Historical review and state of the art in Time Temperature Integrator (TTI) technology for the management of the cold chain of refrigerated and frozen foods

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FOOD QUALITY ASSURANCE

Current philosophy:

- Decrease of focus on end product testing and verification traditional cornerstones of quality and regulatory control
- Development and application of structured quality assurance systems based on prevention by monitoring, controlling and recording of critical parameters through product’s entire life cycle

INTRODUCTION
Monitoring tools for chill chain

Need for development of practical systems to monitor, record and translate the effect of temperature from production to consumption.

Time Temperature Integrators (TTI)

A prerequisite for effective application of a TTI based control system is the determination and kinetic study and modeling of the food quality loss indices and of the response of the TTI.

INTRODUCTION
Active packaging vs Intelligent (Smart) packaging

Direct Quality Indicators vs Indirect Quality Indicators

Time Temperature Integrators (TTI)
CHARACTERISTICS OF THE ACTUAL CHILL CHAIN
Weak links in the chill chain

Electronic dataloggers

1st stage of the survey:

Data loggers were sealed in packages of products and monitored from processing through distribution to delivery and storage in SuperMarkets all over Greece

Survey for temperature conditions (1)
Temperature conditions FROM production TO the retail outlet
Conclusions from chill chain study

Temperature conditions FROM production TO the retail outlet

• Sharp (but short) increases of temperature (during transport)
• Cases of retail storage at temperatures > 7°C
• Significant temperature fluctuations
Survey for temperature conditions (2)
Variations WITHIN the domestic refrigerator

2nd stage of the survey:
4 data loggers were distributed randomly to potential consumers to monitor variations INSIDE the refrigerator
Electronic dataloggers

1: upper shelf
2: middle shelf
3: lower shelf
4: door
Temperature conditions IN the domestic refrigerator
Temperature variation within domestic refrigerators

Average temperature of domestic refrigerators (~400 cases)
Food Refrigeration Innovations for Safety, Consumers’ Benefit, Environmental Impact and Energy Optimisation Along the Cold Chain in Europe

EC 7th Framework RTD Project Grant agreement no.: 245288
Temperature variations in distribution and storage conditions

Justification for continuous monitoring

TTI
APPLICABILITY OF TTI FOR MONITORING THE CHILL CHAIN
TTI PRINCIPLES & APPLICATION
**TTI: main principles**

**Time Temperature Indicators** (TTI) are simple, inexpensive devices that can show an easily measurable, time and temperature dependent change that cumulatively indicates the time-temperature history of the product from the point of manufacture to the consumer, allowing the location and the improvement of the critical points of the chill chain.

**TYPES OF TTI**

- **Diffusion based**
- **Microbial**
- **Enzymatic**
- **Polymer based**
- **Photochemical**

**PRINCIPLES OF TTI**
TTI applications

1. Constant temperature monitoring of the chill chain - elucidation of the “problematic” distribution phases

2. Correlation to food quality deterioration kinetics - prediction of the remaining shelf life at ANY point of the distribution chain.

3. Improvement of the management and stock rotation system (FIFO) – introduction of Least Shelf life Out (LSFO)/ Shelf Life Decision system (SLDS).
Early TTI
Enzymatic TTI

- Enzymatic TTI is based on a colour change caused by a pH decrease which is the result of a controlled enzymatic hydrolysis of a lipid substrate.

Enzyme and substrate are mixed by mechanically breaking a separating barrier inside the TTI.

Hydrolysis of the substrate causes acid release and the pH drop is translated in a color change of a pH indicator from deep green to bright yellow or orange red.

Enzymatic TTI colourscale
Microbial TTI

Accepted food quality

The food quality is not accepted

eO® Cryolog, Gentilly, France
Polymer TTI

Solid state polymerization reaction.
TimeTemp TTI

DIFFUSION REACTION SYSTEM

TimeTemp AS, Norway
Photochemical TTI

Photosensitive compounds are excited and coloured by exposure at UV radiation.

