Module 6. Principles of Thermal Processing

Thermal Processing for Meat and Poultry Products Training

Purpose and Objectives

- Purpose of Module 7
  - Provide concepts used to establish thermal processes
- Performance Objective
  - Identify the techniques involved in the establishment of a thermal process
  - Identify the major factors affecting thermal processes

Key Factor Affecting the Sterilization of Canned Products: Temperature

- Temperature is easily regulated
- Effects are dependent on magnitude and exposure time

Question that Must be Answered for Process Schedule Development

- What time and temperature (heat treatment) is needed to destroy the pathogens and spoilage organisms of concern?
  - Note that spoilage organisms are normally more resistant

Basis for Developing Process Schedules

- Processing authority has extensive knowledge of
  - Food microbiology-heat resistance of contaminating and/or target microorganisms,
  - The characteristics of the product and how it heats,
    - Heat penetration for retorted product
    - Flow characteristics for aseptic processed product
  - The container in which the product is packed, and
  - The thermal processing systems used to heat the food containers

Basis for Developing Process Schedules

- The processing authority must have the ability to communicate with the processor to gather as much information about the overall process and product preparation as possible.

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Basis for Developing Process Schedules

- The processing authority must have the ability to recognize the limitations of the processor and/or the processing system.
  - e.g., can the processor properly measure and control critical factors
  - A critical factor is a characteristic, condition or aspect of the product, container, preparation procedure or processing system that affects the process schedule

What is a Process Schedule?

- The thermal (heat) process selected by the processor required ***under the conditions of*** a ***manufacturer for a given product*** to achieve commercial sterility

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Process Schedule Components

- Thermal processing parameters such as
  - Initial temperature (IT) of product
  - Process time
  - Process temperature
- Critical factors (as needed)
  - e.g., minimum headspace and maximum thickness (consistency) for agitating processes
  - Maximum pH for acidified products

Process Schedule Components (2)

- The product type and style
  - e.g., chili with beans, chili without beans
- The container type and size, and
  - e.g., 300 X 407 can, or 145mm X 200mm X 19mm pouch
- The thermal processing system
  - e.g., aseptic, continuous rotary retort , or water spray retort

Importance of Process Schedule

- An established process schedule is specific to that product, preparation, thermal processing system, and container
- Process schedules and MUST NOT BE ALTERED without consulting a processing authority

PROCESS SCHEDULE DEVELOPMENT

Process Schedule Development: Heat Resistance of Microorganisms

HEAT RESISTANCE OF MICROORGANISMS

PRODUCT HEATING DATA

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CALCULATED PROCESS SCHEDULE

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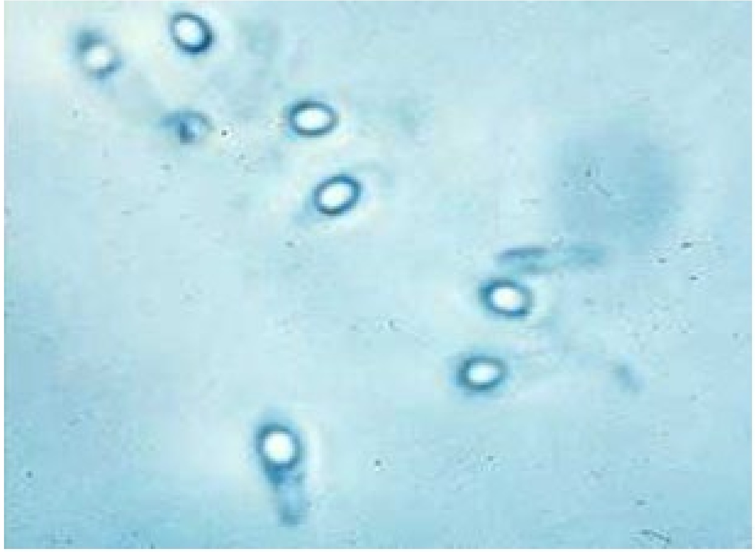
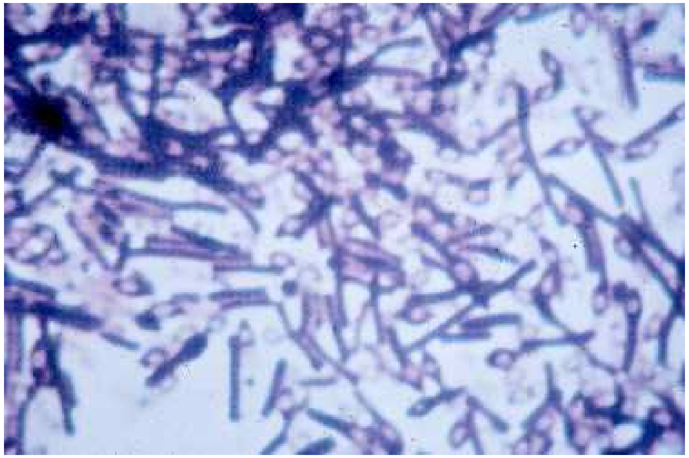
CONFIRMATION BY INOCULATED TEST PACK

Source: FDA STATE TRAINING BRANCH COURSE MANUAL FOR LOW ACID CANNED FOODS, 1988

Target Microorganisms

- LACF
  - *Clostridium botulinum*
  - *C. sporogenes* (PA 3679)
- Acidified LACF
  - Vegetative cells of pathogens and acid tolerant non-pathogenic spores
  - Acidity (pH) controls any surviving spore germination





Heat Resistance of Microorganisms

- Factors affecting heat resistance of the target microorganisms:
  - Growth characteristics of the target organism
  - The media (food product) in which the organism grows
  - The conditions under which the organism grows, and
  - The age of the organism

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Determining the Heat Resistance of Microorganisms

- Thermal Death Time (TDT) studies
  - Inoculate small amounts of substrate (phosphate buffer or food product) with a known number of bacteria
  - Heat buffer or food in containers at the *same temperature* for several time periods
  - Containers are incubated and observed for spoilage or opened and subcultured for direct survivor count
  - Repeat using different temperatures

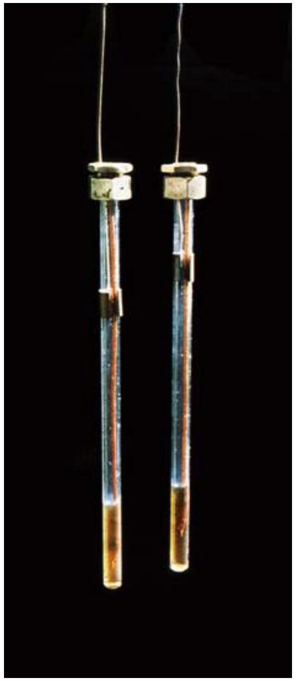
TDT Study Instruments and Equipment

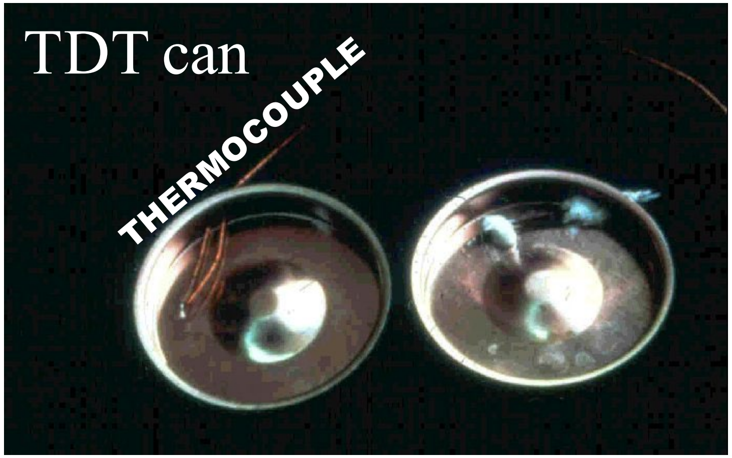
- Three-neck flask
- Thermal death time (TDT) tube
- Mini Retorts

