yoomi

CFD Driven Product Design

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yoomi is a rechargeable, BPA-free, self-warming baby bottle that warms baby's feed to the natural temperature of breast milk at the touch of a button (www.yoomi.com)

- The yoomi bottle design was developed by **Intelligent Fluid Solutions Ltd.** between 2007 and 2009.
- Yoomi is being manufactured by **Feed Me Bottles Ltd.** in China, South Africa and UK.
- The yoomi bottle entered the UK market in Nov. 2009 through John Lewis and is now also available in Mothercare & Boots.
- Yoomi is expanding internationally and is available in Scandinavia, Ireland and continental Europe.

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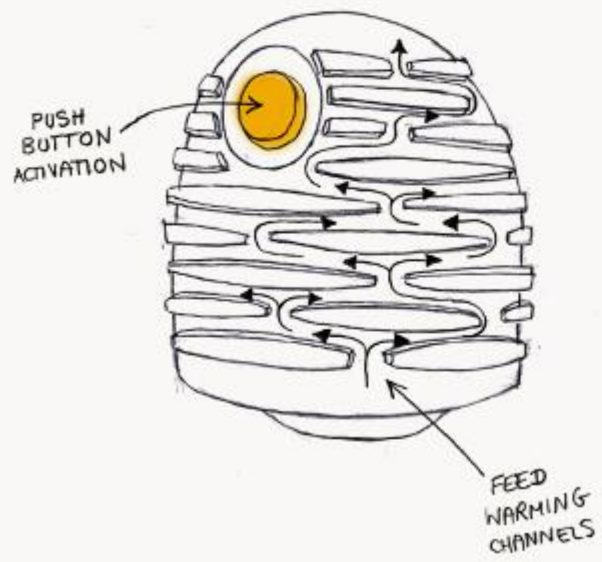

- The bottle exploits the **subcooled nature of sodium acetate mixture**, which remains liquid below its solidification temperature
- The mixture is contained inside a warming unit with channels for the milk flow
- When the solidification process is triggered, latent heat is released
- As the milk flows along the channels, it is heated to the **correct temperature - above 32ºC**
- The warmer is recharged by placing it in boiling water or a steam sterilizer.

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Geometry of the warmer channels is an important aspect of the design and influences overall warmer performance:

- **pressure drop in the feed flow** (defines the flow speed of the feed and the return air from the teat)
- **feed temperature at the first drop** (flow rate of 200 ml/min)
- **feed temperature at steady drinking speed** (flow rate of 20 ml/min).

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It was a technical challenge to design a warmer **to heat the milk from 5ºC to 32ºC for the first drop flow rate (200 ml/min)** and **to maintain steady-flow conditions**

- The first warmer design experienced sluggish milk flow with the milk first drop temperature of just 17ºC
- CFD modelling techniques were used in all stages of the development process to improve the design, and to significantly reduce the development time and costs
- All CFD analyses were performed with **ANSYS simulation software** (ICEM CFD, ANSYS CFX)
- Robustness of the ANSYS CFD package allowed us to build a **complete virtual prototype** of the baby bottle