OnVu, Ciba-Freshpoint Switzerland
Photochemical TTI

- Photochromism in **crystalline state**
- Color fading and activation energies of spiropyran crystals correspond to characteristics of food spoilage

Industrial / High speed chargers

Manual chargers
Development and application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products

A European Commission Research and Technology Development Project

Quality of life and management of living resources

http://smas.chemeng.ntua.gr
Integrated Approach to enable Traceability of the Cold chain of Fresh Chilled Meat and Fish Products by means of tailor-made Time/Temperature Indicators

http://www.freshlabel.net
Project IQ-Freshlabel

Developing novel intelligent labels for chilled and frozen food products and promoting the influence of smart labels application on waste reduction, food quality and safety in the European supply chains
Instrumental measurement of TTI colour

X-rite Eye1pro Colorimeter

Illumination D50

Measurement of visual response with CIE Lab
Instrumental measurement of Photochemical TTI colour

Response function

\[
\frac{\Delta E}{\Delta E_0} = \exp^{-kt}
\]

\[
\Delta E = \sqrt{(L - L_{\text{max}})^2 + (a - a_{\text{min}})^2 + (b - b_{\text{max}})^2}
\]
Instrumental measurement of Enzymatic TTI colour

Response function

\[ X = \frac{(a+b)-(a+b)_{\text{min}}}{(a+b)_{\text{max}}-(a+b)_{\text{min}}} \]

\[ F(X) = \frac{1}{1+e^{\frac{k_1-t}{k_2}}} \]
Kinetics of Food Quality Deterioration

- Degradation of quality index $A$: $f(A) = kt$

<table>
<thead>
<tr>
<th>Apparent reaction order</th>
<th>Quality function $Q(A)t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$A_0 - A_t$</td>
</tr>
<tr>
<td>1</td>
<td>$\ln(A_0 - A_t)$</td>
</tr>
<tr>
<td>2</td>
<td>$1/A_0 - 1/A_t$</td>
</tr>
<tr>
<td>$m$ ($m \neq 1$)</td>
<td>$\frac{1}{m} [A_0^{1-m} - A_t^{1-m}]$</td>
</tr>
</tbody>
</table>

- Temperature dependence of quality function:

$$f(A) = k_{A_{ref}} \exp\left(-\frac{E_a}{R} \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right)$$

FOOD SHELF LIFE MODELLING for TTI MONITORING
Kinetics of Food Quality Deterioration

- Quality deterioration for **variable** temperature distribution

\[
f(A)_t = \int_{0}^{t} k[T(t)] \, dt = k_{A_{\text{ref}}} \int_{0}^{t} \exp \left( \frac{-E_a}{R} \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right) \right) \, dt
\]

**\( T_{\text{eff}} \)**: constant temperature that results in the same quality change as the variable temperature distribution over the same time period

\[
f(A)_t = k_{A_{\text{ref}}} \exp \left( \frac{-E_a}{R} \left( \frac{1}{T_{\text{eff}}} - \frac{1}{T_{\text{ref}}} \right) \right) t
\]

**FOOD SHELF LIFE MODELLING** for **TTI MONITORING**
TTI response kinetics

**X: measurable change of TTI**

**Response function:**

\[ F(\Delta X) = k t = k_{ \text{ref} } \exp \left( - \frac{E_{\text{a}}}{R} \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right) \right) t \]

- **For variable temperature distribution:**
  \[ F(\Delta X)_t = \int_{0}^{t} k \left[ T(t) \right] dt = k_{ \text{ref} } \int_{0}^{t} \exp \left( - \frac{E_{\text{a}}}{R} \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right) \right) dt \]

- **Using effective temperature:**
  \[ F(\Delta X)_t = k_{ \text{ref} } \exp \left( - \frac{E_{\text{a}}}{R} \left( \frac{1}{T_{\text{eff}}} - \frac{1}{T_{\text{ref}}} \right) \right) t \]