TDT Study Instruments and Equipment

Three-neck flask

Thermal death time (TDT) tube





Mini Retorts

Microbiological Parameters Determined from the TDT Study

- 3 microbiological parameters are obtained from the TDT study:
  - D value
  - z value, and
  - F value

The D, z and F values are used to define the heat resistance of a microorganism and indicate how much effect a thermal process will have on a population of that microorganism

D-value (Decimal Reduction Value)

- D value refers to the time, at a constant temperature, required to kill 90% of the organisms present
- This is the same as a one log reduction in the organism's population
- Expressed as $D_{240°F}$ = 4.5 minutes (when it takes 4.5 minutes to reduce the population 1 $\log_{10}$ at 240°F)

Example of Log_{10} - Decimal Reduction

Known # of Organisms = 10,000 10^4

1 min

-90%: 10,000-9,000 = 1,000 10^3

2 min

-90%: 1,000-900 = 100 10^2

3 min

-90%: 100-90 = 10 10^1

4 min

-90%: 10-9 = 1 10^0

“Minimum Health” Thermal Processes for LACF

- Based on the destruction of *C. botulinum* spores
- A 12D (12 log reductions or 10^{-12}) destruction for spores of *C. botulinum* is the industry standard

"Minimum Health" (12D) Process Example

- The typical $D_{250°F}$ for *C. botulinum* spore destruction in most foods is ~0.23 minutes
- Therefore, a 12D destruction would be ~2.76 (12 x 0.23) minutes at 250°F
- To protect public health, a thermal process must provide a lethality (lethal rate) equivalent to 3 minutes (2.76 rounded up) at 250°F

"Commercial Sterility" Thermal Processes for LACF

- Based on the destruction of *C. sporogenes* or PA 3679 spores
- A 5D (5 log reductions or 10^{-5}) destruction for spores of PA3679 is the industry standard

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"Commercial Sterility" (5D) Process Example

- A typical $D_{250°F}$ for PA 3679 spore destruction in most foods is ~1.2 minutes
- Therefore, a 5D destruction would be ~6.0 (5 x 1.2) minutes at 250°F
- To achieve commercial sterility in most foods, a thermal process must provide a lethality (lethal rate) equivalent to 6 minutes at 250°F

Comparison of D Values

- Since PA 3679 spores are 5 times more heat resistance than *C. botulinum* spores ($D_{250°F}$ = 1.2 min. vs 0.23 min.), a 5D process for PA 3679 applied to most foods typically destroys 26 logs of *C. botulinum* spores
  - 6 minute required lethality at 250°F ÷ .23 minute D value at 250°F = 26 logs

Z value

- The change in temperature that changes the D value by a factor of 10 or organism's heat resistance by a factor of 10
- It measures the effect of temperature on the D value, i.e., the change in the death rate based on temperature

F Value

- The number of minutes at a given temperature necessary to destroy a given number of microorganisms
- The F value is the D value times the number of required log reductions of the target microorganism, e.g., *C. sporogenes*
  - $D_{250°F}$ = 1.2 minutes x 5 (5D process or 5 log reductions) = 6 minutes

Process Establishment: Product Heating Data

HEAT RESISTANCE OF MICROORGANISMS

PRODUCT HEATING DATA

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CALCULATED PROCESS SCHEDULE

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CONFIRMATION BY INOCULATED TEST PACK

Source: FDA STATE TRAINING BRANCH COURSE MANUAL FOR LOW ACID CANNED FOODS, 1988

HEAT PENETRATION TESTS

- Monitor the rate of change in temperature of the food ***inside the container*** as it is being heated in a specific retort system
- Temperature sensor or thermocouple located in ***the product*** at the slowest heating region (cold spot) of the container
- Use heat penetration data to “mathematically define” the heating rate

Heat Penetration Tests (2)

- Slowest heating region or container cold spot depends on the:
  - Type of product,
  - Container type and size,
  - Thermal processing method/system, and
  - Heat transfer mechanism

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Heat Penetration Tests (3)

- The number of containers per test run and the number of test runs necessary to ensure the data is adequate depends on the variability of the product and the retorting system
- The more variable the product and/or system, the more test runs and containers per test run are required

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Heat Penetration Tests (4)

- Important to simulate the worst case scenario likely to occur when producing the product
- Need to account for the affect of production variations which are usually critical factors
  - Changing the type and amount starch or protein in the formulation
  - Filling the product differently
  - Improperly soaking/rehydrating ingredients

Heat Penetration Tests (5)

Potential Critical Factors

- Raw or cooked meat
- Moisture content
- Clumping of product
- Particle size and style
- Solids to liquid ratio
- Fill weight
- Consistency/viscosity
- Can orientation
- Product orientation
- Fresh or frozen ingredients
- Formulation ingredients and preparation procedures
- Hold time prior to conduction heat penetration testing

Heat Penetration Tests (6)

Container Fill Weight
Beans in Brine
300 X 407 Can

Fill Weight (oz)	Process Time (min)
7.8	41
9.2	66

Heat Penetration Tests (7)

- Heat penetration tests should be conducted on both product orientations and use the data from the slowest heating orientation

Heat Penetration Tests (8)

- Heat penetration tests should determine if the nesting of the containers affects how the container heats

Heat Penetration Tests (9)

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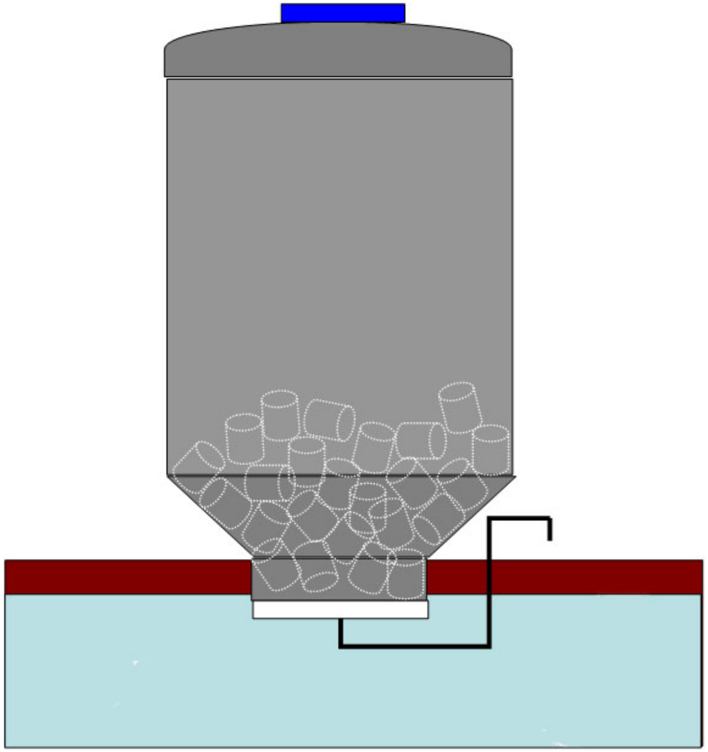
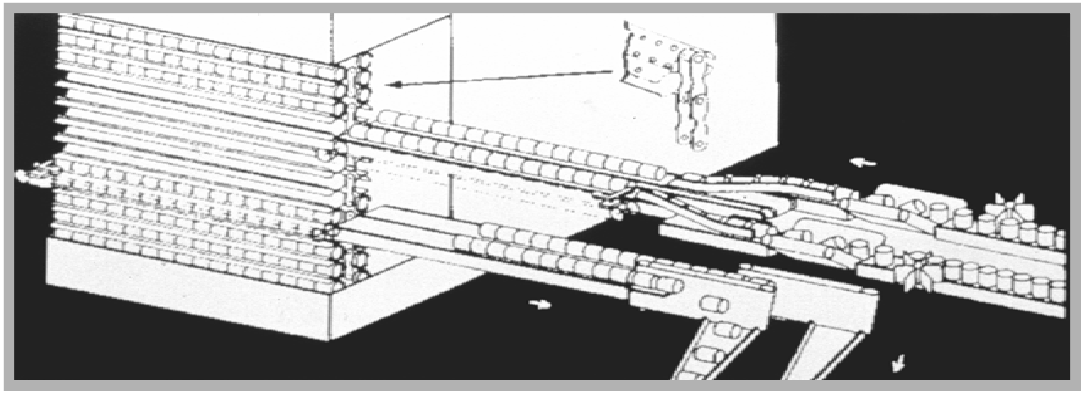
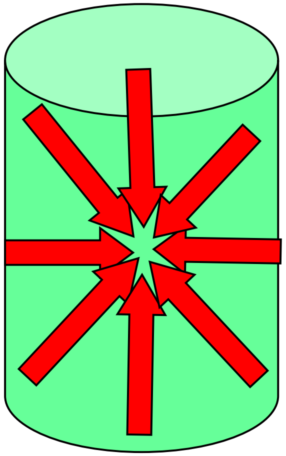


