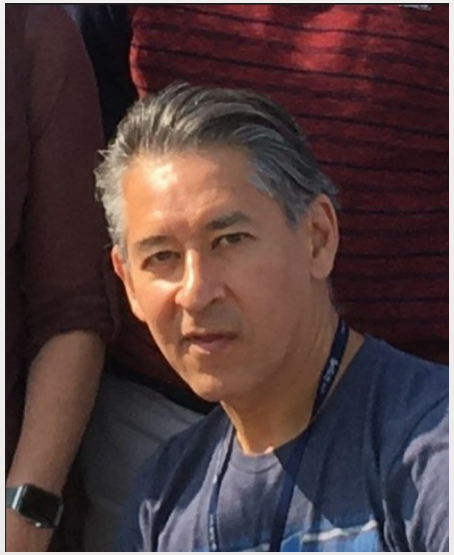
Ernest Perez



Current Role: Principal Engineer / Thermal Process Expert
Nestle Product Technology Center / Marysville, Ohio
Email: ernest.perez@rd.nestle.com Ph: (937)594-7399

Career history:

2009 – present – Sr Engineer; Principal Engineer since 2018 — **NPTC/M Marysville, OH**

- Thermal Process Establishment for pilot plant; Global markets -review thermal process specs for aseptic and retort processes
- Review, write and enforce technical standards and guidelines
- Technical assistance for Nestle markets - CAPEX requests, insterility root cause, co-man assessments, new line commissioning

2007-2009 - Design Engineering Manager — **NWNA, Coppell, TX**

2003-2007 - Project Engineer — **Gerber, Fort Smith, AR**

'89-'92, '94-2001 – Production Supervisor & Aseptic Specialist — **Nestle Nutrition, Eau Claire, WI**

1992-1993 - Process Engineer — **Nestle R&D Konolfingen, Switzerland**

1988 – 1989 - Manufacturing Tech Services & Thermal Process Specialist — **Nestlé Carnation, Los Angeles, CA**

Education:

BS Food Process Engineering - Purdue University
MS Food Science & Technology – University of California, Davis
MBA – University of Wisconsin, Eau Claire

Market Technical Assistance:

Algeria, Argentina, Chile, Colombia, Costa Rica, Egypt, India, Indonesia, Mexico, Nicaragua, Netherlands, Peru, Thailand, Turkey, Venezuela, Vietnam

Hobbies and Interests:

Family, Long Distance Running, NCAA Basketball

Research and Development

Nestlé Good food, Good life

Kinetics of Microbial and Quality Factors in Thermal Processing

Institute of Food Thermal Process Specialists

E. Perez

February 28th, 2023

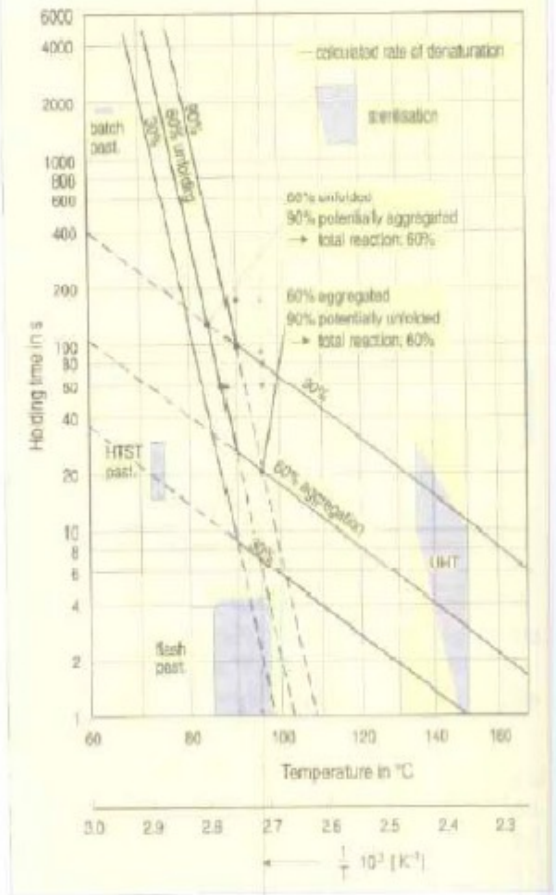
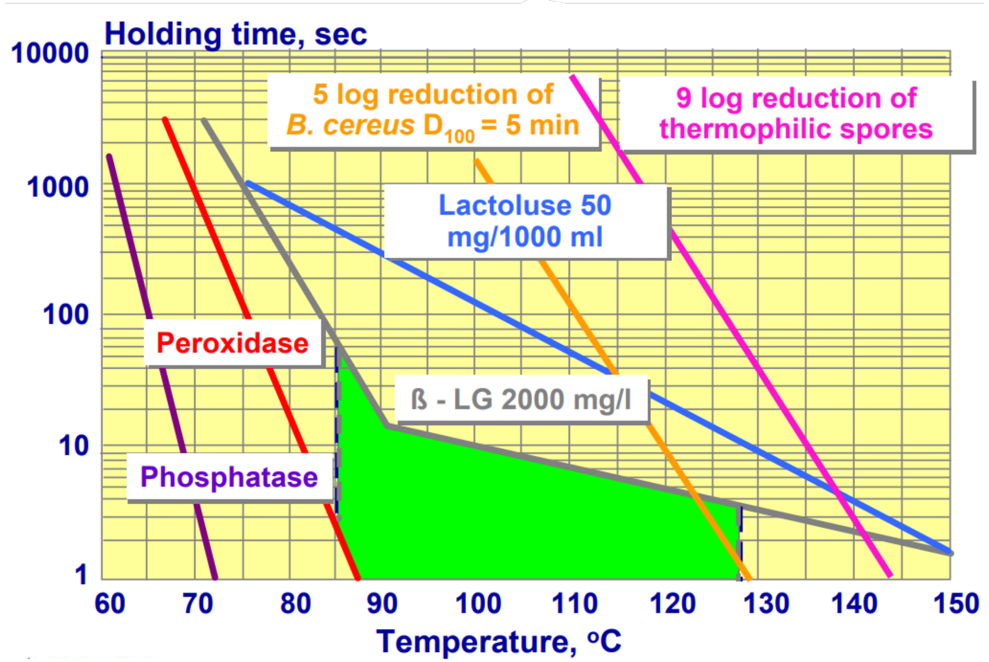


Fig. 6.62. Lines of equal degrees of denaturation drawn to demonstrate the temperature dependent changes in the rate constant

Why Discuss the Effect of Thermal Processing on Quality Attributes?