TTI RESPONSE MODELING
TTI Application scheme

Measurement of the TTI response

Response function:

\[ k_{I_{ref}}, E_{a_1} \]

\[ F(X) \]

\[ T_{eff}^{-1} = T_{ref}^{-1} - \frac{R \ln \left( \frac{F(X)}{k_{I_{ref}}} \right)}{E_{a_1}} \]

\[ T_{eff} \]

Quality function

\[ f(A)_t = k_{A_{ref}} \exp \left( -\frac{E_a}{R} \left( \frac{1}{T_{eff}} - \frac{1}{T_{ref}} \right) \right) t \]

\[ f(A) \]

\[ k_{A_{ref}}, E_a \]

\[ \Delta_t \]

Quality at time t

\[ E_a (TTI) = E_a (food) \]
Studies of different types of TTIs for monitoring chilled food shelf life
Integrated Approach to enable Traceability of the Cold chain of Fresh Chilled Meat and Fish Products by means of tailor-made Time/Temperature Indicators

http://www.freshlabel.net
Shelf life (h) vs. Storage Temperature (°C)

- fresh salmon vacuum packed
- gilthead seabream fillets stored in MAP (20% CO2)
- gilthead seabream fillets stored in MAP (50% CO2)
- gilthead seabream fillets stored in MAP (80% CO2)
- red herring salad
- raw tuna loins vacuum packed
- cold smoked salmon slices
- MAP beef fillets
- marinated salmon trout cuts
- MAP cooked ham

Ciba OnVu Handcharger
Storage Temperature (°C) vs. Shelf life (h)

- fresh salmon vacuum packed
- gilthead seabream fillets stored in MAP (20% CO2)
- gilthead seabream fillets stored in MAP (80% CO2)
- red herring salad
- raw tuna loins vacuum packed
- cold smoked salmon slices
- gilthead seabream fillets stored aerobically
- gilthead seabream fillets stored in MAP (50% CO2)
- MAP beef fillets
- marinated salmon trout cuts
- MAP cooked ham

Ciba OnVu Handcharger
Ciba OnVu Handcharger
Shelf life study of gilthead seabream fillets packed under modified atmosphere
Gilthead seabream fillets (*Sparus aurata*)

- The limited and variable shelf life of chilled fish products is a major problem for their quality assurance and commercial viability.

- Products like chilled fillets from marine cultured Mediterranean fish such as gilthead seabream have high commercial potential if their shelf life can be extended through packaging or minimal processing.
Gilthead seabream fillets (Sparus aurata)

- Marine cultured gilthead seabream fillets were MA packed and stored at controlled isothermal conditions 0, 5, 10 and 15°C.

- 20% CO$_2$ - 80% air
- 50% CO$_2$ - 50% air
- 80% CO$_2$ - 20% air
Microbiological analysis

- Total viable count
- *Pseudomonas* spp.
- Lactic acid bacteria

The microbial growth was modeled using the **Baranyi Growth Model**

pH measurement

Sensory evaluation

- Sensory panel of 8
- Rating on a 1-9 descriptive hedonic scale

  Appearance
  Odour
  Freshness
  Texture
  Taste
Validation of the developed kinetic models under dynamic temperature conditions

- Samples were stored under non isothermal conditions

**Scenario 1:**
- $T_{\text{eff}} = 5.4^\circ C$

**Scenario 2:**
- $T_{\text{eff}} = 9.4^\circ C$

Temperature profiles were obtained from electronic data loggers (COX TRACER™, Belmont, NC)
Gas headspace changes ($CO_2$ and $O_2$) in fish fillet packages

50% $CO_2$ - 50% air

![Graph showing %O2 and %CO2 changes over time for different temperatures (0C, 5C, 10C, 15C) in fish fillet packages.](image-url)
Microbial growth on chilled gilthead seabream fillets packed under MA 50% CO₂ at 0, 5, 10 and 15°C

**Total viable count**

**Pseudomonas sp.**

**Lactic acid bacteria**
Specific growth rates $k \ (h^{-1})$ and kinetic parameters of lactic acid bacteria in MAP (50% CO$_2$ - 50% air)

