Cluster Simulation of Refrigeration Systems

Using COMSOL Multiphysics on HPC clusters to develop environmentally friendly refrigeration systems for transportation of perishable goods.

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Environmental and energy concerns related to fossil fuels have sparked interest in developing "green" and environmentally friendly systems that are both efficient and economically feasible. To that end, focusing on energy intensive industries that have higher environmental impact is the most effective approach. Among the top five energy-consuming industries is the food sector (Energy Information Administration), which, including food transportation, produces 20% of the total greenhouse gas emissions (Tassou et al.).

The refrigerated vehicles used for food transportation (e.g., refrigerated truck trailers) predominantly rely on conventional diesel engine driven refrigeration units. In addition to the low efficiency of these refrigeration units, their greenhouse gas emissions are about 40% of the emissions from the refrigerated vehicle's engine itself (Tassou et al., 2009). The main reason for the relatively low efficiency of transport refrigeration systems, compared to the stationary ones, is the wide range of operating conditions as well as space and weight constraints. Recently, strict regulations on energy consumption and emissions in addition to rising demand in the food market have put enormous pressure on the food industry, especially the food transport sector, to reduce emissions and environmental footprints. That would require developing refrigerated systems that rely on clean energy technologies and are fundamentally different than the conventional diesel-engine-driven refrigeration systems.

Sunwell Technologies Inc., which is the global leader in variable state slurry ice (Deepchill™) production, storage and distribution, has developed refrigerated units that solely rely on Deepchill™ thermo batteries. The size of a refrigerated unit can vary between a small box and the size of a truck trailer. The Deepchill™ thermo batteries are rechargeable and are designed to maintain the refrigerated unit at the desired temperature for 48 hours. The Deepchill is produced and stored in highly-efficient facilities (charging stations) that run on off-peak electricity, and therefore, have minimum environmental impact. To reduce the environmental impact even further, the electricity could be supplied to these facilities by renewable resources; for example, wind or solar. Furthermore, the cooling fluid (Deepchill™) is 100% recyclable and environmentally friendly, because it consists of water and salts, which are benign to the environment.

Deepchill™ cooling fluid is 100% recyclable and environmentally friendly.

Heat and Fluid Simulations

The Computational Multiphase Flows group at UMass Dartmouth has been using COMSOL Multiphysics to provide simulation support to Sunwell's experimental efforts in developing the Deepchill™ thermo battery technology. Computational simulations are a useful and cost-effective means to complement and leverage experiments, which are typically difficult to perform due to the large size of the refrigerated systems, and are associated with high costs and long completion times, especially at the early design stages. COMSOL Multiphysics was used to perform simulations of heat transfer and fluid dynamics in the refrigerated system. Running COMSOL Multiphysics on the UMass Dartmouth's High Performance Computing (HPC) cluster enables the use of three-dimensional (3D) models with fine meshes and excellent completion time that will ultimately increase the accuracy and enhance our understanding of the results.

COMSOL Multiphysics models, varying from 2D-axisymmetric to full 3D, are utilized to investigate specific design criteria, including the thermal load on the system, average and maximum temperatures of specific domains, insulation performance and natural convection, all of which is measurable either via probes

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during the solution process and/or afterwards in the results section.

HPC Cluster Simulations

Large-scale simulations with fine meshes and thus high memory requirements are ported to the UMass Dartmouth's HPC cluster, where COMSOL's direct solver MUMPS with distributed memory is used. Typical HPC cluster simulations utilize 1 to 3 nodes with 8 processor cores each and complete in half a day to a week, depending on the complexity of the underlying physics, e.g. coupled fluid dynamics and heat transfer, and the length of simulation time, which can go up to 48 hours.

A majority of the HPC cluster simulations are run through the terminal by creating a clustersimple batch. For example, a typical command would resemble the following format:

comsol -clustersimple batch -nn [A] [-mpirsh ssh] -inputfile [file.mph] -outputfile [file_results.mph]

Where *A* is the number of threads to use, *-mpirsh* informs the system of which network system to use, and *file.mph* and *file_results.mph* are the COMSOL Multiphysics model file and eventual results file, respectively. The current progress may be reported to a logfile via the *-batchlog [logfile.log]* command, and is used at the end of the foregoing command line. The current iteration number, time step, etc. (same as the log tab in the COMSOL Multiphysics GUI) are reported.