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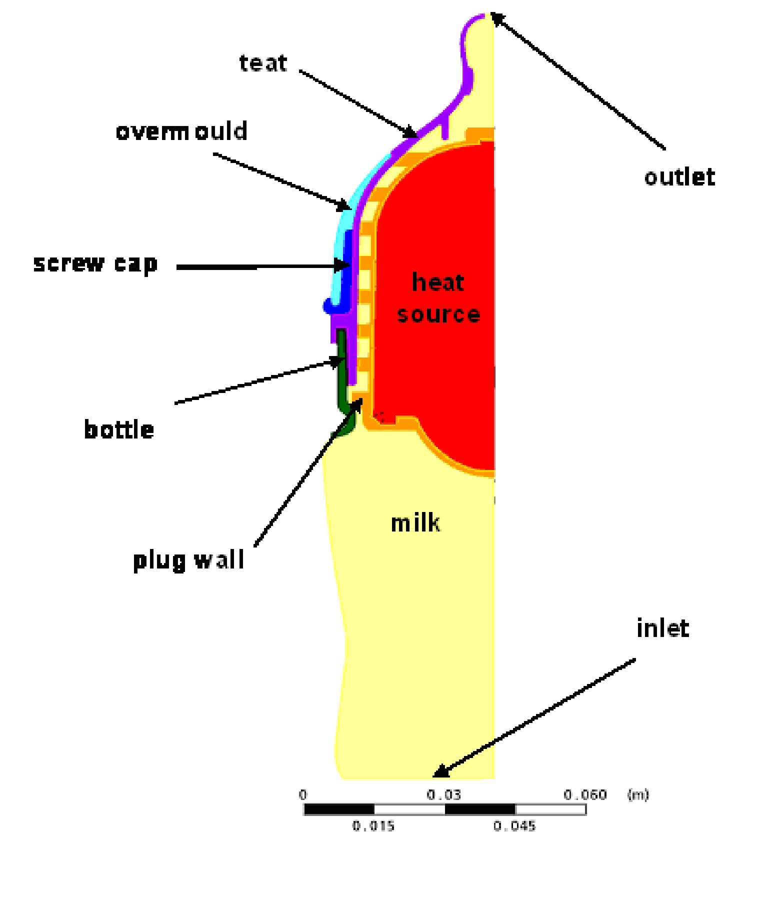

Modelling fluid and heat flow in such device is challenging:

- laminar **flow of milk** from the bottle to the teat
- **air flow** is squeezed from the teat and flows in the opposite direction
- **solidification process** and heat generation
- **thermal material properties** of solid parts
- **heat transfer** (convection & conduction) from the warmer to the fluid flow and the solid parts
- **flow stability**

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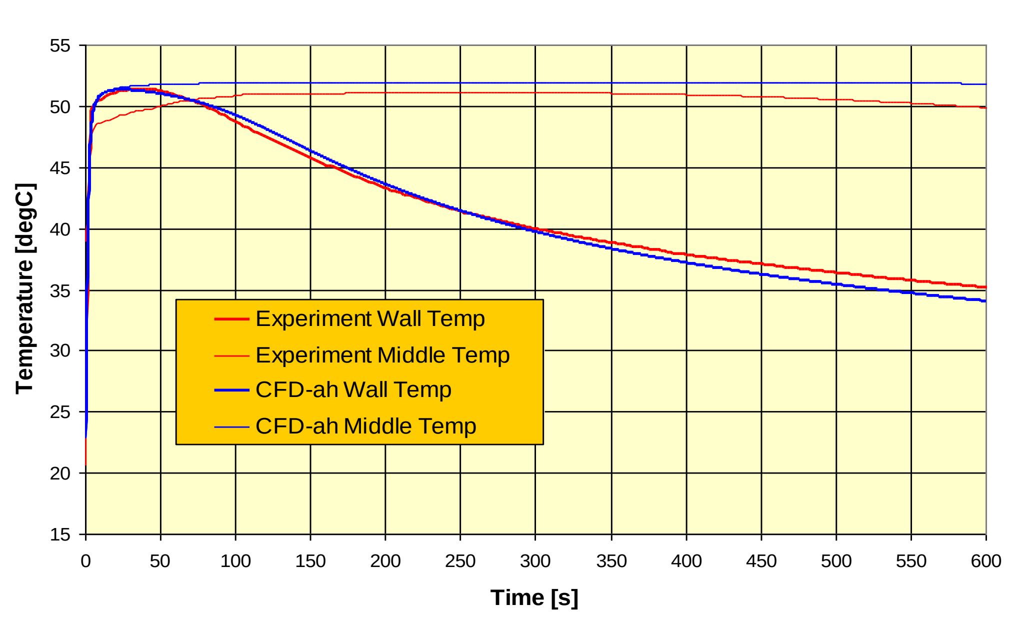
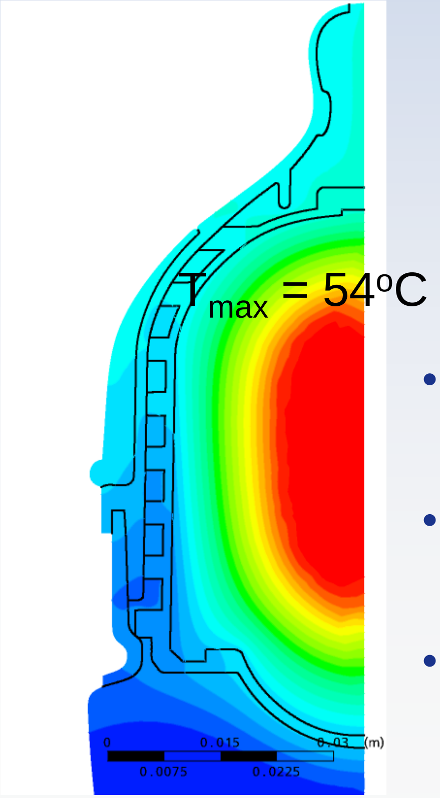
Adequate approximation of the solidification process of the sodium acetate mixture was fundamental to accurately predict time dependent heat transfer





