Packaged for Freshness with Realistic Simulation

Simulation of material and fluids with Abaqus FEA helps decrease development time while improving quality of innovative aseptic packaging

At the turn of this century, many experts compiled "Top-ten" lists for the greatest record-setting athletic performances, the best all-time songs, the top news stories, and many other social achievements of the previous hundred years. The Number One food science innovation of the twentieth century selected by the Institute of Food Technologists — ahead of even concentrated juices, safe canning, and freeze drying — was aseptic processing and packaging.

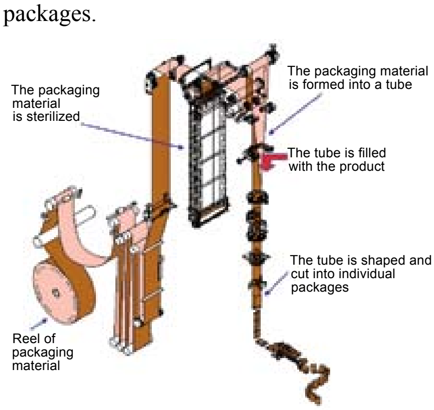
Aseptic processing dates from the early 1960s. It involves ultra-high-temperature (UHT) treatment of milk and other liquid foods for a few seconds in order to remove all harmful micro-organisms while preserving nutrients and flavor compounds better than traditional pasteurization and canning done at lower temperatures for longer times. The result is that UHT food products remain fresh for months during shipping or storage without requiring refrigeration or preservatives. This provides significant cost savings to everyone—from the producer to the consumer—as well as long-life, healthy nourishment in developing countries lacking adequate power grids, cold chains or transportation infrastructure.

Tetra Pak is the world's largest supplier of aseptic packaging. Its founder, Dr. Ruben Rausing, began the company in Lund, Sweden in 1951 with a simple tenet: "A package should save more than it costs." Rausing invented the packaging technology that still forms the basis for much of Tetra Pak's business. Currently the company distributes more than 387 million packages per day in over 150 countries, for a total of more than 141 billion delivered worldwide in 2008.

As the company is committed to providing the lowest-cost packages possible, every new product line presents a challenge: is the thin, lightweight material strong enough to withstand the filling and sealing process? "Complete control over the process is paramount," says Dr. Mattias Olsson, Manager, Virtual Engineering at Tetra Pak. "That requires an in-depth knowledge of the loads and forces involved—both liquid and material."

Cartons, Fluids, and Forces

Both for cost and for control, the packaging process is designed to be as simple as possible. But keeping it simple poses tremendous engineering challenges. A continuous reel of carton-based packing material—a composite of mostly paper, with some ultra thin layers of plastic and aluminum—is fed into the top of a filling machine and sterilized along the way. The flat packaging material is formed into a tube and sealed longitudinally. A pipe from the filling machine enters the top of this packing material tube, filling it with liquid and causing it to expand. A mechanical system folds and transversely seals the package, below the surface of the fluid, keeping it sterile while forming it into the desired shape. The tube is then cut into individual packages.



Schematic of a filling and packaging system for an aseptic liquid container.

Even though the process is simple, the forces it is subject to are not. "Gravity is driving the liquid down," Olsson says, "but the folding and the tube deformation are forcing it backward"—much like the action of putting a kink in a garden hose. A pressure flange (essentially a flat disk with small holes in it) mounted inside the tube, above the folding system, reduces the amount of backflow up the tube. But the packaging tube is subject to deformation under folding and considerable changes in fluid pressure, and it needs to retain its structural integrity without breaking or crimping.

"When designing new package shapes and sizes," Olsson says, "or when modifying the filling machine—for instance by increasing the filling speed—the folding and forming of the package are critical. In the past, these have been difficult to predict." Customarily, the packaging and filling process was verified by physical testing on a nearly finalized machine. But if the test revealed design problems at that stage, it was more expensive to introduce changes than it would have been earlier in product development. "What we needed," Olsson points out, "was a realistic, reliable simulation method that took into account the liquid, the packaging material, and all the major forces acting—and interacting—on them."

So Tetra Pak selected Abaqus finite element analysis software from SIMULIA, the Dassault Systèmes brand for realistic simulation, to evaluate the complexities of its packaging process. The company had previously used Abaqus for structural analyses, but this was the first time that Tetra Pak engineers simulated the dynamics of the fluid-structure interaction during packaging. The resulting analysis generated a greater understanding of the packaging process and provided a means to model it earlier in the design stage. "We anticipate that use of simulation will help save us a significant amount of product development time," says Olsson.

A Model Packaging Process

For their initial trial analysis, the engineers selected the Tetra Fino Aseptic 500 ml, TFA 500s milk package—the mid-range size of an extremely low-cost and high-volume product line. "We already had a strong

knowledge of production parameters for this application," Olsson says, "so it made an excellent choice for our initial analysis." Dr. Anders Magnusson, Technology Specialist at Tetra Pak, worked with Olsson on the simulation.

