Mother of Invention

Simulation helps to deliver a milk warmer to market two years ahead of schedule, saving $54,000 in prototypes.

By Jim Shaikh, Founder, yoomi, London, U.K.

yoomi warmer on left and bottle on right. The warmer fits under the bottle cap and liquid is heated as it flows through the channels of the warmer.

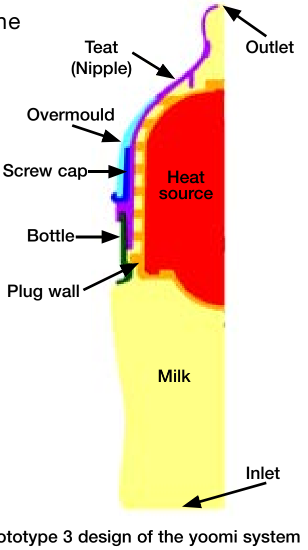
When my first son, Danial, was born, it was my job to take the expressed milk out of the fridge and heat it up while he cried to be fed. My wife said, "You are an engineer. Can't you do something useful?" To see what would happen, I assigned my engineering consulting business, Intelligent Fluid Solutions (IFS) Ltd., to come up with an easy way to warm liquids fed to babies. The concept of the yoomi self-warming baby feeding bottle was thus born. I now work full time with the company yoomi, which has sold thousands of bottle warmers.

The yoomi is a combined package of baby bottle and warmer. At the touch of a button, it gently warms liquid food to the exact temperature of breast milk, quickly and safely. The design challenge was to take fresh milk from 5 C to 34 C within one minute of activation across a full range of baby drinking speeds.

While engineering a way to heat the bottle, IFS engineers looked at a number of chemical and electrical heaters and decided to use sodium acetate trihydrate. This component is used in heating pads and hand warmers because it gives off heat when it changes phase; in addition, it can be easily recharged by boiling. The challenge was that the initial prototype heated the nutritional fluids to only 17 C, half the needed temperature.

The engineering team used fluid dynamics software from ANSYS to simulate the multiphase fluid dynamics of the proposed design. By evaluating many simulation prototypes, they doubled the performance of the initial design concept while building only four physical prototypes. IFS saved $54,000 by avoiding the need for 12 additional physical prototypes, and it delivered the yoomi feed warmer to market two years earlier than otherwise would have been possible.

When sodium acetate trihydrate crystals are melted above 80 C and allowed to cool, the aqueous solution becomes subcooled. Clicking a metal disk releases trapped crystals, causing the solution to crystallize into solid sodium acetate trihydrate and to release heat. In the yoomi feed warmer, the milk or formula runs through channels and is heated by the solidification process just before the baby drinks it. The channels are curved to increase the amount of surface area in contact with the milk.



Prototype 3 design of the yoomi system

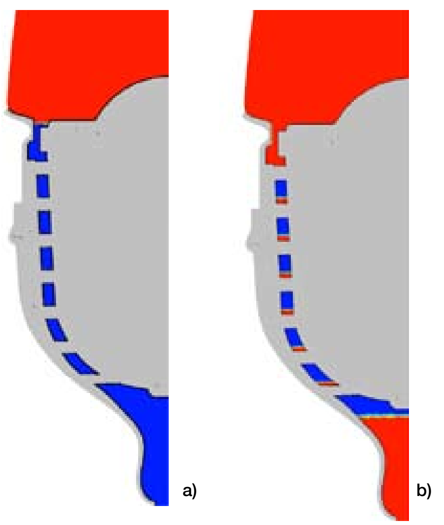
The key to getting the design right was determining the geometry and size of the channels where the heat is transferred to the liquid. Addressing this challenge requires understanding a complex thermal system in which sodium acetate trihydrate goes through a phase change. It also requires consideration of how different channel designs might optimize heat transfer rates to the fluid.

The original concept design was created by conducting very basic numerical analyses based on simple geometries that had been studied in published literature, which had been developed for heat transfer in laminar flows. The literature designs were restricted to straight channels and, therefore, provided results that did not match physical testing: When the IFS engineering team designed and rapid prototyped the initial concept design, the milk heated up to only half the required temperature.