<table>
<thead>
<tr>
<th>$T$</th>
<th>$k \ (h^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0°C$</td>
<td>0.00342</td>
</tr>
<tr>
<td>$5°C$</td>
<td>0.01078</td>
</tr>
<tr>
<td>$10°C$</td>
<td>0.01925</td>
</tr>
<tr>
<td>$15°C$</td>
<td>0.02829</td>
</tr>
</tbody>
</table>

Arrhenius equation

$$\ln k = \ln k_{\text{ref}} + \frac{E_a}{R} \left( \frac{1}{T_{\text{ref}}} - \frac{1}{T} \right)$$

$E_a = 91 \text{ kJ/mol}$

$k_{\text{ref}}(4°C) = 0.00739 \ h^{-1}$

$R^2 = 0.947$
Predicted ($SL_{\text{pred}}$) and experimental shelf life ($SL_{\text{exp}}$) of MAP gilthead seabream fillets under nonisothermal conditions

### Scenario 1: 50% $CO_2$

<table>
<thead>
<tr>
<th></th>
<th>$SL_{\text{exp}}$ (h)</th>
<th>$SL_{\text{pred}}$ (h)</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SL_{\text{exp}}$ (h)</td>
<td>233</td>
<td>235</td>
<td>-1.0</td>
</tr>
</tbody>
</table>

### Scenario 2: 50% $CO_2$

<table>
<thead>
<tr>
<th></th>
<th>$SL_{\text{exp}}$ (h)</th>
<th>$SL_{\text{pred}}$ (h)</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SL_{\text{exp}}$ (h)</td>
<td>112</td>
<td>127</td>
<td>-12.8</td>
</tr>
</tbody>
</table>
Shelf life evaluation of gilthead sea bream stored in MAP (50% CO$_2$)

<table>
<thead>
<tr>
<th>Storage temperature</th>
<th>Shelf life (h) evaluated by microbiological growth (lactic acid bacteria $&lt; 6 \log$CFU/g)</th>
<th>Shelf life (h) evaluated by sensory analysis (total impression $&gt; 5$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0$^\circ$C</td>
<td>612 (25 d)</td>
<td>563 (23 d)</td>
</tr>
<tr>
<td>5$^\circ$C</td>
<td>268 (11 d)</td>
<td>301 (12 d)</td>
</tr>
<tr>
<td>10$^\circ$C</td>
<td>129 (5 d)</td>
<td>140 (6 d)</td>
</tr>
<tr>
<td>15$^\circ$C</td>
<td>76 (3 d)</td>
<td>82 (3 d)</td>
</tr>
</tbody>
</table>

$E_a$ = 90.8 kJ/mol  

$E_a$ = 85.5 kJ/mol
Application of the Arrhenius-type model for shelf life prediction of chilled gilthead seabream fillets under MAP

\[ k = \left( \frac{k_{\text{ref}}}{C_{\text{O}_2}^{\max} - C_{\text{O}_2}} \right) \exp \left( \frac{E_a}{R} \left( \frac{T}{T_{\text{ref}}} - 1 \right) \right) \]

% CO\(_2\) concentration
Temperature T

Shelf life

Limit: \(10^6\) for LAB*

<table>
<thead>
<tr>
<th>CO(_2) concentration</th>
<th>T</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td></td>
<td>14 d</td>
<td>16 d</td>
<td>19 d</td>
<td>23 d</td>
<td>29 d</td>
<td>40 d</td>
<td>61 d</td>
</tr>
<tr>
<td>5°C</td>
<td></td>
<td>6 d</td>
<td>7 d</td>
<td>9 d</td>
<td>10 d</td>
<td>13 d</td>
<td>18 d</td>
<td>28 d</td>
</tr>
</tbody>
</table>

* Based on organoleptic acceptability the end of shelf life coincided with \(10^6\) LAB for MAP stored samples.
Application of the Arrhenius-type model for shelf life prediction of chilled gilthead seabream fillets under MAP

