Temperature, heat transfer and lethality distribution in food processing systems

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Institute For Thermal Processing Specialists

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GUIDELINES FOR CONDUCTING THERMAL PROCESSING STUDIES

The following recommendations are to be considered voluntary guidelines. These **recommendations do not preclude the application of other methods and equipment** for conducting thermal processing studies. These guidelines have been **developed by consensus of the Institute for Thermal Processing Specialists** and should be given serious consideration for adoption as methodology by individuals performing thermal processing studies.

The Institute for Thermal Processing Specialists is a non-profit organization established exclusively for the purpose of fostering education and training for those persons interested in procedures, techniques and regulatory requirements for thermal processing of all types of food or other materials, and for the communication of information among its members and other organizations. This document is a compilation and re-structuring of previously published IFTPS guidance documents. Prior documents were modified to follow a common format and were also updated to reflect current practices. Common sections amongst previously published documents, such as Retort Survey, were placed into separate chapters. Information was added to Chapters on Temperature Distribution, Heat Transfer Distribution, and Heat Penetration to provide recommendations regarding Data Analyses, Success Criteria, and Risks, Issues and Other Considerations.

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Chapter 1 – Definitions

Definitions of terms and symbols commonly used in thermal processing studies

Chapter 2 – Test Equipment and Standardization/Calibration

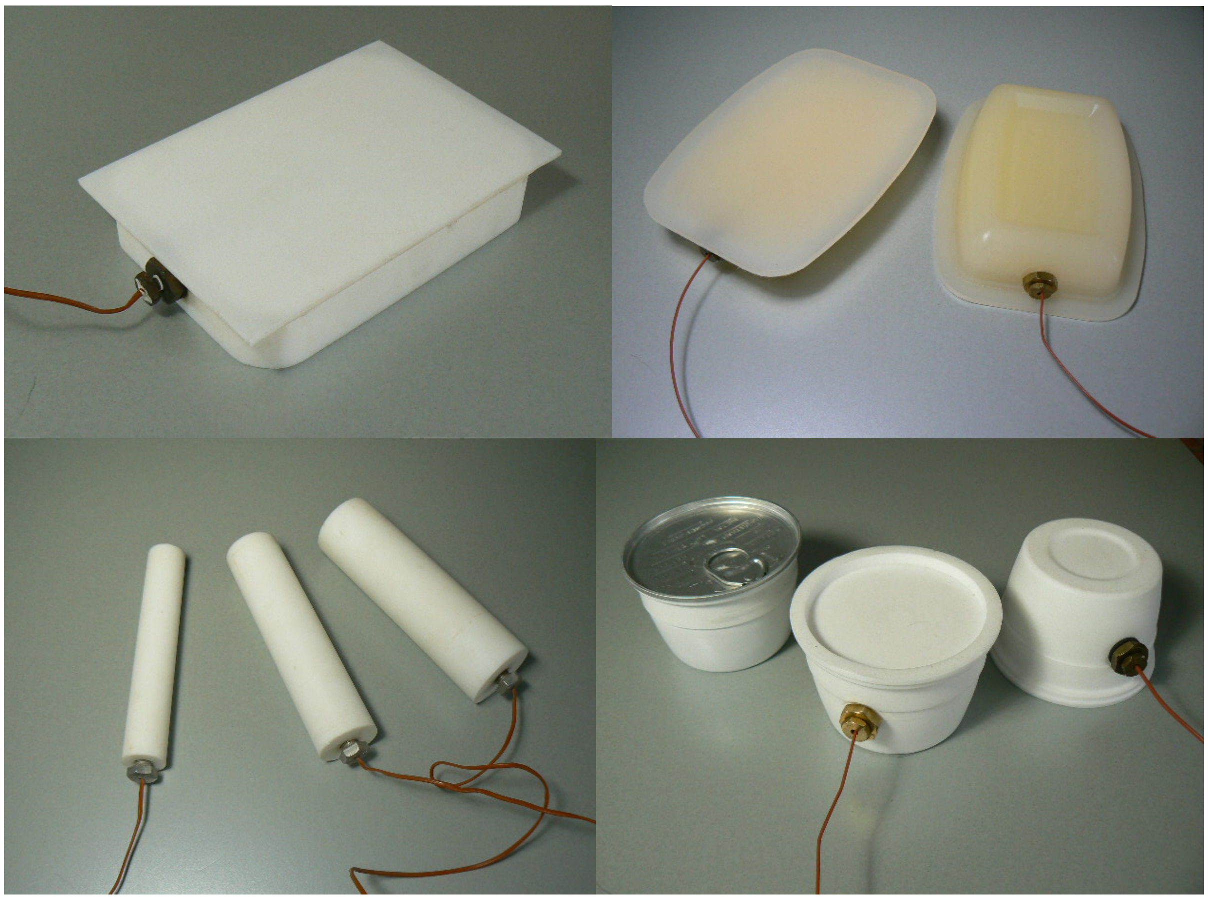
The objective of this chapter is to provide guidance on calibration of the test equipment used to collect thermal process data.

