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COMSOL NEWS

SPECIAL EDITION FOOD INDUSTRY

Ensuring Flavor, Quality, and Consistency

Nestlé optimizes their chocolate bar production process with multiphysics simulation

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COMSOL


Farmers use a simulation-powered app to gauge the freshness of produce in cold storage
PAGE 4

Simulation, a Key Ingredient for Innovation

Better flavor. Faster production. Higher energy efficiency. Food engineers continuously find better ways of producing not just food but also the technology involved in keeping goods fresh and the appliances used for cooking. One crucial ingredient that engineers reach for when optimizing designs and developing new ideas is multiphysics modeling and simulation.

At the very end of the food supply chain sits the hungry consumer expecting a certain level of freshness, safety, and taste. In terms of candy bars, for example, the expectation may be a satisfying snap when biting into a chocolate-covered wafer. Ensuring this snap is one focus of the team we meet on page 8: researchers from the Product Technology Centre who are tasked with optimizing the production process of Nestlé's confectionery products. For ovens and stovetops, consumers may be looking for even cooking and energy efficiency. On page 20, we see how the team at Whirlpool Corporation used simulation to improve the energy efficiency of its oven designs, and on page 22 we get a peek at an innovative solid-state cooking device that yields even cooking for home and professional kitchens.

Between the active steps of harvesting, production, and cooking, goods typically sit in storage. Though the food items are physically resting, the chemistry inside them is not, and they are sensitive to the environment in which they are stored. Temperature dips or spikes can shorten product shelf life dramatically. On page 4, we see how compiled simulation apps help smallholder farmers improve the use of refrigerated storage, thus reducing post-harvest losses and increasing revenue.

Consumers have high expectations when it comes to food and beverages. Above all, the end product must be safe and consistent. As we see in this special edition of COMSOL News, simulation helps food engineers deliver better end products faster.

Enjoy!
Fanny Griesmer
COMSOL, Inc.

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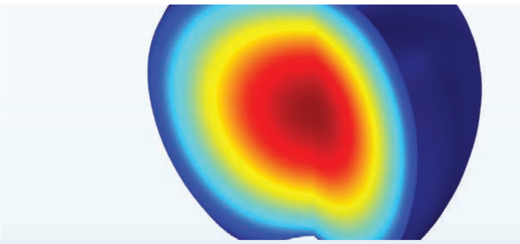
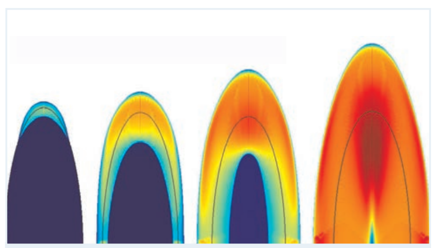
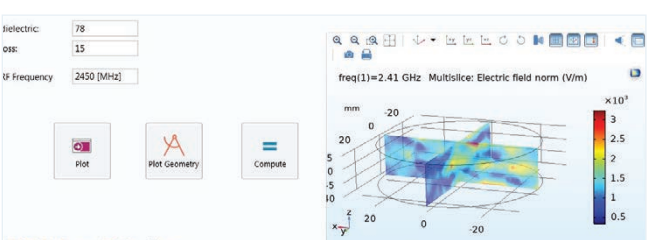
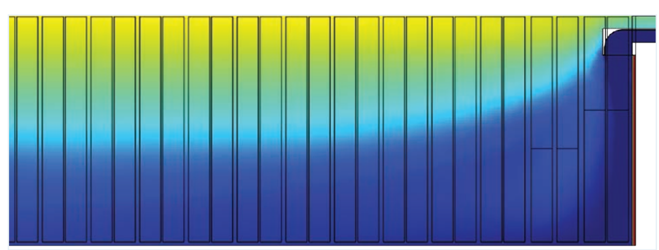








Empa, Switzerland

FORECASTING FRUIT FRESHNESS WITH SIMULATION APPS

Swiss research organization Empa built models and compiled a simulation application that feeds results into a smartphone app used by farmers and traders to predict the shelf life of fresh fruits and vegetables. The work is in support of a multinational coalition whose goal is to improve the use of refrigerated food storage in developing countries.

by **RACHEL KEATLEY**

The post-harvest journey of fresh produce is a notably weak link in the global food supply chain. Each year, approximately one-third of the food produced for human consumption worldwide is lost or wasted. Refrigerated distribution and storage problems play a major role in these losses, especially in developing countries like India, where a mere 6% of food production enters the refrigerated "cold chain" — leaving it vulnerable to decay. Currently, the scarce refrigerated space, such as small, solar-powered cold storage rooms (Figure 1), may be occupied by crops that are already past their peak, even as other shipments decay while waiting for access to a cold room.

FIGURE 1 Cold rooms used for storing crops after harvest.

As part of a multinational consortium of food supply chain stakeholders, the Swiss Federal Laboratories for Materials Science and Technology (Empa) and the Basel Agency for Sustainable Energy (BASE) developed Coldtivate to help alleviate these problems. Coldtivate is a mobile app that informs its users of the cooling and decay process of different types of fruit in real time. It was rolled out to cold storage operators in three regions of India in late 2022 and in Nigeria in 2023, and it is powered by multiphysics simulation. The farmers who use the app do not actually see the underlying multiphysics models or interact directly with the simulation app: they get the results delivered in a way that is actionable to them through the Coldtivate mobile app.

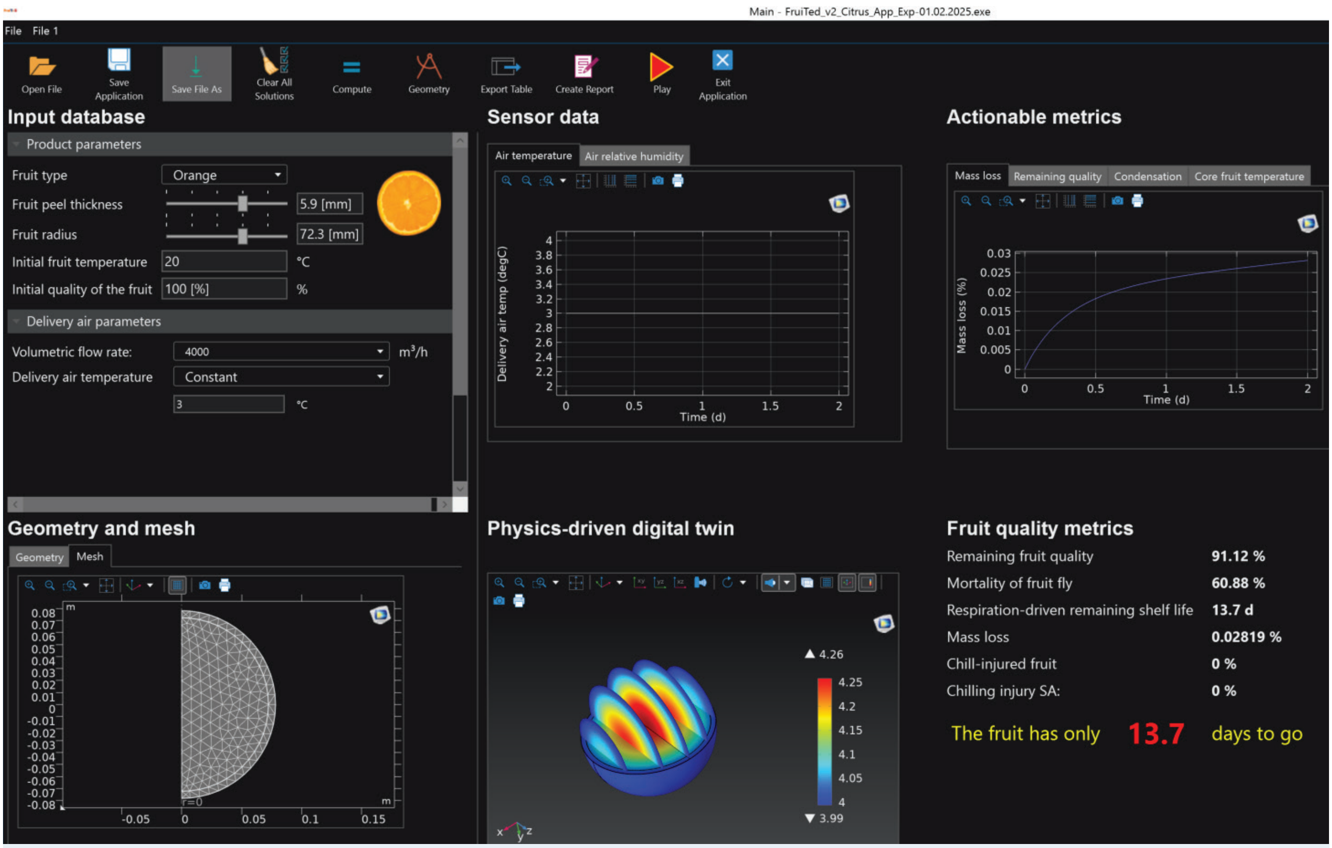


FIGURE 2 Empa's COMSOL app running on a desktop computer, which generates many indicators related to produce freshness.

» SIMULATION-BASED PREDICTIONS TO OPTIMIZE FOOD STORAGE

The Coldtivate mobile app provides data-driven forecasts on the freshness of produce in a cold room. These forecasts are relayed from a simulation app (Figure 2), which Empa built with the COMSOL Multiphysics® software and its built-in Application Builder.

Simulation apps are easy-to-use interfaces that are made from existing COMSOL Multiphysics models, where the app designer decides which inputs and outputs to display. Simulation apps are ready-to-use as is, but Empa and BASE wanted to relay their simulation app's data in a way that would be most familiar to their end users, primarily farmers. Since mobile apps are widely used in modern agricultural practices, they developed Coldtivate to act as the user interface for their end users.

"Our COMSOL app runs on the same headless server that hosts the mobile app," explained Joaquin Gajardo, data scientist at Empa and technical colead for the Coldtivate project. This is what enables both the simulation app and mobile app to relay information back and forth between one another. "We've used the Application Builder to automate the updating of simulations based on changing input parameters [in the mobile app]," said Gajardo. This combines the capabilities of Empa's multiphysics model with the convenience of a purpose-built mobile app. For their simulation app to be used in such a way, they first compiled it into a standalone executable using COMSOL Compiler™.

"Without the Application Builder, it would have been impossible to roll out the digital twins into a mobile app and democratize these multiphysics simulations, and their results, to a broader audience of beneficiaries, like smallholder farmers," said Thijs Defraeye, senior scientist at Empa and professor at Wageningen University & Research.

» THE MODEL BEHIND THE SIMULATION APP

Ambient temperatures directly influence the shelf life of fresh produce. But while thermometers are found inside most refrigerated storage units, the data they provide is insufficient for predicting how long fruits and vegetables will last.

"We cannot establish the expected lifespan of produce with a single temperature or humidity curve from a cold room," said Defraeye. "The COMSOL model of each crate receives actual temperature and humidity data from the cold storage rooms, enabling frequent recalculation of remaining shelf life." This model is what Empa's simulation app is based on.

In addition, a sensor in one section of the storage space does not necessarily reflect the temperature on the surface of an apple buried inside a crate, especially if that crate was only recently brought indoors.

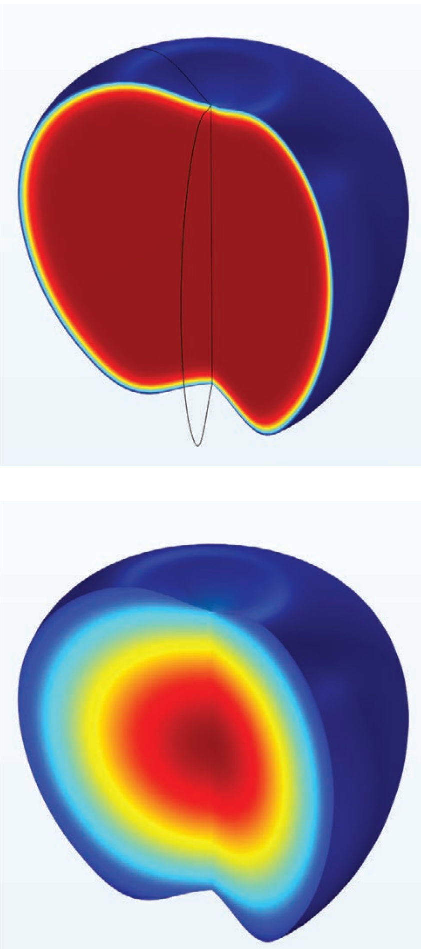


FIGURE 3 Results of Empa's COMSOL model of an apple, showing how surface temperatures will affect internal temperature distribution over time.

To provide a fuller picture of how each shipment of produce may be affected by varying storage conditions, Empa is currently expanding the models to model entire shipments of various fruits and vegetables using COMSOL Multiphysics (Figure 3). "For this, we need to use a porous media modeling approach to generate actionable metrics from sensor readings," said Defraeye.

» THE APP IN ACTION

"Let's say a new shipment arrives at a cold room," Gajardo proposed. "The operator opens the Coldtivate app on their phone and enters the type of produce, current temperature, days since harvest, and other relevant values. The mobile app then generates a text file containing this information. The values in this text file serve as input arguments for the COMSOL app, which then calculates the expected shelf life. This calculation is then written into an output file, and the remaining quality and number of days are subsequently displayed in the mobile app's user interface."

Every six hours, the values shown on the Coldtivate app are recalculated with updated forecasts based on the latest cold room temperature data (Figure 4). Farmers can directly check the remaining shelf life of their crates in the mobile app. If they do not have a smartphone, "warehouse operators can notify them of how long their produce will remain fresh in the cold room," said Gajardo. Ultimately, this information will help farmers avoid distress selling and unnecessary disposal of unsold produce.

» TEAM EFFORT LEADS TO TRUSTWORTHY DATA

Defraeye and his team at Empa have devoted years to building their data-gathering and modeling process. "In early 2021, we were already making models [for analyzing produce freshness], but they were not yet rolled out in actual supply chains," Defraeye said. Inquiries from nonprofit global development organizations sparked the effort that led to the creation of the Coldtivate mobile app (Figure 5).