Temperature (°C) vs. Shelf life (h)

- Aerobically packed
- MAP (20% CO2)
- MAP (30% CO2)
- MAP (40% CO2)
- MAP (50% CO2)
- MAP (60% CO2)
- MAP (70% CO2)
- MAP (80% CO2)
Kinetic Study of the TTIs
Instrumental measurement of TTI colour
Response function

\[ \frac{\Delta E}{\Delta E_0} = \exp^{-kt} \]

\[ \Delta E = \sqrt{(L-L_{\text{max}})^2 + (a-a_{\text{min}})^2 + (b-b_{\text{max}})^2} \]
**B1 TTI response modelling**

**TTI Activation: UV lamp exposure for 2 seconds**

<table>
<thead>
<tr>
<th>Storage temperature (°C)</th>
<th>Rate k (h(^{-1}))</th>
<th>Shelf life (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0,0019</td>
<td>645,98</td>
</tr>
<tr>
<td>2.5</td>
<td>0,0031</td>
<td>396,75</td>
</tr>
<tr>
<td>3.5</td>
<td>0,0037</td>
<td>327,27</td>
</tr>
<tr>
<td>5</td>
<td>0,0049</td>
<td>245,82</td>
</tr>
<tr>
<td>8</td>
<td>0,0087</td>
<td>139,96</td>
</tr>
<tr>
<td>10</td>
<td>0,0125</td>
<td>96,79</td>
</tr>
<tr>
<td>15</td>
<td>0,0308</td>
<td>39,36</td>
</tr>
</tbody>
</table>
B1 TTI response modelling

$E_a = 116\text{KJ/mol}$

TTI Activation: UV lamp exposure for 2s
B1 TTI response modelling
B1 TTI response modeling based on charging energy

\[ k = k_{\text{ref}}(4C,1\text{sec}) \cdot t_c^{-a} \cdot \exp\left(\frac{-E_a}{R \cdot \left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)}\right) \]

\[ k = 0.00667 \cdot t_c^{-0.71031} \cdot \exp\left(\frac{-122071}{8314 \cdot \left(\frac{1}{T} - \frac{1}{277.16}\right)}\right) \]

\[ E_{\text{UV}}(\text{mJ/cm}^2) = 50 \cdot t_c(\text{s}) \]

\[ k = 0.1074 \cdot E_{\text{UV}}^{-0.71031} \cdot \exp\left(\frac{-122071}{8314 \cdot \left(\frac{1}{T} - \frac{1}{277.16}\right)}\right) \]
gilthead seabream fillets stored in MAP (50% CO2)

TTI 2.3s

Ciba OnVu Handcharger
Studies of different types of TTIs for monitoring chilled food shelf life
Study of different types of TTIs for monitoring chilled chopped MAP (80% O\textsubscript{2}, 12% CO\textsubscript{2}, 8% N\textsubscript{2}) beef shelf life

- Kinetic study of three different types of enzymatic TTIs. From each type three TTIs with different concentrations of the enzyme were studied during storage at 2.5, 5, 8, 10 και 15°C.
  - LP: LP-600U, LP-800U, LP-1000U
  - L: L-600Y, L-600R, L-1000U
  - M: M-50U, M-100U, M-200U

- Kinetic study of photochemical TTI exposed at the UV radiation for 0.2, 0.4, 0.6, 0.8 and 1 sec during storage at 2.5, 5, 8, 10 και 15°C.