Test Equipment and Standardization/Calibration

- Data Acquisition System
  - Should be calibrated prior to use

- Together with Various Sensing Elements
  - Calibrated before and after tests
  - Reference Temperature Indicating Device (TID)
  - Temperature Measuring Devices (TMDs)
  - Pressure Sensors, Flow Meters, Stopwatches
  - Heat Input Units (HIUs)

Heat Input Units (HIUs)



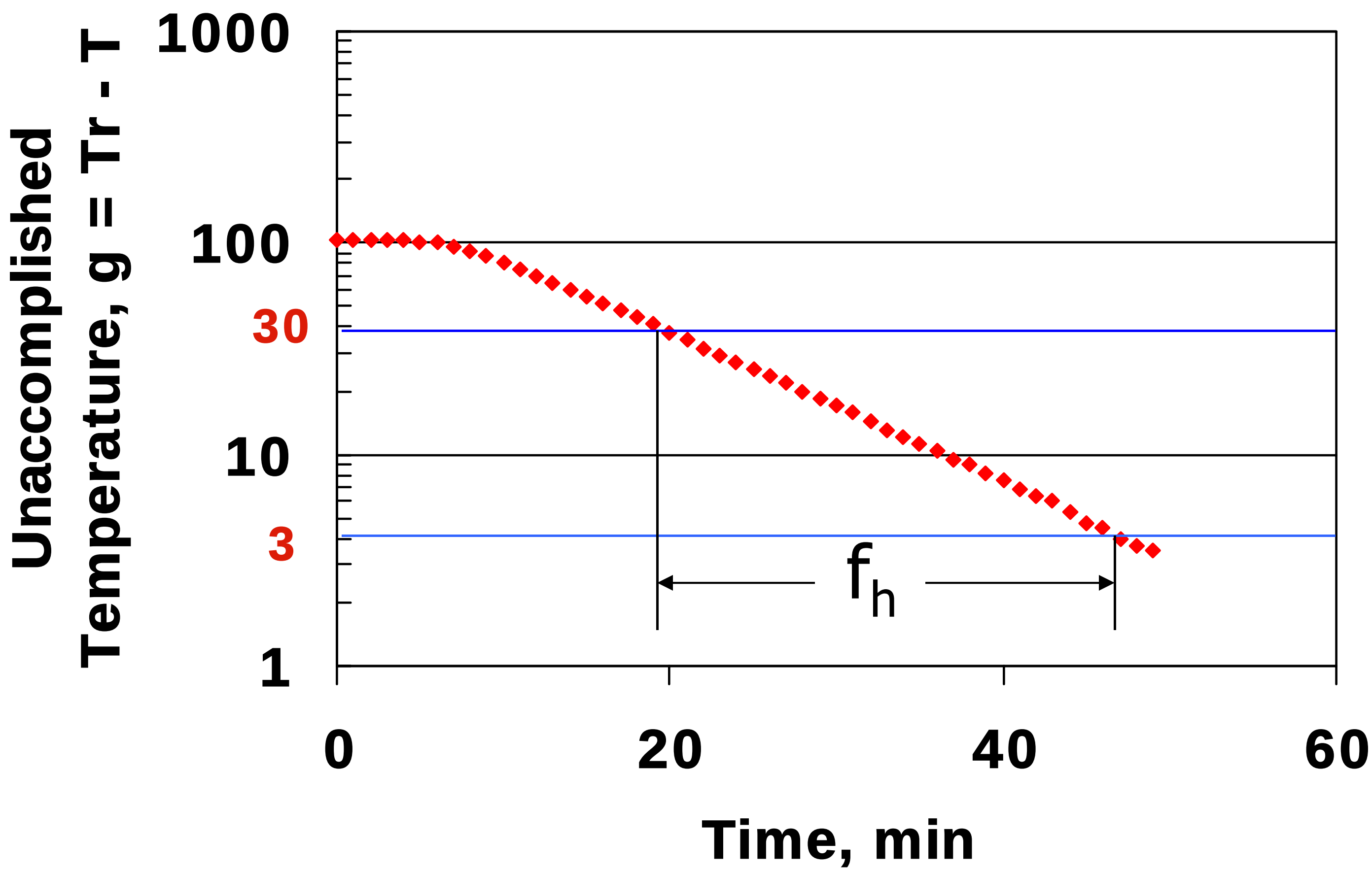
HIU Calibration

- Use either a pilot scale retort or the test retort
- Standardize a complete set of HIUs (12-24 separate units) using expected operating parameters (temperature and pressure)