Purpose

Bring Awareness of the potential effect of thermal processing on food and beverage Quality attributes

Importance

- ❑ Thermal treatments have positive effects and may have *negative* effects
  - Loss of nutrients
  - Color and texture change
  - Formation of Unwanted Compounds

Expectation –

1. Be aware of different methods to quantify effects of thermal processes on food constituents
2. Be aware of effects of thermal processing on food & beverage quality indicators
3. Compare rates of reaction of microbial death kinetics to rates of nutrient degradation

Outline

- **Microbial Death Kinetics as starting basis**
- **Kinetic Models for Thermal Degradation of Nutrients and other Quality Indicator**
- **Compare Microbial Death Curves with Degradation of Food Components**
- **Nestle Thermokinetics App**

Thermal Processing Definitions

- D_{Tref} **Value - Time it takes at <u>specified temperature</u> to kill 90% (1 log cycle) of a population of a specific Micro-organism.**

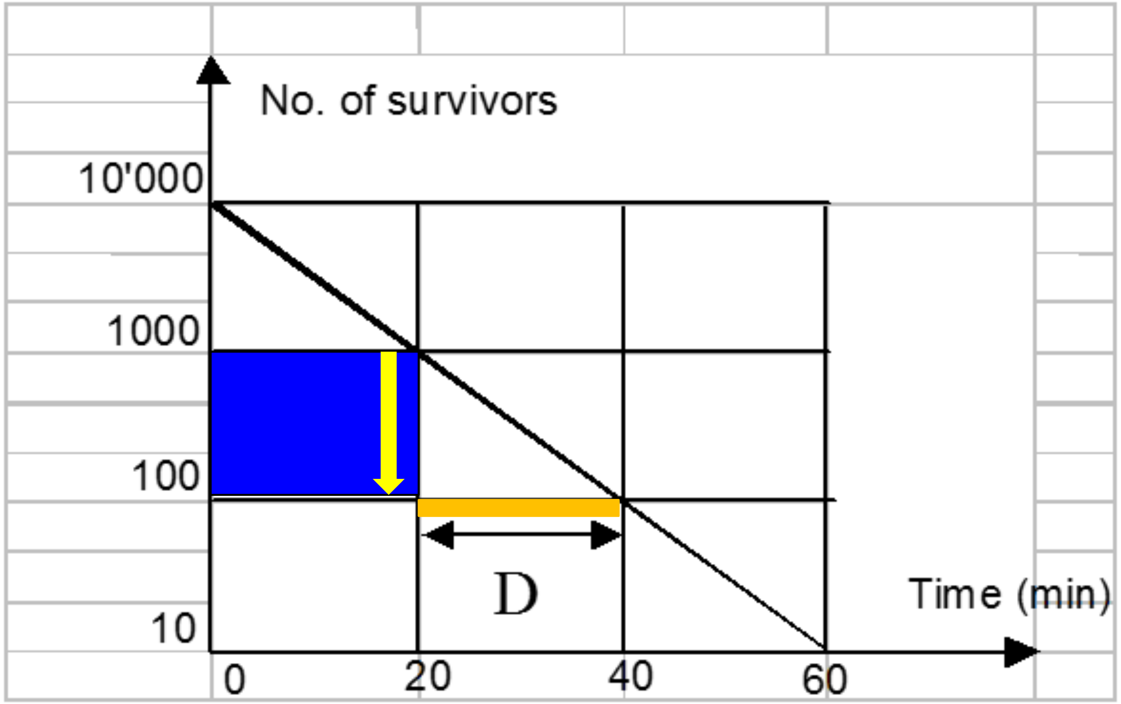
- **z Value - The temperature change required to alter the D Value by a factor of 10.**

  Number of degrees of temperature required for the thermal death time curve (log F vs. T) to traverse one log cycle

- **F Value - Time for Equivalent microbe destruction (in minutes) at a given reference temperature.**

- F_0 **- Equivalent microbe destruction in minutes at 121.1°C when z = 10°C (Used for C. botulinum)**

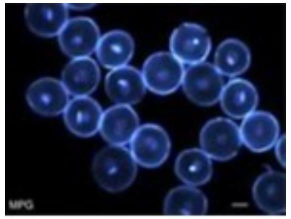
Thermal Processing Definitions - Graphic Representation of D_T Value



