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# **PRODUCT QUALITY IMPROVEMENTS THROUGH PROCESS DESIGN**



# Introduction

- The role of the process design in food manufacturing.
- Improved efficiency through process design.
- Importance of process to ensure product safety.
- Product quality improvements through process design.

# Process Design

- Definition – establishment of the optimum process parameters needed to deliver a food product to the consumer.
- Simple process – establishing the parameters for cooling produce from field temperature to storage temperature.
- Complex process – establishing the optimum combination of temperature, pressure and moisture content to produce the desired texture of product from an extrusion process.

# Process Design for Efficiency

- Most often, the objective of process design is to improve efficiency of operations.
- Efficiency is usually expressed in terms of increased capacity or reduced cost.
- For processes involving food, other considerations are required.
- Process design models for food are unique.

# Process Design for Product Safety

- Most processes for preservation are design to ensure product safety or shelf-life.
- Process design models for these processes require knowledge about the response of microbial populations to a preservation treatment.
- Based on the response, the length (time) of the process is established.

# Process Design to Enhance Quality

- Some processes for food are designed to enhance product quality.
- Often, the time for a cooking process is based on the time needed to achieve a desired texture or flavor in the product.
- Many processes for product safety have a negative impact on product quality attributes.

# Objectives

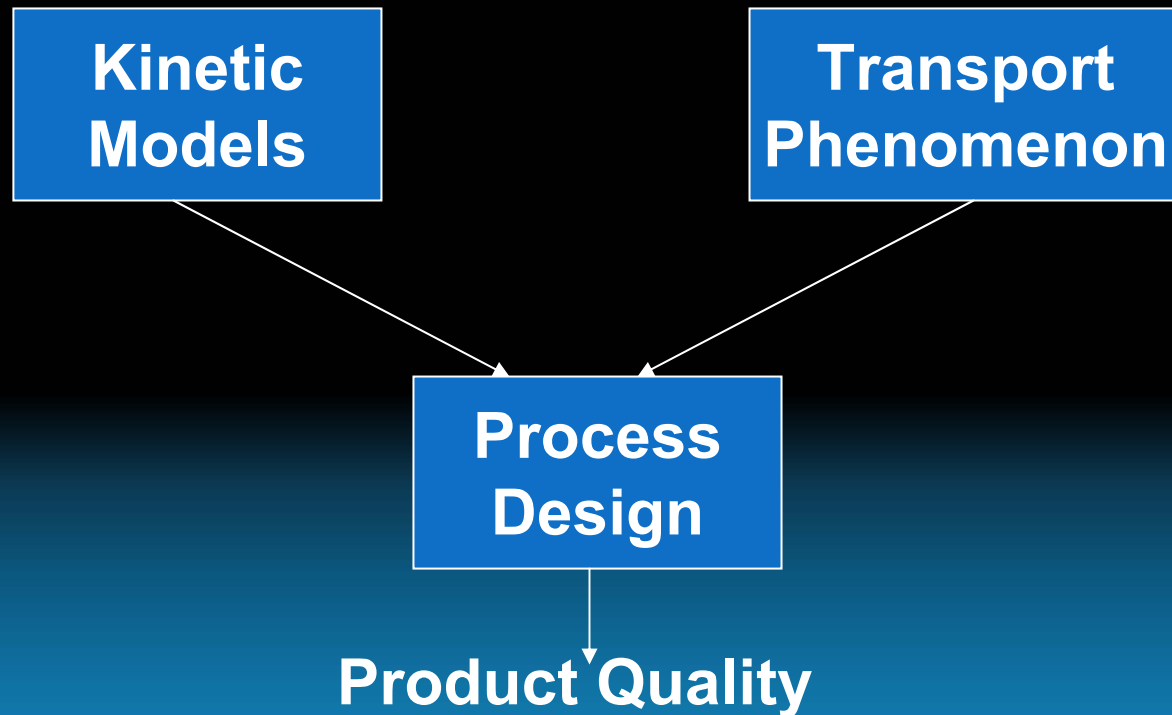
- To present and discuss the typical parameters considered in design of processes for food products.
- To describe the process considerations required when establishing a process involving efficiency, safety and quality.
- To use case studies to illustrate the value of process design models for food products.

# Process Design for Optimum Quality

- Processes for food preservation can consider both safety and quality.
- These process design models require input information about both the microbial population and the product quality attributes.
- Process design based on “the integration of reaction kinetics with transport phenomenon to accomplish process design”

# Food Process Design Model

Research Model –



# Reaction Kinetics in Food Systems

- Use of models to describe changes in the food or ingredient:

$$dA/dt = -k A$$

where  $k$  = rate constant describing change in food product attribute (A).

- Note that “A” may be the microbial population, or intensity if a product quality attribute.
- Rate constants as function of process intensity:

$$k = f(T, a, P, \text{etc.})$$

# Transport Phenomenon in Food Systems

- Development of models to describe heat, mass and momentum transfer in food systems:

$$\partial N / \partial t = \alpha \nabla^2 N$$

where N is the intensity of the process parameter; temperature, moisture, pressure etc.

- Transport properties ( $\alpha$ ) include a variety of parameters that vary with intensity of process parameter.

$$\alpha = f (T, a_w, P, \text{ etc.})$$

# Process Design

- Prediction of outcomes from process in terms used to quantify product attributes:

$$A = \int k(N) dt$$

- These relationships predict the fate of the microbial population, or the product quality attributes based on the process conditions.
- Multiple attributes may be considered as long as appropriate kinetic data are available.
- Process optimization is achieved through analysis of multiple attributes.

# Process Design Examples

- Prediction of safe processes for shelf-stable foods, while retaining quality attributes.
- Selection of package specifications to ensure product shelf-life.
- Prediction of changes in dry product quality during process and/or storage conditions.
- Stability of product quality attributes during product freezing or frozen food storage.

# Case Study #1-Thermal Process Design

- Priority on food safety – ensuring that risk due to surviving pathogens is minimized.
- Process is dictated by thermal treatment needed to ensure food safety risk is eliminated or rate of spoilage is acceptable.
- For applications of model to product in a container, process is dictated by slowest heating location.
- Process time becomes integrated influence of temperature and time on the survival rate of the microbial population.