Heat Input Units (HIUs)

- Locate the HIUs in close physical proximity to each other during the standardization/calibration study.
- Locate calibrated TMDs next to the HIUs
- Establish a baseline for the heating performance based the heating rate index (f_h) calculated for each HIU

Heating Rate Index



Heat Input Units (HIUs)

- Use the coefficient of variation of the f_h values to determine acceptable standardization for the use of a set of HIUs

- CV = (standard deviation/mean) * 100%

- A CV ≤ 1% would be acceptable for a set of HIUs to be used to collect heat transfer distribution data.

Heat Input Units (HIUs)

- If product-based HIUs are used
  - The product chosen heating characteristics should be representative of the product heating type (e.g., conduction, convection) to be studied during heat transfer distribution tests.

Chapter 3 – Documenting Processing Equipment & Test Conditions

Objectives

- Documentation of test retort(s)
- Documentation to identify the selected retorts for temperature distribution, heat transfer distribution, and heat penetration studies
- Documentation of “as existing” conditions may also be used as part of an overall change control program.

Chapter 4 – Conducting Temperature Distribution Studies

Objectives

- Establish vent schedules and come-up requirements
- Identify the slowest to come to process temperature location(s), as well as temperature stability and uniformity during the cook

Objectives

- Temperature distribution data may also provide insight into the impact of changes made to processing equipment, utilities, and other identified critical factors

General Approach

- Locate thermocouples or other TMDs throughout the retort and observe resulting temperature history data

Data Analyses

- Plot or tabulate the minimum and maximum measured temperatures for all TMDs within the retort load at each scan/time interval
- Evaluate the TID, Controller and Chart temperatures at specific time points relative to the TMD temperatures

Data Analyses

- Evaluate the difference between the minimum measured temperature and the programmed or set-point minimum process temperature at specific time points to establish or confirm temperature off-sets and to establish come-up time.

Data Analyses

- Identify the location of the TMD that was the slowest to achieve come-up criteria. Identify the time this TMD achieved come-up criteria.

- Identify the minimum Initial Temperature used in the experiments.

Success Criteria

- Come-Up
  - The TID should be at or above minimum process temperature at the end of come-up.
- Cook/Hold
  - All TMDs should be within 1F° (0.5C°) of minimum process temperature at the end of come-up.
  - All TMDs should be at or above the minimum process temperature within 1 minute of starting the hold time.

Success Criteria

- Cooling
  - If specific cooling profiles are critical to the process delivery, the temperature distribution during cooling must support those profiles.

Success Criteria

- Other
  - The location of all TMDs must be confirmed at the end of all studies. Any TMD that shifted during data collection should be evaluated for impact on study outcomes.
  - The integrity of test packages/ballast should be confirmed to be acceptable.
  - All critical retort operating parameters (e.g., Temperature, Rotation, Pressure, Flow, Water Level, and Fan Speed) were achieved as planned and/or programmed.

Success Criteria

- Other
  - Situations or conditions that do not meet these criteria should be critically evaluated.
  - Identify the minimum Initial Temperature for which the temperature distribution is valid.
  - Identify all other aspects of the product, package, ballast, loading pattern, and so forth for which the temperature distribution is valid.