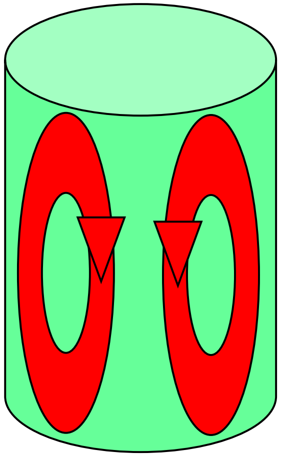


- Heat penetration tests should be conducted on different can orientations and use the data from the slowest heating orientation

Heat Transfer Mechanisms

- Convection
- Conduction
- Convection/conduction
- Induced convection





Conduction Heating

- Particle to particle heat transfer with no particle movement
- Product is typically viscous with little free liquid
- Container’s geometric center is slowest heating region
- Examples- refried beans, pumpkin, stews, corned beef hash, etc
- Simple heating or straight line

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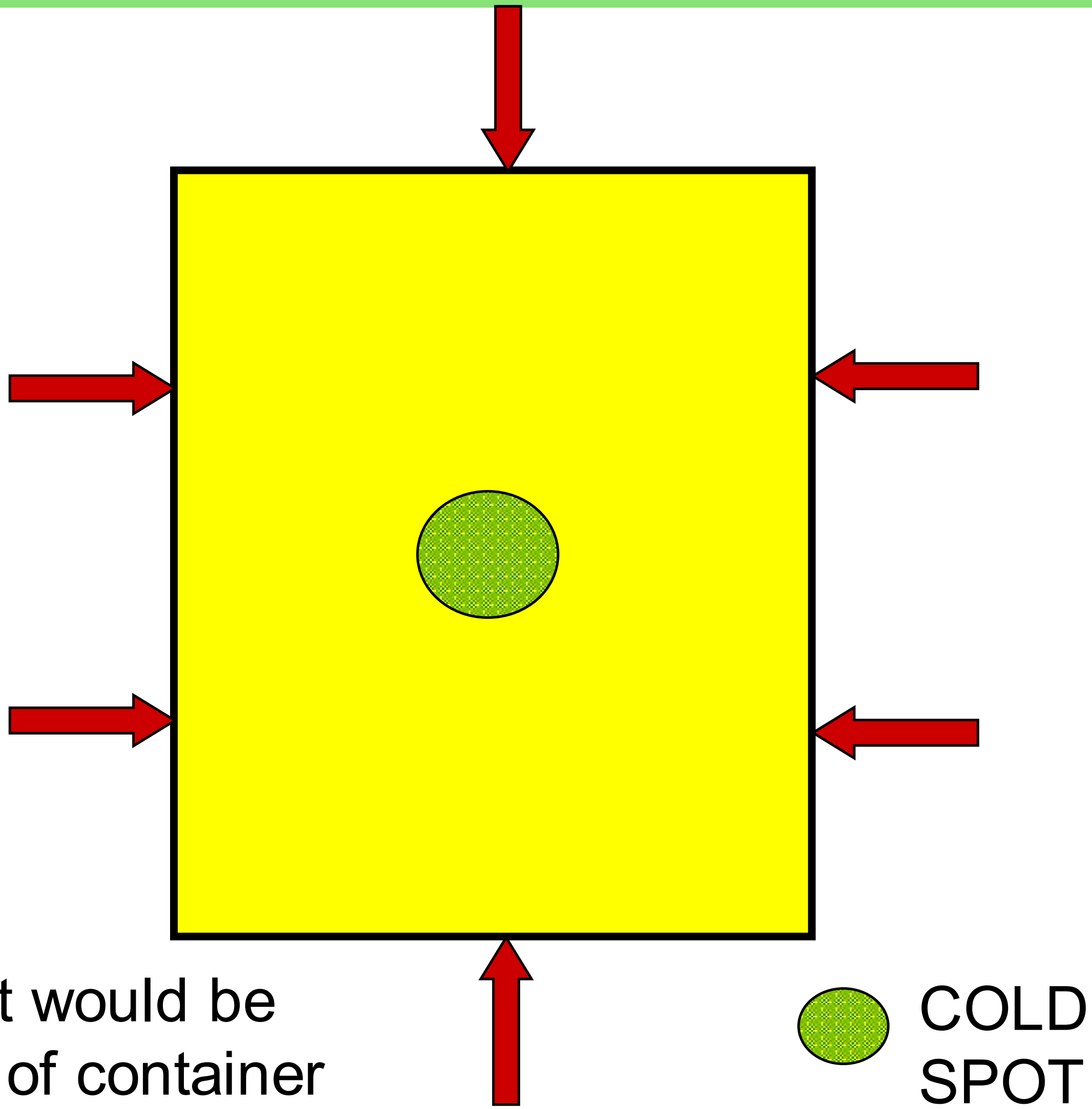
Conduction Heating (2)



Cold spot would be in center of container

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Convection Heating

- Particle to particle heat transfer with particle movement
- Product typically less viscous with free liquid
- Slowest heating region is usually 1/4 container height from bottom but can vary
- Examples- broths, brine packed products, (olives, green beans, carrots, etc)
- Simple heating or straight line

Convection Heating (2)