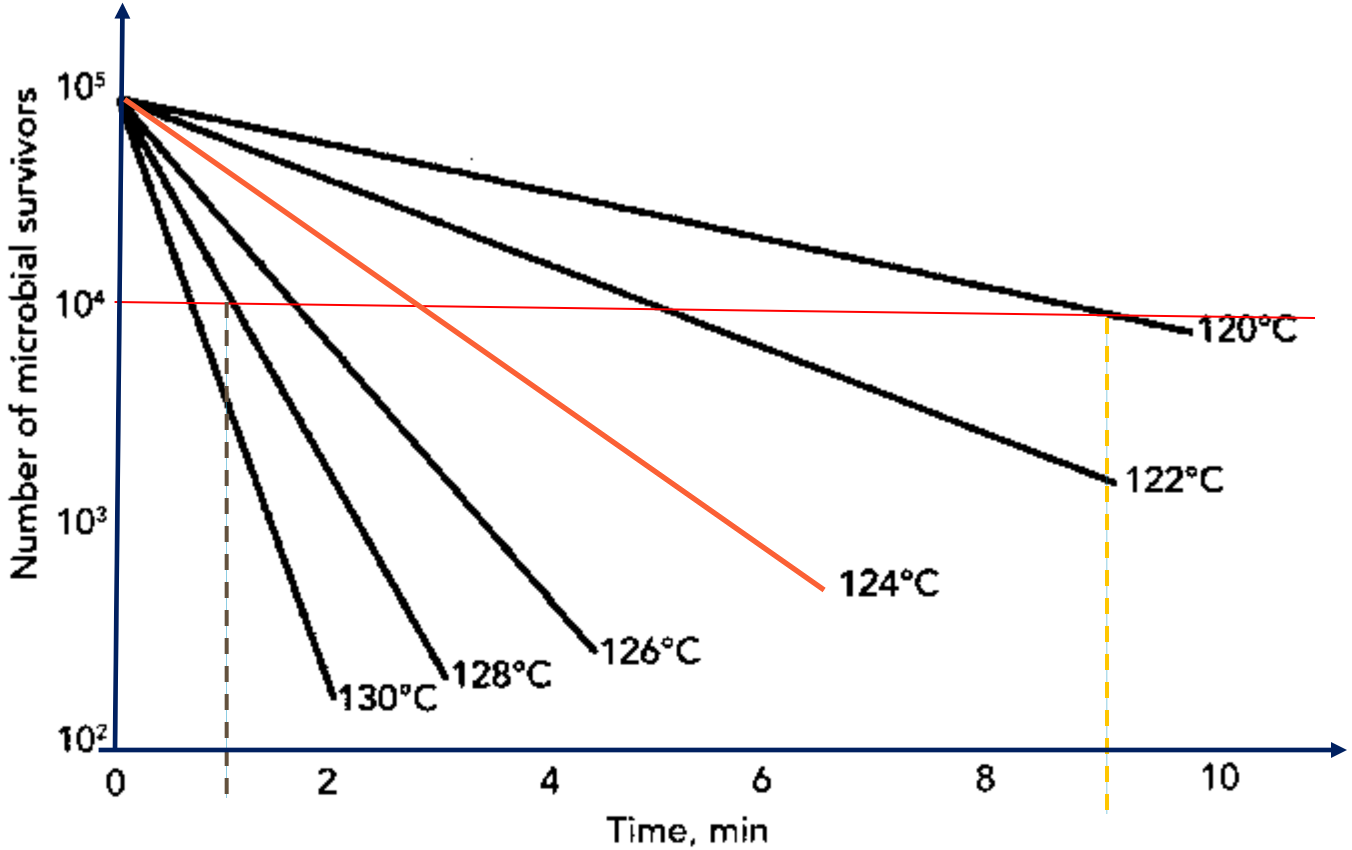
- D_T - value: Time in minutes at a specific temperature to reduce a population by 90%.

What is the D_T Value in this exmple?

VS



Thermal Processing Definition
Graphic Representation of D Values at Different Temperatures



$D_{120} > D_{128}$

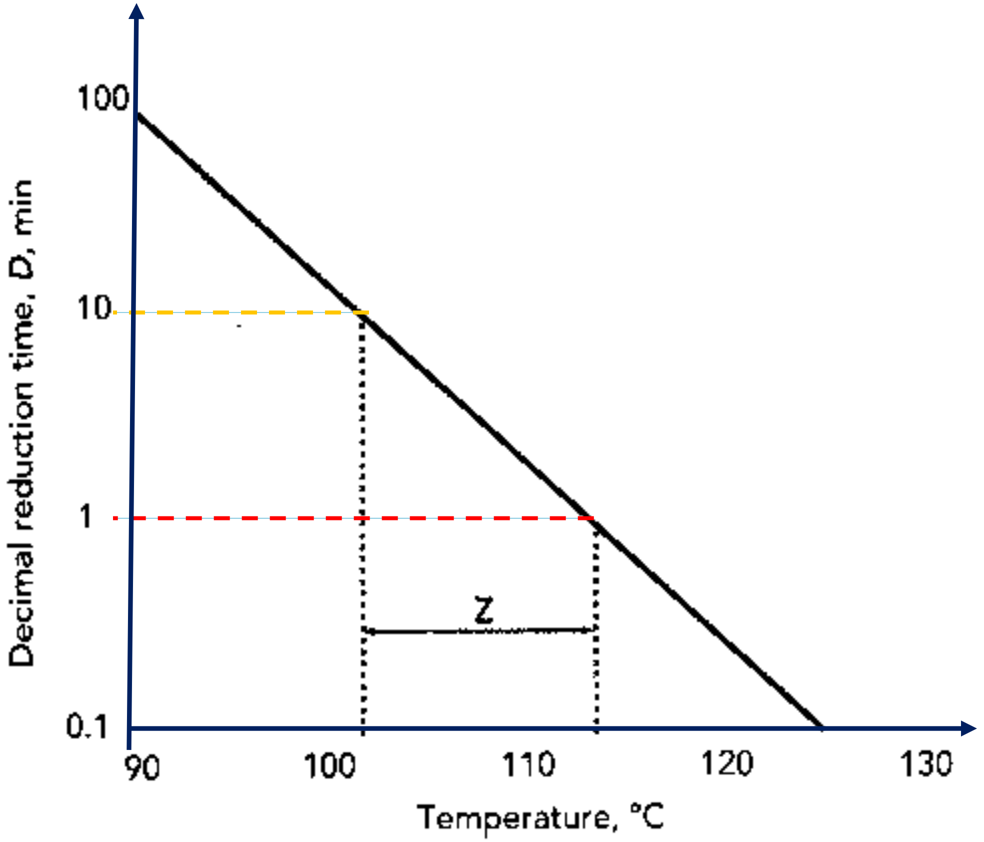
D_{120} = ~9.0 min

D_{128} = ~1.0 min

Decimal reduction (survivor curves) at different elevated temperatures

Research and Development

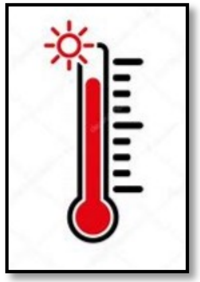
Thermal Processing Definitions -
Graphic Representation of z Value



Thermal resistance curve of a microbial population

- Z – value: the temperature increase required to cause a one log cycle reduction in the decimal reduction time

What is the z value in this example?