- OnVu B1

- Kinetic study of the TTIs at a variable time-temperature profile (5°C -> 4 h, 9°C -> 4 h, 12°C -> 4h)

- Kinetic study of the microbial growth of the chopped meat

- Correlation of the kinetic characteristics of the main microbial growth of the chopped meat with the kinetic characteristics of the TTIs and selection of the appropriate one
Enzymatic TTI response

chilled chopped MAP beef shelf life
### Kinetic characteristics of the Enzymatic TTIs

<table>
<thead>
<tr>
<th>Enzymatic TTI</th>
<th>$E_A$ (kJ/mol)</th>
<th>$k_{1\text{ref}}$ (h$^{-1}$)</th>
<th>$k_{2\text{ref}}$ (h$^{-1}$)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP-600U</td>
<td>185.7</td>
<td>39.68</td>
<td>11.24</td>
<td>0.956</td>
</tr>
<tr>
<td>LP-800U</td>
<td>181.8</td>
<td>27.80</td>
<td>9.24</td>
<td>0.974</td>
</tr>
<tr>
<td>LP-1000U</td>
<td>149.0</td>
<td>16.65</td>
<td>6.05</td>
<td>0.967</td>
</tr>
<tr>
<td>L-600R</td>
<td>192.8</td>
<td>74.43</td>
<td>33.68</td>
<td>0.943</td>
</tr>
<tr>
<td>L-600Y</td>
<td>194.6</td>
<td>107.88</td>
<td>42.98</td>
<td>0.909</td>
</tr>
<tr>
<td>L-1000U</td>
<td>179.4</td>
<td>132.47</td>
<td>49.98</td>
<td>0.915</td>
</tr>
<tr>
<td>L5-8R</td>
<td>145.3</td>
<td>55.3</td>
<td>17.44</td>
<td>0.981</td>
</tr>
<tr>
<td>M-50U</td>
<td>95.8</td>
<td>81.79</td>
<td>19.09</td>
<td>0.980</td>
</tr>
<tr>
<td>M-100U</td>
<td>97.3</td>
<td>41.64</td>
<td>8.94</td>
<td>0.974</td>
</tr>
<tr>
<td>M-200U</td>
<td>107.2</td>
<td>24.61</td>
<td>5.32</td>
<td>0.992</td>
</tr>
</tbody>
</table>
Correlation of the response of the Enzymatic TTIs with *lactic acid bacteria* growth

chilled chopped MAP beef shelf life
Determination of a total mathematic model of the Enzymatic TTIs

The following mathematic model describes the effect of the time, temperature and the concentration of the enzyme of the TTI on the response of the TTI:

\[
X = F(X_C) = \frac{1}{1 + \exp \left( \frac{2363.9 \cdot C^{-0.8663} \cdot \exp \left( \frac{E_A}{R} \left( \frac{1}{T} - \frac{1}{T_{ref}} \right) \right)}{675.27 \cdot C^{-0.9217} \cdot \exp \left( \frac{E_A}{R} \left( \frac{1}{T} - \frac{1}{T_{ref}} \right) \right)} \right) - t}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{ref}(°C))</td>
<td>4</td>
</tr>
<tr>
<td>(Ea) (KJ/mol)</td>
<td>105.5</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.987</td>
</tr>
</tbody>
</table>
Correlation of the response of the Enzymatic TTI M-45U with the chopped beef shelf life

For the selection of the appropriate enzymatic TTI for monitoring chopped meat shelf life the total mathematic model was used…
Photochemical TTI response

OnVu B1-0.2UV

OnVu B1-0.4UV

OnVu B1-0.6UV

OnVu B1-0.8UV

chilled chopped MAP beef shelf life
Correlation of the response of the Photochemical TTI with lactic acid bacteria growth

chilled chopped MAP beef shelf life
Kinetic characteristics of the Photochemical TTI

<table>
<thead>
<tr>
<th>Photochemical TTI</th>
<th>$E_A$ (kJ/mol)</th>
<th>$k_A$ (h$^{-1}$)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>OnVu B1-0.2UV</td>
<td>165.6</td>
<td>0.1296</td>
<td>0.974</td>
</tr>
<tr>
<td>OnVu B1-0.4UV</td>
<td>179.4</td>
<td>0.0061</td>
<td>0.967</td>
</tr>
<tr>
<td>OnVu B1-0.6UV</td>
<td>188.9</td>
<td>0.0041</td>
<td>0.965</td>
</tr>
<tr>
<td>OnVu B1-0.8UV</td>
<td>178.0</td>
<td>0.0037</td>
<td>0.992</td>
</tr>
<tr>
<td>OnVu B1-1UV</td>
<td>166.2</td>
<td>0.0035</td>
<td>0.994</td>
</tr>
</tbody>
</table>
Determination of a total mathematic model of the Photochemical TTI OnVu B1