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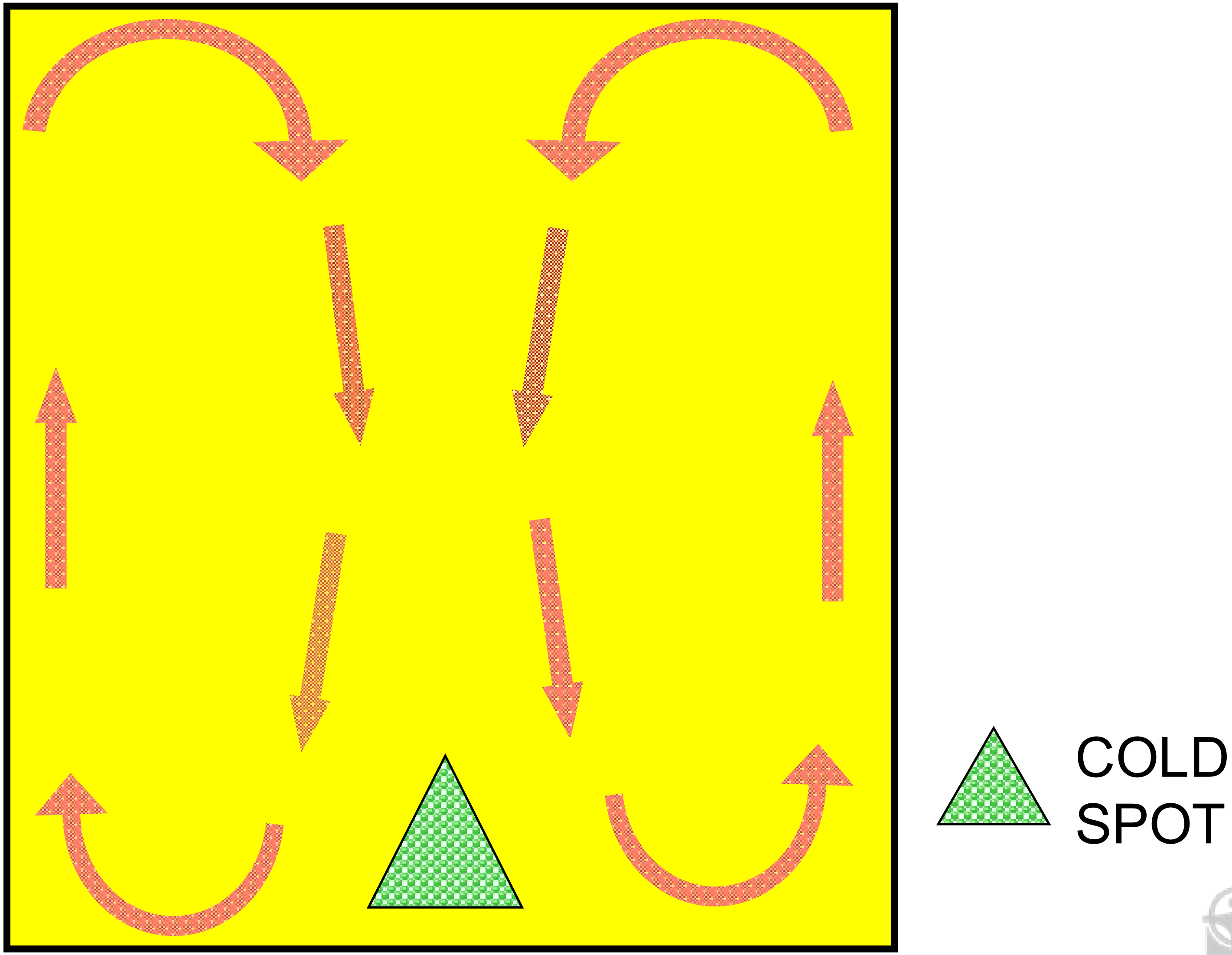

Convection Heating (3)

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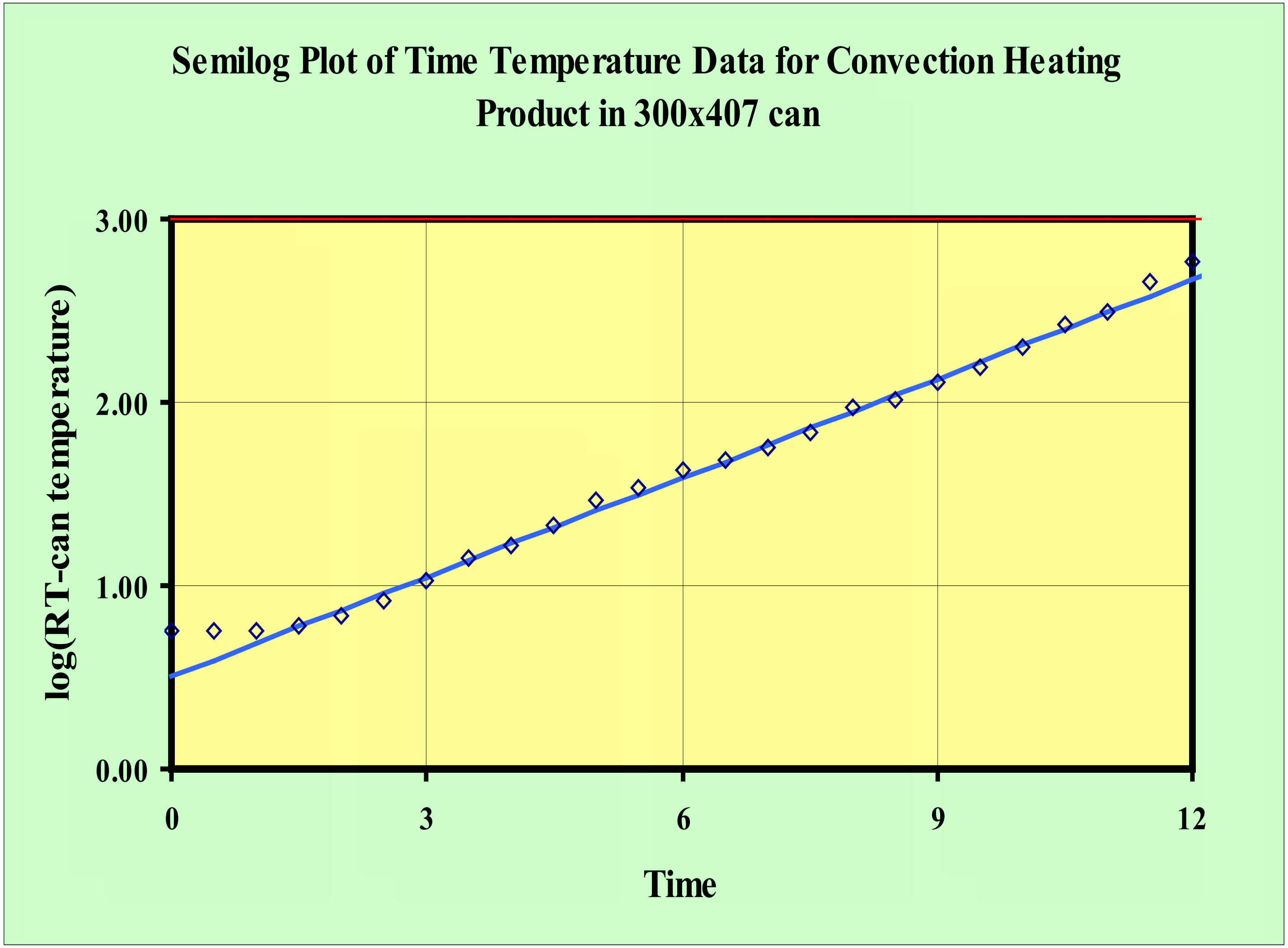

Source: Center for Food and Pharmaceutical Process Safety

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Convection/Conduction Heating

- Brine pack product with large particles and liquid
  - Liquid by convection
  - Particles by conduction
- Products where thickening occurs
  - Starts as convection heating and goes to conduction heating due to thickening of product

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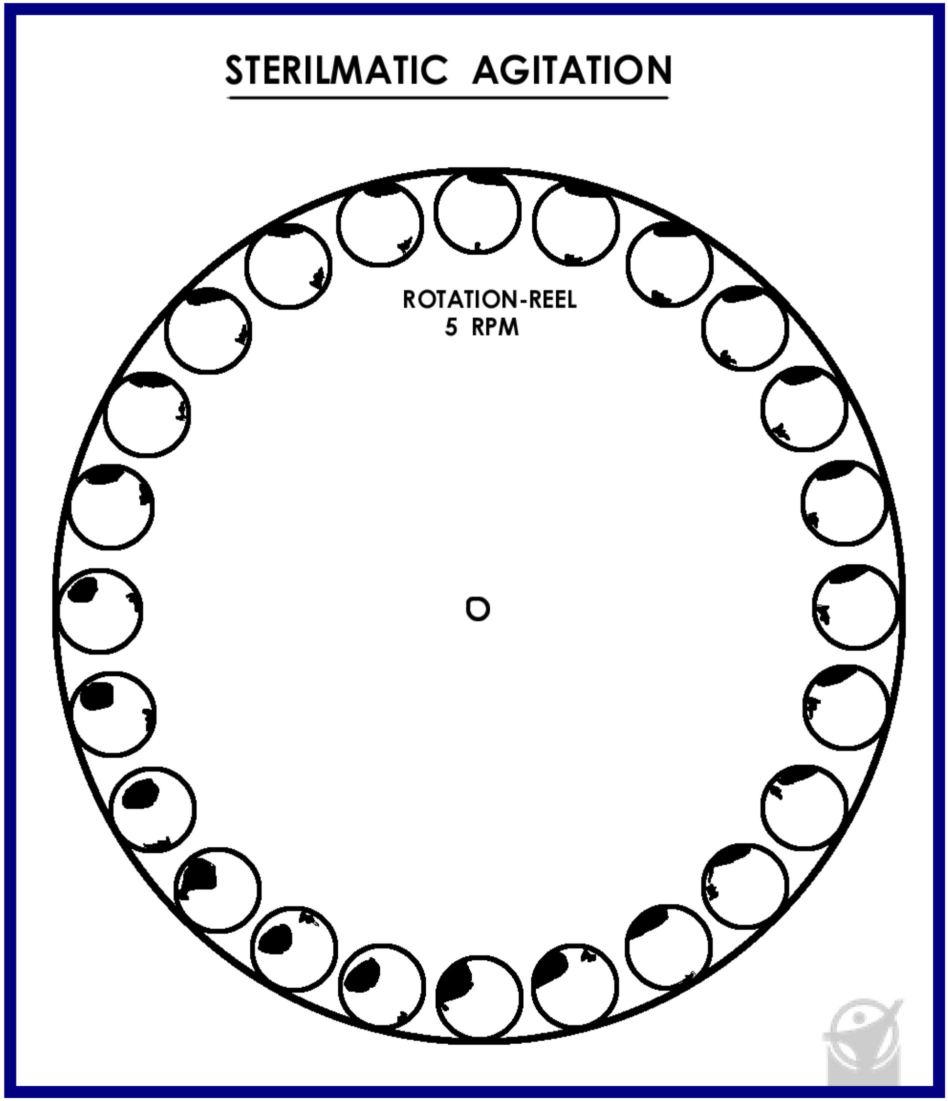
Convection/Conduction Heating (2)