# Model for Thermal Process

- For microbial population –

$$N = f(k)$$

where  $k$  is rate constant from survivor curve

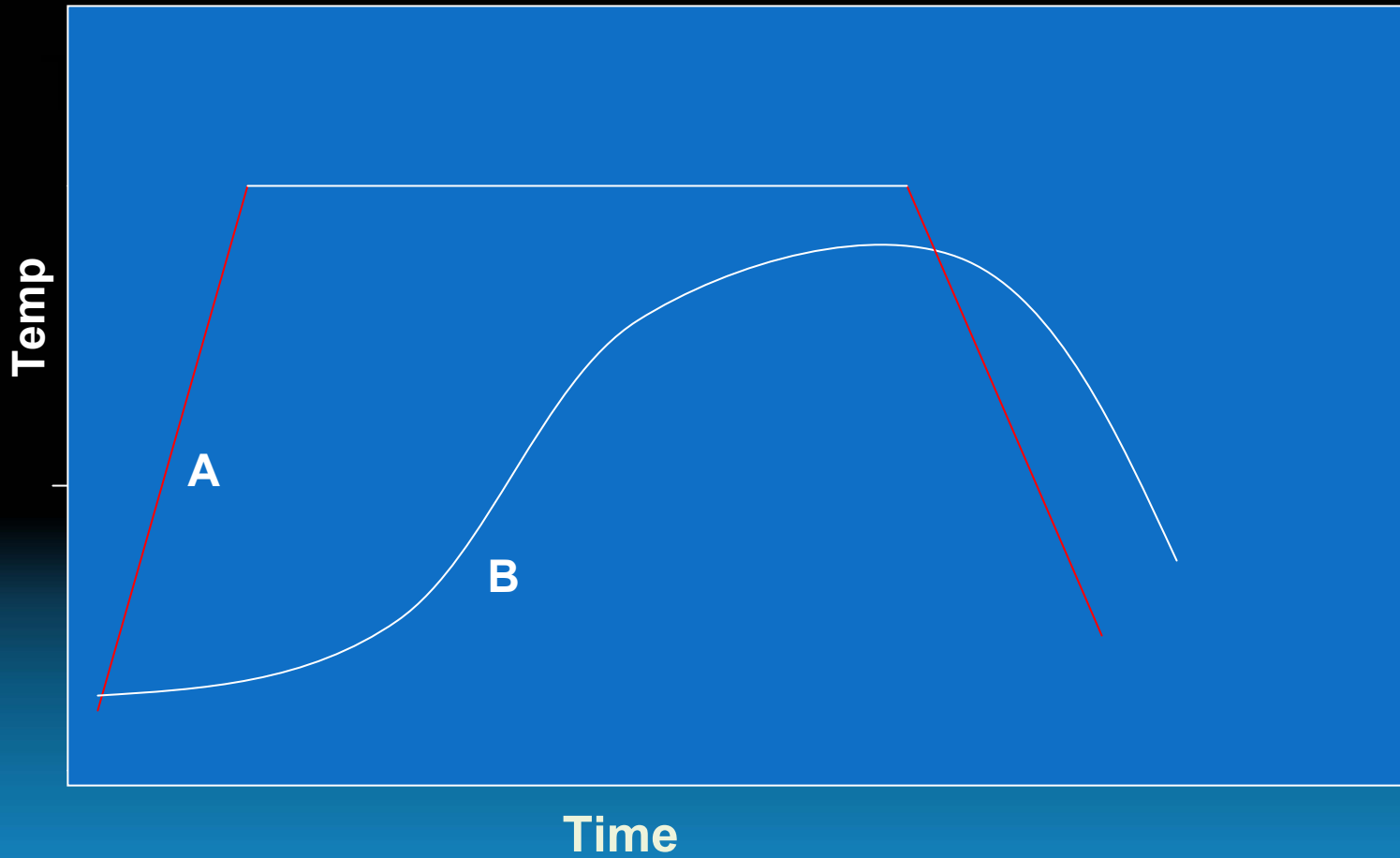
- For quality retention –

$$Q = (k')$$

where  $k'$  is rate constant for quality retention

- Both  $k$  and  $k'$  are dependent on temperature –

# Temperature at Center of Container



A = heating medium

B = product center

# Thermal Process Model

- Both  $k$  and  $k'$  are dependent on temperature

–

$$T = f( T_m, r, H, t )$$

where

$T_m$  = heating medium temperature

$r, H$  = location with container

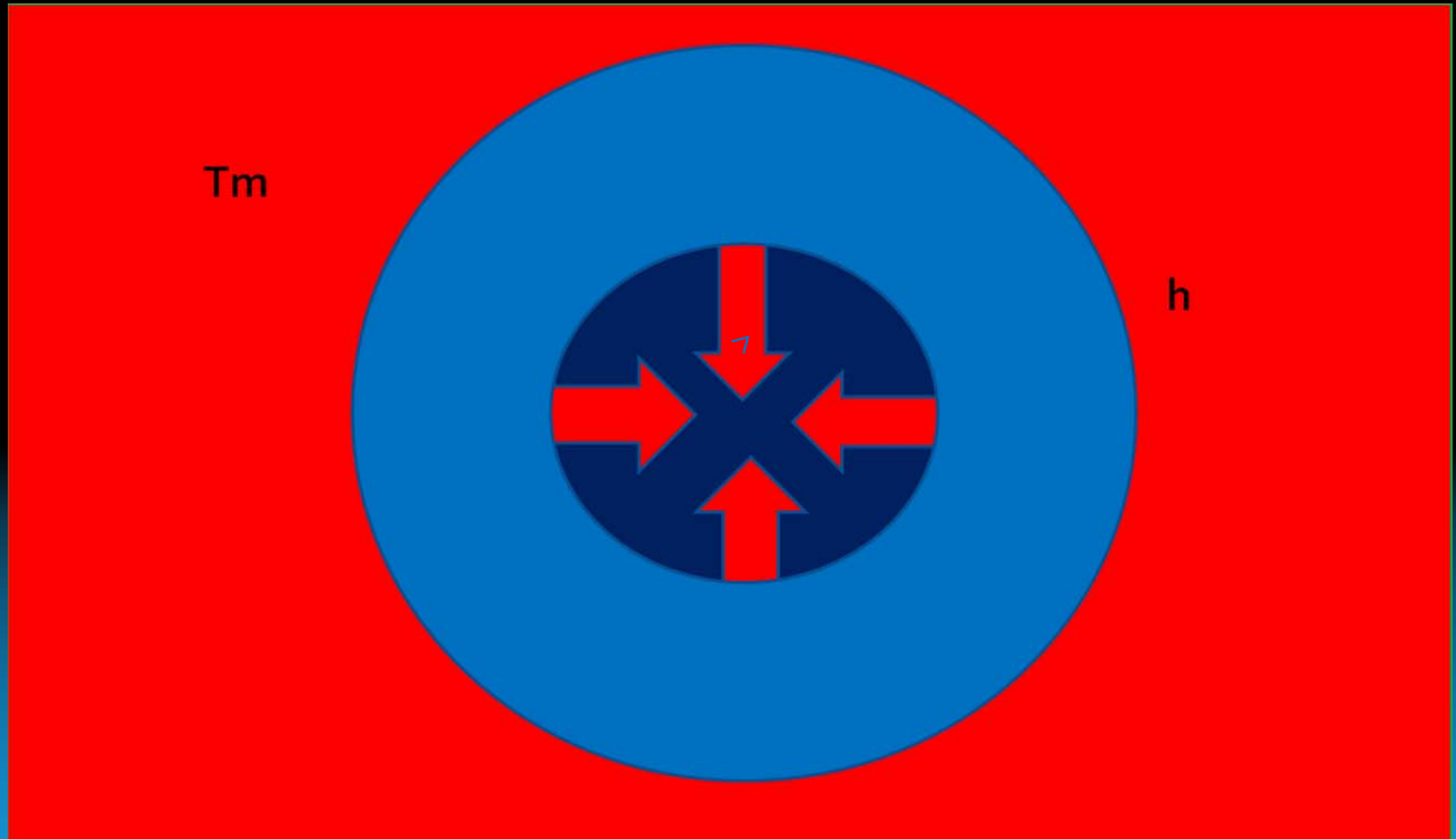
$t$  = time

- Then –

$$N = \int k(T) dt$$

$$Q = \int k'(T) dt$$

# Heating Characteristics of Food



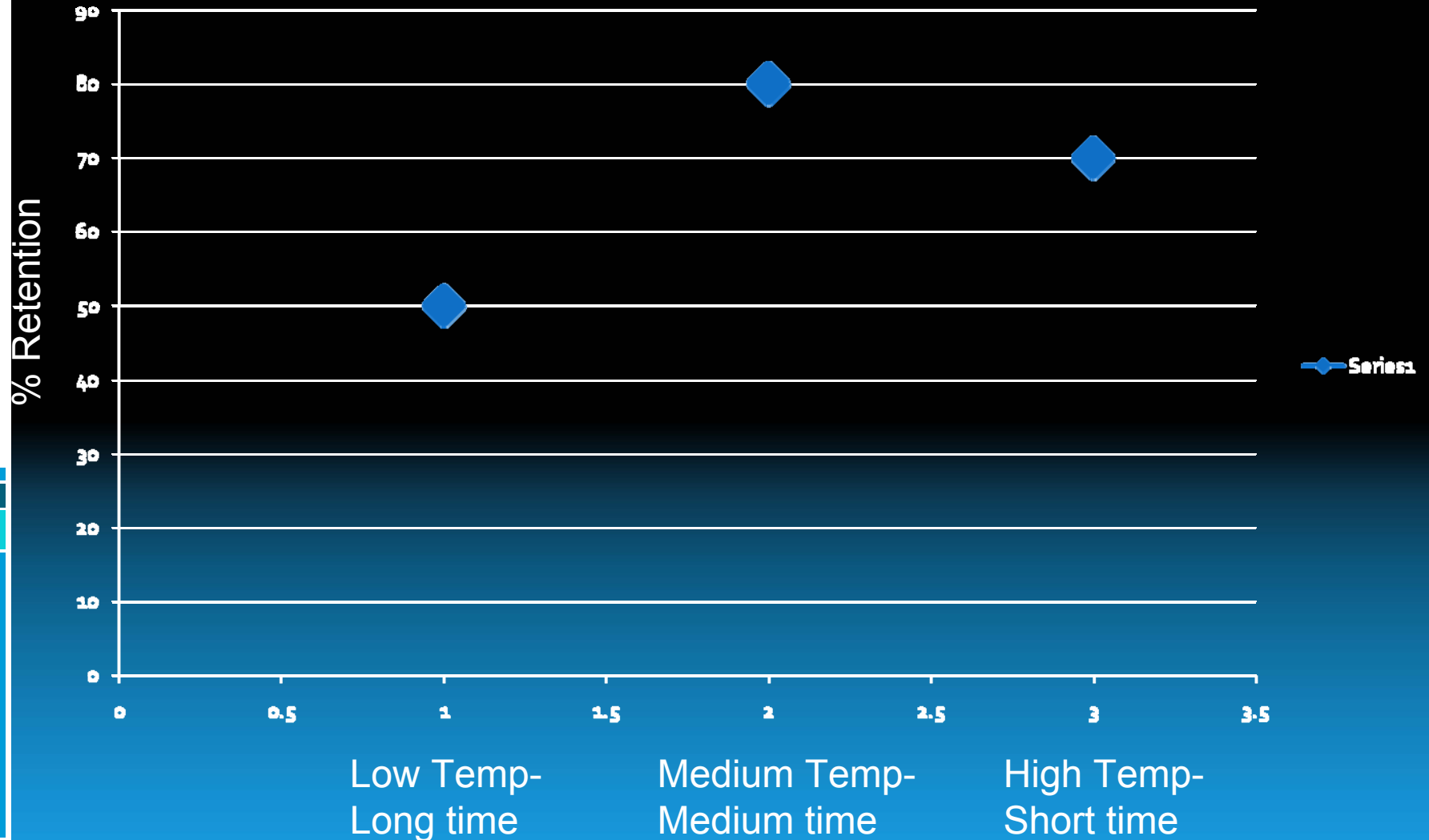
# Thermal Process Model

- In a cylindrical can –
  1. The slowest heat location is the geometric center.
  2. Process must reduce microbial population at that location.
  3. All other locations receive process greater than required.
  4. Kinetics of quality retention favors a higher temperature and shorter time process.

# Thermal Process Optimization

- Model can be used to evaluate impact of various conditions on retention of quality while ensuring product safety.
- A low temperature heating medium for a longer time.
- A medium temperature medium for an intermediate time.
- A high temperature medium for a shorter time.

# Process Optimization



# Case Study #1

## Conclusions

- An optimum set of process parameters can identified to:
  1. ensure product safety or desired shelf-life
  2. provide maximum retention of product a quality attributes.
- Process models require experimental inputs for kinetic parameters of microbial populations and the product quality attributes, as well as physical properties of product.

## Case study #2 -- Package Design for a dry food

- Establishment of the package film characteristics for optimum dry food shelf-life.
- The quality attributes of dry foods depend on maintaining low water activity of the product.
- The water activity of the product is maintained by limiting water transmission through the package film.