Chapter 5 – Conducting Heat Transfer Distribution Studies

Some Background

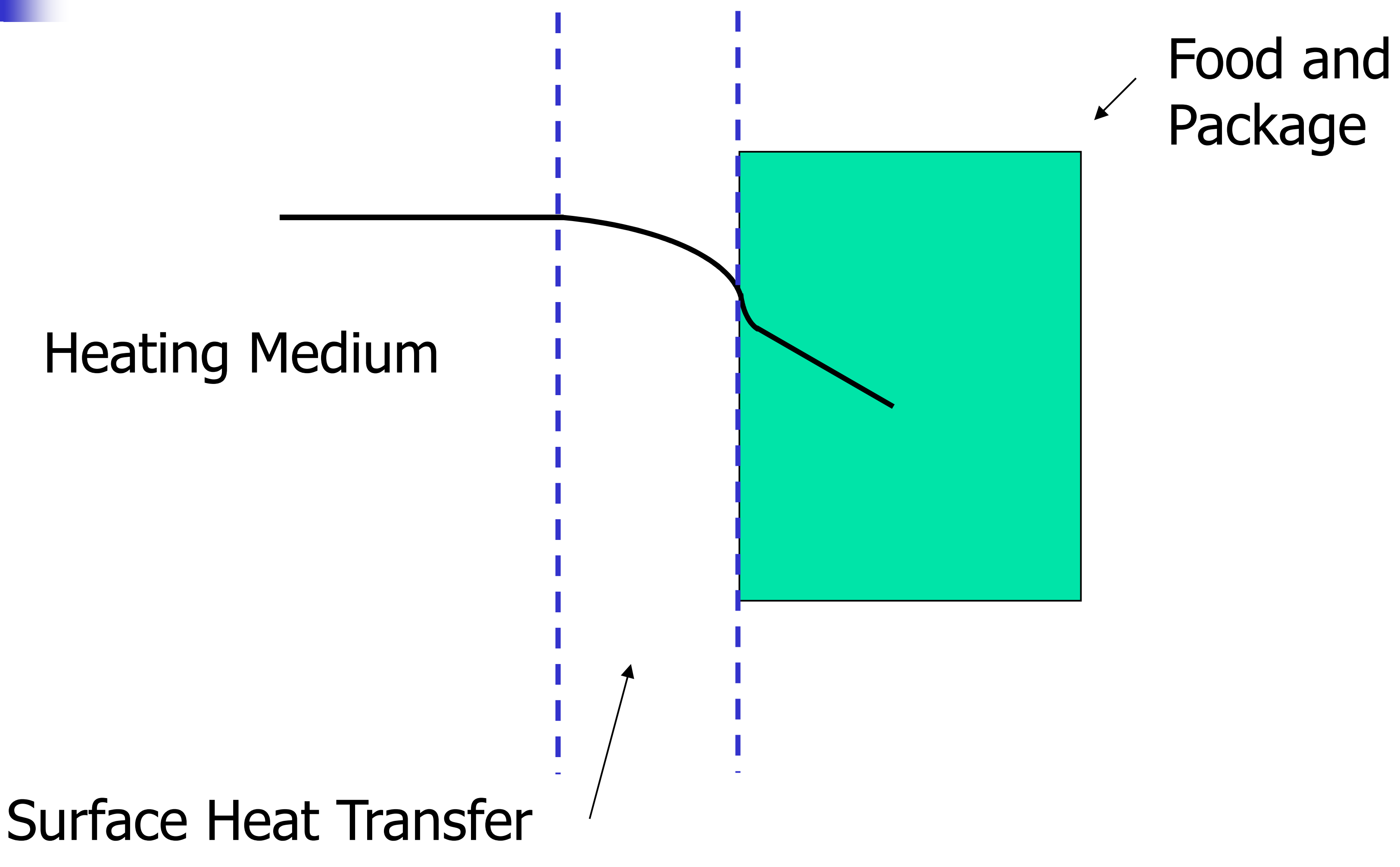
Temperature and Heat Transfer

- Temperature distribution has generally been mapped using thermocouple measurements.
- In properly vented steam retorts, there is essentially an infinite or unlimited surface heat transfer coefficient.
- Under those conditions, product heating is controlled by the package dimensions and the thermal diffusivity of the food.

Overpressure Processing

- Plastics soften at retort temperatures
- Headspace gases expand
- Differential pressure across the package must be minimized
  - To maintain package shape
  - To reduce stress on the hermetic seal
- If surface heat transfer conditions are limiting in some or all retort locations product heating may be affected.

Heat Transfer to the Product



Retort System

Heat Transfer by Convection

$$q_c = hA\Delta T$$

q_c = rate of heat transfer

h = surface heat transfer coefficient

A = heat transfer area

ΔT = temperature difference between fluid and surface

Convective Heat Transfer Coefficients

	Btu/h ft^2 F	W/m^2 K
Air, free convection	**1 – 5**	**6 – 30**
Superheated steam or air, forced convection	**5 – 50**	**30 – 300**
Water, forced convection	**50 – 2000**	**300 – 6,000**
Water, boiling	**500 – 10,000**	**3,000 – 60,000**
Steam, condensing	**1,000 – 20,000**	**6,000 – 120,000**

Package

Classical Heat Conduction Equation

- For a finite cylinder

$$\frac{\partial T}{\partial t} = \alpha \left[\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial h^2} \right]$$