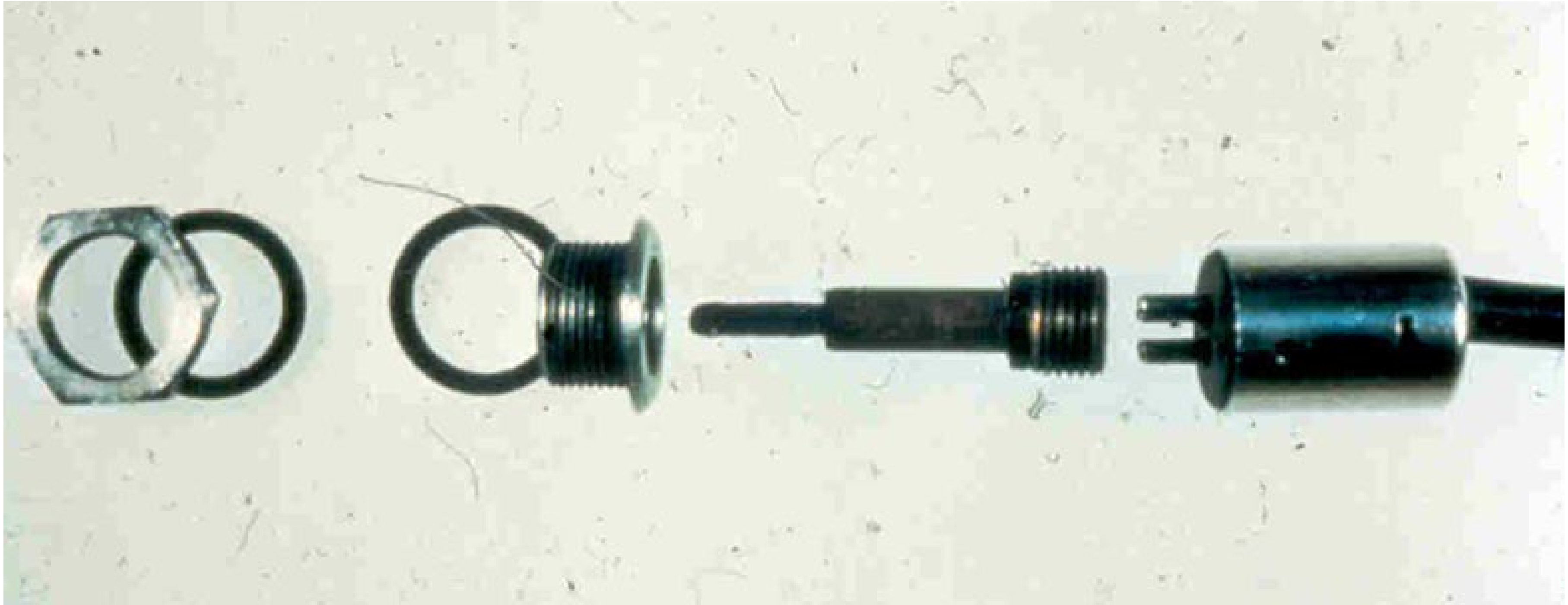
- Slowest heating region-is usually 1/4 container height from the bottom and at particle center but can be variable
- Examples: meatballs in sauce, hot dogs in brine, whole chicken in a can, stews with starch, etc
- Broken line heating or 2 straight lines

Induced Convection Heating

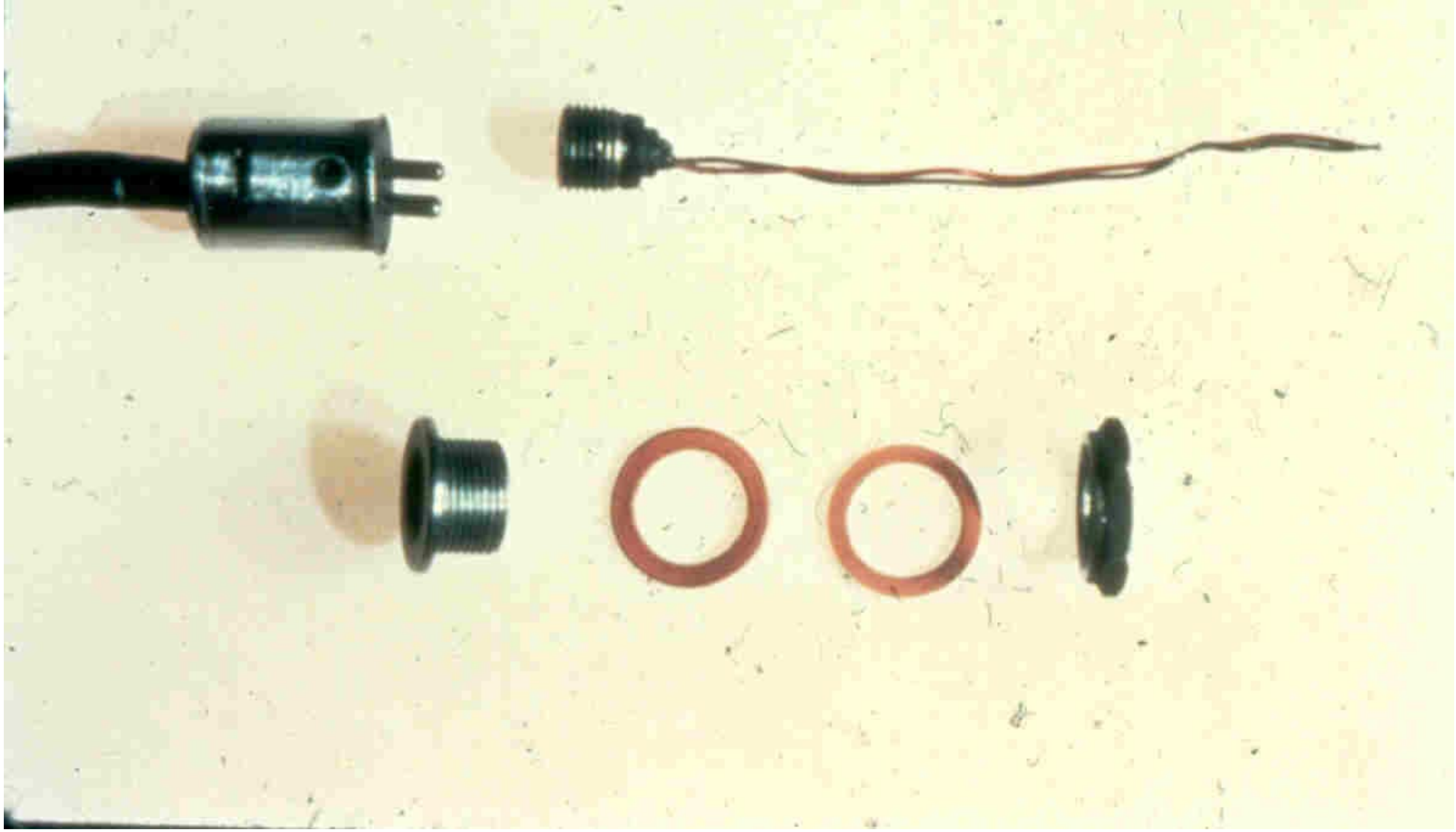
- Mechanical agitation which creates product movement to enhance convection heating of the product
- Container's geometric center is slowest heating region