- Due to the subcooled state of the mixture, the **solidification reaction is fast** and limited only by the mixture temperature
- A reaction model was **developed** and **calibrated** based on the available thermocouple readings
- The numerical grid of the warmer validation model contained approx. 120k nodes. Using 0.1s timestep, it took 12h to simulate 20 min of the heating time on a 4 processor workstation.

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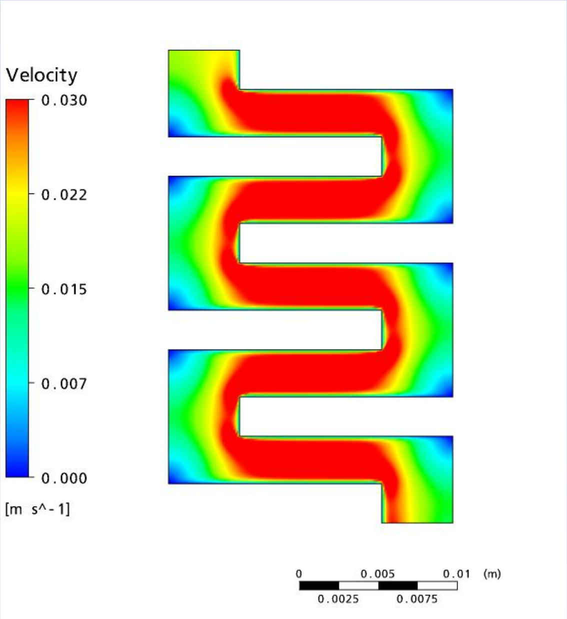

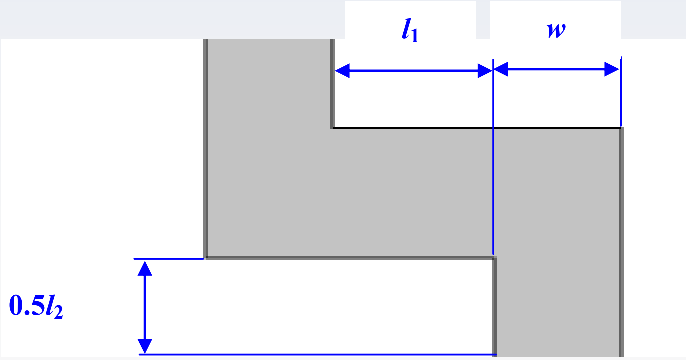

Heat transfer and **pressure drop** in the warmer channels were studied in details:

- In order to improve the heat transfer from the warmer to the milk flow, the milk travelling time or the channel distance were maximized
- CFD was used to analyse a number of channel designs in order to obtain a **heat transfer coefficient correlation $h(x)$** and a **friction factor correlation $f(x)$**
- These channel CFD models had approx. 50k grid nodes. The steady-state simulations required 30 min to reach a converge solution

The calculated correlations (h and f) were used to build a **parametric model of the warmer channels**