# Model for Case Study #2

- Water transfer through package film is described by:

$$dM = P A (a_{wo} - a_{wi}) dt$$

where

M = amount of water transfer through film

P = water permeability of package film

A = surface area of package

$a_{wo}$  = relative humidity outside package

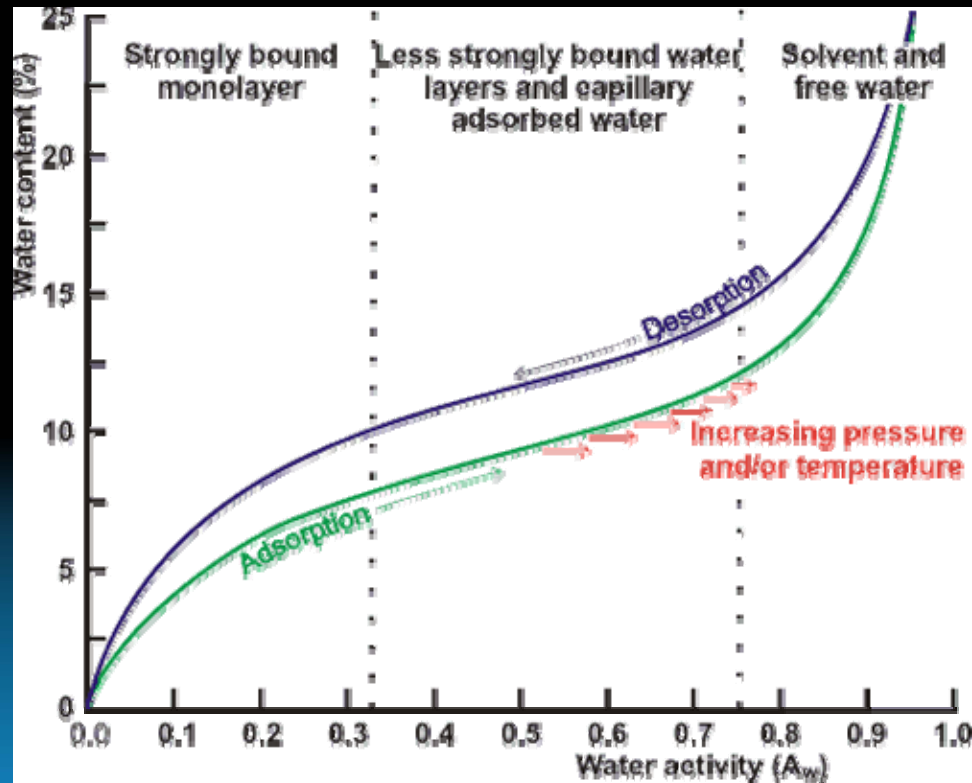
$a_{wi}$  = water activity of product.

- The permeability (P) is dependent on moisture diffusivity of film and the film thickness.

# Model for Case Study #2

- The relationship between moisture content and water activity is the “equilibrium moisture isotherm”.
- During storage, moisture transfers through the film and results in an increase in product moisture content.
- The increase in moisture content causes an increase in product water activity, and an increased rate of quality deterioration.

# Equilibrium Moisture Isotherms



# Case Study #3 Model

- The retention of product quality is:

$$Q = f(k)$$

where

$k$  = rate constant for change in a quality attribute.

