, next to the "Create mesh" tab. Set the applied magnetic field in the "Hx", "Hy" and "Hz" and set the temperature of the refrigerant. Then, in the "Run" panel you can select which simulation you desire, such as magnetic field, magnetocaloric effect and rotating magetnocaloric effect.

The rotating magnetocaloric effect is an emerging alternative method of inducing the magnetocaloric effect (https://doi.org/10.1088/2515-7655/ad1c61). It uses the demagnetizing field to generate the change in temperature, by rotating a sheet of Gd inside a uniform magnetic field. For the rotating magnetocaloric effect, FEMCE considers the user's applied magnetic field as the initial configuration and then rotates that magnetic field by 90° around the y axis. The change in internal magnetic field from the rotation of the applied field will induce the rotating magnetocaloric effect (see https://doi.org/10.1088/2515-7655/ad1c61).

Press the MCE option and wait a few seconds. The results are then displayed in the "Simulation" tab below the "Properties" tab (Figure 5).

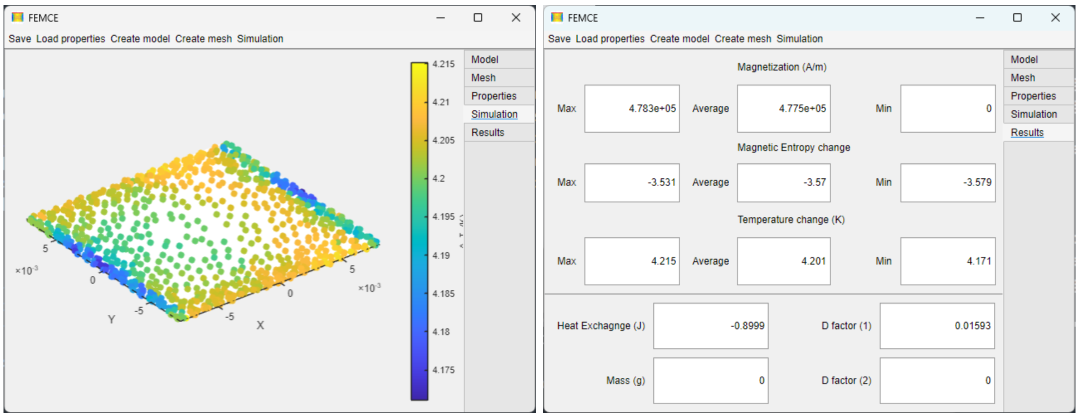

Figure 5: The heterogeneous ΔT (left) and the results table (right).

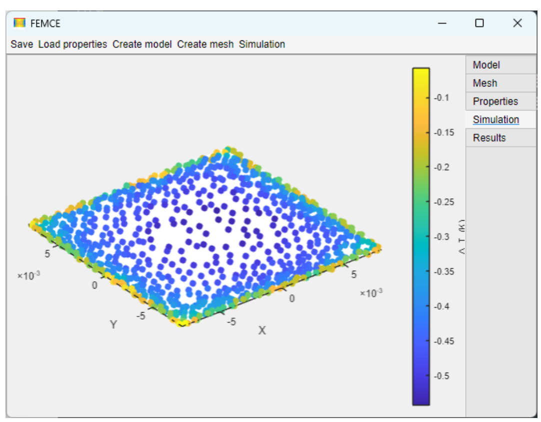

Figure 6: The heterogeneous demagnetizing field induced magnetocaloric effect.