"We were contacted by BASE, which develops innovative business models to help farmers make better use of available resources," Defraeye said. "The idea was to combine a pay-per-use business model with intelligence that could improve access to cooling. To do that, we needed other partners with close links to the people we wanted to help." These partners included cooling companies and other stakeholders in the Indian states of Bihar, Himachal Pradesh, and Odisha, who joined BASE and Empa in an initiative called Your Virtual Cold Chain Assistant (Your VCCA).

"Trust is the key ingredient," said Defraeye. "The simulations allow us to peek inside what happens to produce over time, and the smartphone app puts that info into the hands of people who can use it, such as cold room managers or farmers. The goal is to add transparency at the point of sale, where it can make

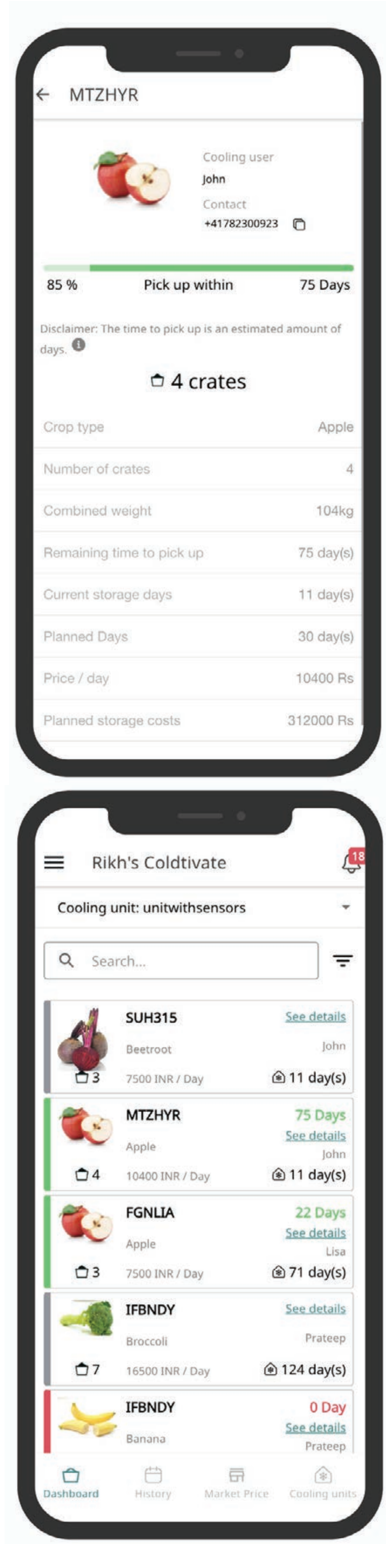


FIGURE 4 The Coldtivate app showing relevant information about a farmer's crate in storage, including the remaining quality and expected shelf life.

a big difference. If the farmers and cold room operators can trust the forecast, that helps them trust each other as well."

» COLDTIVATE IN THE FIELD

In August 2022, the Coldtivate app was released to selected cold room operators along with training on how to use the app to track produce in their facilities (Figure 6). To date, the simulation-powered app has been piloted in 17 cold rooms, serving more than 300 farmers, who are reporting a 20% increase in their incomes and a reduction of their post-harvest food losses by 20%. Empa and its partners are now working to expand Coldtivate's impact.

Future iterations of the app will deliver additional relevant info, such as market price forecasts, and even predictions of crop quality based on photos of produce. Now, BASE and Empa are working with organizations in Nigeria and the Philippines to bring Coldtivate's benefits to more of the world.

The scale of global post-harvest crop losses is daunting, but the coalition behind the Coldtivate project has proven that progress is within reach. "We're seeing how access to simulation-based predictive tools can improve access to cooling," Defraeye said. "Now we need more than incremental baby steps; we need bold action to expand our impact. We do this by putting technology into the hands of more people who can use it to make a difference." ◎

ACKNOWLEDGEMENTS

The development of Coldtivate was funded partially by the data.org Inclusive Growth and Recovery Challenge grant "Your Virtual Cold Chain Assistant", supported by The Rockefeller Foundation and the Mastercard Center for Inclusive Growth, as well as by the project "Scaling up Your Virtual Cold Chain Assistant", commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) and being implemented by BASE and Empa on behalf of the German Agency for International Cooperation (GIZ). The project team wishes to thank the main project partners, Koel Fresh Private Ltd., Oorja Development Solutions India Private Ltd., and ColdHubs Ltd., for their contribution in testing and fine-tuning the shelf-life model.

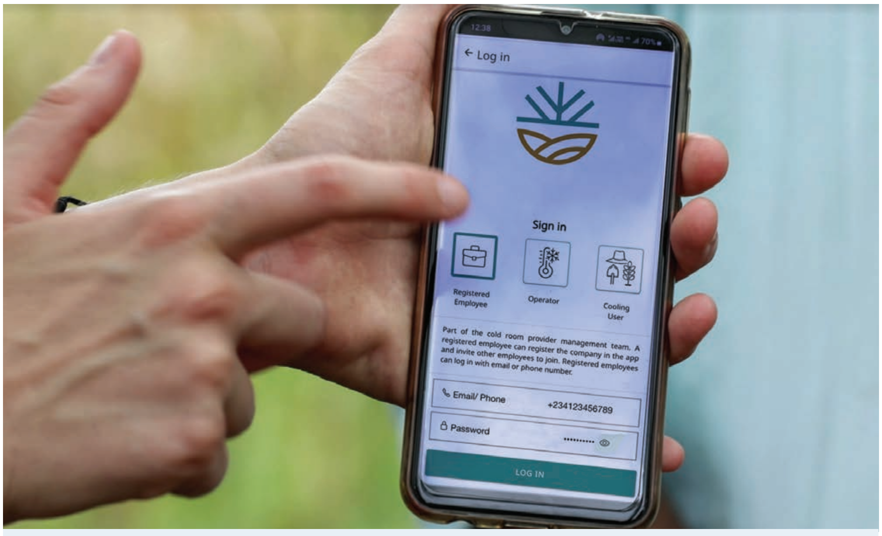


FIGURE 5 The Coldtivate smartphone app in the hands of a user.

FIGURE 6 Farmers and cold room operators in Odisha, India, attending app training.

"Without the Application Builder, it would have been impossible to roll out the digital twins into a mobile app and democratize these multiphysics simulations, and their results, to a broader audience of beneficiaries, like smallholder farmers."

— THIJS DEFRAEYE, SENIOR SCIENTIST AT EMPA

Nestlé Product Technology Centre, United Kingdom

THE SWEET SIDE OF SIMULATION BEHIND THE SCENES AT NESTLÉ

Researchers at the Product Technology Centre in York, UK use simulation to perfect chocolate production at Nestlé.

by **ALEXANDRA FOLEY**

At Nestlé, the research, design, and manufacturing that goes into producing one perfect bar of chocolate candy is a mesmerizing process, not entirely different from the spectacular world of Willy Wonka's chocolate factory. While there may not be oompa-loompas overseeing candy production, a lot of thought and quite a bit of simulation goes into perfecting the process

Engineers at Nestlé's Product Technology Centre in York, UK (PTC York) work, among other things, on the research and development of three different products: a chocolate depositor for making candy bars; a wafer baking plate; and an extruder, used to cook and sort cereals at the same time. At PTC York, which is home to the research and development of Nestlé's confectionery products, engineers rely on multiphysics simulation to optimize and streamline the production process.

» CHOCOLATE R&D

Candy bars, such as Kit Kat®, Aero®, Crunch, and solid milk chocolate bars are produced using a chocolate depositor that fills a mold with molten chocolate. Chocolate enters the depositor via an arm at the top and exits into a mold through each of the nozzle tips (see Figure 1).

"Ensuring that the amount of chocolate in every bar is consistent means that the flow rate and pressure of the chocolate exiting each nozzle must be the same," says William Pickles, a process engineer at Nestlé. "Not only do we need to make sure that each chocolate bar is the same weight for cost effectiveness and standardization, but we are also committed to guaranteeing that the calorie information on the package is correct as well. This allows us to deliver products with exact nutritional content that fit in with our customers' balanced diets." In order to achieve this standardization, the uniformity in flow and pressure between each nozzle tip must be precise to within a narrow margin.

To achieve this consistency, Nestlé uses a combination of modeling and simulation tools. The chocolate depositor shown in Figure 1 was first designed using SOLIDWORKS® software and the geometry was then imported into the COMSOL Multiphysics®

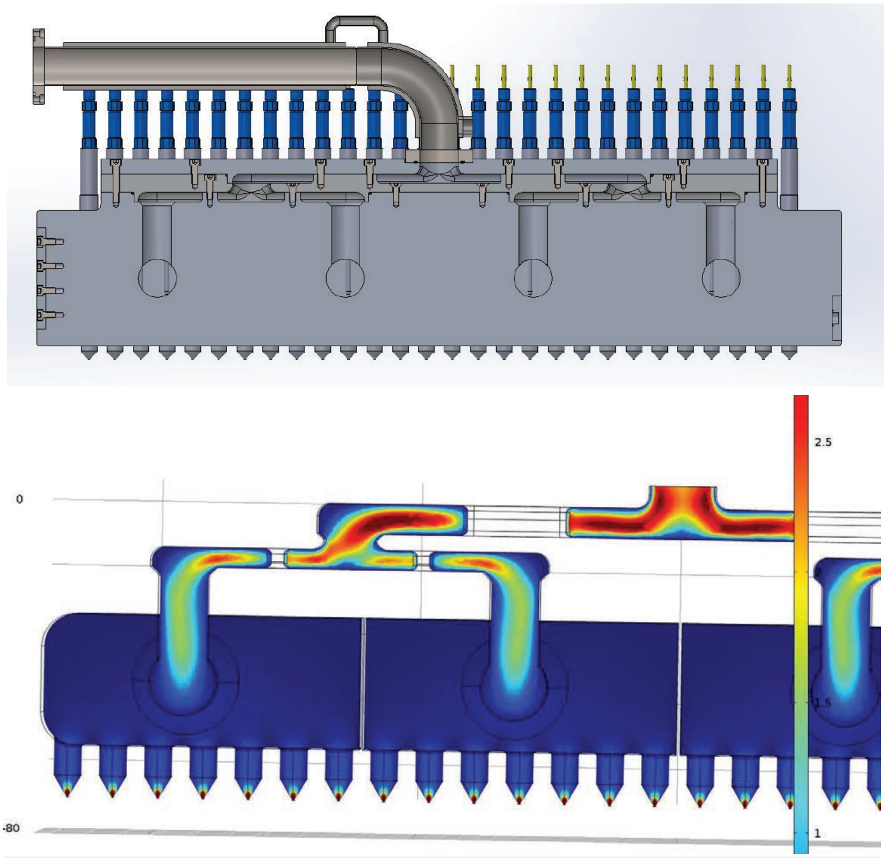


FIGURE 1. Top: SOLIDWORKS® software geometry of the depositor. Bottom: COMSOL Multiphysics® simulation showing the magnitude of chocolate flow in the depositor's nozzles and flow channels.

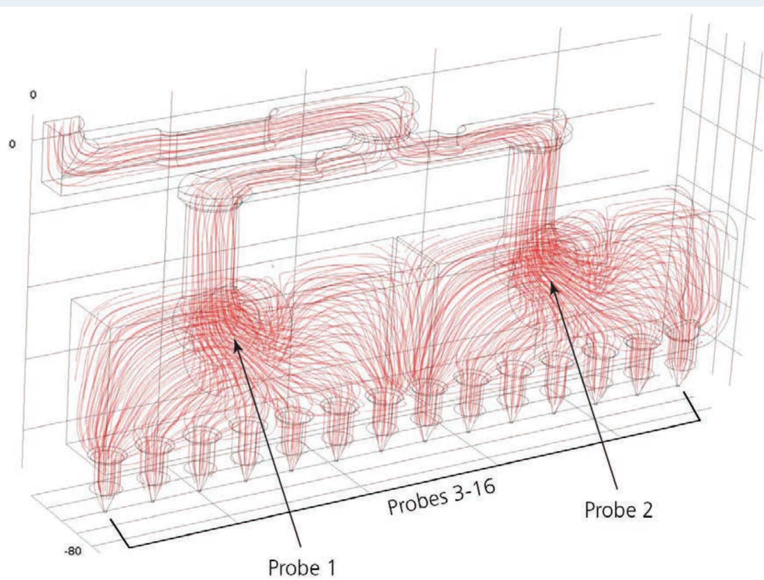


FIGURE 2. Probes located at each of the nozzle tips and in the flow channels demonstrate that the chocolate flow rate and pressure within the depositor and nozzles vary within specifications. Streamlines show the direction of chocolate flow.

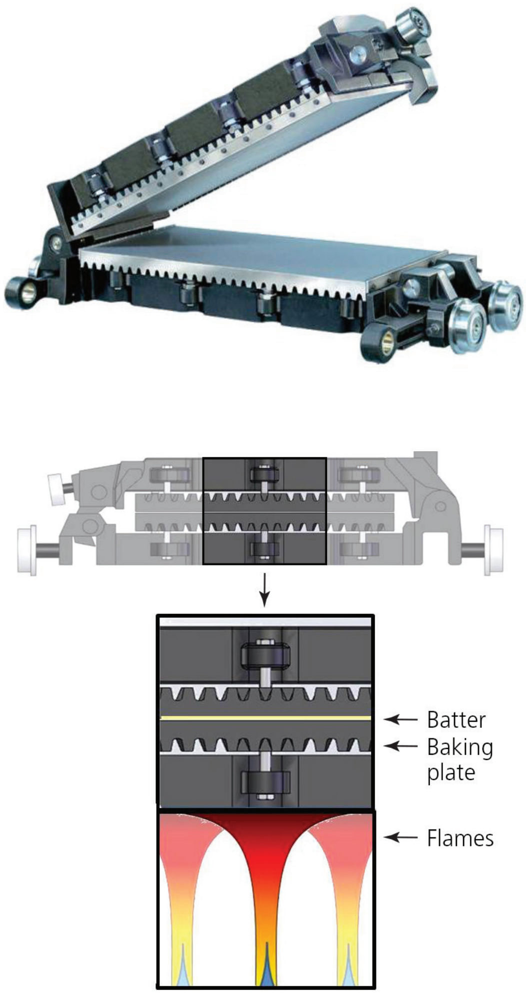


FIGURE 3. Two wafer-baking plates (a) are used to bake Kit Kat® wafers. The top and bottom plates compress the batter (b), while the flame underneath the plates bakes the wafer (c).