and

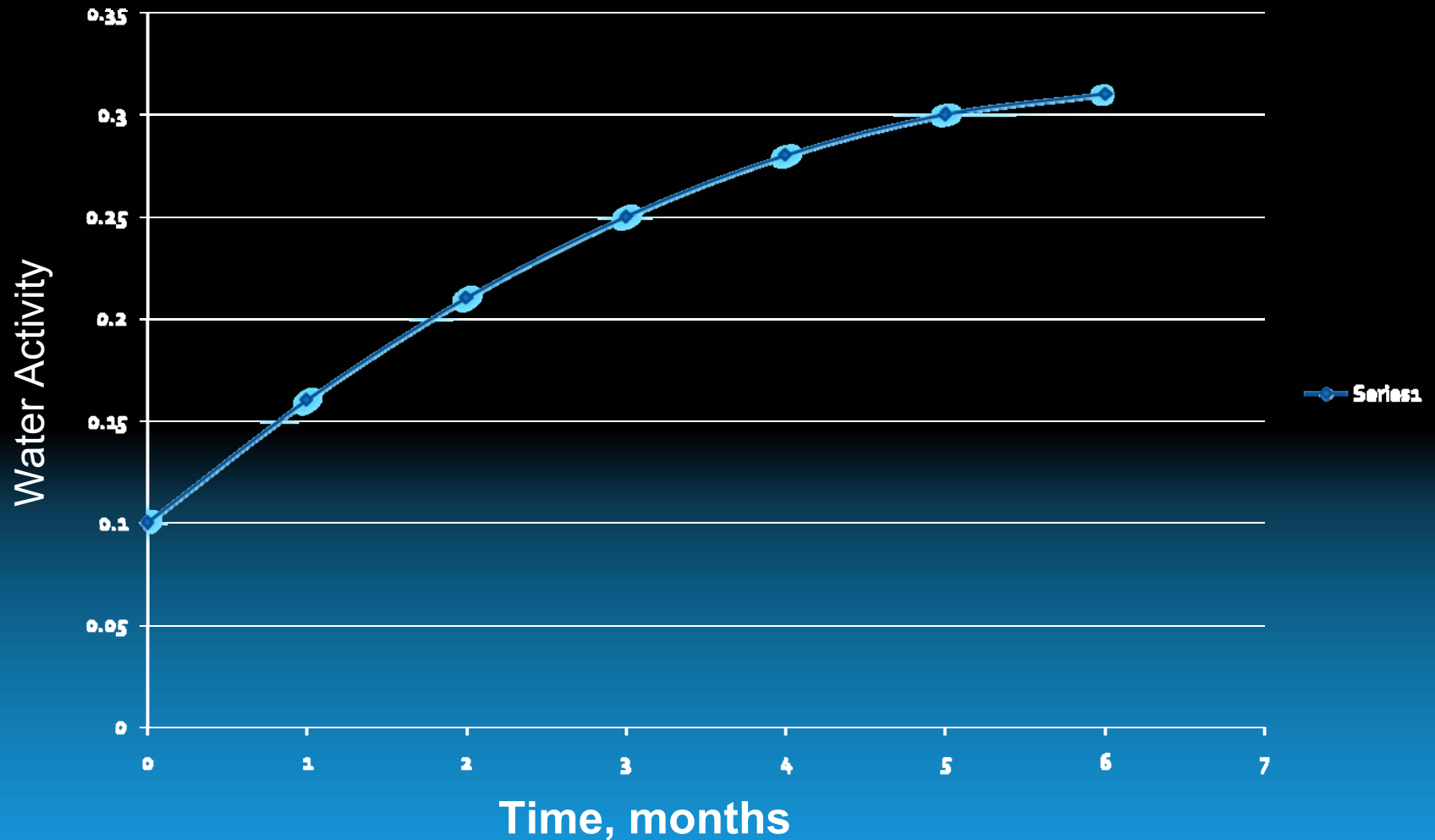
$$k = f(a_w)$$

- The retention of product quality

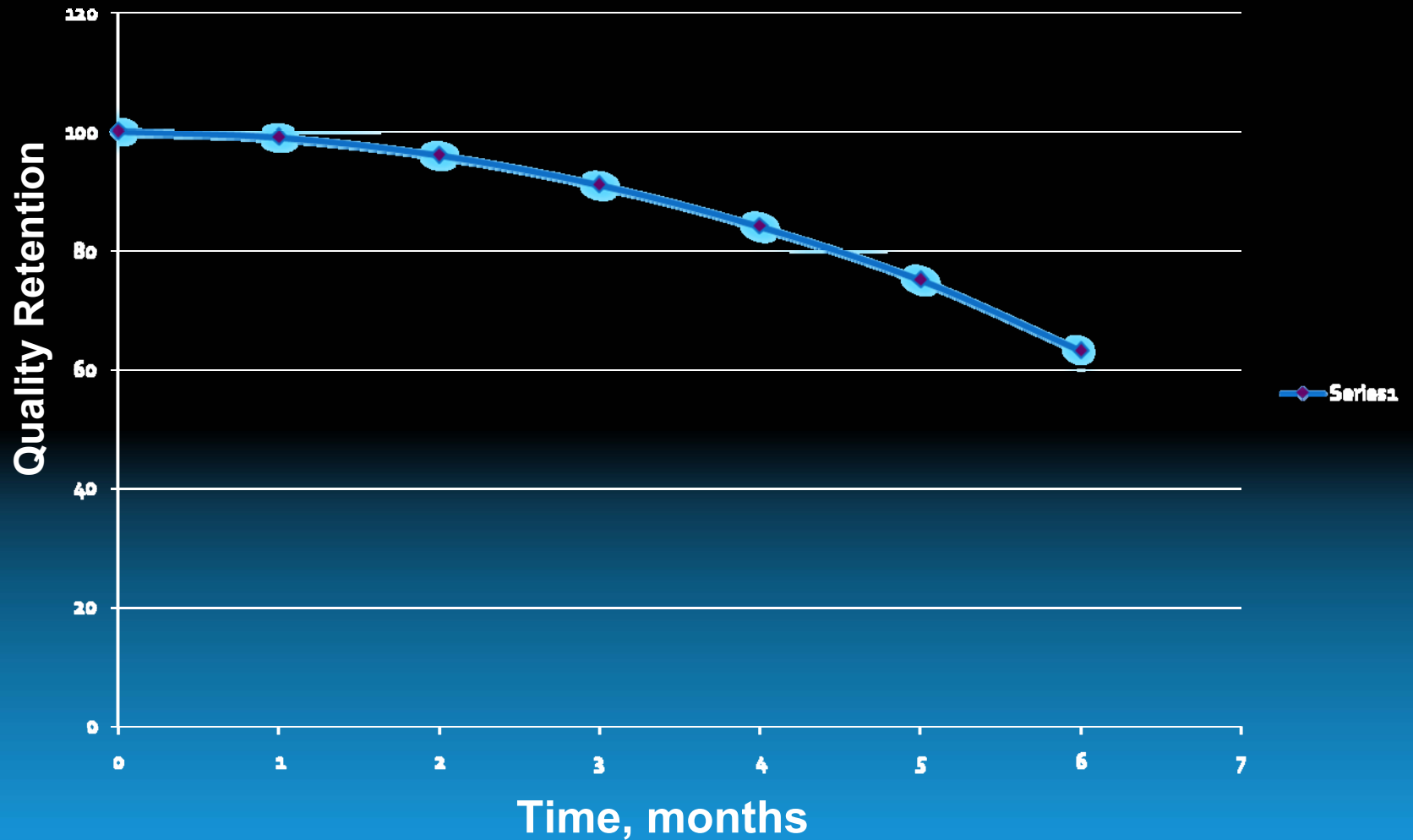
$$Q = \int k(a_w) dt$$

where the water activity is a function of time as predicted by the moisture transfer expression