VS

Research and Development

D and z Values for Spore-Forming Bacteria

Micro-organism	Approximate growth range (°C)	D-value range at 121°C (sec)	z-value range (°C)	Target D-value at 121°C[1] (min)	Average z-value[2] (°C)
Geobacillus stearothermophilus	**40-72**	41-375	5.6-12	**3.99**	**8.8**
Bacillus licheniformis	**15-60**	0.1-49	6.3-17.6	**0.215**	**9.2**
Bacillus coagulans	**25-65**	1-94.8	8.1-24.1	**.987**	**11.1**
Clostridium sporogenes	**18-45**	6-102	7.8-12.4	**1.19**	**10**
Clostridium botulinum[3]	**3.3-48**			**0.21**	**10**
Bacillus pumilus	**15-45**	0.1-3.5	6.5-13.2	**-**	**-**
Bacillus sporothermodurans	**10-50**	5-904	6.7-21.8	**4.15**	**12.6**
Bacillus cereus	**3-55**	0.03-4	7.1-14.5	**0.032**	**10.3**

Research and Development

Thermal Processing Definitions -

Fo Value from General Method of Bigelow

Definition of F_o-value with constant Temperature

$$F_0(min) = \frac{t}{60} * 10^{(T-121.1)/z}$$

t = heating time, seconds
T = heating temperature, °C
z = 10 deg C the increase in temperature necessary to obtain the same lethal effect in one tenth of the time
F_o = 1.0 when product is heated one minute at 121.1°C

If, Temperature is dynamic

$$F_0(min) = \left(\frac{1}{60}\right) * \int_{t=0}^{t} 10^{(T-121.1)/z} dt$$

Expressed in equivalent minutes at a reference temperature of 250°F or 121.1°C.

Microbial Sterilization Index:

- **Measure of the level of sterility or microbial destruction delivered by a thermal process or heat treatment.**

Food Reaction Kinetic Models

Cook Value Model

$$C\ (\text{min.}) = \frac{t}{60} * 10^{(T-100)/z}$$

$$C = \left(\frac{1}{60}\right) * \int_{t=0}^{t} 10^{(T-100)/z} dt$$

Where

t = heating time, seconds
T = heating temperature, °C
z = the increase in temperature necessary for obtaining the same temperature effect in one tenth of the time

Original z value proposed for Cook value calculations is 33°C

Research and Development

Thermal Processing Kinetics -

D and z Values for Thermal Degradation of Food & Bev Nutrients

Component	Medium	Z (°C)	$D_{121°C}$ (min)
Vitamin B12	Liquid Multi-Vitamin	28	1.94 days
Vitamin C	Liquid Multi-Vitamin	28	1.12 days
Lysine	Soybean Meal	21	13.1 hrs
Thiamine	Carrot Puree	25	158
Chlorophyll	Spinach	51	13

Source – "Principles of Food Science – Physical Principles of Food Preservation" –ed. By Owen Fennema, Dekker, 1975

Example of Relation between Fo and C values with varying temperatures

Temperature (°C)	Min Res Time (sec)	Fo (minutes) z = 10°C
121	360	6.0
130	45	6.0
135	14	6.0
140	**5**	**6.0**
141	5	8.3

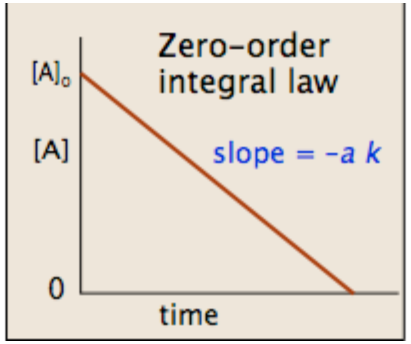
Reaction Kinetics – Reaction Rate Order and Rate Equations

Zero-order Reaction

- Rate does not vary with increasing nor decreasing reactants concentrations.
- Destruction rate of a component is equal to a rate constant, k, for that reaction.

$$Rate = -\frac{d[A]}{dt} = k[A]^0 = k = constant$$

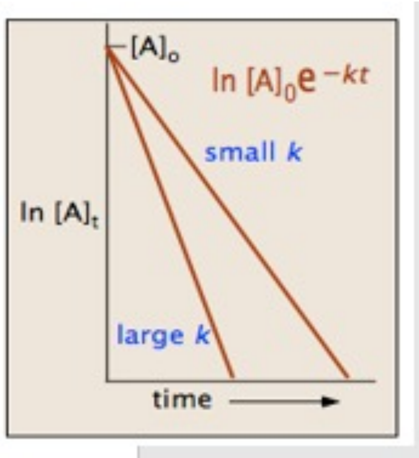
$$[A] = [A]_0 - kt$$



First-order Reaction

- Proceeds at a rate that depends on (only) one reactant concentration.
- Destruction rate of a component is dependent on the concentration of the component.

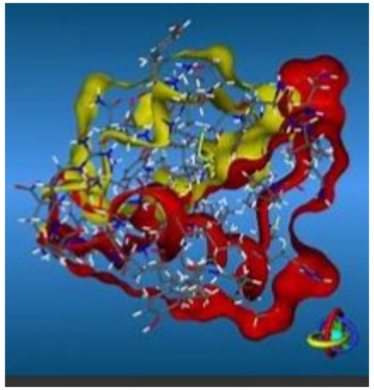
$$Rate = -\frac{d[A]}{dt} = k[A]$$

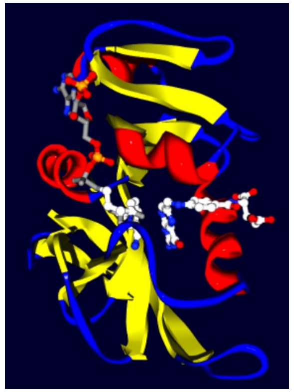


The thermal destruction of microorganisms, vitamins and quality properties generally follow 1st order Reaction Kinetics

Food Reaction Kinetic Models

Arrhenius Model



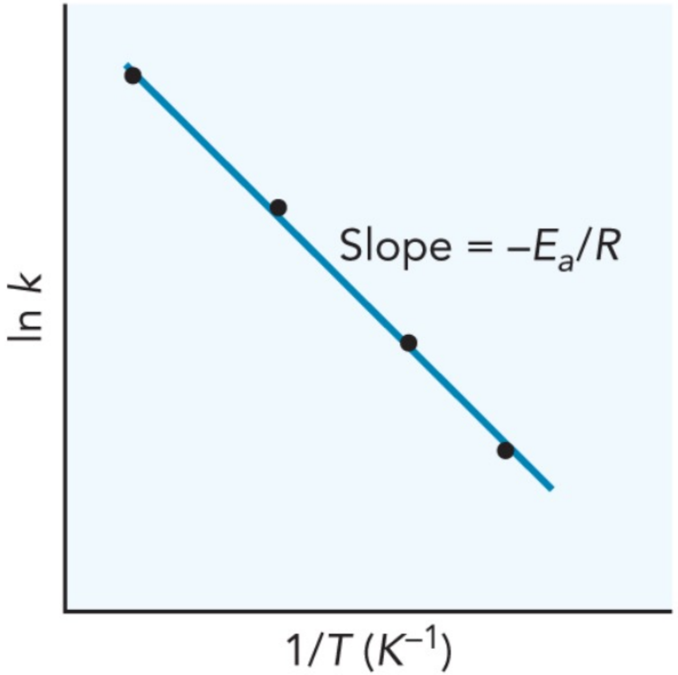


The dependence of the Reaction rate constant, k, on temperature is given by the Arrhenius equation:

$$k = k_o e^{-E_a/RT}$$

Where:

k_o = a constant known as frequency factor (min^{-1})
E_a = Activation energy (cal/mole)
R = ideal gas law constant (1.98 cal/mol K)
T = absolute temperature (K)