There were a number of challenges to modeling the process. The packaging material was very thin and flexible, which made for large deformations under pressure changes. The cross-section of the tube rapidly changed from circular cross-section to fully closed when folded. Most important, there was a strong fluid-structure interaction to be modeled that had to take into account the changing pressure waves in the fluid and their effects on the packaging material.

The model for analysis included the following components:

- The composite packaging material (a paper, aluminum and plastic carton tube, modeled as a homogenous material)
- The packaged fluid, including its flow and pressure properties
- The flotation device that rests on top of the fluid surface
- The system that folds the packaging material
- The pressure flange that controls (dampens) pressure waves inside the tube

With the exception of the deformable packaging-material tube and the liquid, the components were modeled as rigid bodies. These structural items were modeled in a Lagrangian framework, which is a commonly used method of simplifying the application of forces to objects and quantifying their reactions.

The flexible packaging material was modeled with shell elements calibrated to represent the laminated material as though it were homogenous, which reduced the computation time for the analysis.

The fluid was modeled using an Eulerian approach that captures the characteristics of non-viscous fluid flow. By coupling this with the Lagrangian approach, Tetra Pak's engineers could now model the interaction of the packaging tube and the fluid in one analysis. "The Coupled Eulerian-Lagrangian capability in Abaqus allowed us to include effects from the packaging dynamics—tube deformation under flow and pressure changes—that we had never simulated in a single model before," Magnusson says. Abaqus' strong contact and nonlinear capabilities were also essential to the analysis.

Because the packaging process is axially symmetric, the engineers were able to model one-half of the system to substantially reduce processing time. The model involved roughly 220,000 elements, with approximately 700,000 variables. The analysis ran on a Linux 86-64 platform with an Intel Xeon Dual core processor, with the runs taking about 24 hours on 8 to16 processors.

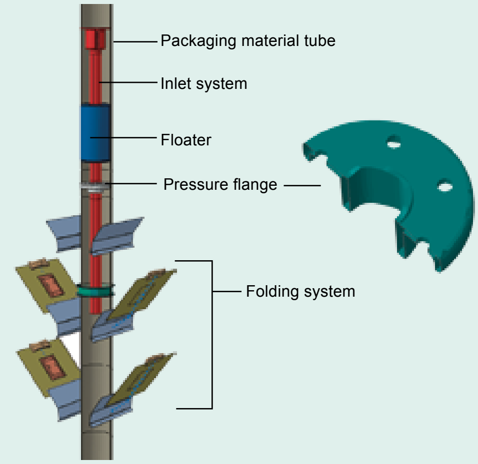
Once the Coupled Eulerian-Lagrangian approach enabled the simulation to capture the deformation of the packaging material, the behavior of the fluid and the interaction between them entirely within a single FEA model, the engineers were able to model and define a variety of design parameters:

- Sequencing the folding system action, including the deformation of the material
- Determining the choice and suitability of the packaging material
- Establishing the correlation between fluid injection rate and formed packaging volume
- Defining the tensile load applied to the material so as to prevent breakage or crimping

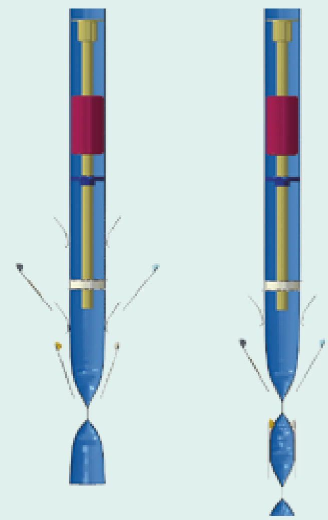
"We were trying to model all the aspects of packaging that we had tested in physical prototyping," Magnusson says. "In the end, we were able to simulate all the important forces of the process, from flow under gravity and pressure changes in the liquid, to deformation in the material."

The Results—Good to Go

The FEA analysis realistically captured the packaging process, right down to arriving at the desired final shape of the filled and sealed package. It also demonstrated that including the interaction of the fluid and the packaging material in the simulation is imperative in order to calculate the degree of package deformation during filling and sealing. The simulation showed the need and effectiveness of the pressure flange device to control the gross bulk motion of the fluid, reducing the dynamic interaction between the fluid and the tube of packaging material. "Originally it was believed that modeling the role of the pressure flange would be difficult using the Coupled Eulerian-Lagrangian method, since physical tests had demonstrated turbulence effects," Olsson observes. "But our analyses, with and without the flange, proved that this method could capture the fluid behavior well." The next step is to verify the results with physical testing.



Half symmetry model of the structural components of packaging system.



Deformation of the packaging tube as the packaging seals.

In the long run, the Abaqus simulation will aid Tetra Pak as it develops new packages and upgrades existing machines. Using simulation early in design is expected to decrease the development time of the packaging processes while increasing package quality—an important goal for a packaging company whose motto is "Protects What's Good," and that strives to provide healthy and nutritious food throughout the world.

"Tetra Pak's vision is that we commit to making food safe and available everywhere," says Olsson. "This FEA analysis is a part of that vision, and it has significantly strengthened our understanding and knowledge of the physics at play in our packaging systems. SIMULIA will be important to our process development method going forward."

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