# Process Model for Water Activity versus Time



# Process Model for Quality Retention



# Case Study #2

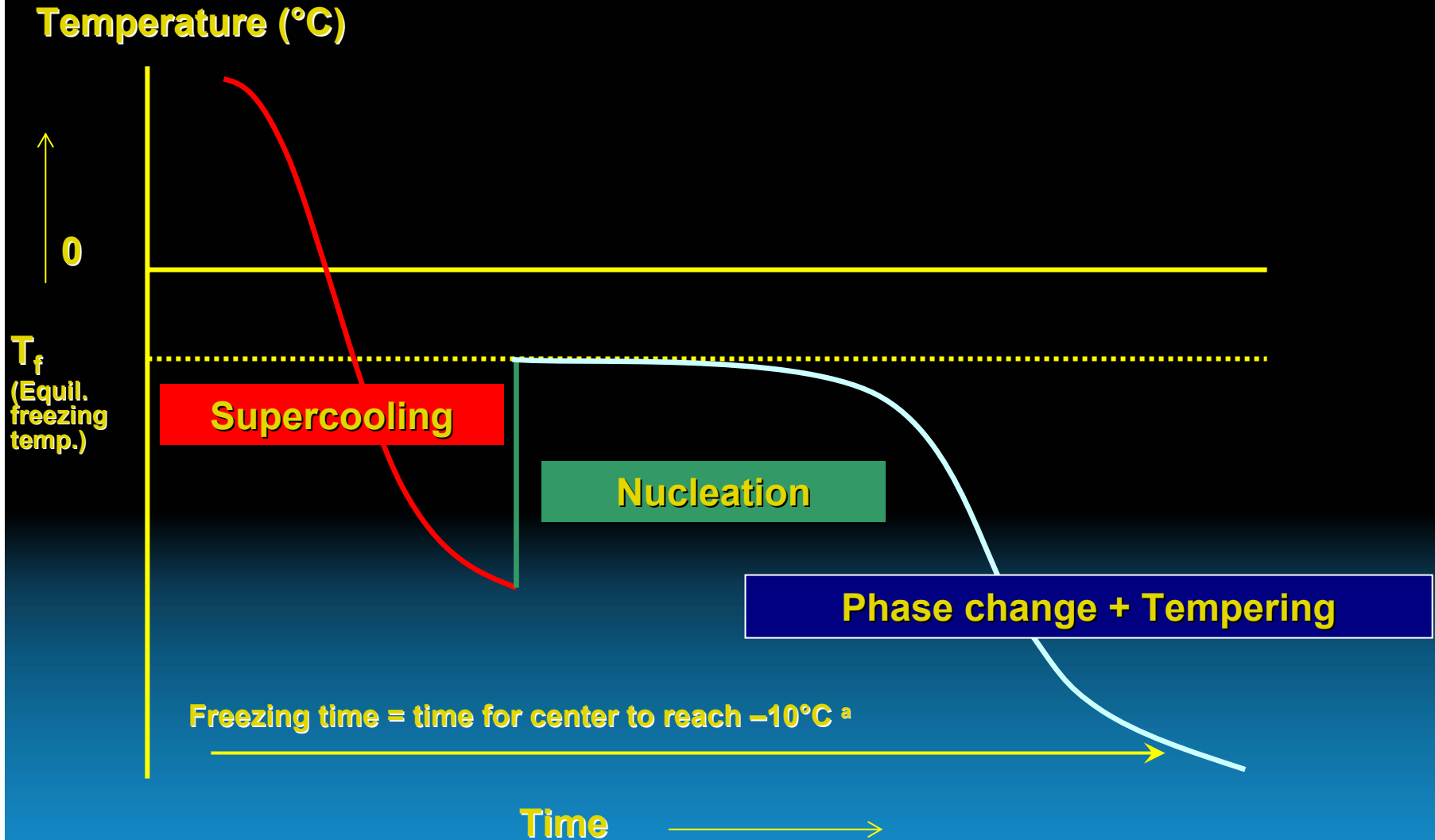
## Conclusions

- Process model is used by following steps:
  1. Select desired shelf-life, based on accepted amount of quality retention.
  2. Use computational model to select the permeability (P) requires to accomplish goal, given a defined relative humidity (and temperature) of the storage environment.
  3. The permeability (P) is selected, based on film diffusivity and thickness.

# Case Study #3 -- Frozen Food Quality

- Establishing the process parameters and storage conditions required to create maximum product quality.
- In general, maximum frozen food quality is achieved by small ice crystals within the product structure.
- Small ice crystals are the result of rapid freezing;

# Typical Freezing Curve for a Food Product



<sup>a</sup>(International Institute of Refrigeration, 1972) according to (Cleland and Earle, 1979).  
Adapted from (Li, J. and T.-C. Lee., 1998).

# Model for Case Study #3

- Thermal energy transfer with phase change –

$$\partial T / \partial t = \alpha \nabla^2 T$$

where:

$\alpha$  = thermal diffusivity and latent heat of fusion for the product.

- Solution of expression, with boundary condition to account for convective heat transfer coefficient, provides temperature distribution histories within the product during process.

# Model for Case Study #3

- The relationship between internal and external heat transfer can be expressed by the Biot Number:

$$NB_i = h d / k$$

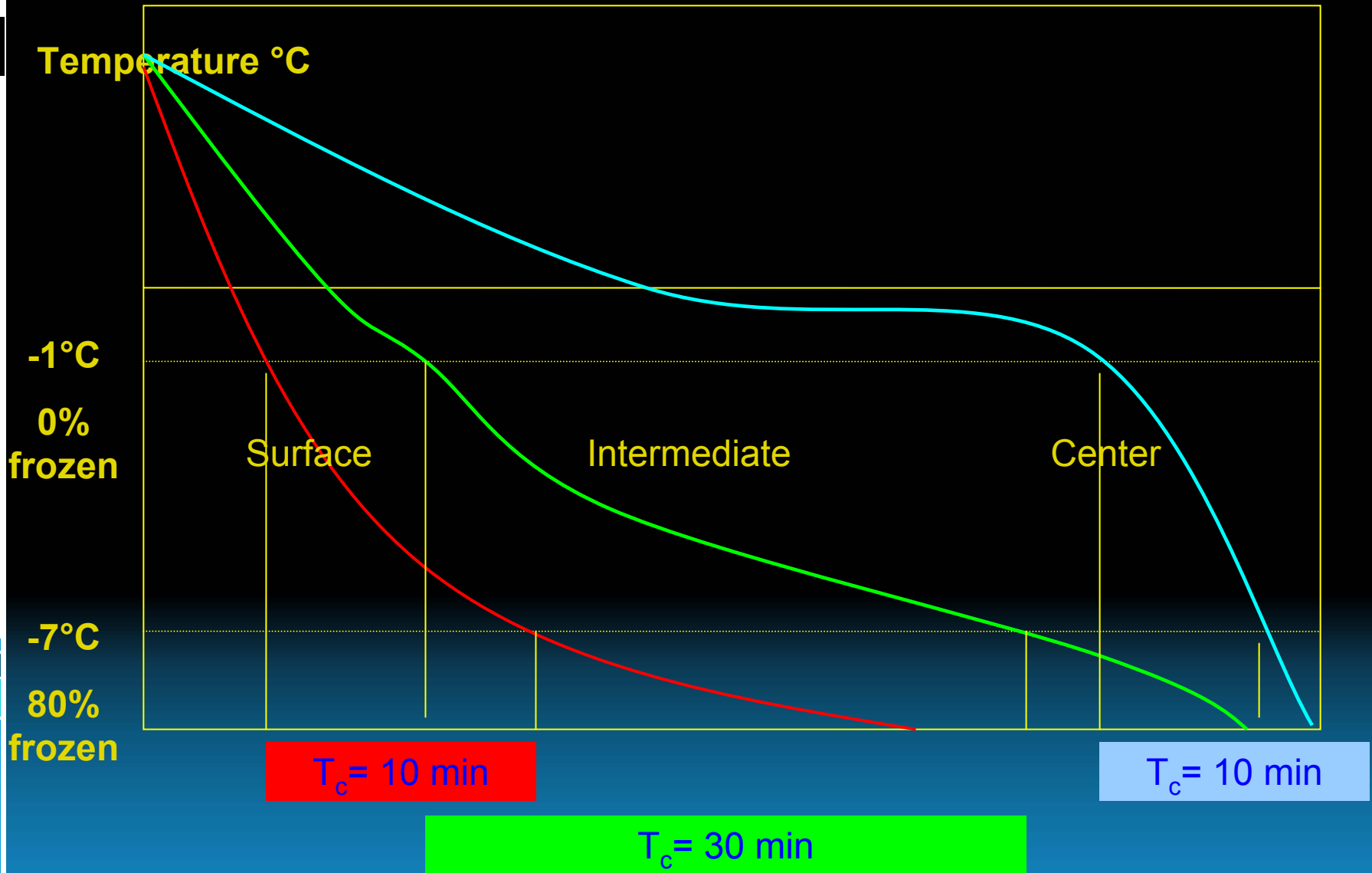
h = convective heat transfer coefficient

d = characteristic dimension

k = thermal conductivity of product

- The Biot number increases with higher values of “h” and with larger dimensions of product.