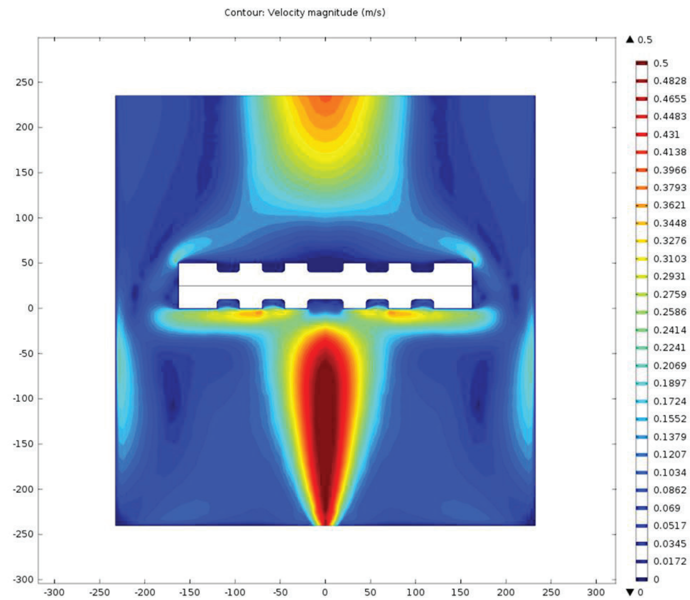


FIGURE 4. Airflow around the baking plates.

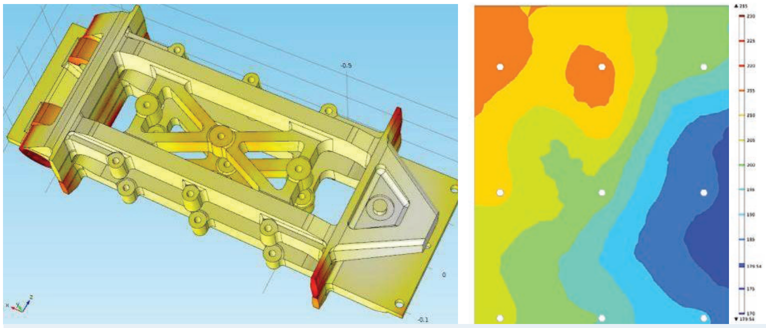


FIGURE 5. Left: Temperature distribution in the baking plates' supporting frame. Right: Temperature profile at the surface of the top baking plate, where warmer spots can be seen at the location of the bolts (white circles).

simulation software for analysis. Simulation was used to perform fluid flow optimization, test mechanical stress, and analyze the thermal properties for a particular geometry.

"Every chocolate manufacturer has their own special recipe that produces chocolate with unique characteristics," says Pickles. "We were able to fully model the non-Newtonian behavior of Nestlé's signature chocolate by setting up a simulation where an experimental curve relating the shear rate to the shear stress of the fluid was imported into the software. This way, we were sure that we were modeling chocolate with the same fluid properties as the real product."

Using simulation, the team identified areas of high and low flow rates and determined the differences in flow between each of the depositor needles. Numerical probes in the flow channels and at the tips of the nozzles were used to analyze conditions at certain locations of the geometry.

"By optimizing the depositor design, we were able to achieve a flow rate through each of the nozzles that is consistent to within a tenth of a percent of the desired value," says Pickles. These results of this simulation are shown in Figure 2.

» SIMULATION SAVES THE CRUNCH

What would a Kit Kat® be without the well-known snap of the wafer baked inside? When baking a wafer, uneven heating can cause different moisture concentrations within the wafer, ruining its crunchy texture or even causing it to spontaneously snap.

The wafer baking process at Nestlé uses two baking plates that compress the batter between them (see Figure 3). During baking, the plates are passed above a series of about 40 flames.

"We are using simulation to optimize the baking plate design by looking at the flow of hot air below and around the plates to ensure that we have an even temperature profile across the plates' surfaces," describes Pickles. "Our aim for this study is to correct burner power and orientations to give the best wafer, while simultaneously reducing the amount of fuel we use." This fits with Nestlé's policy of continually seeking to improve efficiency in all of its manufacturing processes.

The flames underneath the baking plates were modeled as jets of hot air, where heating proceeds via convection. Figure 4 shows the profile of the flame underneath the baking plate and the airflow around the plate.

"We were able to validate our model against baking plates used in experiments, and we found that our simulation results were in very good agreement," says Pickles. The results also show how warmer spots occur due to increased heat conduction through the bolts holding the baking plates together (see Figure 5).

"The next step will be to optimize this design to distribute the heat as evenly as possible across the top of the plate and minimize temperature peaks," says Pickles.

» COOKING WHILE EXTRUDING

Cereals such as Cheerios®, Trix®, Nesquik®, and many others are made at Nestlé using an extruder. "The high-temperature extruder used at Nestlé to make certain types of cereals works by forcing dough through a die. The pressure and friction created during this process causes the dough to cook through viscous heating," says Pickles, referring to the extruder shown in Figure 6. "Extruders are common because they are a compact, cost-effective way of manufacturing products."

Pickles is working on designing the housing for a viscometer that can be placed within the extruder to measure the viscosity of the dough entering the die. This will ensure consistent quality of the dough so that it will cook in a predictable manner. "For our design, we needed to make sure that the viscometer housing could withstand the high pressure within the device," says Pickles.

In the original extruder design, the pressure was too high for the viscometer housing to withstand.

"We redesigned the housing, which helped to reduce the pressure. We were then able to make sure that the die design didn't exceed the yield stress so that the viscometer could safely be housed inside it," says Pickles. Additionally, simulation was used to check that the displacement of the extruder was consistent, as varying displacement of the device would cause the cereal being produced to have uneven shapes and sizes (see Figure 7).

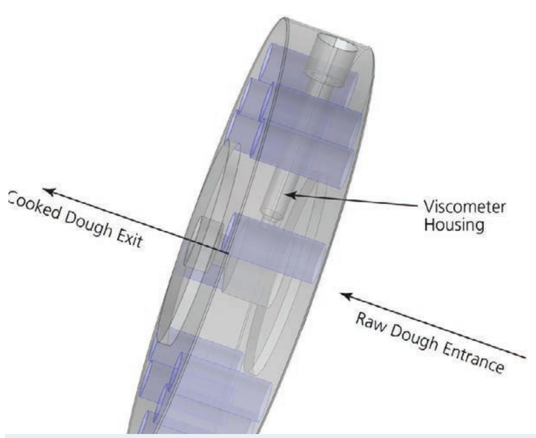


FIGURE 6. Left: Extruder geometry.

» BETTER, SAFER PRODUCTS WITH MULTIPHYSICS SIMULATION

At Nestlé, simulation is a big part of the design process, from producing chocolate to wafers to cereals and everything in between. "Since Nestlé products are going to be consumed by our customers, we need to be able to ensure that our designs will hold up in the real world," concludes Pickles. "We are confident in the results obtained from our simulations, and we know that they can be trusted to help us produce the best and safest designs possible. This in turn allows us to consistently deliver tastier and healthier products. ◎

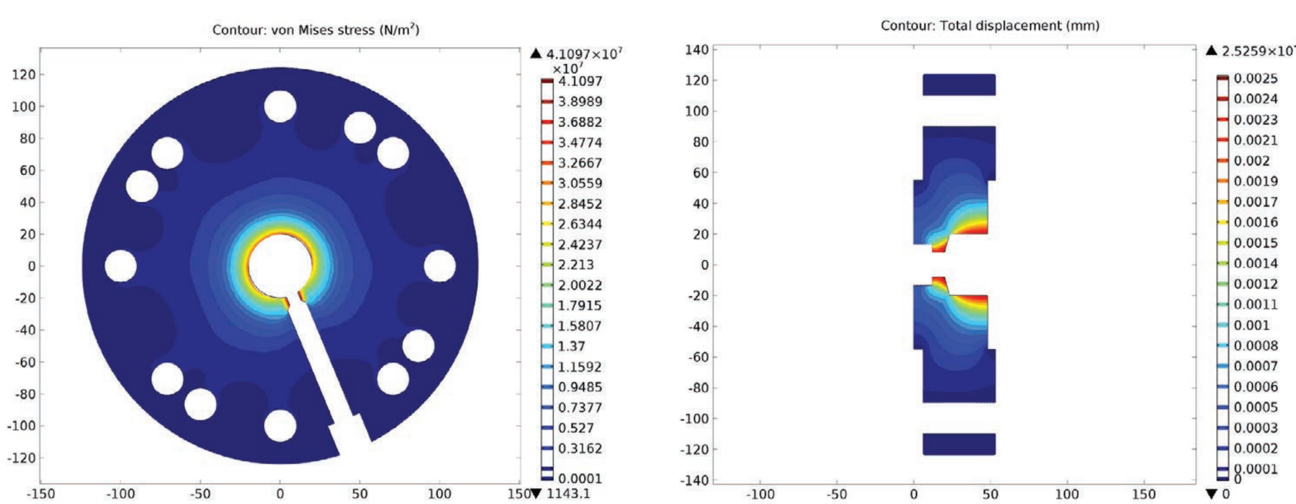


FIGURE 7. Viscometer housing and die simulation results. Left: Contour of von Mises stress. Right: Slice plot of the total displacement.

mieletec FH Bielefeld, Germany

MULTIPHYSICS SIMULATION HELPS MIELE TO OPTIMIZE INDUCTION STOVE DESIGNS

Less than a decade ago, if you were to ask a master chef which type of cook stove he preferred, he would have answered gas, without question. Now, however, Miele has provided both professional chefs and at-home cooks with another, better option: the induction cook stove.

by ALEXANDRA FOLEY

Induction cook stoves are known for their efficiency, with over 90% of the energy used going directly into heating the food being prepared. That is a tremendous amount when compared to gas or electric stoves, which in contrast demonstrate a mere 50% efficiency rate. If an induction cook stove could provide chefs with better precision and speed than a traditional stove, while still retaining optimal efficiency, the resulting cooktop would be a substantial breakthrough in the cooking appliance industry.

It was the mission of Miele, a world leader in domestic appliances and commercial machines, to create just such an induction stove. Researchers at mieletec FH Bielefeld, a joint research laboratory between Miele & Cie. KG and the

FIGURE 1. The stovetop remains cool; in fact, the ice cubes are hardly melting, while the water inside the pot is boiling.

University of Applied Sciences Bielefeld, Germany, used simulation and the multiphysics approach to improve, verify, and optimize their induction stove designs.

Using field-coupled simulation, Christian Schröder, co-founder and scientific director of mieletec, designed an optimized induction stove that lived up to Miele's motto of "immer besser." Translated from German, this means "forever better" and it drives the company to create long-lasting, functional, and great designs. "We're very happy with what mieletec has developed," says Holger Ernst, co-founder and scientific director of mieletec and head of the Innovations Department at Miele. "Mieletec was able to create an induction stove that's more precise than a gas stove, while still providing better energy efficiency."

» A WATCHED POT NEVER BOILS—UNLESS IT'S ON AN INDUCTION STOVE

A watched pot never boils. Whoever coined this phrase has probably never used an induction stove. Unlike gas or electric stoves, which can take ten to fifteen minutes to boil a pot of water, an induction stove can bring a cold pot of water to boiling in a matter of minutes. This is achieved using an entirely different heating technique than that of traditional stoves: induction heating.

An induction stove heats up a pot placed on the surface of the stove. While this sounds similar to the way in which a gas or electric stove functions, it's actually an entirely different process. Induction stoves heat the metal of the pot, not the stovetop (see Figure 1). "Instead of heating taking place on the stove," describes Schröder, "heating actually takes place inside the pot itself, leaving the stove cool to the touch." Traditional stoves heat the surface of the stove, which then heats the pot through conduction.

The working principle of an induction stove is based on the inductive heating effect. First, a pot is placed on copper coils located underneath the stovetop. When an alternating current (AC) is passed through the copper coils, it generates a magnetic field that induces currents inside the metal of the pot. These induced currents, called eddy currents, heat the pot by the Joule heating effect. The contents of the pot are then heated through conduction first and then convection.

Initially, induction stoves were designed using a trial and error process, where researchers relied on their experience for an initial estimation of what the frequency, coil size, and power output should be. The results were then altered until the best performance was seen, and this became the final design. However, this process can be very expensive and time consuming, and the engineer is left without enough information to know what is happening in the system, and whether the process has truly been optimized.

"Simulation allows you to extract data that you would never be able to get from an experiment," says Schröder. "With simulation, you can get a better idea about what's going on inside a coil or pot, so that you know what it is that you need to optimize."

Using COMSOL Multiphysics and CAD geometries from Miele, Schröder and his team of researchers from mieletec were able to find the optimal set of conditions for the stove's design. "Essentially, we were able to simulate the whole system, allowing us to improve upon the energy efficiency of the stove," says Schröder. The accuracy of their simulations allowed them to optimize their results within COMSOL Multiphysics, so that when the first prototypes were built, they already had a clear idea of how they would perform.