Thermal Processing Kinetic Parameters with Arrhenius Constants

Data for Milk from NIZO Institute

Component	Concentra-tion in Raw Milk	Type of Reaction	Temperature Range (deg C)	ln k	E_a, Activation Energy (kJ/mol)	Reaction Order
Bacillus stearothermophilus spores	100cfu/ml	Destruction	100 – 140	101.15	345.4	1.0
Bovine serum albumin	0.4 g/l	Denaturation	70 - 98	83.91	268	1.0
Catalase	100%	Inactivation	60 - 80	180.72	529	1.0
Color (browning)	0	Formation	50 – 160	29.09	116.0	0
Phosphatase	100%	Inactivation	60 – 80	135.15	393	1.0
Furosin	0 µmol/liter	Formation	120 – 150	24.28	81.6	0
Hydroxy-methylfurfural	0 µmol/liter	Formation	130 – 160	39.69	139	0
Lipase	100%	Inactivation	60 – 90	53.7	160	1.0
Lysine	2880 mg/lt	Loss	130 – 160	15.68	109	2nd
Lysino-alanin	0 µmol/liter	Formation	110 - 130	27.76	101.4	0
Thiamin	0.4 mg/lt	Loss	120 – 150	22.87	100.8	2nd

Food Reaction Kinetic Models
Q_{10} Model

Q_{10} is defined as the increase in Reaction Rate for 10 degree C increase in temperature

$$Q_{10} = \frac{Rate_{T+10^o}}{Rate_T}$$

The Q_{10} values for most biochemical and enzymatic reactions fall within the range of 2 - 3

The relationship between z and Q_{10} is:

$$z(^oC) = \frac{10^oC}{\log Q_{10}}$$

Q_{10} concept applied for the prediction of a product's *shelf life* under "real-*life*" conditions compared to "accelerated" storage tests conducted at higher temperatures.