The engineers could have gone back to the drawing board, changed the design and built another rapid prototype. But each prototype cost about $4,500 and took a week to build. In addition, the properties of the rapid prototypes did not match the production version of the bottle warmer. It probably would have taken 16 prototypes over four years to develop a marketable product using the prototyping method.

IFS engineer Dr. Andrej Horvat used ANSYS CFX fluid dynamics software to model the actual channel geometry. Viewing the simulation results, Horvat was able to substantially improve heat transfer efficiency by redesigning the channels to increase the fluid path. He adjusted channel width and depth to improve heat transfer. Using this approach, he was able to increase the temperature of the milk coming out of the device to 22 C — better but still not good enough.

Milk volume fraction in prototype 3: **a)** *t* = 39.3 s, **b)** *t* = 51.9 s



Milk volume fraction in prototype 4: **a)** *t* = 39.3 s, **b)** *t* = 51.6 s

With each iteration, channel geometry was adjusted to allow for more consistent liquid flow.

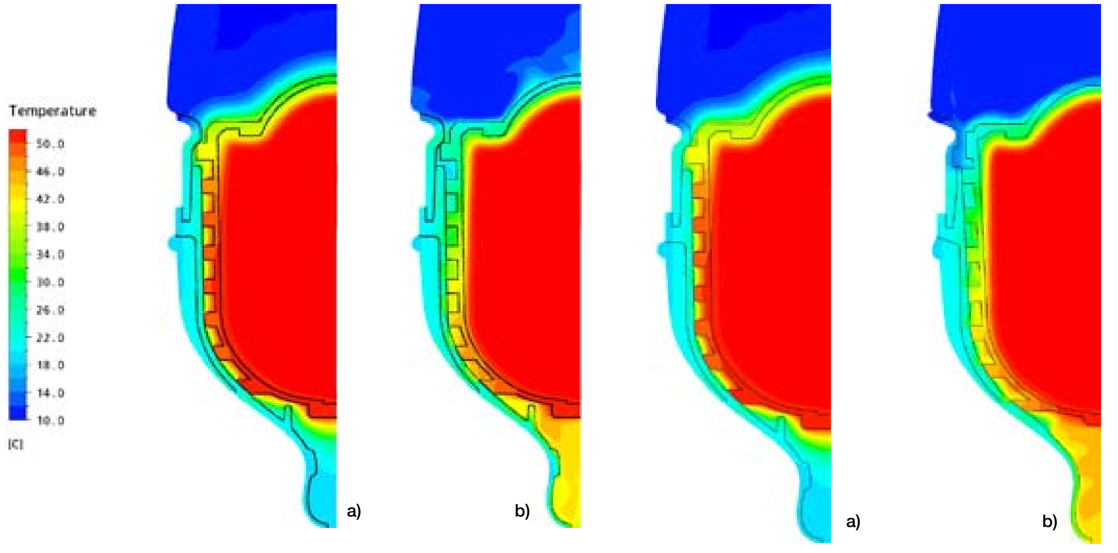
Next, Horvat built a model that simulated the phase change of sodium acetate trihydrate to better understand how the heat is generated, transferred through the walls of the channels and passed to the feeding liquid. This required an accurate model of the solidification process. He used a solidification model of the behavioral characteristics of sodium acetate trihydrate from the literature and calibrated it using the experimental data. Horvat then created user-defined functions and embedded them into the ANSYS CFX software.

The fluid dynamics tool provided outstanding performance to obtain convergence using time steps large enough to provide meaningful results for this complex analysis. With this accomplished, the team was able to visualize the complete physics, including how the liquid progresses through the warmer channels, how it pushes air in the opposite direction, and how it picks up heat from the phase change material.

The multiphase simulation demonstrated that solidification is not a stable process. As the material goes from fluid to solid, it releases energy, but if the energy is not removed, the reaction stops. As the team reduced the number of channels to improve the efficiency of heat transfer, there was a tendency for the liquid flow rate to vary from channel to channel. This meant the temperature was too cold in some channels. The team applied fluid dynamics to carefully balance the flow between channels.