» DESIGN CHALLENGES—WHEN POTS ARE SINGING AND MOVING ON THE STOVE

The magnetic field induced by the coils creates a few interesting design challenges. "One of the biggest issues we faced is the noise that the pots emit when eddy currents are flowing through them," says Schröder. "The electrical current produces a high-pitched noise that is very difficult to get rid of. The only way to eliminate

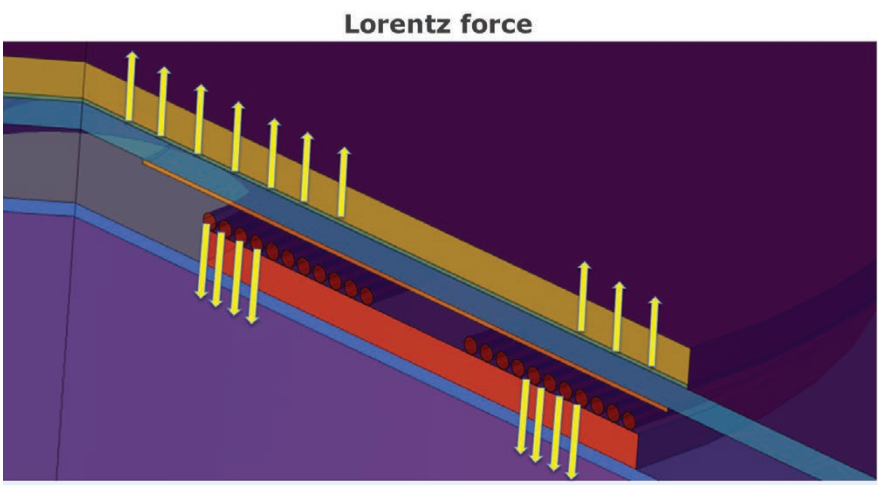


FIGURE 2. The simulated geometry consists of induction stove and pot. Several materials are taken into account (from bottom to top): aluminum (blue), ferrite (red), windings of the copper coil (brown), mica (orange), glass-ceramics (turquoise), metal pot (green and dark yellow). Lorentz forces acting on the induction stove-pot system are also shown (light yellow arrows).

FIGURE 3. Setup of a test campaign performed by staff scientists Werner Klose (left) and Mikhail Tolstykh (right). Because the stovetop has been removed, you can see the internal workings of the stove.

the noise is to adjust the frequency of the alternating current and geometry of the coil, so that the noise produced is at a higher pitch than what the human ear can pick up."

For example, in Germany the current from a household outlet is standardized at 220 V and 50 Hz. Utilizing an AC/AC converter, the frequency of the current in the coil can be increased until the noise produced by the pot is no longer audible. "Using simulation, we found the recipe for current frequency and coil design that produced the least amount of noise possible," comments Schröder. By increasing the frequency to 30 kHz, and optimizing the coil, mieletec built an induction stove that is almost silent to the human ear. Why almost silent? Because, even if the working frequency is not in the audible range, different noise generating phenomena, like magnetostriction (see Figure 2), can still occur at lower, audible frequencies.

The induction heating process was simulated using COMSOL Multiphysics in combination with the AC/DC Module and Heat Transfer Module. In order to obtain an accurate description of what happens in the stove and pot, heat transfer was solved simultaneously with electromagnetics and optimized to determine the best operating conditions. "At the moment, this is something that every manufacturer has to deal with," Schröder continues, "however, in the future, we hope to create an induction stove that really is silent."

Another challenge occurs because of the magnetic forces generated by the system. Since induction cookware is made of a paramagnetic metal, its interaction with the magnetic field results in an attraction force that can cause the pot to move around when placed on the stove top. This occurs

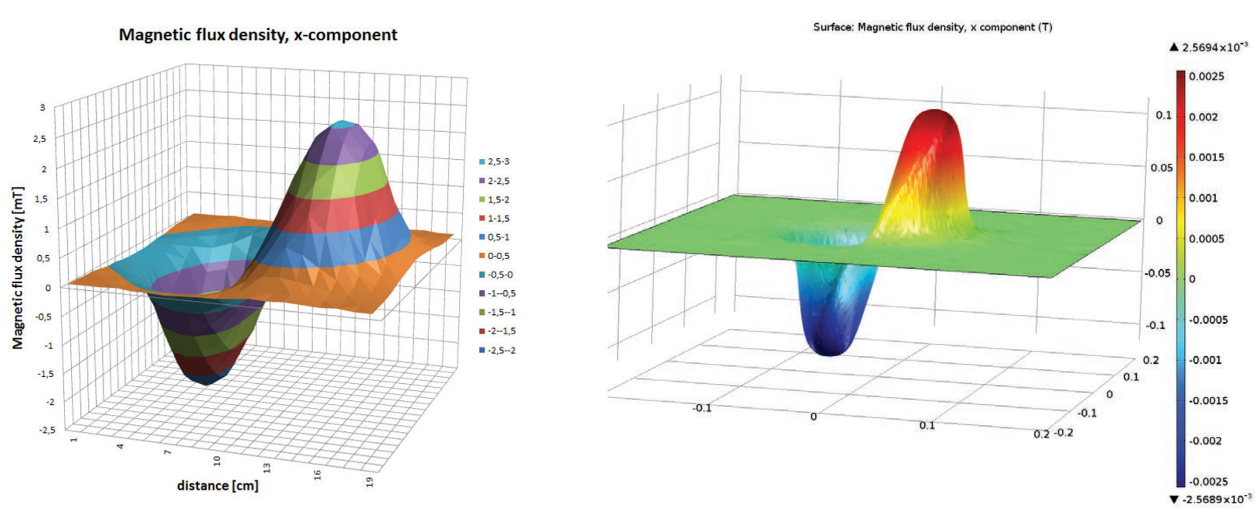


FIGURE 4. x-component of the magnetic flux density for a special coil design. There is a very good agreement between measurement (left) and simulation (right).

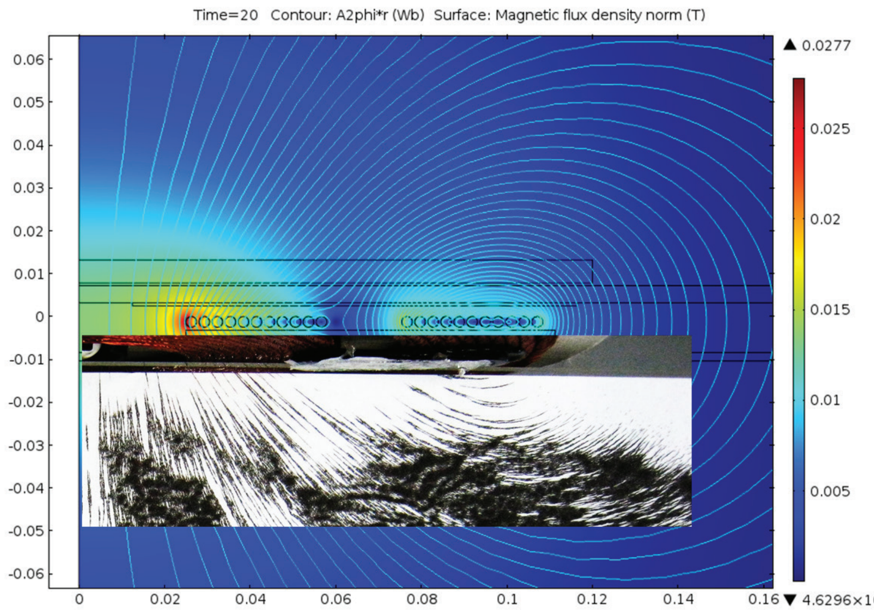


FIGURE 5. The comparison between COMSOL Multiphysics results (magnetic flux density norm) and experimental field lines shows that simulation is accurate and can be used to test other coil designs before building a prototype.

because the eddy currents in the pot generate a magnetic field that interacts with the one generated by the coils. If the magnetic forces do not cancel each other out, the resulting net force will cause the pot to move across the stove.

"We needed to know the size to make the coils, what shape, and what materials to use," says Schröder, "It all boils down to material science." Using simulation, Schröder and his team (see Figure 3) were able to gain an understanding of how the properties of different materials affect their design with respect to thermal and electromagnetic performances. This enabled them to create a coil design that ensured the pot would stay put, while still providing the right amount of power for cooking.

» COMPARING SIMULATIONS WITH PROTOTYPES

When it came to testing their prototypes, mieletec was impressed with the results that they found. "It was amazing," says Schröder. "We found that the results predicted by our simulations were in very good agreement with what the measurements on the prototypes displayed, which rarely happens with other software." Examples of these results can be seen in Figure 4 and Figure 5.

Because their simulations accurately demonstrated how the prototypes would perform, mieletec was able to save a lot of development time and reduce the number of experiments needed to finalize their designs by 80%.

In order to test that their induction stoves heat food homogenously, mieletec uses a pancake to assess heat distribution across the surface of the pan. "If the standard pancake comes out burnt in some places, and undercooked in others, then you know the stove isn't heating effectively," Schröder describes. "You want the pancake to be one smooth color and evenly cooked." Stiftung Warentest (www.test.de), a trusted German authority on consumer goods, ranked Miele stoves as the best in energy efficiency and more importantly, able to prepare a delicious, nicely browned pancake."

» SIMULATION OF TRADITIONAL APPLIANCES

Mieletec is also working on additional kitchen appliances, such as convection ovens. In this application, a complete understanding of the materials and multiphysics interactions taking place were once again important when developing an optimized oven. In order to verify the optimized design, a test is performed in which a porous stone saturated with water is placed inside the oven. Over several days, the stone is passed through various heating cycles to evaluate the oven's heating rate and energy efficiency.

"We had to work with a natural convection heat transfer simulation, where porous media flow was also involved, a truly multiphysics application," comments Schröder. "The simulation allowed us to measure the temperature of the stone at points in the experiment that were inaccessible to real sensors. Simulation allowed us to gain a better understanding of the design," he continues. "A test that in practice lasts for a few days took only a few hours to achieve when simulated. This resulted in important saving of time and resources. Not to mention the fact that our conventional ovens achieved the highest energy efficiency rating."

» THE FUTURE OF DOMESTIC APPLIANCES

Thanks to simulation, mieletec is delivering designs from which consumers are already benefitting in terms of improved energy efficiency and a better cooking experience. The next step is to reach a deeper understanding of the whole induction heating system by including complex multiphysics effects like magnetostriction and aging of materials.

Additionally, mieletec is working on the next generation of induction stoves, known as multicoil induction stoves, which will allow a consumer to place their pots and pans anywhere on the stovetop, instead of inside predefined boundaries. The stove will automatically be able to sense the location of the pot, and adjust accordingly to produce optimal cooking conditions by turning on a certain set of coils. These hot new designs in cooking appliances are revolutionizing the cooking industry, making safer and more energy efficient stoves available for at-home and professional chefs. "We're looking forward to seeing mieletec continue to deliver cutting-edge technologies using COMSOL Multiphysics to facilitate the design process," concludes Ernst.

Cornell University, USA

ENGINEERING PERFECT PUFFED SNACKS

A Cornell research team supports the food industry with mathematical models of rice puffing.

by **LEXI CARVER**

A common snack in parts of Asia for centuries, puffed grains have become a staple in mass-produced cereals and snacks on grocery store shelves around the world. The delightful crunch of rice cakes, varieties of puffed corn, and crispy bites in chocolate desserts is familiar (and delicious) for many.

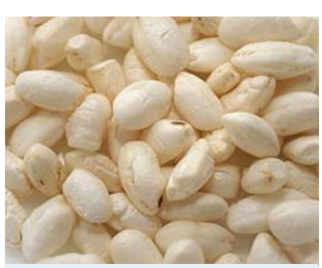


FIGURE 1. Parboiled rice, unpuffed (Left) and puffed (Top).

Also familiar is the less desirable sensation of biting into a puffed snack and discovering that it is too soft, too chewy, too dry, or slightly soggy straight out of the bag. What causes these abrupt mishaps?

What happens inside a rice kernel during puffing, for instance? To a casual observer watching the process, a single piece would heat up and then suddenly and explosively changes shape, like popcorn (Figure 1).

But the physics of rice puffing involves an incredibly complex interplay of mass, momentum, and energy transport; rapid water evaporation; material phase transition; pressure buildup; and plastic deformation.

Food companies have put in many hours working to achieve the right moisture and texture in puffed food that will keep customers happy. They've worked to create reliable processing conditions so that the occasional rubbery piece is an anomaly and not the norm. For scaling up puffing methods for production, food companies need to optimize processing for consistent texture, flavor, moisture content, and in some cases, food safety.

» RESEARCHING OPTIMAL PROCESSING CONDITIONS

Using a research grant from the United States Department of Agriculture

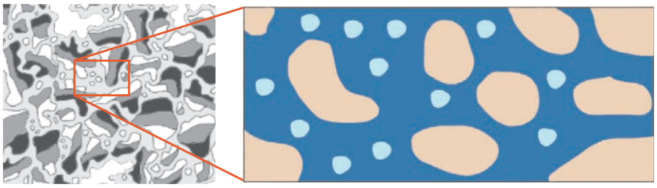


FIGURE 2. Depiction of rice as a porous, elastoplastic solid. The kernel contains liquid water subject to capillary diffusion, convection, and phase change (dark blue); gas composed of water vapor and air, subject to bulk flow, binary diffusion, and phase change (light blue); and a solid starch skeleton that undergoes large deformations (beige).

(USDA) Agriculture and Food Research Initiative (AFRI) program, Cornell University has performed a study of the transport processes in deformable porous media with phase-dependent properties, with a focus on food. Prof. Ashim Datta, from the Department of Biological and Environmental Engineering, led a team to model the dynamics and material behavior during the puffing of parboiled rice.

In addition to studying the intricacies of phase change, energy transfer, and mechanical behavior during puffing, their extensive investigations looked into the effects of salt preconditioning, temperature, and initial moisture levels to facilitate the desired final texture.

At the core of their research was the need for a modeling methodology that would be transferrable to many scenarios. “We built a framework for studying the physics of food processes and made it applicable to different problems; for example, frying incorporates a certain set of physical phenomena, while baking involves a somewhat different set but within the same framework,” explains Prof. Datta. He elaborates on the particular concerns of the food industry: “Consumers want the texture of fried food, but without the health cost; the same quality, but not the same method.