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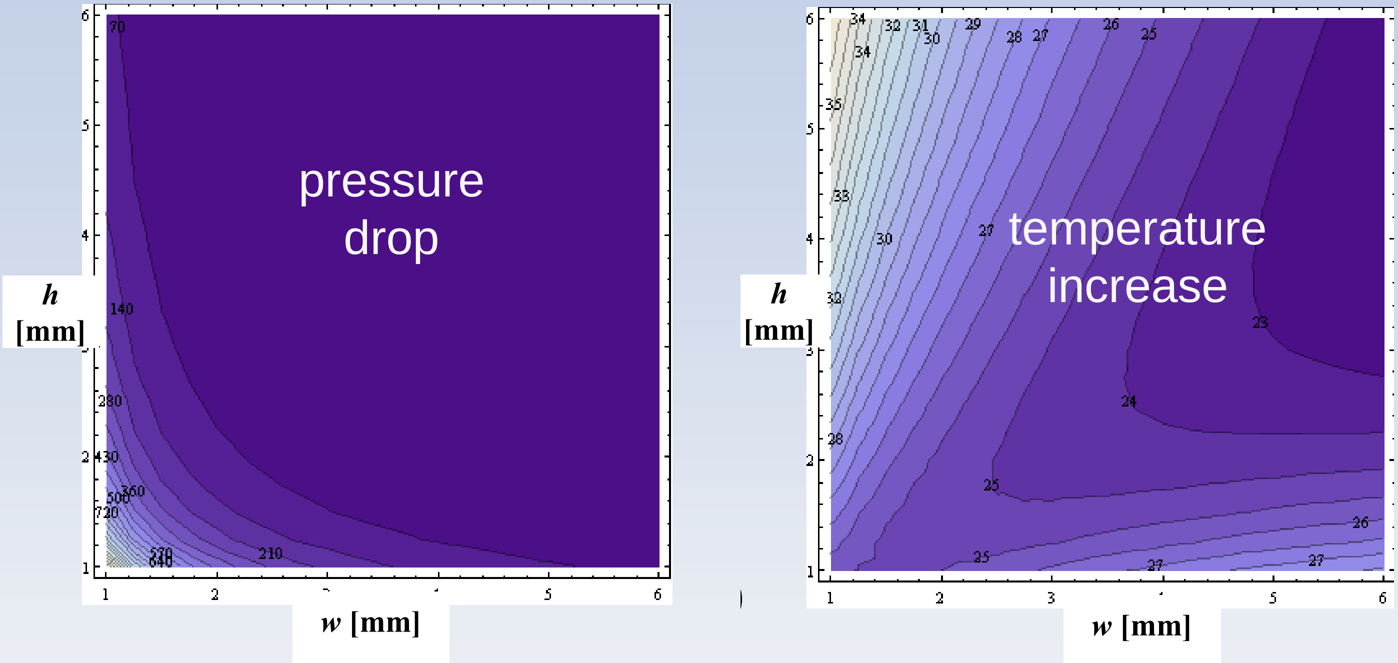

- **Parametric space of the warmer design** was explored in terms of the channel width w and height h
- A number of contour maps of the pressure drop and the temperature increase were produced to help determine the optimum channel design
- **This part of the design exploration can be also done within ANSYS Workbench**