  - T = temperature

    t = time

    α = thermal diffusivity

    r = radial position in cylinder

    h = vertical position in cylinder

Thermal Diffusivity

$$\alpha = \frac{k}{c\rho}$$

α = thermal diffusivity, m^2 / s

k = thermal conductivity, W/mK

c = specific heat, J/kgK

ρ = density, kg / m^3

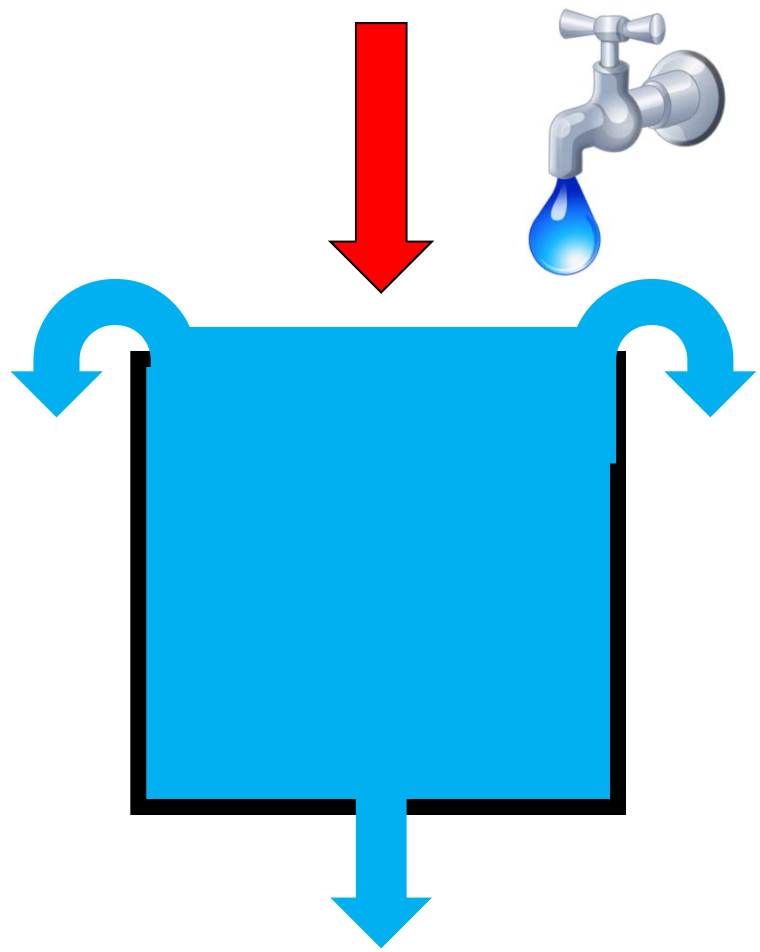
Determining the Thermal Diffusivity

- Measure experimentally, calculated from thermal properties or derive from the heating rate index, f_h

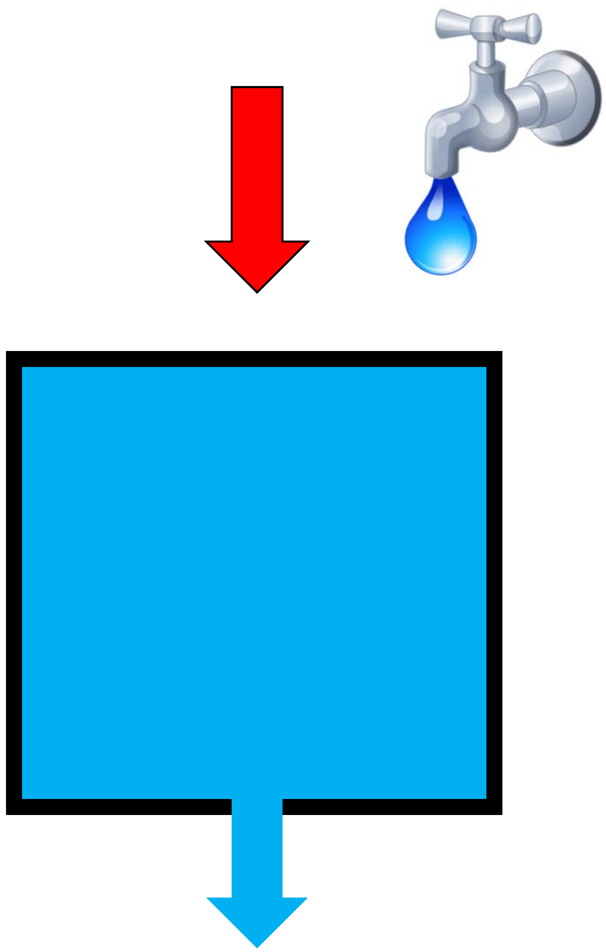
- $f_h = 0.398 / (1/r^2 + 0.427/h^2)\ \alpha$