“So food companies looked into baking and ‘popping’ as an alternative to frying. They are constantly updating products and processes. When they change something, they have to know the new optimal conditions. The framework we developed allows us to swap conditions more easily to test the effects of different processes on the final food product.

“Once we know how various combinations of temperature and moisture for one way of processing lead to certain mechanical properties, we can see whether other processing routes will produce the same food quality. We wanted to determine how different processes affect texture, water or oil content, and even the corresponding health implications.”

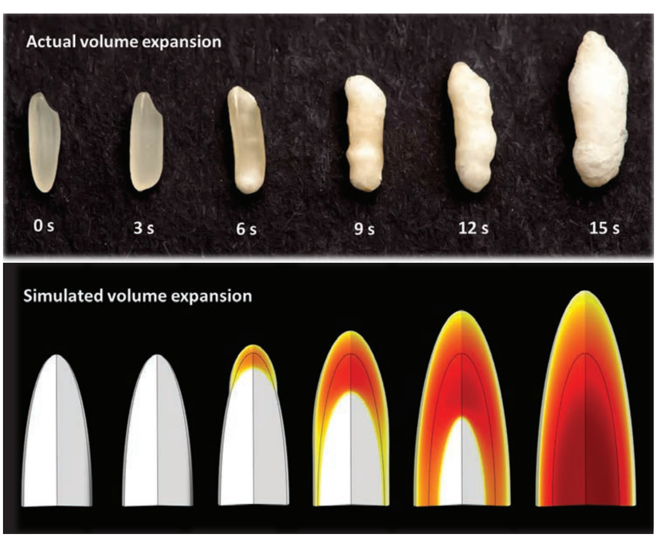
One of the biggest challenges facing the research team was the fact that so many different factors influence the final state of the food. Heating a parboiled rice kernel to temperatures of 200°C leads to the rapid evaporation of liquid water, resulting in large gas pressure buildup and a phase transformation in the grain. It transitions quickly from a rigid, glassy state to a soft, compliant (rubbery) one that allows the kernel to balloon into its final shape. Heating time and initial water and salt content also play a deciding role.

» MODELING INTERCONNECTED PHYSICS

In order to understand how these factors work together and hone in on the ideal processing conditions, Tushar Gulati, (a student of Prof. Datta at the time), headed up the work to break down the mysteries of rice puffing.

He used the COMSOL Multiphysics® software to analyze the interconnected mechanical, thermal, material, and fluid behavior within a puffing parboiled rice grain.

“Numerically, this is a very challenging problem,” Prof. Datta commented. “The team studied flow through the porous medium, multiphase transport, solid mechanics, heat transfer, and in other situations incorporated the



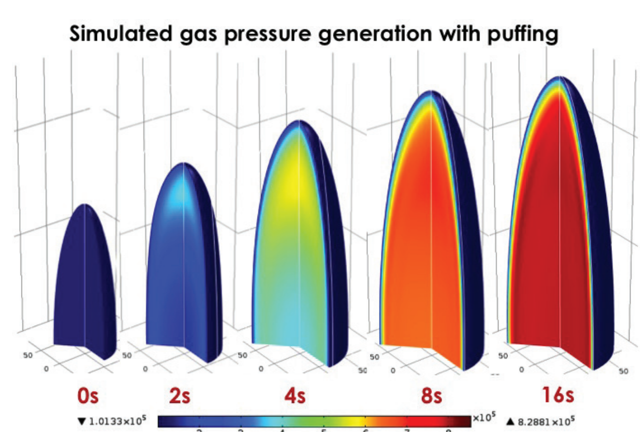


FIGURE 3. Left: Measured volume expansion and simulated volume expansion during a 15-second puffing sequence. Right: Simulation showing gas pressure generation.

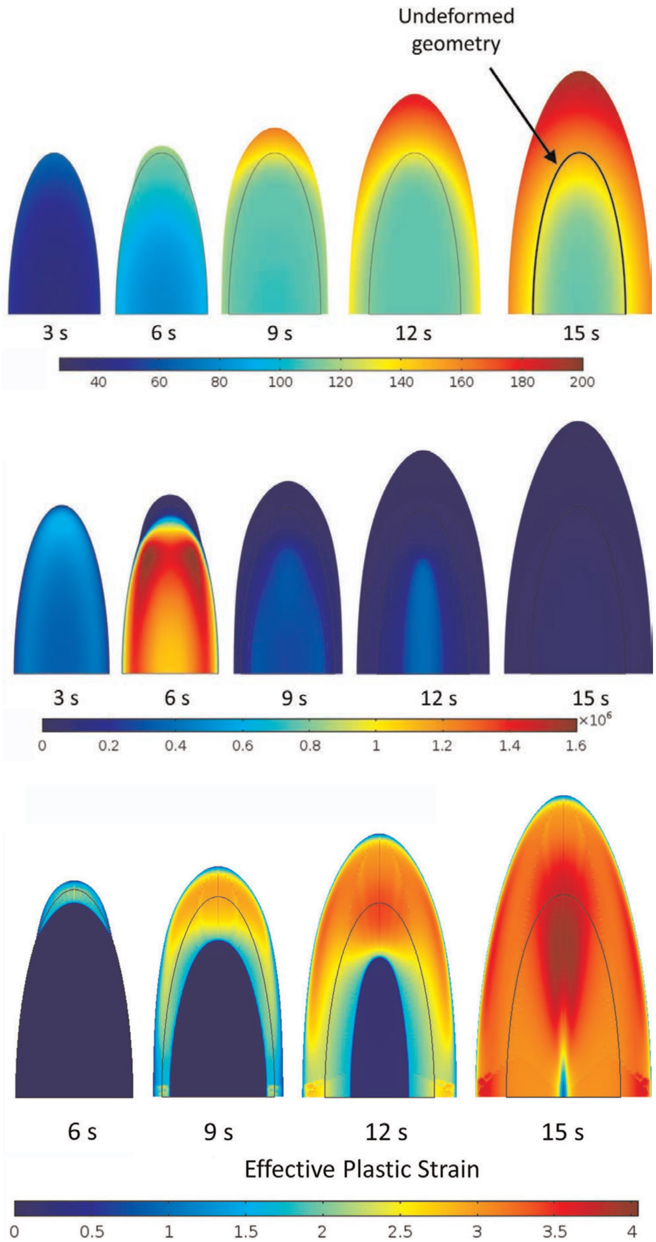


FIGURE 4. Temperature (top, shown in degrees Celsius); first principal tensile stress (center, shown in Pa); and effective plastic strain (bottom) during puffing.

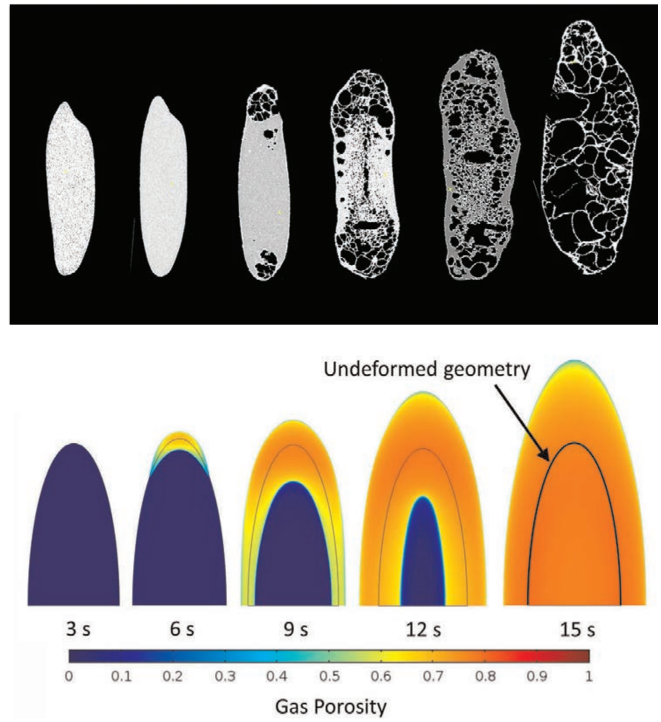


FIGURE 5. Top: CT scan of rice at different times during puffing. Bottom: Simulation showing predicted porosity profiles.

electromagnetic behavior involved in microwave heating."

Gulati built a multiphase porous media model to study the mass and momentum changes, energy transport, and large volumetric expansion. The model analyzed the different phases of solid rice, liquid and gas water, and moisture transport modes such as capillary flow, binary diffusion, and pressure-driven flow. He assumed the rice to be an elastoplastic material and obtained mechanical displacement and expansion.

The corresponding simulation revealed the spatial and temporal distributions of temperature, moisture, pressure, evaporation rates, volumetric strain, porosity, and stress levels at different times during puffing (Figures 3 and 4).

The team validated the computational model using a reconstruction of micro-CT images used to determine the expansion ratio and visualize the microstructure development. Gulati also found that the expansion ratio was sensitive to evaporation rates and the intrinsic permeability of the modeled solid matrix.

By the end of his work, they had a fully coupled model that linked the different behaviors occurring during puffing, including the phase change. Gulati coupled the transport model to the large deformation, and also tested how different levels of salt affected volumetric expansion, evaporation, and material properties. Salt lowers the glass transition temperature, meaning that the rice puffs more quickly and at lower temperatures.

"The simulation illustrated how properties vary within the rice grain initially, as well as how they change over time during heating," Prof. Datta adds. "This would be impossible to measure experimentally. The model tells how the rice grain expands, dries, and shrinks."

The model also provided an understanding of how the porosity developed, illustrating pore formation beginning at the kernel tip and progressing inward (Figure 5).

Based on the results, they determined the optimal amount of salt, moisture content, temperature, and heating time to produce the ideal puffed rice grain. The simulation also showed the conditions needed to maximize the expansion ratio.

» LOOKING FORWARD IN FOOD ENGINEERING

In addition to this model framework, Prof. Datta's research team has extended their simulation practices to studies of food safety. This has big implications for food companies that need to predict the health benefits of certain foods, know when they will expire, and ensure that their processes are safe.

Prof. Datta is currently the PI on a USDA NIFA-funded project where his students are using COMSOL to not only build simulations, but also construct computational apps that extend the analyses to nonengineers. At Cornell University apps are deployed on a large scale via the COMSOL Server™. Apps are beneficial for students and teachers because they don't need to invest in the software or hardware directly.

"Simulation apps bring new opportunities to education," he remarks. "In a food safety class, apps enable multidisciplinary learning where students can simulate many what-if scenarios realistically." The app developed at Cornell is used by several universities around the US.

They have provided food scientists with an app that covers canned food, for analyzing how the necessary heating time for sterilization varies with different container sizes (Figure 6). The app user can adjust the temperature and calculate how long it will take to heat food to a safe temperature for a given can. It also provides an adjusted rate of bacteria dying, to confirm whether or not the final product will be safe for consumption.

Prof. Datta says that, while puffed rice was the starting point, their work is easily transferrable to other biomaterials such as corn — or even to completely different applications. "The physics and modeling knowledge is useful in other industries," he says. "For example, one of my students later studied microwave drying of molds for cars' catalytic convertors, using simulation techniques similar to those we developed here." While he teaches the next generation of engineers about the fundamentals of physics modeling, he looks forward to seeing what comes next for the food industry. ◎

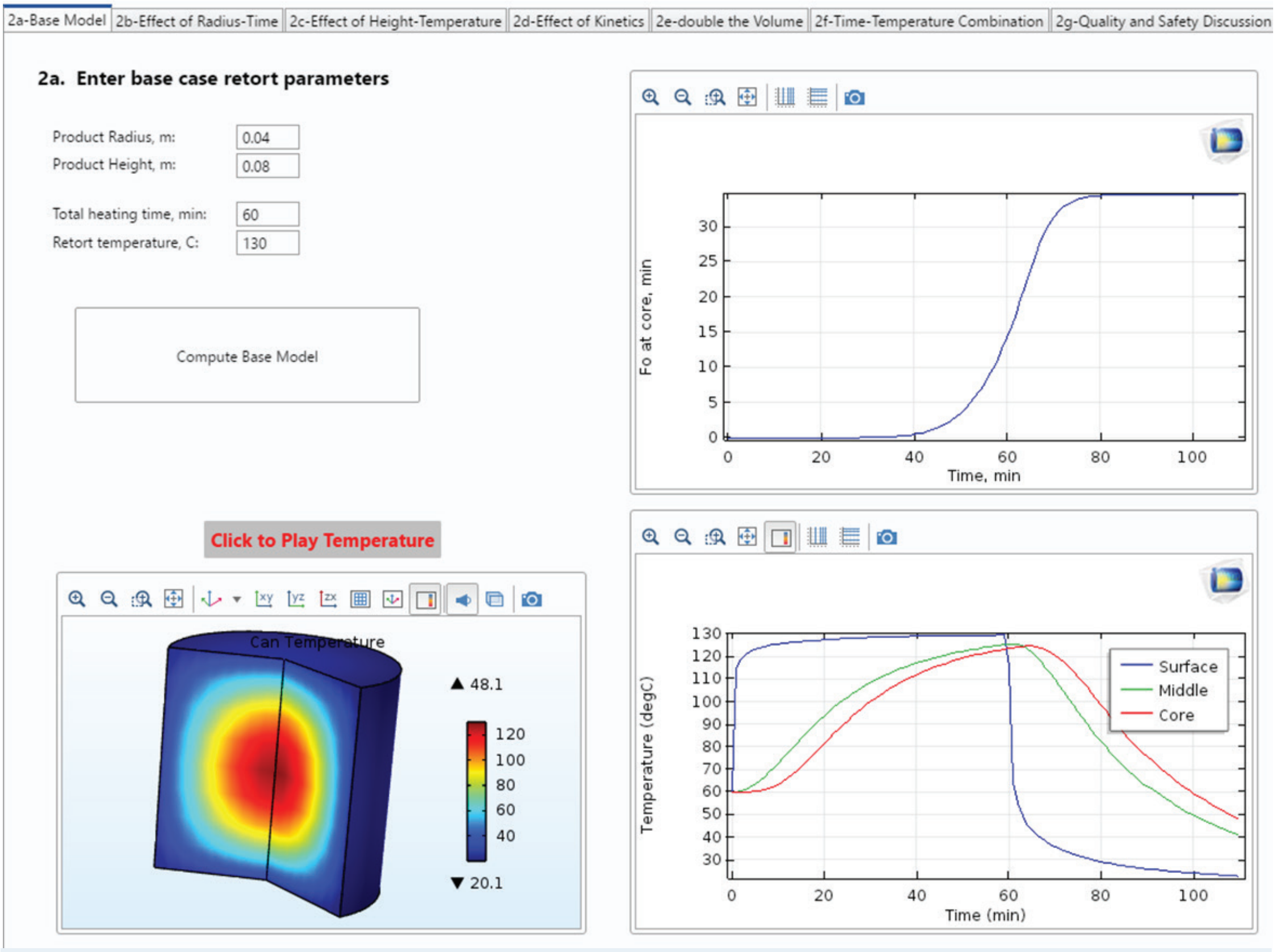


FIGURE 6. The computational app created by Prof. Datta's students for studying canned food. Users can change parameters such as the can dimensions and heating time.