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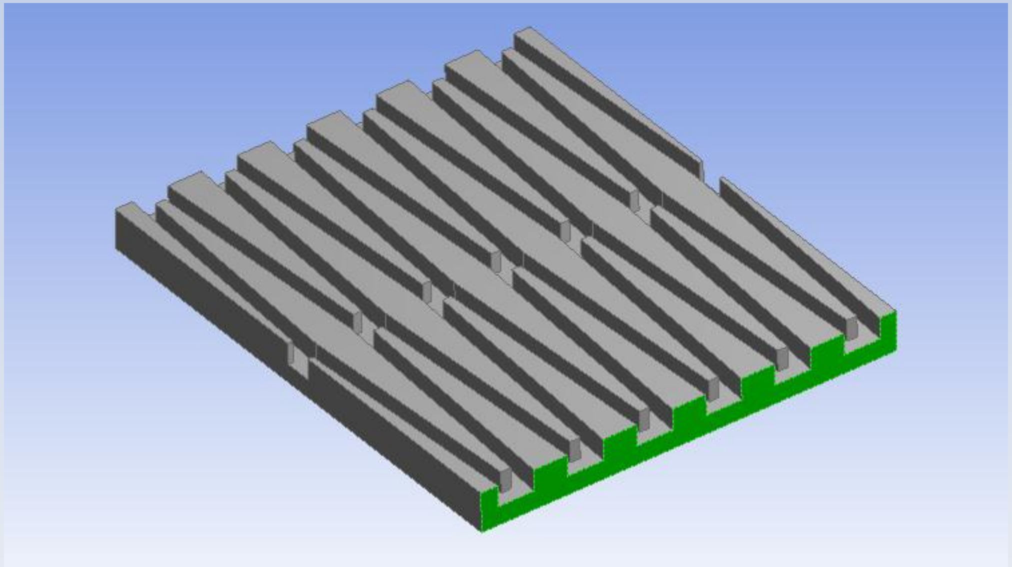
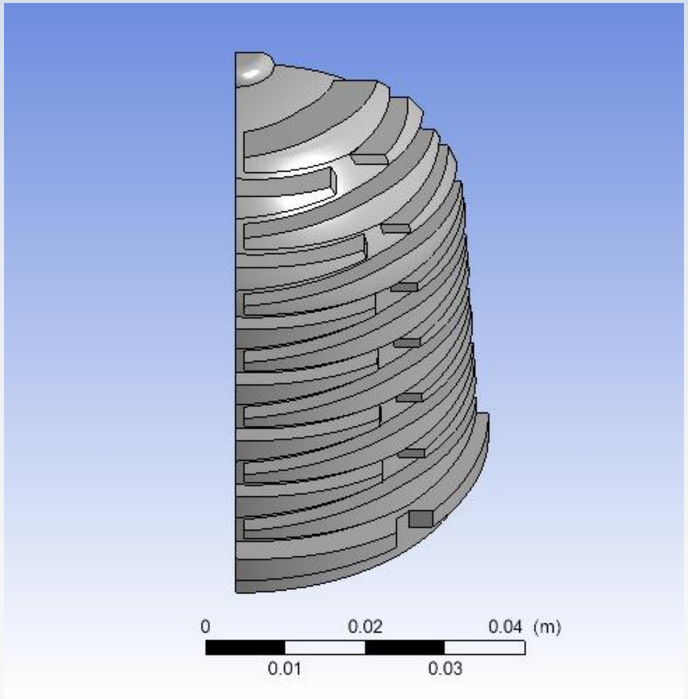


The result of the design optimisation exercise was a zig-zag channel of the specific width w and height h



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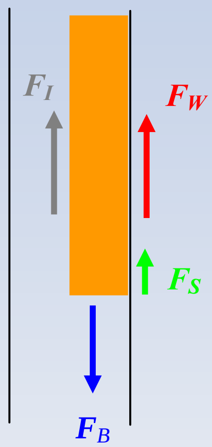