Research and Development

Some Potentially Undesirable Effects of Thermal Treatment

Vitamin Degradation

Maillard Browning compounds

- HMF – Hydroxymethyl-furfural
- Furans
- Lysino-alanin

Lysine Blockage

Acrylamide

Color Change

De-stabilization of Emulsions

Fouling

Cooked Flavors

Vitamins - Comparison of Heat Treatment with Other Stressors

★ – Stable

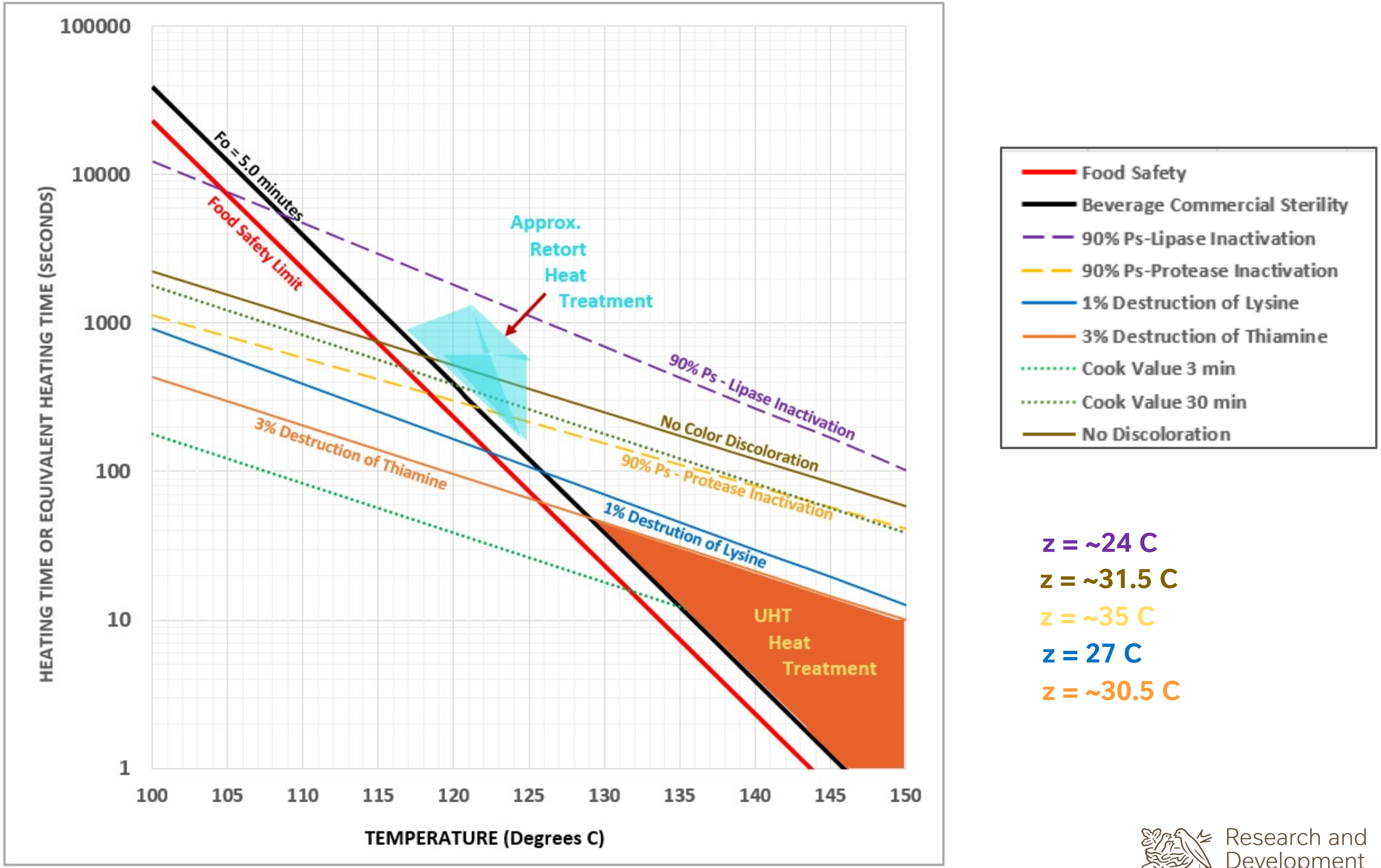
★★★★ – Very Unstable

Qualitative Effects of Heat, Light, Oxygen and Metals on Vitamins

	Vitamin	Heat
Oil Soluble	Vitamin A and D	★★★
	Vitamin E	★★
	Vitamin K	★
Water Soluble	Ascorbic Acid (C)	★★★
	Thiamine (B1)	★★★★
	Riboflavin (B2)	★
	Niacin (B3)	★
	Pyridoxine (B6)	★
	Cyanocobalamin (B12)	★
	Pantothenic Acid	★★★
	Biotin	★
	Folic Acid	★

From "Food Product Development: From concept to marketplace" ed. By Ernst Graf and Israel Sam Saguy, 1991 by Van Nostrand Reinhold

Differences in Destruction Curves – Microbial Spores versus Quality Indicators



z = ~24 C

z = ~31.5 C

z = ~35 C

z = 27 C

z = ~30.5 C

Medium = Milk

Source: *H.G. Kessler Dairy Engineering; Tetra Pak Dairy Handbook*

Research and Development

Nestle THERMOKINETICS – *Published Internal Nestle Application*

- What can THERMOKINETICS calculate?

Reactions in a Thermal Process

Chemical

Maillard Reaction
Destruction of Vitamin
Formation of Lysinoalanine

Enzymatic

Lipase Inactivation
Protease Inactivation

Physical

Protein Denaturation
Color Change

Microbe Destruction

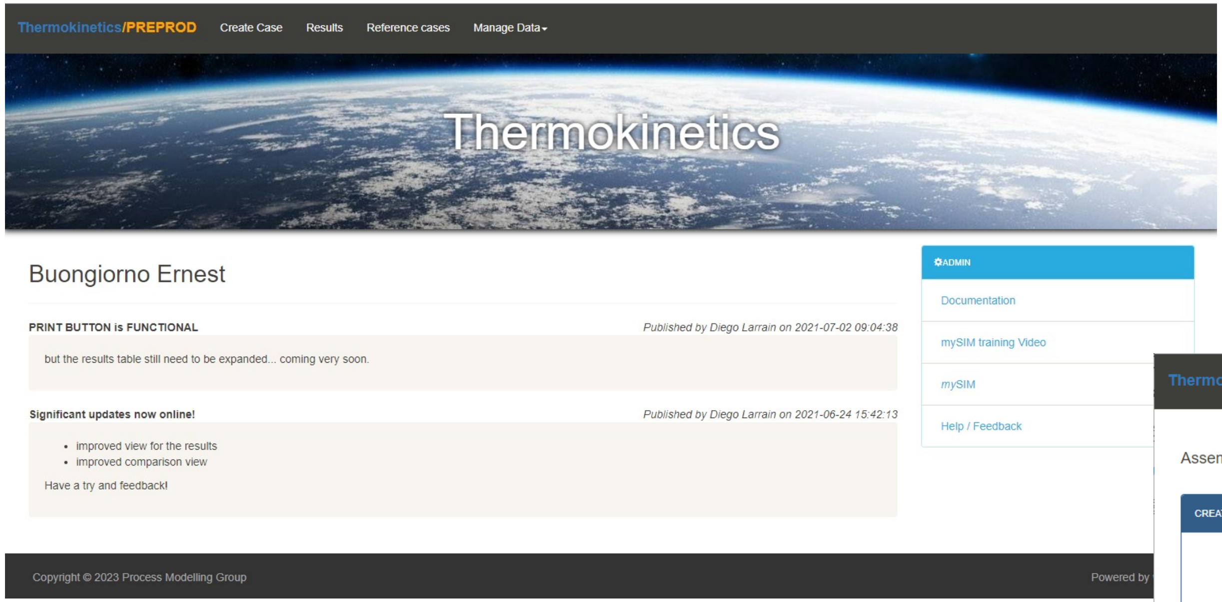
Fo
Mesophilic spores
Thermophilic spores
Pathogens

What are some Limitations?

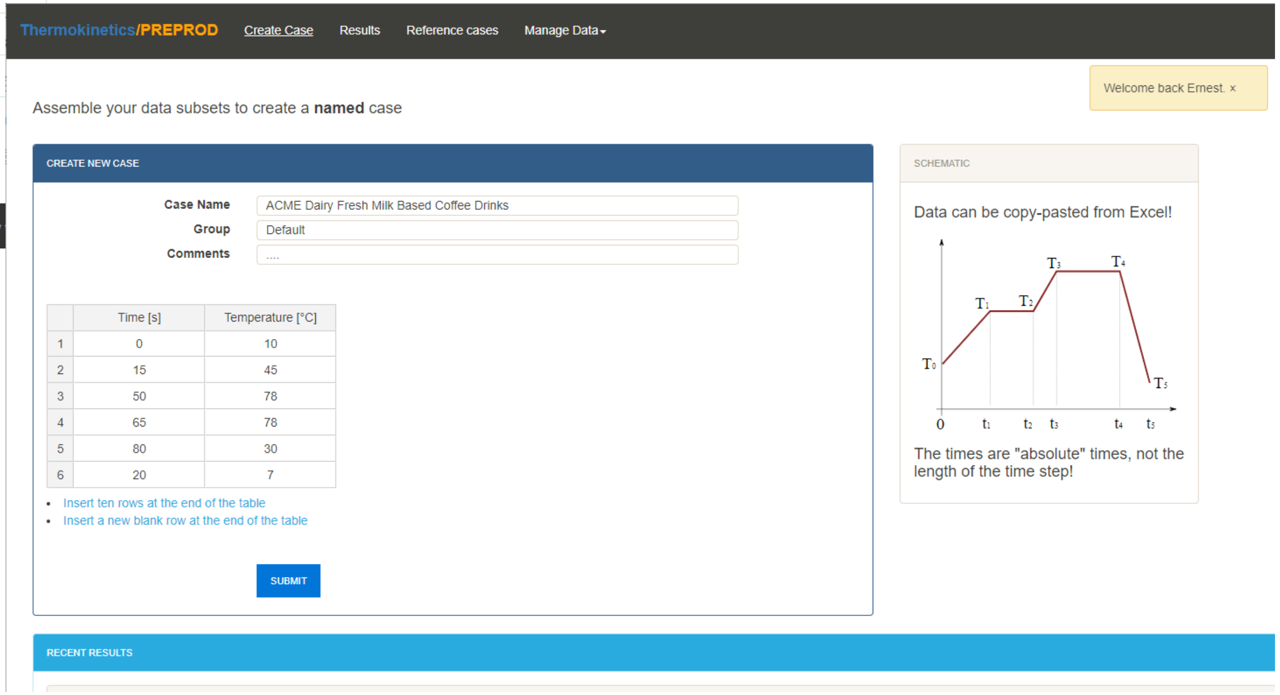
1. Mainly based on Dairy Science and Technology
2. Limited raw materials – mainly liquids and not powders
3. Considers thermal reactions…parallel reactions could also exist