Whirlpool R&D, Italy

SIMULATION TURNS UP THE HEAT & ENERGY EFFICIENCY

Researchers at Whirlpool Corporation are using simulation to test innovative and sustainable technologies for new oven designs.

by **ALEXANDRA FOLEY**

In terms of energy consumption, ovens have the most room for improvement of any appliance in the kitchen, with only 10 to 12 percent of the total energy expended used to heat the food being prepared. This is one of the reasons why Whirlpool Corporation, the world's largest home appliance manufacturer, is exploring new solutions for enhancing the resource efficiency of their domestic ovens. Using a combination of experimental testing and finite element analysis (FEA), Whirlpool engineers are seeking solutions to improve energy efficiency by exploring new options for materials, manufacturing, and thermal element design.

In partnership with the GREENKITCHEN® Project, a European initiative that supports the development of energy-efficient home appliances with reduced environmental impact, researchers at Whirlpool R&D (Italy) are studying the energy consumption of their ovens by exploring the heat transfer processes of convection, conduction, and radiation. "Multiphysics analysis allows us to better understand the heat transfer process that occurs within a domestic oven, as well as test innovative strategies for increasing energy efficiency," says Nelson Garcia-Polanco, Research and Thermal Engineer at Whirlpool R&D working on the GREENKITCHEN® project. "Our goal is to reduce the energy consumption of Whirlpool's ovens by 20 percent." Even if only one electric oven is installed in every three households in Europe, the resulting increase in efficiency would reduce the annual electricity usage of European residential homes by around 850 terawatt-hours. This would lead to a reduction of about 50 million tons in CO_2 emissions per year.

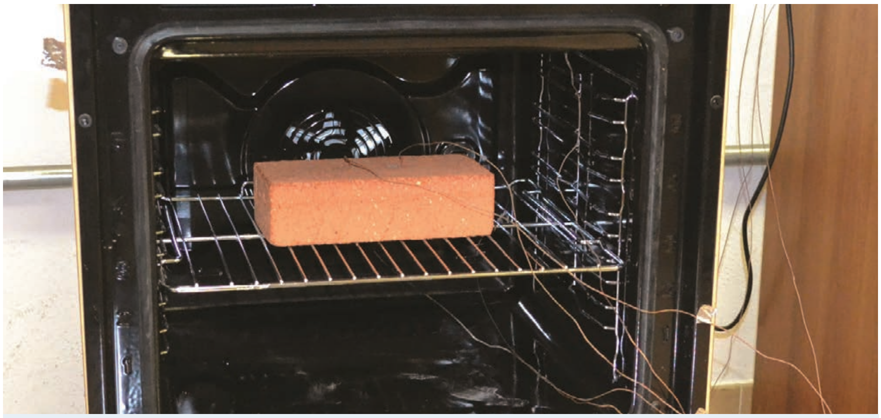


FIGURE 1: Whirlpool's Minerva oven set up for the "brick test."

» LIGHT AS A FEATHER, NOT THICK AS A BRICK

A loaf of bread should be as light as a feather, not, as they say, as thick as a brick. Ironically, the standard test for energy consumption in the European Union, known as the "brick test," involves heating a water-soaked brick and measuring temperature distribution and evaporation during the process. "A brick is used since it offers a standard test for all ovens. The brick is created to have similar thermal properties and porosity as that of many foods, making it a good substitute," says Garcia-Polanco.

During the experiment, a wet brick

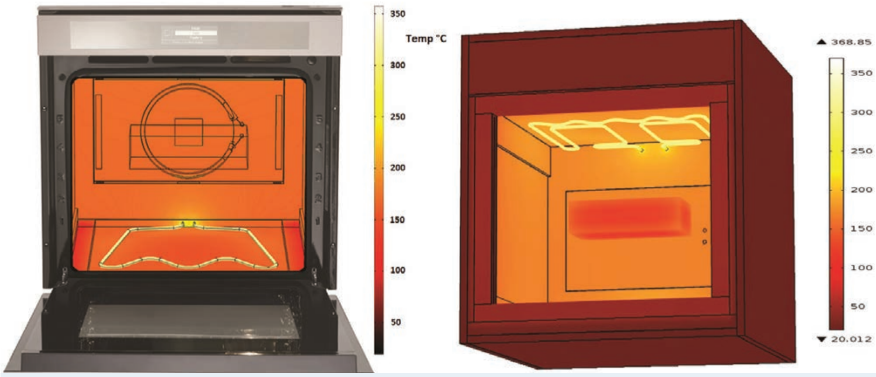


FIGURE 2: Predicted temperatures of the oven surfaces (color scale in ˚C) after 50 minutes in a broil cycle (right) and a bake cycle (left). Simulations where created using the Heat Transfer Module in COMSOL Multiphysics.

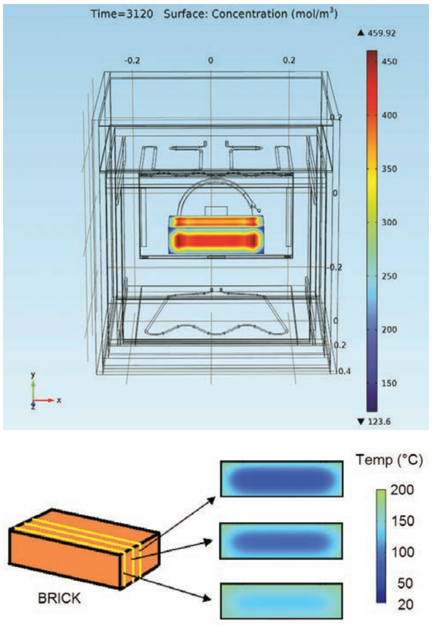


FIGURE 3: Top: Brick surface moisture concentration (in moles per cubic meter) at the end of the simulated test. Bottom: Predicted temperature profiles at different slices of the brick after 50 minutes at 200˚C.

with an initial temperature of 5°C is placed in the oven's center and is heated until the brick reaches a previously defined "delta" temperature (in this case, 55˚C). The temperature and amount of water evaporated from the brick are recorded throughout the experiment. Using the simulation software COMSOL Multiphysics, Garcia-Polanco and the team created a model of Whirlpool's Minerva oven to explore its thermal performance during this test (see Figure 1).

» ACCURATE SIMULATIONS PROVIDE THE RIGHT SOLUTION IN LESS TIME

The secret to efficient cooking lies in the heat transfer rate, which describes the rate at which heat moves from one point to another. Inside an oven, food is heated by a combination of conduction, convection, and radiation. "The static cycle heats the oven from the bottom (bake) and the top of the cavity (broil) using the corresponding heating elements, while the forced convection cycle uses the same configuration along with an internal fan," says Garcia-Polanco. "Therefore, radiation is most important during a static cycle, and convection dominates during the forced convection cycle." The simulation took into account the different heat transfer rates of the various heating methods (see Figure 2) as well as a combination of different elements including material properties, oven shape, and the type of food being prepared.

There are several factors that proved especially important when considering the transient behavior of the oven model. "We considered the emissivity of the glass door, the thickness of the walls, and the material properties of the walls," says Garcia-Polanco. "We made a detailed comparison of the results of both the simulation and actual experiment throughout the heating cycle, which helped verify that our simulation was accurate."

In addition to predictions of the temperature of the oven surfaces, detailed information about the temperature profiles and moisture concentrations within the brick were acquired. "We looked at the temperature behavior within the brick," says Garcia-Polanco (see Figure 3). "When we compared data from our simulation with the experimental data, we found that our predictions about the internal temperature of the brick closely matched that of our experimental data." Knowing that the simulation is accurate will allow Whirlpool's team to probe the oven and brick at any point in space and time with confidence in the results they obtain. "For our future experiments, this knowledge will help us to save both time and money by reducing the number of prototypes and design iterations we go through before settling on a final oven design."

The team also looked at the water concentration in the brick throughout the experiment. The experimental results were very close to the simulation, with an average predicted value of 166 grams of evaporated water after 50 minutes and an actual value of 171 grams. "Knowing the rate at which water evaporates from the brick will help us to conduct further studies into different strategies for reducing energy consumption without decreasing the final quality of the product," says Garcia-Polanco.

» A RECIPE FOR HIGH-QUALITY, HIGH-EFFICIENCY COOKING

The results from this verification study will help further the mission of GREENKITCHEN® project to empower innovative households to reduce national energy consumption and improve energy efficiency in Europe. A proven, reliable model simplifies the verification of new design ideas and product alterations, helping designers to find the right solution in less time. "This study confirmed that our model is accurate, allowing us to be confident in the results when we test future design ideas," concludes Garcia-Polanco. "Our next steps will be to use this model to optimize the use of energy resources in the oven and to deliver a robust, energy-efficient design to the European market." ◎

Illinois Tool Works (ITW) Food Equipment Group, USA

ITW USES MULTIPHYSICS SIMULATION TO COOK UP SMART MICROWAVE OVEN DESIGNS

Engineers at ITW use multiphysics simulation and applications to analyze smart appliance designs, improving the tools kitchen professionals need to cook food faster and more evenly with solid-state, convection heating capabilities.

by **THOMAS FORRISTER**

What makes an electronic device "smart"? Connectivity, certainly, is a large factor, and it is now commonplace to seamlessly switch from a phone or tablet to a computer using Bluetooth®, wireless internet, or 4G LTE and 5G protocols. Another sign that earns the smart (and sometimes artificial intelligence) label is a device's computing capabilities, which help us more easily perform everyday tasks. Take the smart home concept, for example. Thanks to the broader software capabilities of many devices, consumers are now able to automate their lives and save energy costs by using robot vacuum cleaners and adjusting lighting and heating settings on a timer.

Inside the kitchen, appliances such as refrigerators, dishwashers, and microwave ovens with smart features are becoming part of daily life. Smart appliances also have a place in professional kitchens. By designing cutting-edge smart appliances for these professional spaces, Illinois Tool Works (ITW) Food Equipment Group, the world's largest commercial food equipment company, is revolutionizing the way chefs cook, manage their time during service, and build menus.

» GENERATING MICROWAVES WITH SOLID-STATE TECHNOLOGY

ITW provides industrial appliance products ranging from drink service refrigeration to hot holding equipment, and uses the COMSOL Multiphysics® software to build and distribute simulation applications, improving manufacturing processes and designs.

One of their latest commercial offerings, IBEX (Figure 1), is a microwave and convection oven that is designed for the professional kitchen. The IBEX product

FIGURE 1. The IBEX solid-state microwave/convection oven by ITW.

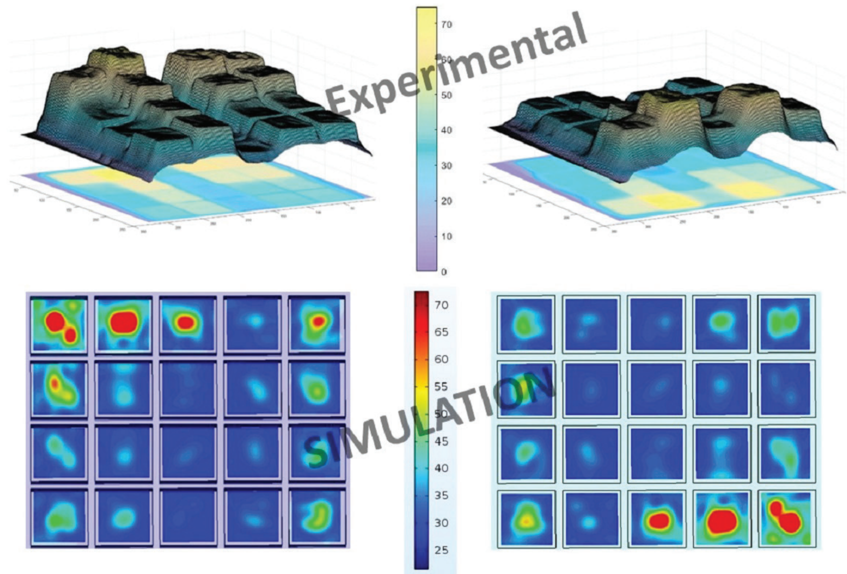


FIGURE 2. The improved uniformity when combining different heating patterns.

includes a number of smart features and changes the way food is cooked by heating food differently than other smart combination ovens.

RF technology provides consistent performance during the varied load conditions required for cooking. Engineers at ITW are harnessing the power of RF energy with a solid-state RF power amplifier and receiver, which directs the energy in a smarter, more uniform, and more efficient way than with a traditional magnetron — depending on the type of food or how much food it is heating. This technology achieves the quality of a combination oven, but with a rapid-cook oven time.