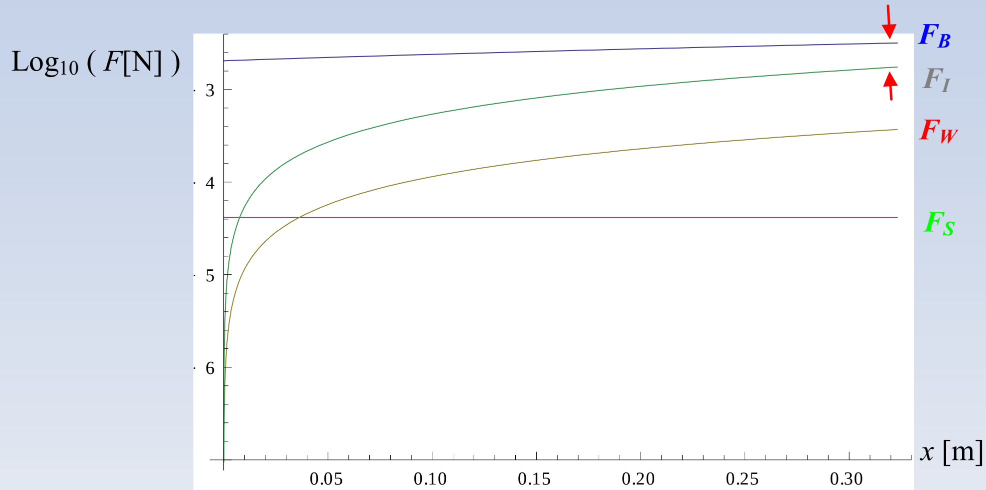

- The design optimisation process did take into account only single-phase flow conditions
- In order to prevent occurrence of slugs (i.e. to maintain smooth milk flow) a **force balance** was analysed taking into account **buoyancy force** (F_B), **wall friction** (F_W), **interphase drag** (F_I) and **surface tension force** (F_S)

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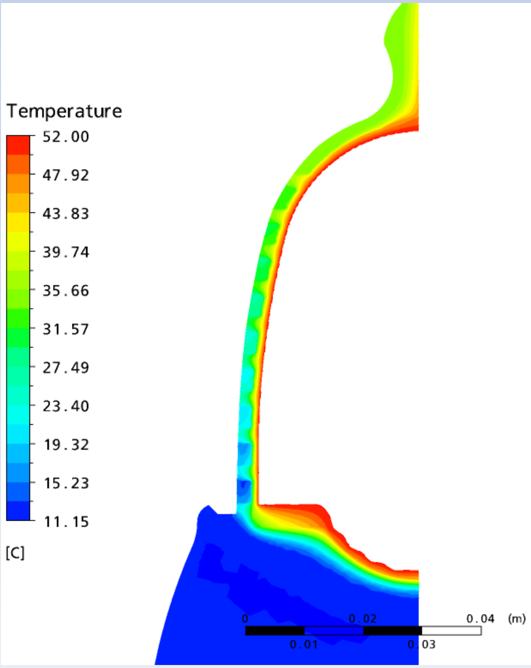

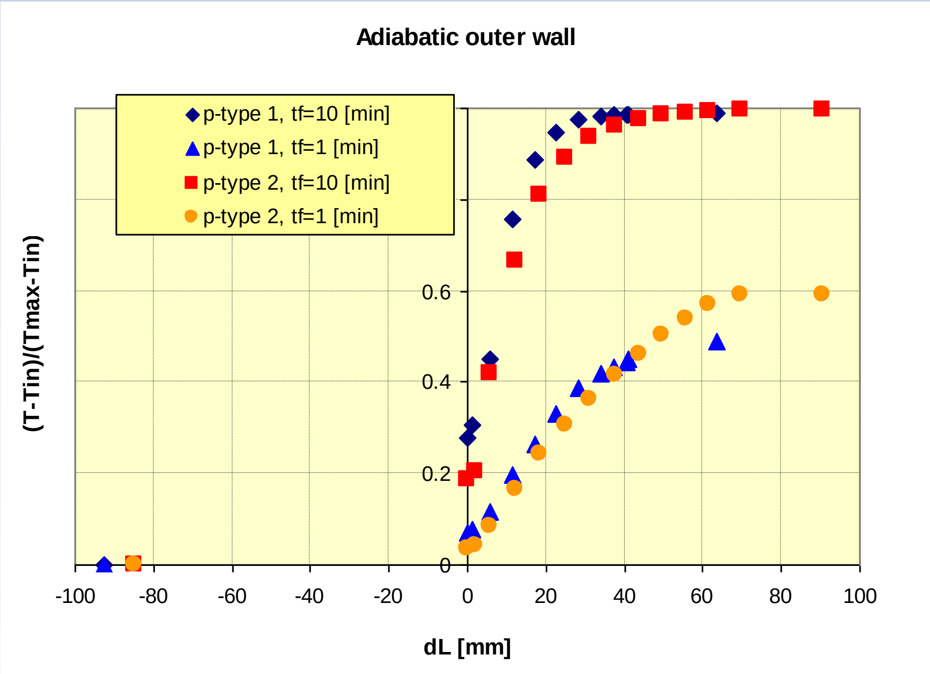

- CFD analysis of the selected warmer designs were performed to predict their thermal behaviour
- The initial CFD simulations were performed for a steady-state milk flow taking into account the milk volume only
- ¼ of the bottle geometry was used for the CFD model. It took approx. 24h to obtain a well converged solution using a numerical mesh with 1.6 mil nodes