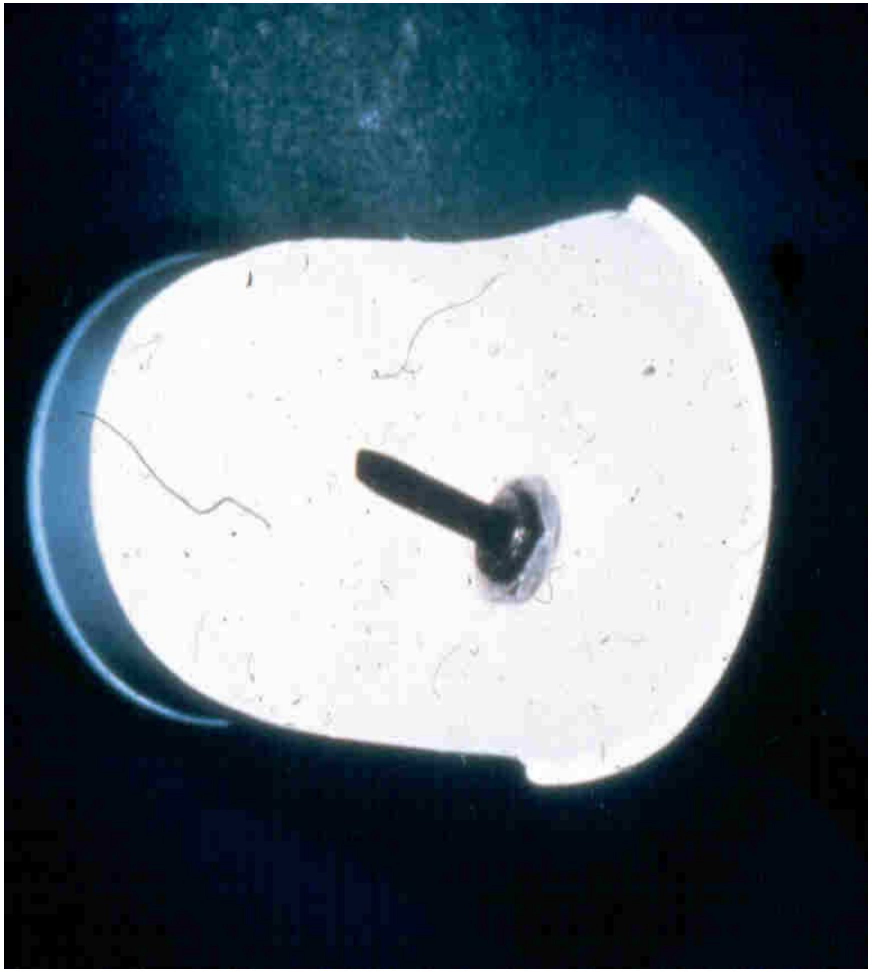
Molded Thermocouple



Flexible Thermocouple: Can be Inserted into the Product



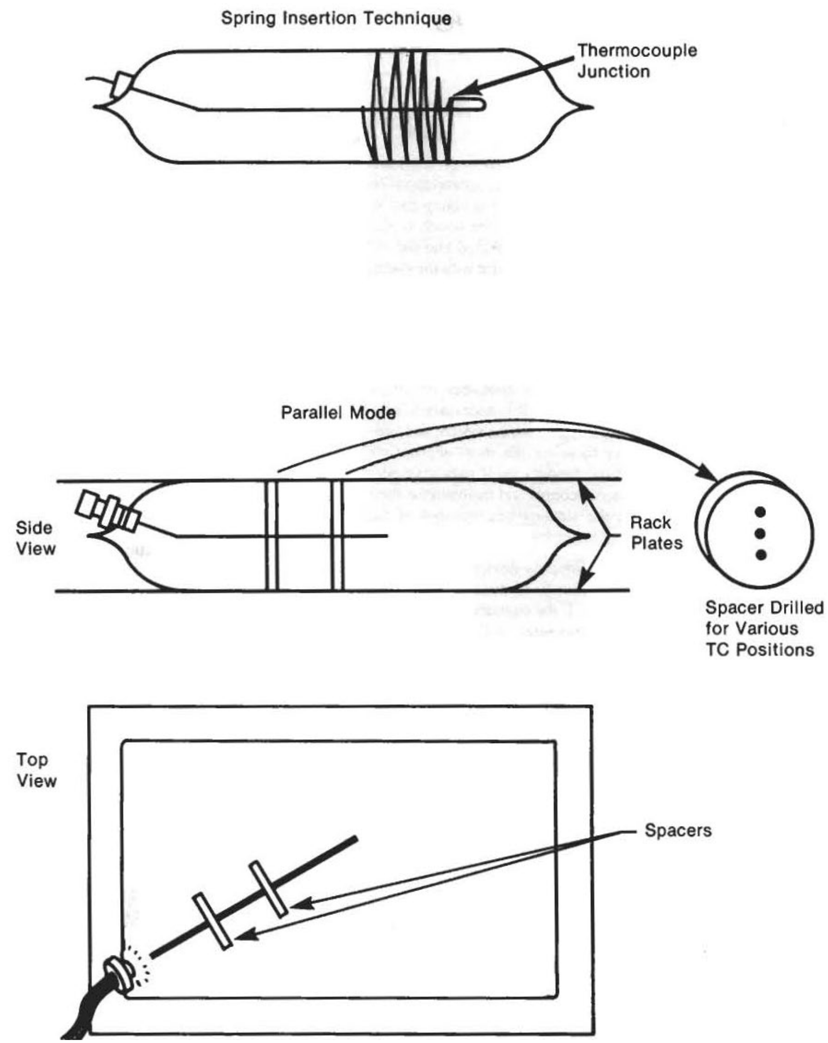
Thermocouples Installed in Cans



Thermocouples Installed in Jar Caps

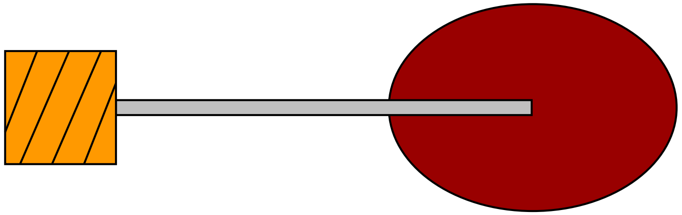
Thermocouple Location and Mounting

- Must be located in the slowest heating region (cold spot) of the product
- Mounting must place and maintain thermocouple at the desired location



Thermocouple Location and Mounting (2)