The targeted heating capabilities help automate tasks for chefs and other kitchen staff. Aside from the efficiency of solid-state heating, the IBEX oven is able to use algorithms to help professionals program recipes and custom menus, as well as perform common functions as they go about their work. No smart device would be complete without the connectivity factor: The IBEX has a USB port to easily expand menus via upload or transfer.

Adding smart features helps kitchen professionals, but what about tools that aid in designing the equipment? "When trying to optimize food heating with microwave/RF energy, simulations can be used to gain an approximate understanding of what to expect," says Christopher Hopper, sr. RF systems engineer at ITW. "Using simulation to get an idea of the heating patterns available in a solid-state oven allows for a more informed experimental setup."

He adds that the team also saves on food and labor costs, because there are virtually no trial-and-error runs of an experiment — they can do it all ahead of time to find the optimal design for both the appliance and the related experiments.

» WORKING SMART WITH A COMBINATION OF SIMULATION AND EXPERIMENTS

Setting up experiments by first using the COMSOL® software and add-on RF Module helps Hopper and his team study varying loads, uniformity, hot spots in the food, and more. Then they take advantage of LiveLink™ for MATLAB® to reduce computational time by combining parametric sweeps with complex postprocessing. Hopper finds this interfacing capability especially beneficial, as he uses the MATLAB® software extensively.

One of their important experiments considers the efficiency of the solid-state RF IBEX design. Hopper and his team were interested in how well the oven can maintain a high efficiency for different food containers that have varied volumes and load distribution, so they used simulation to help them test the containers and identify where there was room for uniformity improvement. A cubic arrangement of thin layers and an array of cylinder-shaped loads were compared. For each type of container, the solid-state oven could maintain highly efficient energy delivery to the load.

Current rapid-cook ovens on the market are unable to adjust parameters such as phase, frequency, and output power, which leads to large swings in efficiency when the load volume, distribution, and number of items change. Alternatively, the effectiveness of convection or combi ovens depends on the surface area of the load, so increasing the number of items does not necessarily lead to an increase in time required for cooking or reheating. In contrast, the IBEX oven's efficiency stays high for a multitude of load configurations, thus combining the quality of a combi/convection oven with the speed of commercial rapid-cook ovens.

However, simply having the ability to control frequency, phase, and output power is not enough to maintain highly efficient energy delivery. Instead, they relied on the closed-loop feedback system to evaluate opportunities for

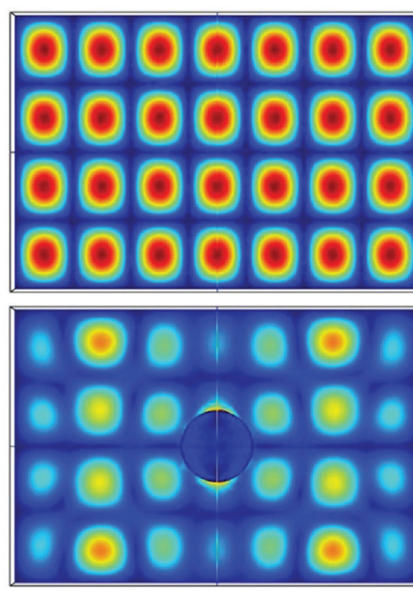


FIGURE 3. Electric field pattern comparison for loaded and unloaded cavity modes within a microwave oven.

improving cooking configurations. Closed-loops, as opposed to open-loop-type ovens, allow the device to learn the initial conditions, apply specialized heating configurations, and adapt to the changing physical properties of the load during cooking. By using closed loops as a form of control, engineers can feed the system's generated output back into the system. By comparing the actual output with the desired output, they can design this type of system to automatically sense and monitor the difference in output via an error signal, and thus change the loads, food properties, and other conditions to improve the cooking process.

Using feedback from the cavity/load system, they are able to run tests to see that cooking configurations can be combined to improve uniformity and consistent energy delivery (Figure 2) while using less nominal power to achieve the same result.

From there, the team can continue to refine tests and confirm and understand the simulation results. "COMSOL Multiphysics® allows our team to perform accurate coupled electromagnetics and thermal simulations of food materials, or loads," says Hopper. "The properties of these loads change with temperature and frequency, and we have found that the software can account for these changes and provide good approximations for the heating pattern, electromagnetic field magnitude, and power loss density."

For example, when they create simulations of loaded and unloaded cavity modes, the team can see where hot spots are most likely to be located (Figure 3). Evaluating likely heating patterns and potential cavity and cookware absorption using simulation can assist them in structuring their experiments in which thermal and electromagnetic data will be collected using multiple frequencies (Figure 4). Furthermore, they can be sure that the simulation results are accurate by creating an intentional temperature difference between foods like bread and eggs.

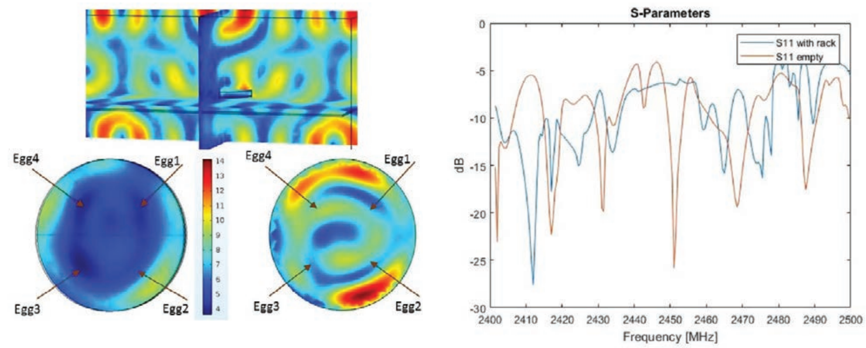


FIGURE 4. Left: The probe placement in the oven and eggs for collecting thermal and electromagnetic data. Right: S-parameters for an oven with and without a rack.

» THE MORE COOKS IN THE SMART APPLIANCE DESIGN KITCHEN, THE BETTER

In addition to more complex simulations, Hopper creates simulation applications so that colleagues are able to interact with the design by changing parameters such as frequency or phase response, temperature and time (in terms of recipe creation), sample size and location effects, dielectric properties, and more.

There are many advantages to deploying applications within an organization. "When working in a diverse team with different skill levels and backgrounds, I have found that tailoring applications to a person's interests and job duties lightens the workload on the simulation experts," says Hopper.

He also sees building simulation applications as an opportunity to educate others. In fact, some of the applications of the IBEX oven (Figure 5) have been created specifically to introduce new team members and interns to the basics of wave interference, dielectric and loss factor dependencies, and RF heating.

Solid-state cooking devices present many promising advancements in the culinary arts, with targeted food heating being just one of them. By continuing to use important ingredients like simulation, applications, and postprocessing tools, engineers and manufacturers in the food equipment industry can design more efficient and reliable smart appliances for both professional and home kitchens.

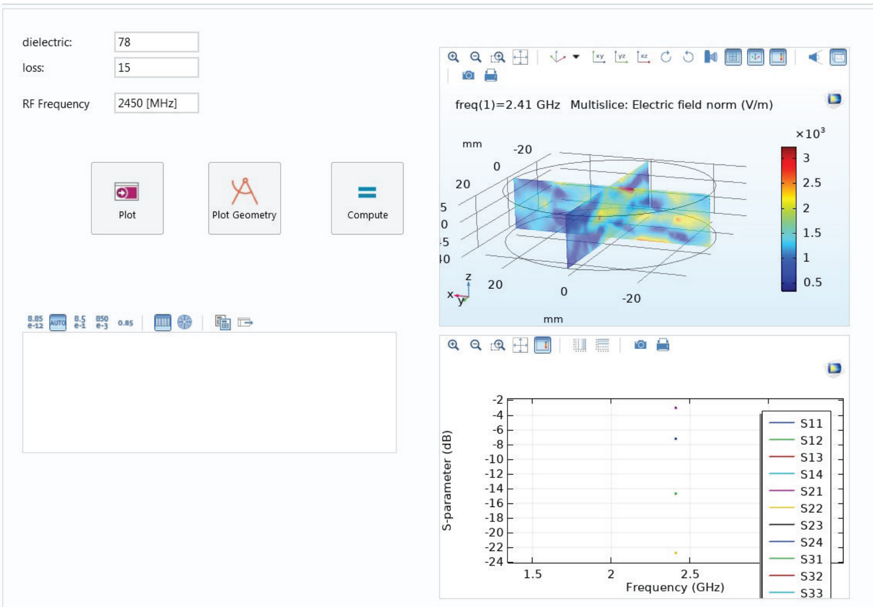


FIGURE 5. User interface for an IBEX oven simulation application.

thermofin GmbH, Germany

OPTIMIZING HEAT EXCHANGER DESIGNS FOR REFRIGERATION & COOLING TECHNOLOGY

Cooling an indoor ski slope, providing air conditioning to a prestigious old castle, or chilling and freezing consumer goods — these scenarios all require heat exchanger technology. thermofin GmbH ensures that their heat exchanger devices are optimized for a variety of client needs using multiphysics simulation.

by RACHEL KEATLEY

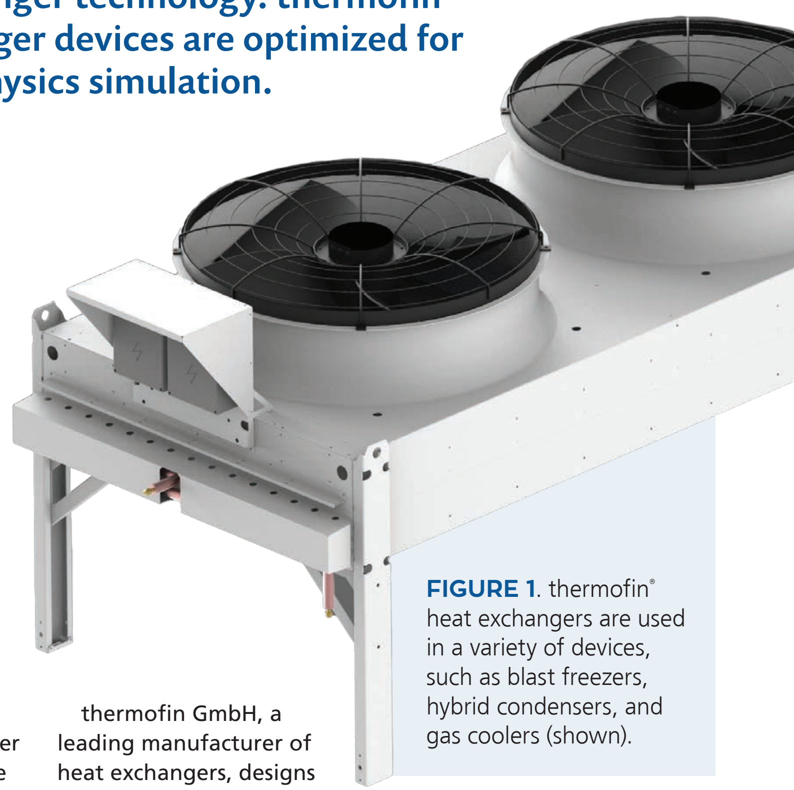


FIGURE 1. thermofin® heat exchangers are used in a variety of devices, such as blast freezers, hybrid condensers, and gas coolers (shown).

An estimated 93.4 million tonnes (103 million tons) of food went to waste in the United States alone in 2018 — a number greater than the weight of 600 thousand average-sized blue whales. A majority of food waste ends up in landfills, where it decomposes and produces methane. The United States Food and Drug Administration (FDA) even reports that food waste accounts for the largest percentage of material in landfills. Food can be wasted during any stage of its lifecycle, which is why it is important for consumers and the food industry alike to be aware of solutions to help alleviate this problem. One way to help reduce food waste on an industrial level is to ensure that consumer goods are being properly stored before they end up in customers' homes.

thermofin GmbH, a leading manufacturer of heat exchangers, designs technology to help make this solution a reality. Their heat exchangers are used in air conditioning and refrigeration systems in commercial and industrial buildings around the world. Their devices can be found in supermarkets, cold storage facilities, ice arenas, power plants, and more. Julius Heik, a thermodynamics development engineer at thermofin GmbH, performs simulations to ensure that their heat exchangers are optimized for specific use cases and client needs.

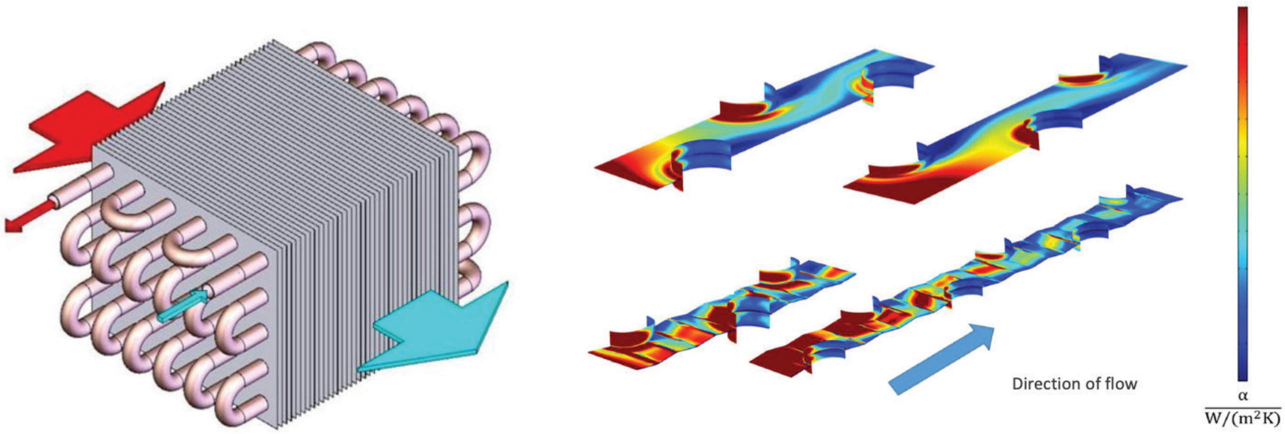


FIGURE 2. Left: Geometry of a thermofin® heat exchanger. The large arrows represent the airflow, while the small arrows represent the refrigerant flow. In addition, the red and blue colors indicate a temperature change. For example, airflow is hot at the inlet (red) and cold at the outlet (blue). Right: thermofin® heat exchangers contain slats or fins of varying material properties and spacing requirements. To better understand how these slats work, thermofin GmbH uses simulation to analyze the direction of flow.