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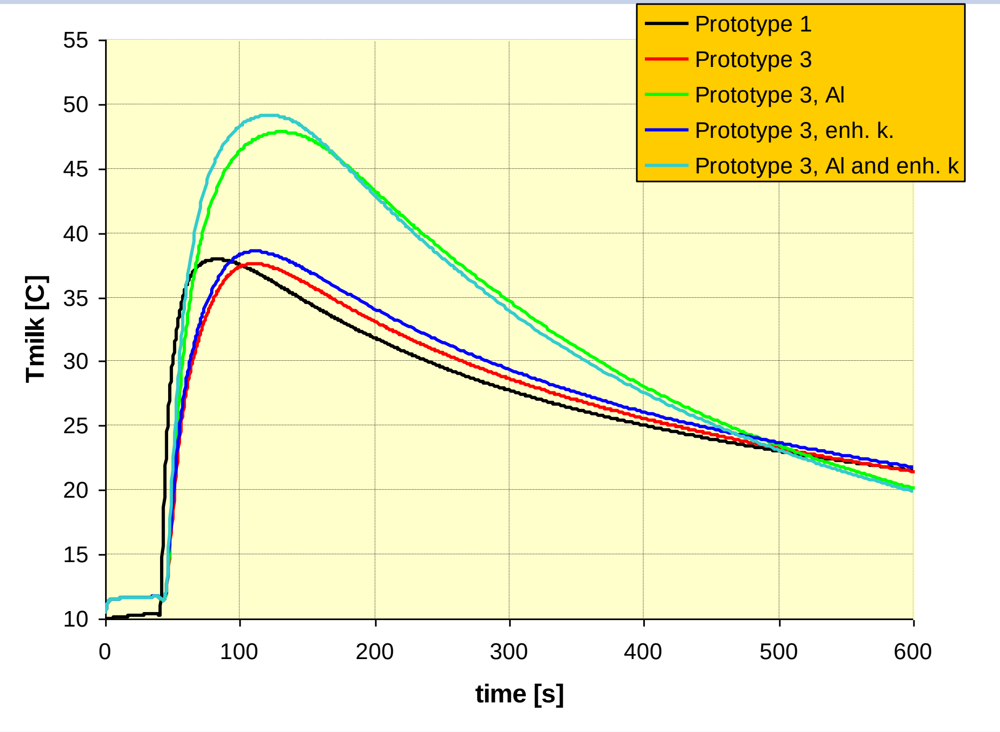

These initial CFD simulations did provide valuable information on the warmer thermal characteristics:

- milk temperature at steady drinking speed
- sensitivity to the material properties
- sensitivity to the milk flow rate and thermal boundary conditions

but were significantly over-predicting the milk first drop temperature due to the single-phase flow representation

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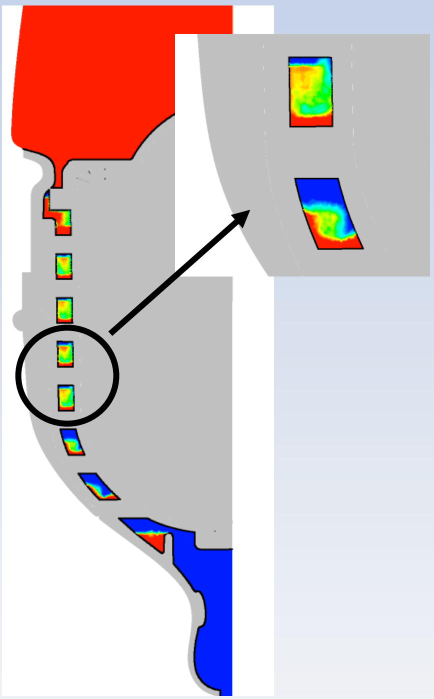