# The Characteristic Freezing Time



(Pham, Q. T. and Mawson, R. F. , 1997)

(Bevilacqua, A.E., Zaritzky, N.E., and Calvelo, A. , 1979; Añón, M. C. and A. Calvelo. 1980).

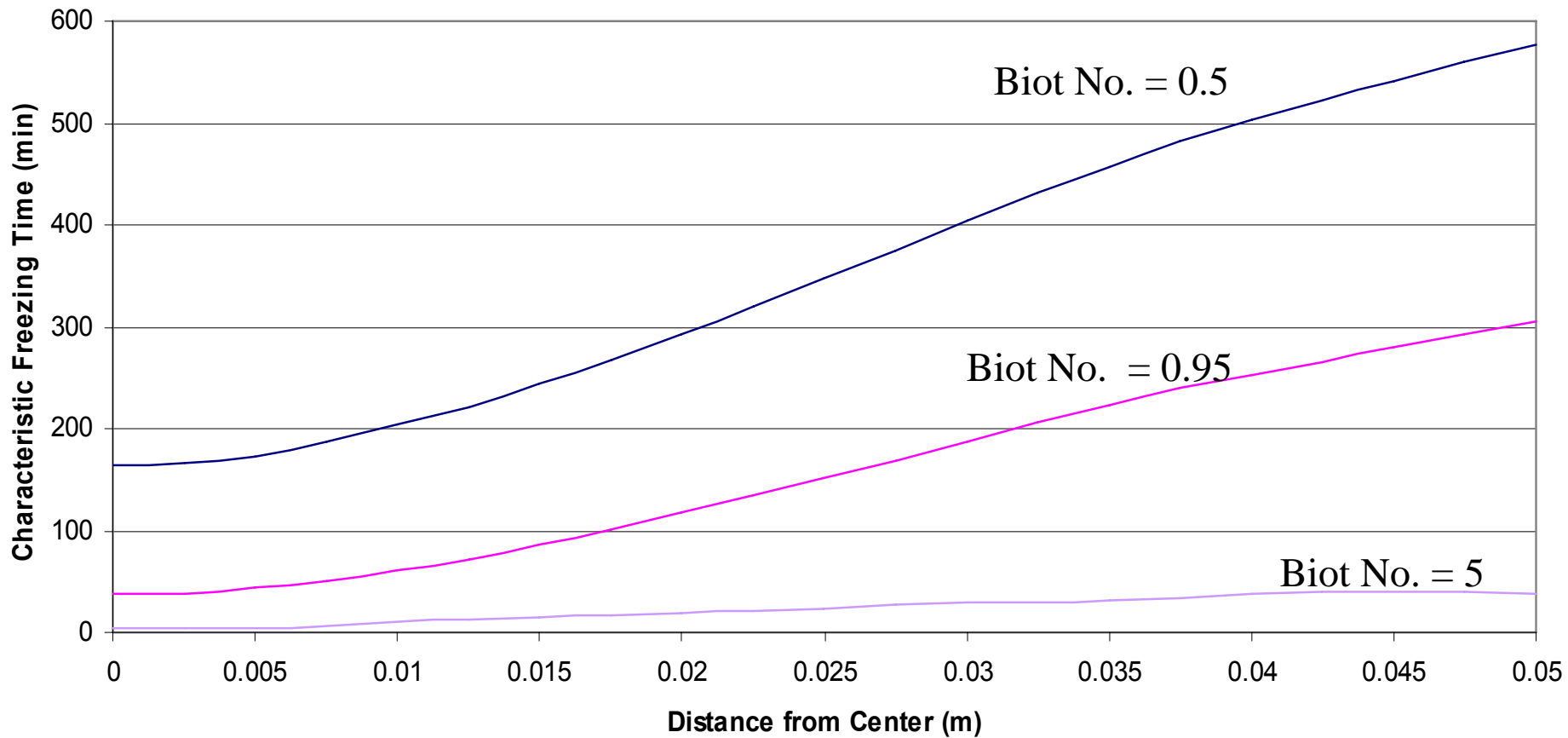


Fig 4. Influence of location on characteristic freezing time.

