Temperature and Energy Performance of Open Refrigerated Display Cabinets Using Heat Pipe Shelves

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Overview

- Open refrigerated display cabinets use
- Retail requirements for proper food storage
- The heat pipe shelves
- Experimental apparatus
- Temperature distribution results
- Energy consumption results
- Acidity levels results
- Outcomes
Open Refrigeration Cabinets

- 50% of the total energy consumption
- Air curtain: aero-thermodynamic but not physical barrier
- Inefficient cooling in sites where the products are in direct contact with the shelf
- Large temperature variations & significant temperature rises during defrost cycles
Refrigeration Requirements

All foodstuffs shall be maintained at a temperature below 5°C

- 70% of foodstuffs are maintained at temperatures above 8°C
- 60% of the products are maintained at a temperature of 10°C or more
- Highest temperatures at the front of the shelves and bottom shelves

Vitamin Content  Odour  Taste  Appearance
The Innovation

Better heat transfer rates between the food product and the shelf can be achieved, by positioning the product in direct contact with a cold base

3 Extra Heat Transfer Mechanisms

- **Conduction** from the heat pipe’s upper surface to the food placed on it
- **Convection** between the product and the shelf above it
- **Radiation** from the product and the shelf above it


*Jouhara H, Tassou S. Heat pipe shelf. 1423037.9, (2014)*
The Experiments

Environmentally Control Test Chamber
ISO Class 0 Testing: 20°C & 50% RH

ISO 23953:2005
The Experiments

Temperature distribution  Power consumption of cabinets  Acidity (pH) levels of products

<table>
<thead>
<tr>
<th>Product</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lasagne</td>
<td>96 units of 300g</td>
</tr>
<tr>
<td>Soft Cheese</td>
<td>48 units of 300g</td>
</tr>
<tr>
<td>Butter</td>
<td>36 units of 250g</td>
</tr>
<tr>
<td>Coleslaw</td>
<td>16 units of 250g</td>
</tr>
<tr>
<td>Taramasalata</td>
<td>60 units of 250g</td>
</tr>
</tbody>
</table>
Experiments

Thermocouples Positioning

Position A or C
Position B or D
Position A or B
Position C or D

Products on top of each product’s column
Products in contact with the shelf
Products in back row
Products in front row
# Results – Thermal Distribution

<table>
<thead>
<tr>
<th>Product</th>
<th>Heat Pipe Shelves Temperatures</th>
<th>Conventional Shelves Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Shelf</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>Lasagne</td>
<td>3.7°C Position B</td>
<td>4.7°C Position C</td>
</tr>
<tr>
<td>Soft cheese</td>
<td>3.7°C Position B</td>
<td>5.3°C Position C</td>
</tr>
<tr>
<td>Coleslaw</td>
<td>3.6°C Position B</td>
<td>4.7°C Position C</td>
</tr>
<tr>
<td>Middle Shelf</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>Taramasalata</td>
<td>2.2°C Position B</td>
<td>4.7°C Position C</td>
</tr>
<tr>
<td>Lasagne</td>
<td>2.8°C Position B</td>
<td>4.7°C Position C</td>
</tr>
<tr>
<td>Butter</td>
<td>2.6°C Position B</td>
<td>3.7°C Position C</td>
</tr>
<tr>
<td>Base Shelf</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>Soft cheese</td>
<td>2.8°C Position B</td>
<td>4.1°C Position C</td>
</tr>
<tr>
<td>Taramasalata</td>
<td>2.6°C Position B</td>
<td>3.8°C Position C</td>
</tr>
<tr>
<td>Coleslaw</td>
<td>3.5°C Position B</td>
<td>4.7°C Position C</td>
</tr>
</tbody>
</table>

*Heat Pipe Shelves:*
Middle & Base: much lower core temperatures
Hot spots: always position C

*Conventional Shelves:*
Top: lower core temperatures
Hot spots: front row products
Results – Thermal Distribution

Top Shelves

Conventional Shelves

Heat Pipe Shelves
Results – Thermal Distribution

Middle Shelves

Conventional Shelves

Heat Pipe Shelves
Results – Thermal Distribution

Base Shelves

Conventional Shelves  Heat Pipe Shelves
Results – Thermal Distribution

Top Shelf

- *Lasagna*
  - Position B: 3.7, 3.8, 3.9, 3.9
  - Position A: 3.6, 3.7, 3.8, 3.7