- $f_h = GF * 1/\alpha$

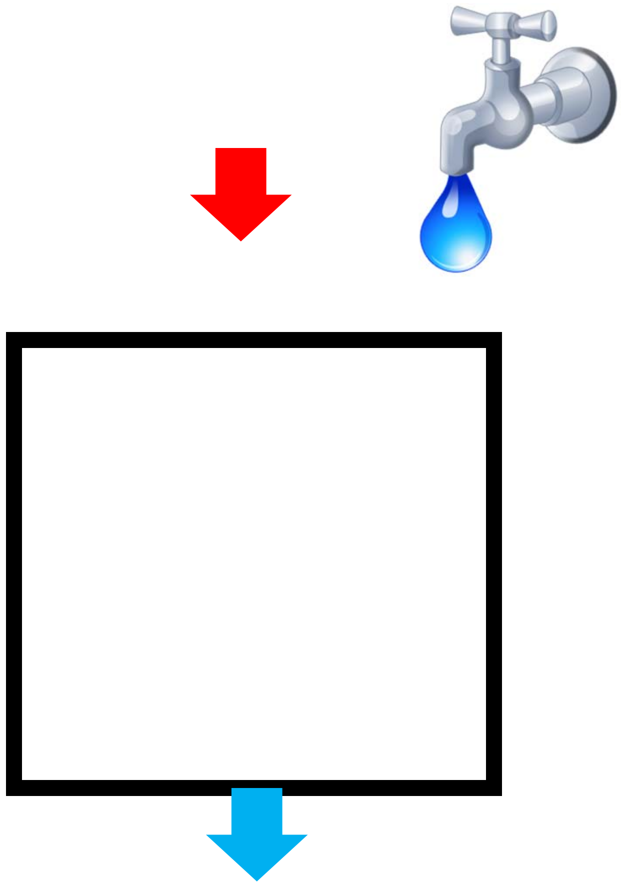
Unlimited Surface Heat Transfer

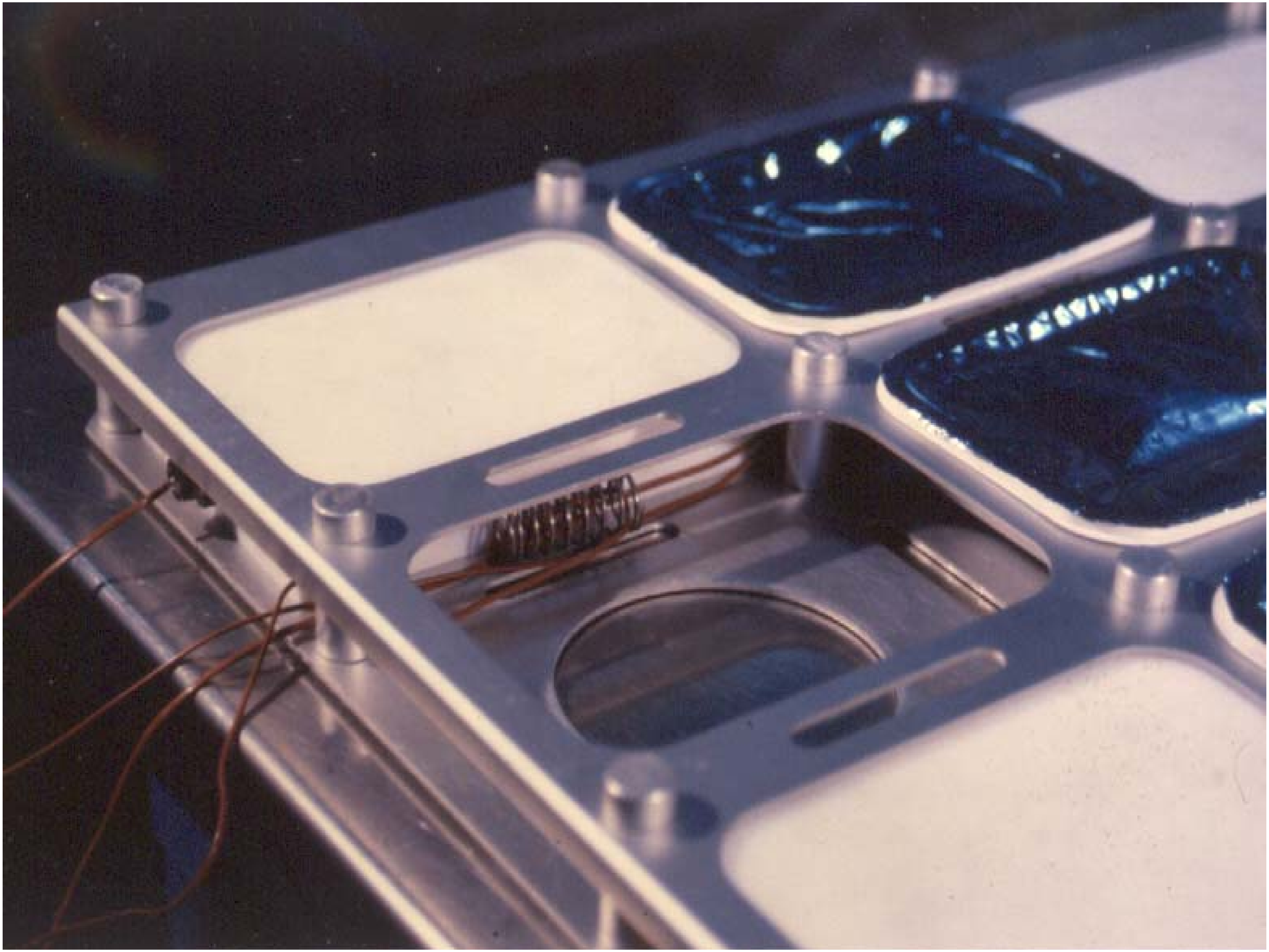


Critical Surface Heat Transfer

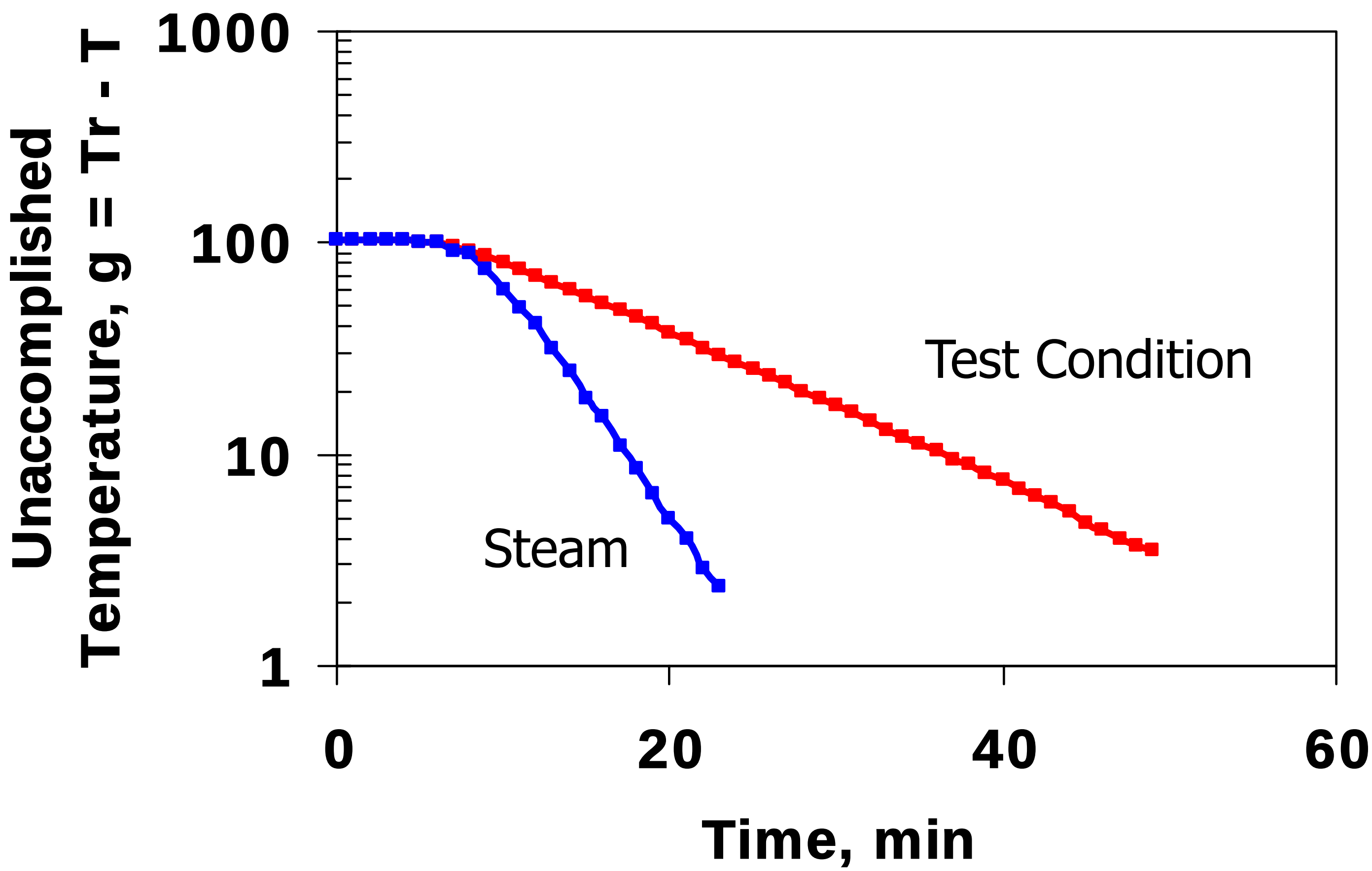


Limited Surface Heat Transfer





Heating Rate Index, f_h



Equation of the Heating Curve

- $t_B = f_h(\log j_h g_{ih} - \log g)$

- if f_h increases
  - t_B must also be increased, or
  - less lethality is delivered for a given t_B