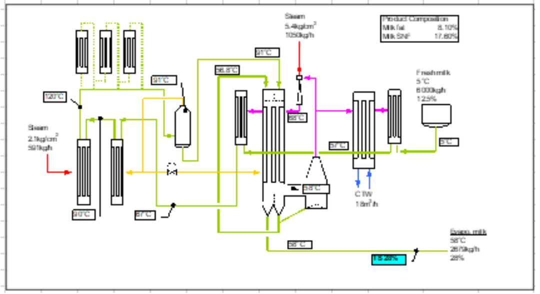
Research and Development

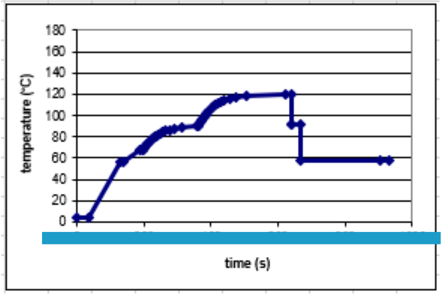
Nestle THERMOKINETICS



- Once you are in...



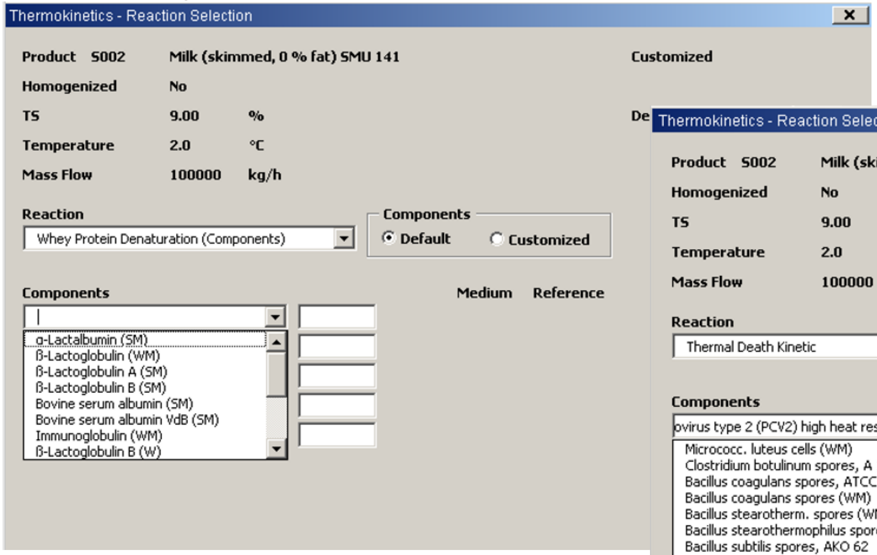




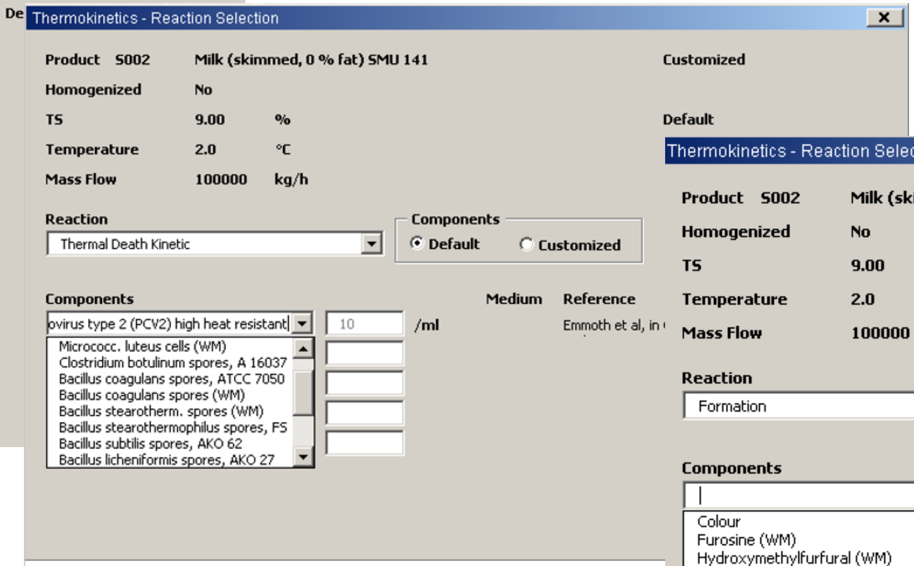
Research and Development

Nestle THERMOKINETICS

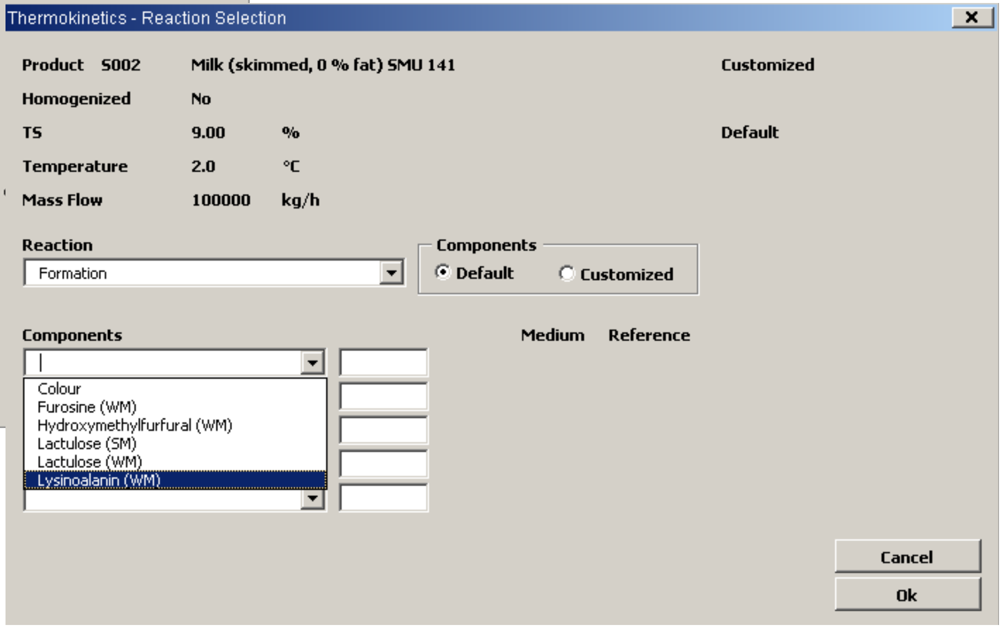
Whey Protein Denaturation



Microbial Death



Formation of Rxn Compounds



1. 1st Order and Zero order Reactions
2. 33 Total Reactions reported
3. Destruction and formation Rxns based on Ea and ln(k) values
   a) Exception is Fo calculation

Research and Development

Nestle THERMOKINETICS

- Case Study:

Dairy Co-Man in India

1. Existing Fresh Milk (>82%) + sugar and coffee recipes
2. Existing FW Immersion Retort with high C values
3. New larger WS Retort – Temp Dist and Heat Pen Study
4. Desired Fo Target > 18 minutes
5. Flavor match important

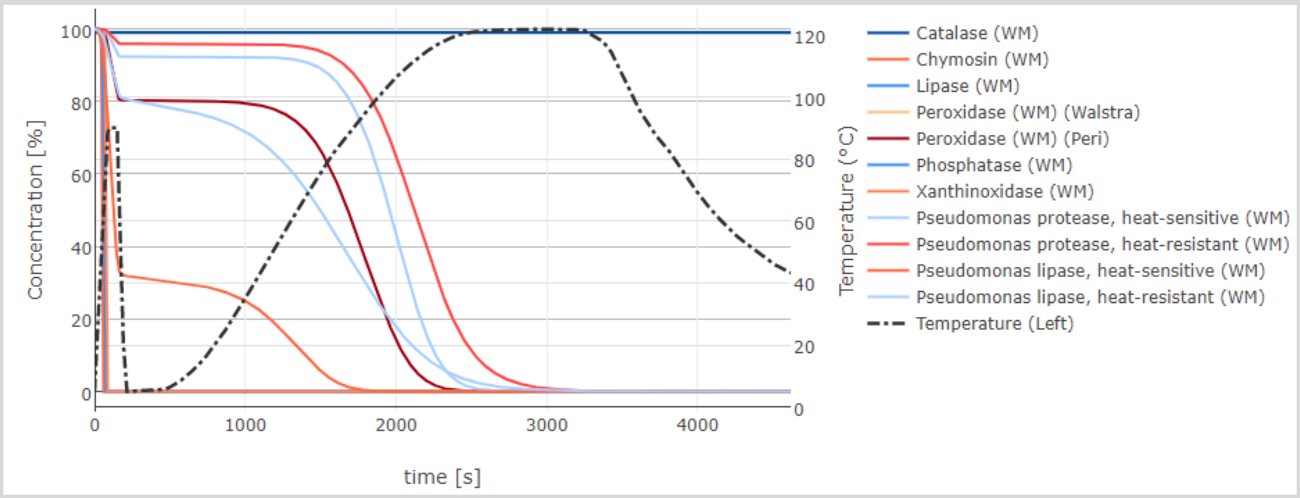
4. How much Furosine and HMF (Maillard chemical markers) are formed?
5. How well is heat resistant protease dealt with?
6. How much Lysine is retained?
7. How much Thiamine is retained?

- HTST Treatment of Fresh Milk Based RTD Beverage
  - ❑ 90 deg C / 60 seconds
- 6 Basket Water Spray Retort Process
  - ❑ 34 minute Come Up Time to 123°C
  - ❑ 16 minute Sterilization Hold Step @ 122°C
  - ❑ Cooling to RT < 35°C