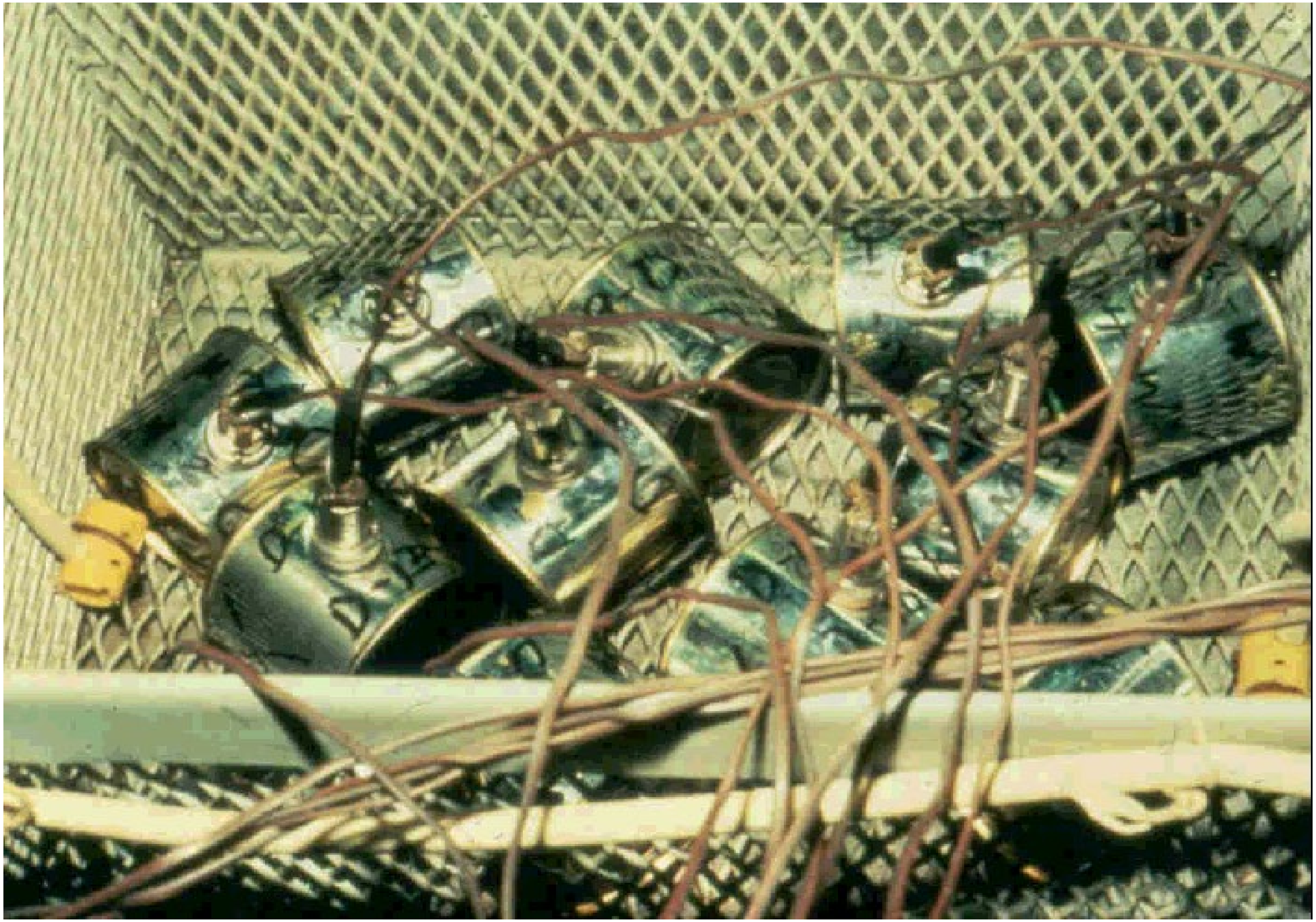
- May need to impale particle with thermocouple
  - Formulated particles
  - Non-Formulated particles
  - Vegetable particle
- Use needle or thin wire sensor



Food Particle Impalement

- Formulated particle – ½-inch or larger meatball, ravioli, etc., in the geometric center
- Meat particle – ½-inch or larger chicken or beef cube in the geometric center
- Vegetable particle – ½-inch or larger potato chunk, beet dice, whole carrot, etc., a ¼-inch below surface

Ready for the Heat Penetration Test



A Production or Laboratory Retort Can be Used

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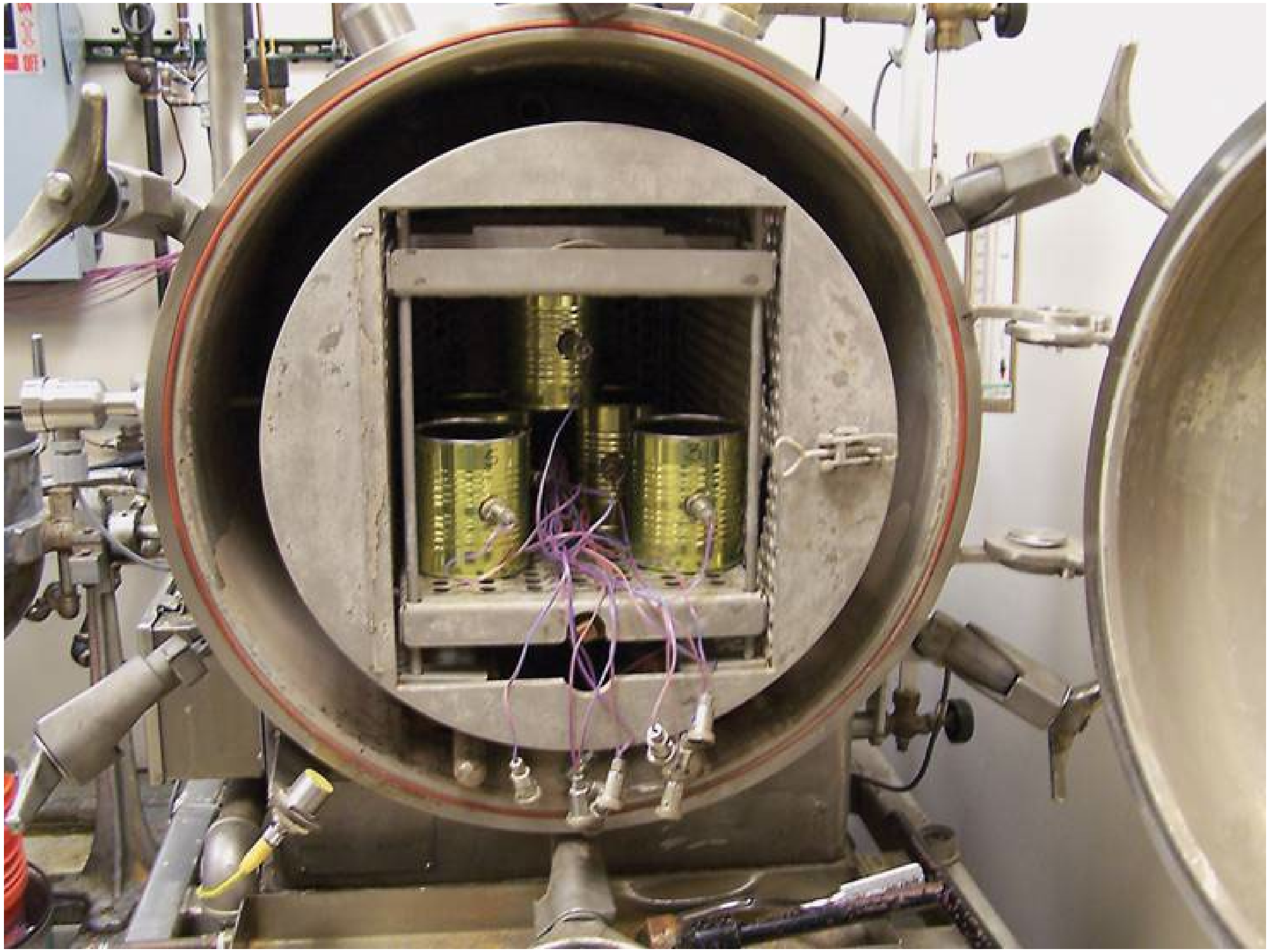
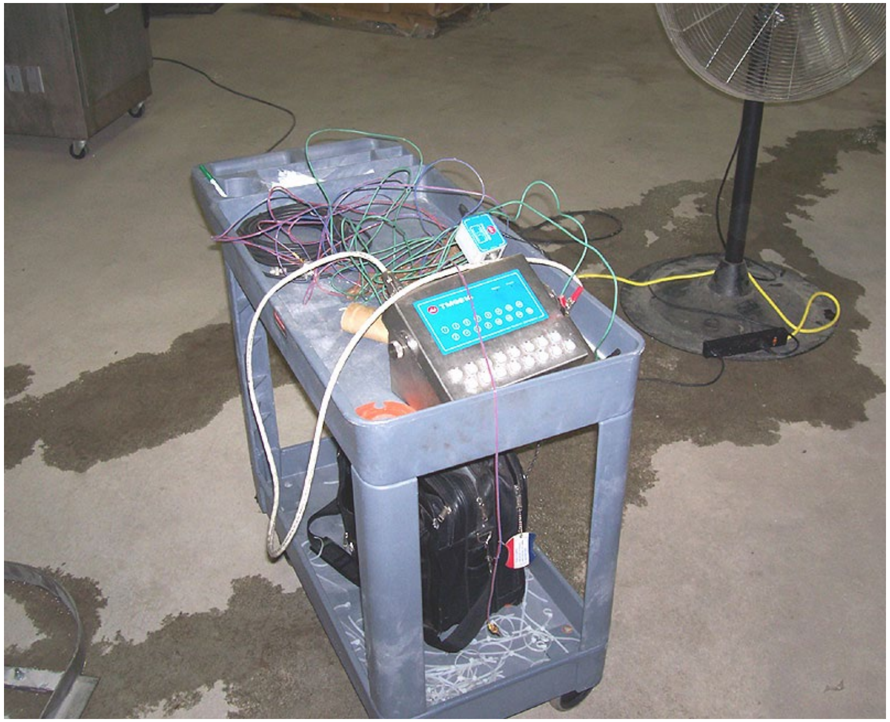