- *Soft Cheese*
  - Position B: 4.1, 4.1, 4.1, 4.1
  - Position A: 4.0, 4.1, 4.1, 4.1

- *Coleslaw*
  - Position B: 4.7, 4.8, 4.7, 4.6
  - Position A: 4.6, 4.6, 4.6, 4.6

Middle Shelf

- *Taramasalata*
  - Position B: 3.4, 3.5, 3.6, 3.5
  - Position A: 3.4, 3.4, 3.4, 3.4

- *Lasagna*
  - Position B: 3.7, 3.7, 3.8, 3.7
  - Position A: 3.7, 3.7, 3.8, 3.7

- *Butter*
  - Position B: 2.4, 2.5, 2.4, 2.4
  - Position A: 2.4, 2.4, 2.4, 2.4

Bottom Shelf

- *Soft Cheese*
  - Position B: 4.4, 4.4, 4.3, 4.3
  - Position A: 4.4, 4.4, 4.4, 4.4

- *Taramasalata*
  - Position B: 3.7, 3.7, 3.7, 3.7
  - Position A: 3.7, 3.7, 3.7, 3.7

- *Coleslaw*
  - Position B: 4.0, 4.0, 4.0, 4.0
  - Position A: 4.0, 4.0, 4.0, 4.0

Shelf Surface Temperatures (12h)
- Conventional Shelf
- Heat Pipe Shelf
Results – Power Consumption

Average Daily Electrical Power Consumption

- 7.6 kW – Heat Pipe Shelves Cabinet
- 8.6 kW – Conventional Cabinet

12% Energy Savings

Financial Gain of £44 per year per cabinet

*Electricity price being at 0.12 £/kWh (≈ 0.1435 €/kWh)
# Results – Acidity Levels

<table>
<thead>
<tr>
<th>Shelf</th>
<th>Food Product</th>
<th>Initial pH Values</th>
<th>pH Values of Products Placed on the Heat Pipe Shelves</th>
<th>pH Values of Products Placed on the Conventional Shelves</th>
<th>Days beyond or before products expiry date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Shelf</td>
<td>Lasagne</td>
<td>5.9</td>
<td>5.0</td>
<td>5.1</td>
<td>19 beyond</td>
</tr>
<tr>
<td></td>
<td>Soft cheese</td>
<td>4.9</td>
<td>4.9</td>
<td>4.5</td>
<td>51 before</td>
</tr>
<tr>
<td></td>
<td>Coleslaw</td>
<td>4.7</td>
<td>4.8</td>
<td>5.0</td>
<td>20 beyond</td>
</tr>
<tr>
<td>Middle Shelf</td>
<td>Taramasalata</td>
<td>4.7</td>
<td>4.8</td>
<td>4.4</td>
<td>21 beyond</td>
</tr>
<tr>
<td></td>
<td>Lasagne</td>
<td>5.9</td>
<td>5.5</td>
<td>5.2</td>
<td>19 beyond</td>
</tr>
<tr>
<td></td>
<td>Butter</td>
<td>6.4</td>
<td>6.3</td>
<td>5.9</td>
<td>16 before</td>
</tr>
<tr>
<td>Base Shelf</td>
<td>Soft cheese</td>
<td>4.9</td>
<td>4.8</td>
<td>4.5</td>
<td>51 before</td>
</tr>
<tr>
<td></td>
<td>Taramasalata</td>
<td>4.7</td>
<td>4.7</td>
<td>4.9</td>
<td>21 beyond</td>
</tr>
<tr>
<td></td>
<td>Coleslaw</td>
<td>4.7</td>
<td>4.6</td>
<td>4.4</td>
<td>20 beyond</td>
</tr>
</tbody>
</table>
Results – Conclusions

- More uniform temperature distribution along the shelves and the cabinet
- More gradual cooling down profiles
- Less temperature fluctuations
- Lower preservation temperatures
- Energy savings of 12%
- Acidity levels close to the initial values as the first day of product placement
THANK YOU