- 2nd Scenario with Extended Hold to try to match existing retort process
  - ❑ 26 minute Sterilization Hold Step

Recommendation – Run 2 simulations in each scenario

1. Fo and Microbial Death Kinetics – Cold Spot Temperature and minimum residence time
2. Average Temperature and flow velocities for other reactions

Simulation Output:



Tabular Comparison of 2 Different Thermal Processes with Different Sterilization Hold Times - 16 min vs 26 min @ 122 deg C

CUT (minutes)	Sterilization Step Time (minutes)	Total Fo (min)	Cook Value, C (min)	Log Rdxn *Geobacillus stearothermophilus* spores, FS 1518	Formation of Furosine (Micromol/liter)	Formation of HMF (Micromol/liter)	Inactivation of Pseudomonas heat-resistant protease (% Remain)	Loss of Lysine (Based on skim milk) % Remain	Loss of Thiamine (Based on skim milk) % Remain
34	**16**	19.8	121	7.5	807	190	0.06%	87.5%	58.8%
34	**26**	31.9	175	12.1	1150	285	0.003%	82.4%	46.1%

Conclusion

- Quick Review of 3 approaches to quantify thermal degradation
  - ❑ Cook Value
  - ❑ Arrhenius equation
  - ❑ Q_{10}

- Compared Microbial death kinetics with thermal degradation kinetics

- A case study of a program we can use in Nestle R&D to calculate the effects of thermal process on various quality attributes using the approaches presented

Nestlé Research

THANK YOU!