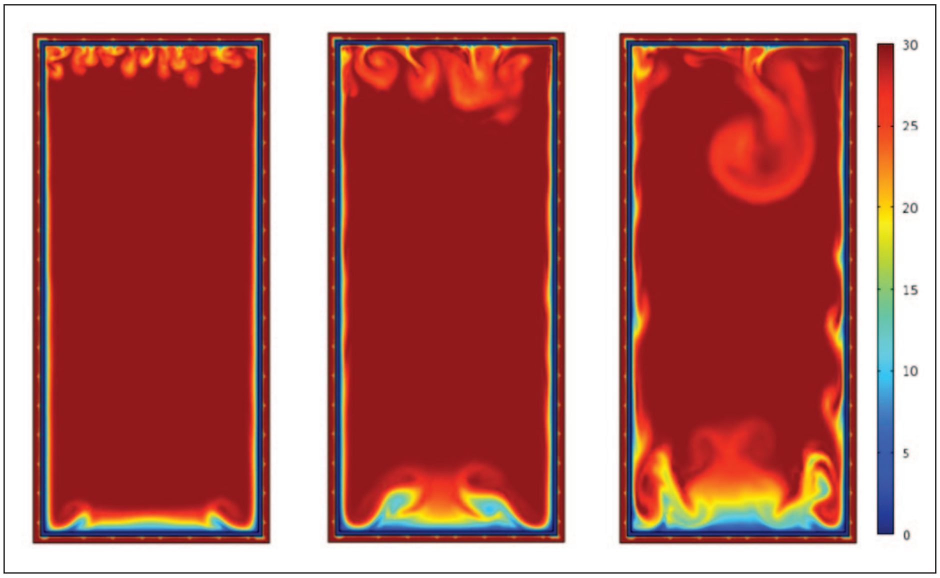

Figure 1: Natural convection and temperature distribution during cooling of a refrigeration unit by using the Deepchill™ thermo batteries (left to right: t = 5, 8 and 12 seconds).

In situations where probes are required to read live data as the simulation is running, interactive sessions from a workstation to the HPC cluster are utilized. Similar parallel computing parameters, for example, number of threads, are entered in the *Study > Job Configurations > Cluster Computing* tab. Ultimately, this provides the same GUI as workstation simulations, but with the computational power of a HPC cluster.

Results

Figure 1 presents a two-dimensional COMSOL Multiphysics simulation of a refrigerated unit that is cooled by the Deepchill™ thermo batteries. The unit is initially at 30 °C and the thermo batteries are at 0 °C. The simulation captures the Rayleigh-Taylor instabilities seen on the top surface. The instabilities occur because a layer of cold, heavy air is sitting on warm lighter air, which represents a configuration that is physically unstable. As can be seen, the instabilities grow and merge (middle image), and form large mushroom-type fluid structures (right image). The natural convection of air is also clearly seen on the sidewalls.

The COMSOL Multiphysics simulations in this project were performed on the UMass Dartmouth's Scientific Computing Group HPC cluster. The HPC cluster consists of 72 nodes, each with two Intel Xeon (quad-core) E5620 2.4 GHz processors and 24 GB of DDR3 ECC 1333 MHz RAM. There are 60 Nvidia Tesla M2050 GPUs on the HPC cluster. The nodes are connected via a Mellanox ConnectX-2 VPI Single-port QSFP QDR IB/10GbE PCIE 2.0 HCA with a 10m IBM Optical QDR InfiniBand QSFP Cable, and run 64-bit Red Hat Enterprise Linux distribution version 5.5. COMSOL Multiphysics version 4.2 is utilized. ■

The refrigeration systems study team (from left): Mehdi Raessi, Stephen Codyer, Jessica Currie, and Vladimir Goldstein.

References

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Tassou et al. "Food transport refrigeration — Approaches to reduce energy consumption." *Applied Thermal Engineering* (2009): 1467-1477.