Numerical Investigation into the Product’s Weight loss and Display Shelf life inside the Serve-over Cabinet

Dr A Hadawey
London South Bank University
Prof. Savvas Tassou
Brunel University
Shatha Haddowe & Raveendran Sundararajana
London South Bank University

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Recent years have seen an increase in customer demand for fresh food, which has caused a major increase in the volume of sales of unwrapped chilled food in display cabinets.

The UK market for chilled ready meals has grown from an estimated £173 million in 1988 to £11876 million in 2017.

Surface drying has been identified as the main reason for commercial loss from unwrapped chilled food in display cabinets.

The output of this work will provide the required knowledge to build a database that may provide some of the process information that industry requires to both improve existing refrigerated display cabinets and design new display cabinets for unwrapped chilled food products.
OBJECTIVE

To develop a CFD model for a serve-over display cabinet to include evaporating losses, which can be used to predict the drying rate and display shelf life of a product inside the cabinet under specific operating conditions.

MODELLING CONCEPT

A meat baguette sandwich, consisting of baguette and meat (beef) as filling was considered in this investigation.

Representation of the sandwiches in the 2D CFD model of the serve-over display cabinet.
MODELLING THE EVAPORATING LOSS

Mass transfer from any food item depends on evaporation, where the water vapour transfers from the product surface to the surrounding air and on diffusion, where the water from within the food moves to the surface.

The process of weight loss is not a steady state process; it is a function of the environmental boundary conditions and food characteristics. Modelling the evaporating losses in Fluent only considers the evaporating from food surface during steady state.

Modelling the evaporating losses in Fluent involved adding a source of water vapour (H2O) on the food surface. The cells that in direct contact with the food surface are therefore, considered to be a source of water vapour (H2O).

The evaporating losses will contribute to the latent load of the display case by increasing the amount of water vapour (mass fraction of H2O) entering the evaporator coil. The drying rate $kg/sec$ was evaluated by obtaining the mass flow rate of the evaporated water vapour from the beef inside the cabinet by running the CFD model with and without the source of H2O, the difference of the water vapour mass flow rate at the air-on section for both models represents the amount of water vapor evaporated.

Cross-Section of the Beef Baguette Sandwich with Water Vapour Source Cells
MODELLING THE EVAPORATING LOSS

The rate at which a food product loses weight through its surface depends on two related processes: evaporation and diffusion.

Dalton’s law
\[ \frac{dM}{dt} = AK_e(P_s - P_a) \]

\[ P_s = a_wP_{ws} \]

\[ P_a = HrP_{wa} \]

Antonine equation
\[ P_w \approx \exp \left[ \frac{23.4795 - 3990.5}{(T + 233.833)} \right] \]

\[ Hr = \frac{wP}{P_{wa}(0.622 + w)} \]

\( Hr \) is the ratio of the actual water vapour pressure to the saturation water vapour pressure and cannot be applied directly in Fluent; it has to be introduced in terms of a mass fraction of water vapour \( w \).

The drying rate (kg/s.m²) was obtained by dividing the evaporation losses by the surface area of the beef. The shelf life was then determined using the showing figure.
**CFD RESULTS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator coil air-off temperature (K)</td>
<td>275.5</td>
</tr>
<tr>
<td>Evaporator coil air-off moisture content (mass fraction of H₂O or water vapour) (kg/kg)</td>
<td>0.0033</td>
</tr>
<tr>
<td>Ambient test temperature (K)</td>
<td>298</td>
</tr>
<tr>
<td>Ambient test moisture content (mass fraction of H₂O or water vapour) (kg/kg)</td>
<td>0.0083</td>
</tr>
<tr>
<td>Emissivity of walls of test chamber and product</td>
<td>0.7</td>
</tr>
<tr>
<td>Product conductivity (W/m. K)</td>
<td>0.2279</td>
</tr>
<tr>
<td>Evaporator coil air-off velocity (m/s)</td>
<td>1.48</td>
</tr>
<tr>
<td>Turbulent model</td>
<td>Renormalisation group $k$ – $\varepsilon$ model</td>
</tr>
<tr>
<td>Radiation model</td>
<td>Discrete ordinates (DO) model</td>
</tr>
</tbody>
</table>
Comparison of experimental temperature (°C) with simulation results inside the display cabinet

Comparison of experimental relative humidity (%) with simulation results inside the display cabinet

Comparison of experimental air velocity (m/s) with simulation results inside the display cabinet
Comparison between drying rate and display shelf life predicted by the model with experimental results at 25 °C and 40 % RH

<table>
<thead>
<tr>
<th>Position</th>
<th>Drying rate predicted by CFD (kg/s.m²)</th>
<th>Experimental drying rate (kg/s.m²)</th>
<th>Shelf life predicted by CFD (min)</th>
<th>Shelf life determined from experiment (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>6.35 e-5</td>
<td>6.10 e-5</td>
<td>87</td>
<td>90</td>
</tr>
<tr>
<td>C</td>
<td>4.52 e-5</td>
<td>4.23 e-5</td>
<td>126</td>
<td>135</td>
</tr>
<tr>
<td>D</td>
<td>4.82 e-5</td>
<td>4.60 e-5</td>
<td>118</td>
<td>125</td>
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<tr>
<td>F</td>
<td>5.78 e-5</td>
<td>5.60 e-5</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>G</td>
<td>5.34 e-5</td>
<td>5.05 e-5</td>
<td>105</td>
<td>110</td>
</tr>
</tbody>
</table>
SIMULATION RESULTS

Effect of air-off (air curtain) on the local air boundary conditions

Effect of air-off (air curtain) on drying rate

Effect of air-off (air curtain) on display shelf life
SIMULATION RESULTS

Effect of air-off (air curtain) on the local air RH

Effect of air-off (air curtain) RH (%) on the drying rate

Effect of air-off (air curtain) RH (%) on the display shelf life
SIMULATION RESULTS

**Effect of air-off (air curtain) velocity on the drying rate**

**Effect of air curtain velocity on the local air boundary conditions**

**Effect of air-off (air curtain) velocity on the display shelf life**
The CFD model was able reasonably to predict the drying rate of unwrapped food product inside a refrigerated display cabinet under different boundary conditions of air temperature, velocity and relative humidity.

The relative humidity had the most prevalent effect on the drying rate.

Temperature changes had smaller effect on drying rate compared to the changes in either relative humidity or air velocity.

Air velocity directly affects the drying rate and this is related to the relative humidity. The magnitude of the effect increases as relative humidity decreases.

The display shelf life was mostly affected by air relative humidity and velocity. Changes in air velocity at high relative humidity had more effect on display shelf life than at low relative humidity.