The following mathematic model describes the effect of the temperature and the charging time on the TTI rate constant (k):

\[
k = k_{\text{ref}} \left(T_{\text{ref}}, t_c = 0.6s \right) t_c^{-\alpha} \exp \left( \frac{-E_a}{R} \left( \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right) \right)
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(k_{\text{ref}}(h^{-1}))</td>
<td>0.002</td>
</tr>
<tr>
<td>(\alpha)</td>
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<td>(E_a (KJ/mol))</td>
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Correlation of the response of the Photochemical TTI B1-0.4 s UV with the chopped meat shelf life
Development and application of a TTI based Safety Monitoring and Assurance System for Chilled Meat Products

A European Commission Research and Technology Development Project

Quality of life and management of living resources

http://smas.chemeng.ntua.gr
Current practice: First In- First Out (FIFO)

Disadvantages:
✓ ignores variations of product characteristics
✓ ignores the REAL time-temperature history of the product

Proposed practice: SMAS

Main Advantages:
✓ variations of product characteristics are considered
✓ the REAL time-temperature history of the product is taken into account based on TTI response
The contribution of SMAS in the chill chain management can be visualized as a minimization of risk for illness and optimisation of the product quality at the time of consumption.
One out of a trillion
One out of 10 billions
One out of 100 millions
One out of a million
One out of 10,000
One out of 100

% of products

FIFO

SMAS

School of Chemical Engineering
National Technical University of Athens, Greece
One out of a trillion
One out of 10 billions
One out of 100 millions
One out of a million
One out of 10,000
One out of 100

% of products of probability of illness:

<table>
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<th>% of products</th>
<th>SMAS</th>
<th>FIFO</th>
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Field Test Design

120 samples of MAP minced beef

Distribution center (decision point)

Local market

Export market

Laboratory simulated conditions

consumers

chilled chopped MAP beef shelf life
Field test Design

1st step
- 60 packages without TTIs
- TTI tag attached on each package

2nd step
- 24 h at various T conditions

3rd step
- Local market
  - 12, 24, 36 hours
- Export market
  - 48, 72, 96 hours

4th step
- Microbiological analysis

Decision point
- TTI based split

TTI reading
- TTI profil1
- TTI profil2
- TTI profil3
- TTI profil4
- TTI profil5

120 packages
FIELD TEST RESULTS

Distribution of Lactic acid bacteria growth for all samples at time of microbiological analysis - time of ‘consumption’.

The distribution of microbiological growth moves to the left, to lower values, for the TTI bearing products.
FROZEN FOODS
FROZEN FOOD QUALITY ASSURANCE

- Quality of optimally processed frozen food products depends on the temperature conditions of storage, handling and distribution. Monitoring and control of these conditions would allow chill chain optimization and reliable product shelf life prediction.

INTRODUCTION
It has been reported that a substantial portion of frozen products are exposed, throughout the distribution, including retail and domestic storage, to effective temperatures that deviated significantly from the recommended range.

Average storage temperatures measured in different types of retail freezers in several stores of a large supermarket chain. (Temperature data from recent surveys conducted by NTUA in collaboration with a leading supermarket chain).
Optimization of shelf life distribution of frozen products based on modelling and TTI monitoring
Project IQ-Freshlabel

Developing novel intelligent labels for chilled and frozen food products and promoting the influence of smart labels application on waste reduction, food quality and safety in the European supply chains
Thank you for your attention!
ICEF11 welcomes you in 2011 in Athens

http://www.icef11.org
Abstract submission is now open
Login and submit your abstract!

http://www.icef11.org

Abstract Submission Deadline

15 October 2010