Heik's favorite part about working with simulation? You are able to gain knowledge before actual measurements are carried out.

» DESIGNING OPTIMIZED HEAT EXCHANGERS

Since its founding in 2002, thermofin GmbH has expanded from 6 employees to more than 800, with production sites on several continents. Their dependable heat exchangers have made them a popular choice in the refrigeration and air conditioning industry.

Heat exchangers sound like a simple concept, but they can actually be quite challenging to design. The essential task in cooling a product is to get rid of unwanted heat so that thermal energy from perishable goods is extracted. This is where the refrigerant of a refrigeration cycle comes into play. By changing the refrigerant phase from a liquid to a vapor state, the heat exchanger is removing heat from its ambient surroundings. This heat then has to be passed over to a second heat exchanger, which emits this energy to the outside environment.

In transcritical CO_2 refrigeration cycles, a so-called gas cooler chills the refrigerant inside a heat exchanger. Often, people get confused by the name "gas cooler", as if it uses gas to chill its surroundings. Designing heat exchangers in general, and gas coolers in particular, presents a fair amount of difficulties, according to Heik. When striving for better, more energy-conserving refrigeration cycles, well-engineered heat exchanger designs serve as a main contribution.

Like many cooling systems, gas coolers are designed to have a minimal direct impact on the environment, so they use the natural refrigerant CO_2. For example, in the supermarket sector, CO_2 is now used almost exclusively because it is classified as a nonhazardous gas (safety group A1). Due to its properties, however, it must dissipate its heat at air temperatures above 20–25°C, in the so-called transcritical range. That is why these systems have a large temperature difference, consist of many different circuits, and are made up of a wide range of materials. Using simulation, Heik is able to efficiently and simultaneously analyze

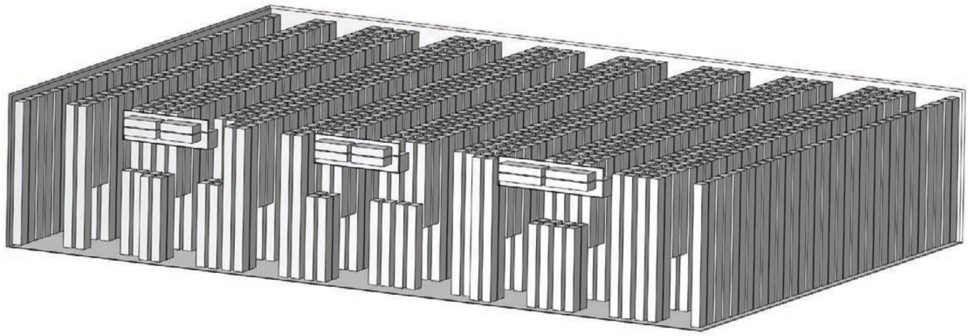


FIGURE 3. Geometry of a cold storage warehouse from another project, where air is distributed via the cold lake principle, in which cold air is introduced toward the floor, spreads out due to density differences there to rise at the other end of the room, and is drawn back in at roof height. The model takes into account the high stacking density of the storage racks with forklift passages.

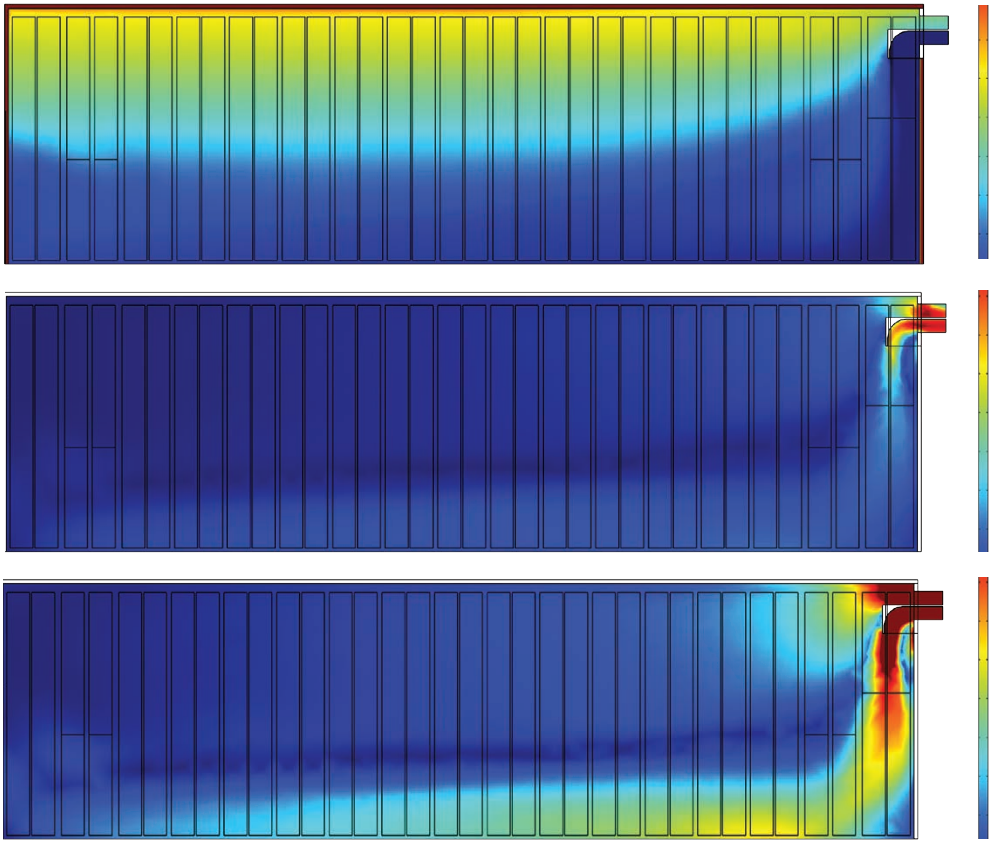


FIGURE 4. Simulation of the cold storage room's temperature distribution (top) and speed distribution of the airflow (center, bottom).

the airflow and material properties of these devices.

Designing the inner finned tubes presents another unique challenge when developing heat exchangers. These tubes are used in heat exchangers to transform a hot fluid into a cold fluid or vice versa. The arrangement, diameter, material (stainless steel is required if using ammonia), and fin spacing of these finned tubes all depend on the type of heat exchanger in which they are being used. "There is not a lot of measured data available on how these tubes work," said Heik. With simulation, he can get a better understanding of how finned tubes affect a heat exchanger design by modeling multiple tube geometries and investigating their inner and outer heat transfer capabilities. The finned tube geometries that offer the best performance are built and tested at an in-house experimental station. "We look to see if the calculations and results are the same or similar, and then we take the best tube for our industrial line," said Heik.

» COLD STORAGE ROOM SIMULATIONS

In addition to performing simulations of heat exchanger technology, thermofin GmbH also simulates their customers' cold storage warehouses. For one specific project, a customer asked for help designing a meat storage room, which would include several robotic machines that hold the meat. In this storage room, meat enters at room temperature and needs to be cooled before it can be brought into a different cold storage room. "It was important that the air velocity in the room wasn't too high so that the meat wouldn't fall off the robotic [machines], and on the other hand, it was really important that every area in the room gets the same or similar amount of air," said Heik.

When performing cold storage simulations like this one, there are several criteria that need to be taken into account, including temperature distribution, airflow distribution, relative humidity, adjacent heat loads, and natural convection. At first, thermofin GmbH believed that their customer would need to use five heat exchangers in order to get an even amount of air distribution within the storage room.

After simulating a room with five devices, Heik noticed a problem. "The backflow of the air would partly bypass into the intermediate ceiling," said Heik. To fix this issue, Heik simulated some air-guiding veins in the room, which would help ensure a smooth backflow, ultimately reducing the amount of vortexes in the room. Following the advice of thermofin GmbH, the customer ended up using five thermofin® units and built their storage room with air-guiding veins. According to Heik, the customer is happy with the results and has thankfully not experienced any occurrences of falling meat.

» THE FUTURE OF HEAT EXCHANGER TECHNOLOGY

As thermofin GmbH continues to expand globally, their plans for innovative simulation work continue to grow as well. "In our future research plans, we want to design [heat exchangers with a] new fin shape," said Heik. A change like this requires that the heat exchanger's tubes expand in diameter. To successfully implement this change, thermofin GmbH first needs to find the optimal way to space out these tubes. "For a new fin geometry, we would have to simulate it before we buy the tools to produce it ourselves," said Heik. A modification like this could help enhance the heat transfer capabilities of their heat exchanger designs. ◎

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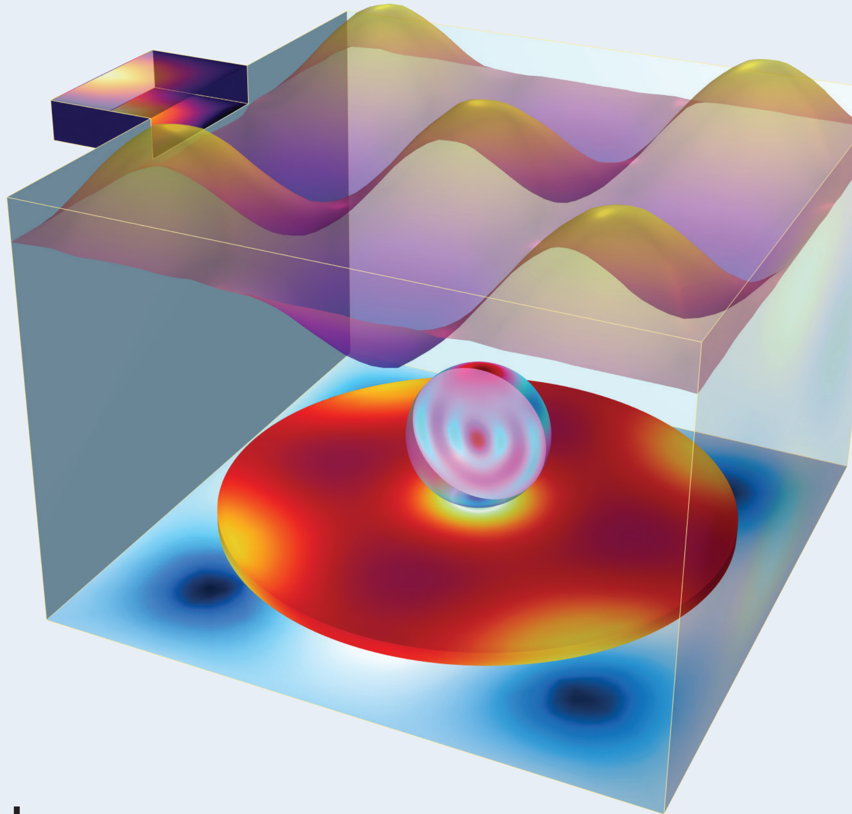
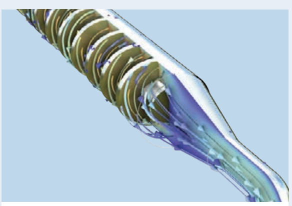
Food Industry Modeling



The COMSOL Multiphysics® simulation software is useful for analyzing food and beverage products, processes, and devices that are challenging or resource intensive to test physically, as well as for proposing new and optimizing existing designs.

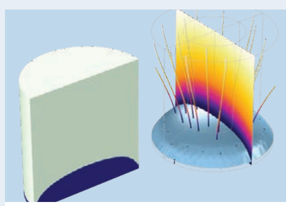
COMSOL Models for Download



Pasta Extruder

Application ID: 100121

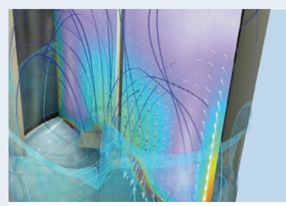
Simulates the nonisothermal flow of pasta dough through an extruder to predict the quality of the final product.



Freeze Drying

Application ID: 3924

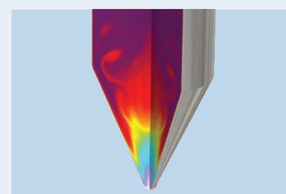
Displays a test case for modeling the freeze-drying process, which involves phase change.



Modular Mixer

Application ID: 16903

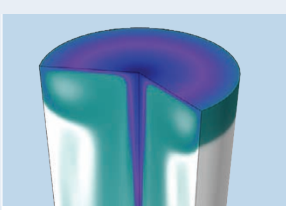
Studies how different vessel and impeller designs affect mixing results.



Fermentation in Beer Brewing

Application ID: 27281

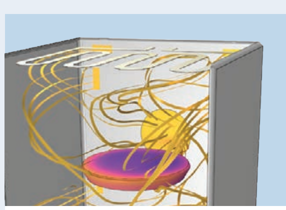
Models fermentation to evaluate the parameters that affect the final alcohol content and taste.



Carbonation in Water

Application ID: 67701

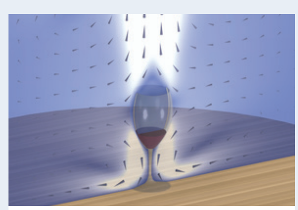
Models the carbonation process via the dissolution of CO_2 in water.



Domestic Oven

Application ID: 103081

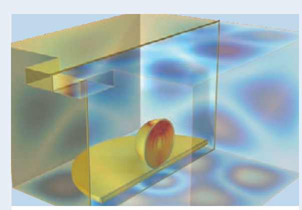
Shows the impact of conductive, convective, and radiative heat transfer on food in a domestic oven.



Wine Glass

Application ID: 108751

Simulates the evaporation of ethanol and water from a glass of wine.



Microwave Oven

Application ID: 1424

Analyzes the heating process in a microwave oven to show how heat is distributed in the food.