The results showed that air plays an important role in the performance of the yoomi warmer. For example, when the bottle is tipped upside down so the baby can drink, the air rushes out of the nipple and into the heating channels just as the milk is entering the these channels. In early designs, simulations showed that air was keeping the feed from flowing into the nipple. Horvat corrected this problem by changing the channel geometry to adjust the air and feed flow ratios so the air could flow in one direction and the milk in the other. It would have taken much longer to understand and correct this problem without the help of CFD simulations.

Modeling the multiphase behavior of the heating compound substantially improved the agreement between the simulation results and physical test results. This understanding of how the whole system works was critical to developing an optimized design in minimal time, and it would have been impossible without fluid dynamics. Using the more accurate simulation results, Horvat was able to



Temperature in prototype 3: **a)** *t* = 39.3 s, **b)** *t* = 51.9 s

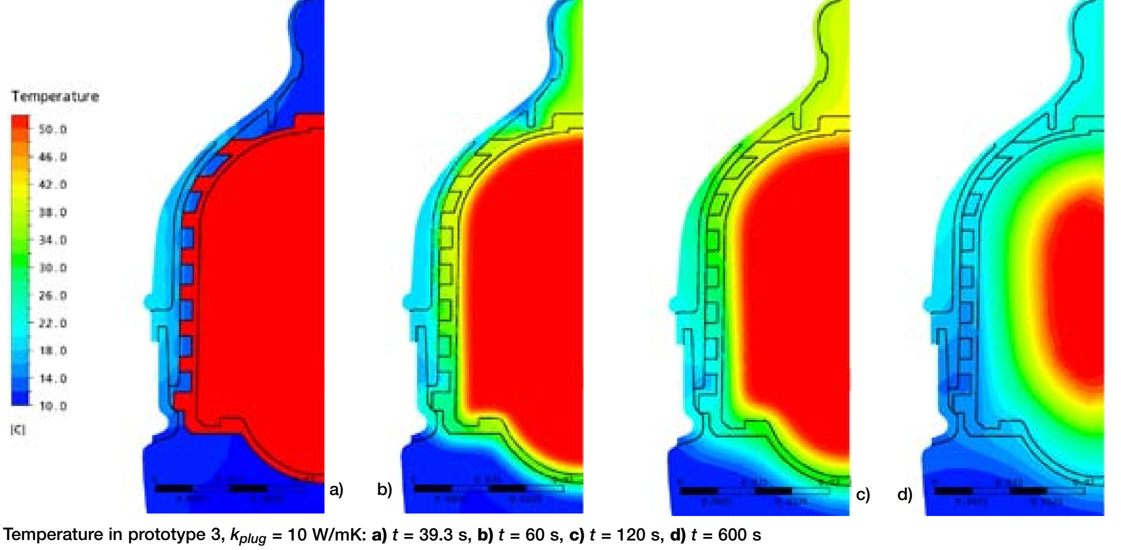
Temperature in prototype 4: **a)** *t* = 39.3 s, **b)** *t* = 51.6 s

The design of the feed warmer was iterated to bring the milk at the nipple to an optimal temperature.

further refine the geometry and increase the temperature of the milk to 28 C, a significant improvement but still far from the goal.

The team believed they could rapidly improve the design if they were able to evaluate a wider range of geometries more quickly. So Horvat performed a series of design studies using the simulation software, and he used the results to build a simpler analytical model that evaluated designs in less time than full-blown fluid dynamic simulation would take. He applied the analytical model to crunch through thousands of possible geometric alternatives, then picked the best designs and performed a full fluid dynamics analysis on these. Using this method, engineers were able to increase the temperature to the target of 34 C.

Fluids simulation from ANSYS saved a huge amount of time and money on this project. If the engineers had followed the conventional approach of build-and-test prototypes, they estimate that they would have spent $54,000 over four years readying the product for market. Instead, fluid dynamics simulations correctly predicted the physics of the product and made it possible to meet design objectives in half the time with only four prototypes. When the yoomi bottle was launched on the web, the initial production run sold out in just four days. Production has been ramped up to meet demand, and distribution channels are being expanded to include other U.K. and international retailers.



Temperature in prototype 3, k_{plug} = 10 W/mK: **a)** *t* = 39.3 s, **b)** *t* = 60 s, **c)** *t* = 120 s, **d)** *t* = 600 s

Temperature of the warmer over a long period of time