Back to the Guidelines

Data Analyses

- Calculate f_h values and the associated CV
- Identify the slower to heat locations within the retort load using the f_h data
- Confirm adequate Temperature Distribution including come-up time.
- Confirm that retort control and process conditions were achieved as designed.

Data Analyses

- Determine product slower and faster to heat locations for the HIUs/product-filled test package combination. The slowest to heat location is determined based on the largest f_h value.

Data Analyses

- All subsequent Heat Penetration studies should be conducted with test packages in the slowest to heat locations determined from Heat Transfer Distribution studies.

- If desired, determine product slowest and fastest to cool locations.

Success Criteria

- If the CV of the f_h values was ≤5% within and across replicate studies
  - Uniform heat transfer conditions have been confirmed and Heat Penetration containers may be located anywhere in the retort

Success Criteria

- If CV of the f_h values was >5%
  - Confirm that sensors used were consistent with accuracy stipulations
  - Additional Heat Transfer Distribution studies needed to ascertain that the slowest to heat locations have been determined
  - Thereafter, all Process Establishment Heat Penetration Studies be conducted at the identified slowest to heat locations.

Success Criteria

- Alternatively
  - If the CV is >5%, changes could be made to the retort, controls, load density, rack design, etc. in an attempt to reach a CV ≤ 5%.
  - Once changes have been completed, replicate Heat Transfer Distribution studies should be conducted.
  - Note: temperature distribution studies are a pre-requisite to conducting heat transfer distribution studies after making the changes prior to conducting additional heat transfer distribution studies.

Risks, Issues and Other Considerations

- HIU geometry should not interfere with the normal flow pattern and mixing of the heat transfer medium within the retort load.

- Heat Transfer Distribution data are not used for Process Establishment

Risks, Issues and Other Considerations

- Sufficient quantity of probed packages/HIUs to conduct a valid statistical evaluation of the f_h variability within a test is required
- Typically this will require that more than 6 values are used to calculate a mean f_h and the associated standard deviation
- In general, a larger number of values will provide more robust results

Risks, Issues and Other Considerations

- Replicate studies are recommended. The number of replicate studies will depend upon the number of retorts being evaluated and whether you are studying a new retort/process/package/formulation or if this is part of a periodic (e.g., annual) re-verification program. When replicate studies fail to meet Success Criteria for Heat Transfer Distribution, additional studies are needed.

Risks, Issues and Other Considerations

- Since f_h and the associated % CV are used as the primary measures to assess adequacy of Heat Transfer Distribution, data do not necessarily need to be collected at the highest allowed overpressure for the product/package being studied.

- This is in contrast to Heat Penetration studies where the "worst case" retort conditions as defined by the Scheduled Process must be used.

Risks, Issues and Other Considerations

- It is important that the amount of overpressure used during Heat Transfer Distribution Studies be representative of the expected production condition for the product/package being studied.

- Non-product based HIUs may be a preferred option to product-filled packages when the food being studied heats primarily by conduction.

Chapter 6 – Conducting Heat Penetration Studies

Objectives

- The purpose of a heat penetration study is to determine the heating and cooling behavior of a product/package combination in a specific retort system for the establishment of safe thermal processes to deliver commercially sterile products and to assist in evaluating process deviations.

Objectives

- The study must be designed to adequately and accurately examine all critical factors associated with the product, package and process which affect heating rates.

Objectives

- Before commencing a heat penetration study, an evaluation of retort temperature distribution and heat transfer distribution should have been completed.
- A goal is to identify the worst case temperature response expected to occur in commercial production as influenced by the product, package and process.

Appendices

- Literature Cited
- Documenting Processing Equipment and Test Conditions
- Temperature Distribution – Data Monitoring/Collection Points by Retort Type
- Heat Penetration Documentation Checklist

Thank you for your attention

Your thoughts?

Upcoming Meetings

- 2nd SE Asia Technical Outreach Seminar
  - Bangkok, Thailand - November 4-5, 2014
- 34th Annual Meeting
  - San Antonio, Texas - March 2015
- 5th European Conference
  - Seville, Spain – October 2015

SPEAKERS WANTED

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