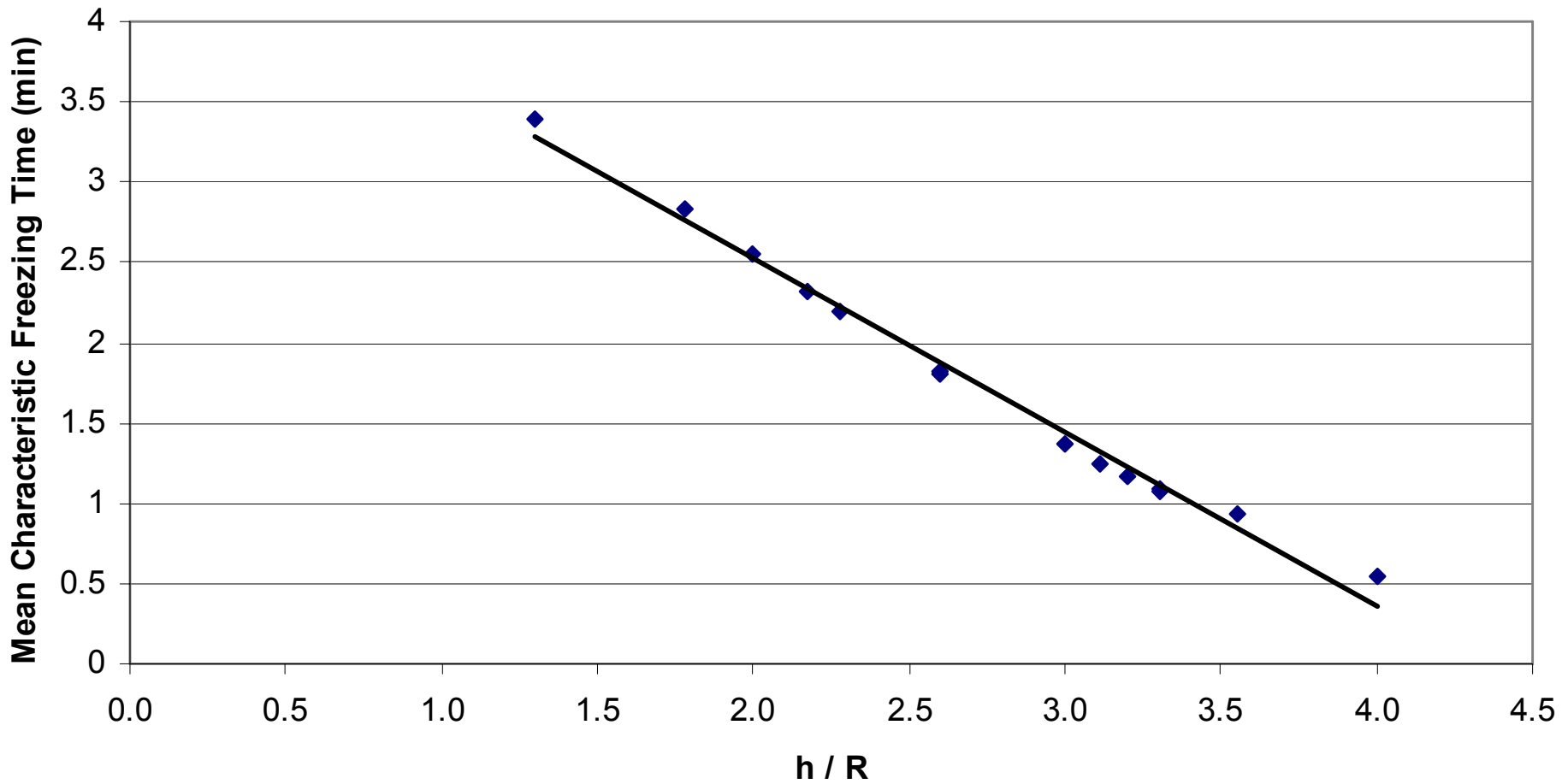


Fig 13. Relationship between the logarithm of mean characteristic freezing time and the logarithm of  $h/R$ , at  $T_m$  of  $-25$  C and  $T_i$  of  $10$  C.

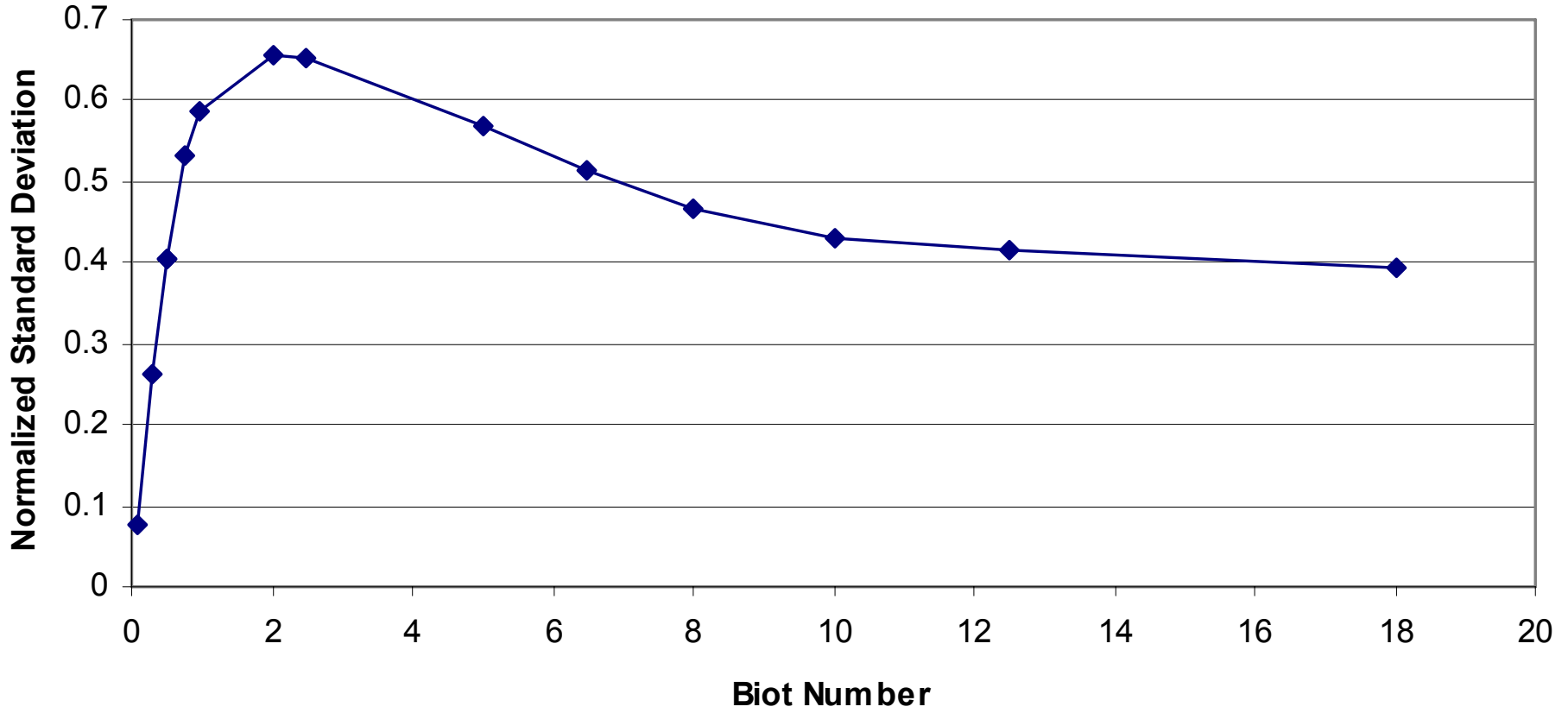


Fig 14. Relationship between normalized standard deviation and Biot Number, at  $T_m$  of -25 C and  $T_i$  of 10 C.

# Conclusions from Case Study #3

- The process model for food freezing been used to identify a region of freezing system parameters creating a lack of uniformity in ice crystal size.
- Based on the outcomes from the model, the freezing process parameters needed to ensure more uniform ice crystal sizes with the product, and the more desirable quality attributes.

# General Conclusions

- Process models can provide insights into operations efficiency, product safety and quality retention.
- Process models for foods consider kinetics of microbial population change and/or quality retention, and the transport phenomenon within the product during the process.
- Case studies indicate product quality can improved or optimized though the use of process models.