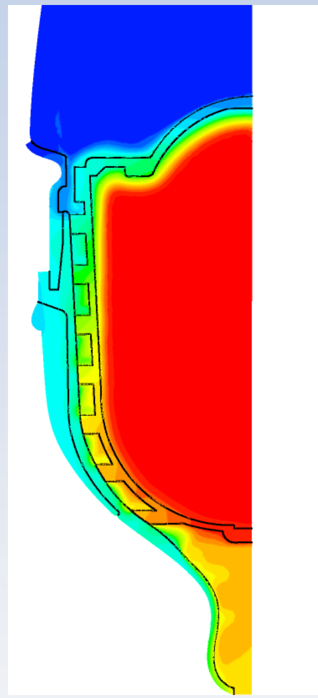

An accurate prediction of the first drop temperature and the pressure variations inside the channel required

- **multiphase CFD analysis**
- **modelling of conjugate heat transfer through solid parts**
- **solidification reaction of the mixture**

Using such multiphase CFD analysis, we were able to predict the first drop temperature with accuracy of 2-3^{o}C in comparison to the experimental measurements

These transient multiphase CFD simulations were especially challenging:

- The numerical grid contained 2.5 mil nodes.
- A small time step of 0.004 s was used.
- To simulate the first 20 s of the bottle operation, it required a week of computation on a 8 processor workstation

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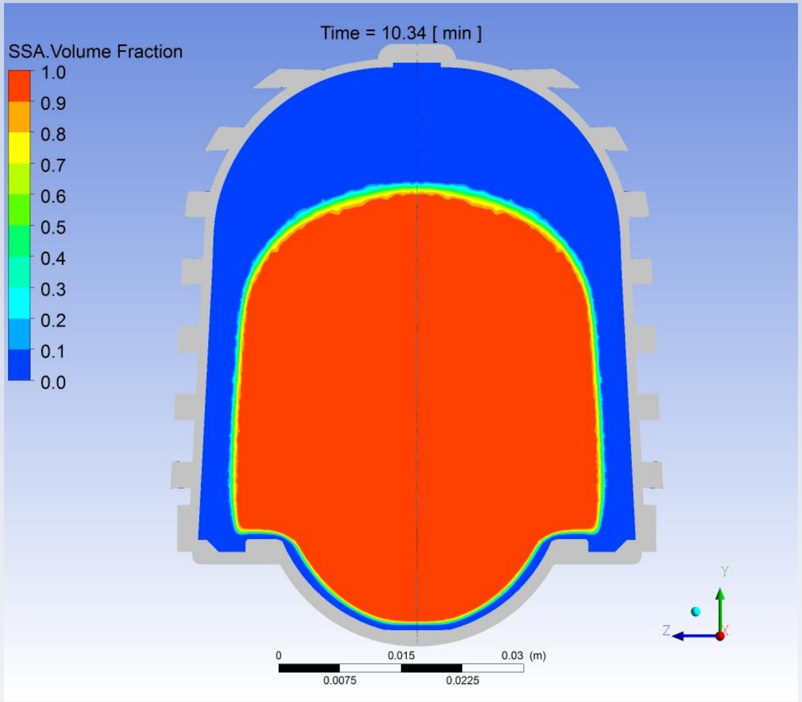

- The validation of the CFD analysis results gave us confidence to use the developed CFD model to further refine the warmer design
- Currently, the modelling efforts are focused on shortening the mixture melting process

It is important to acknowledge that for the presented case the robustness of the multiphase CFD simulation process has been crucial to fully model all aspects of the product operation

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- Use of CFD simulation techniques saved a large amount of time and development costs
- The product was developed in just 2.5 years and most of the time was spent on the problems related to production, marketing and distribution
- Four physical prototype were ever built, only 2 of them to test thermo-hydraulic performance of the bottle
- The **simulation driven product development** not only helped to meet the design objectives, but also enable us to better understand the physical processes and, therefore, to improve the performance of the product

For more information on this work and Intelligent Fluid Solutions, please contact andrej.horvat@intelligentfluidsolutions.co.uk or visit www.intelligentfluidsolutions.co.uk