Heat Penetration Data Collection

- Heat penetration thermocouples are connected to a data logging system or multipoint recorder



Heat Penetration Test Recordkeeping

- Product preparation and formulation sheets for product formula tested
- Filled and sealed test product information, e.g., fill weights, gross weights, fill temperature, particle size
- Data logger information, e.g., thermocouple time and temperature printouts
- Post heat penetration test information, e.g., gross weights, drain weights

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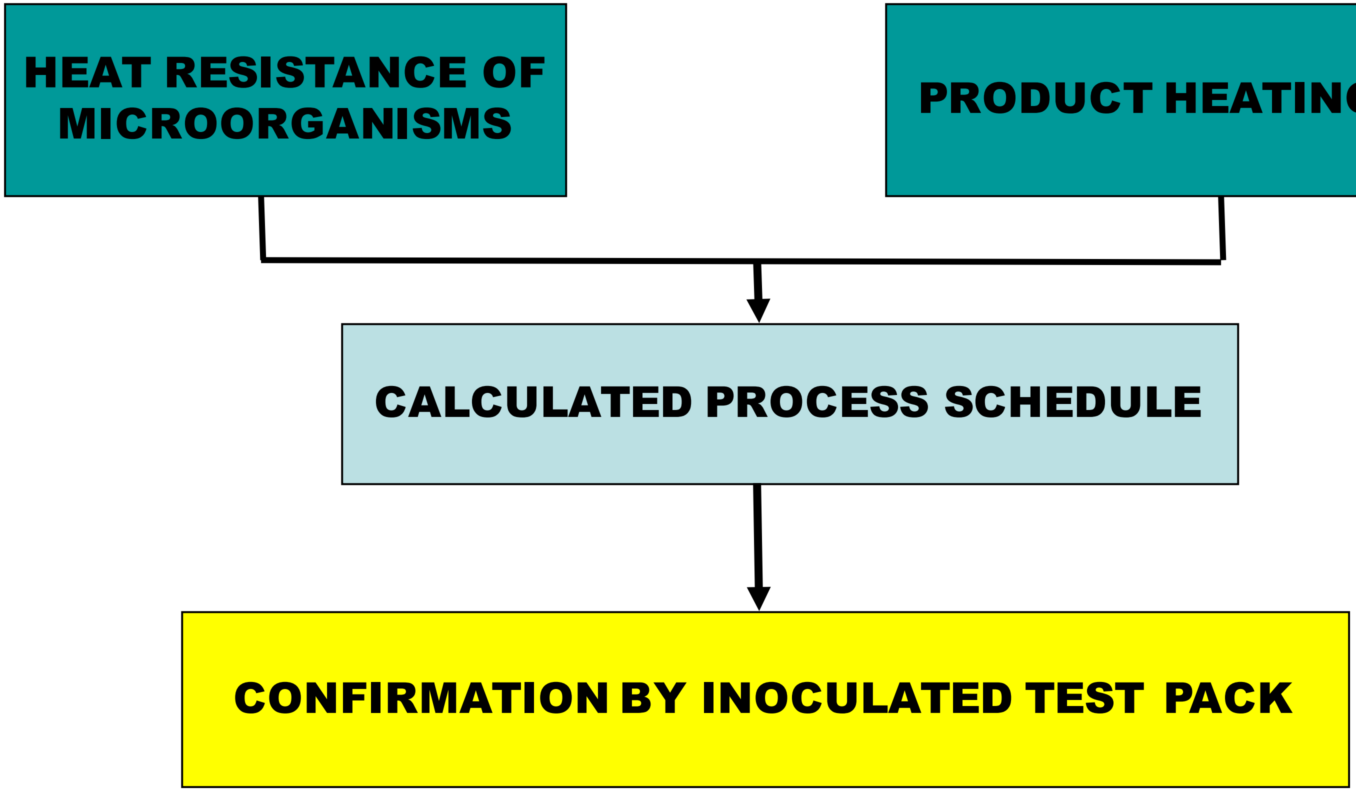
Process Establishment: Calculated Process



Source: FDA STATE TRAINING BRANCH COURSE MANUAL FOR LOW ACID CANNED FOODS, 1988

Keys to Calculating a Process Schedule

- Use the thermal resistance data for the target microorganism
- Use the heat penetration data for the product
- Use of a scientific method to calculate the process schedule for the product

Purpose of Process Schedule Calculation

- The purpose of a process schedule calculation is to:
  - Demonstrate (document) that the thermal process is capable of delivering the required lethality (destruction of the microorganism or F_o)
  - Determine how changes in the product formula, preparation parameters, or filling affects the lethal treatment
  - Measure the effect of a processing deviation

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Determining Process Schedules

- There are two scientific methods for determining process schedules (thermal processes) that will achieve the sterilization (F_o) value for a given product
  - The general or graphical method, and
  - The formula method

General Method

- Lethality (F_o) is calculated directly from the HP time and temperature data using a z value of 18°F and the reference temperature of 250°F
- Lethality (F_o) = lethal rate X time
- Lethality (F_o) is determined at small time increments and added up over the duration of thermal process and if desired during the cooling period

General Method (3)

Temperature °F	Lethal Rate
212	.008
221	.024
230	.077
232	***.100***
239	.246
248	.774
250	***1.00***
257	2.45
260	3.60
268	10.00

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General Method (4)

- Advantages
  - Measures the ***exact*** sterilizing value for the process
  - A simple equation is used
- Disadvantages
  - Specific for process conditions-minimal room for error and the process schedule is established for the tested conditions (i.e., RT and IT ***are set***)
  - Cannot easy evaluate process schedule deviations
    - Processing deviations may have to be recreated to evaluate the thermal process

Mathematical Formula Models

- Numerous mathematical models have been developed over the years
- The model that has received the most use is the **Ball formula method (1923)**
- With the use of computers, numerical methods have also become popular today

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Ball Formula Method Steps

Perform Heat Penetration Test

↓

Determine Heating Factors

↓

Perform Calculations

↓

Verify F_o or
Determine Process Time
to Achieve Required F_o

Heating Factors

- j value
  - a number representing the time lag before the heating curve assumes a straight line
- f_h value
  - the slope of first straight line
    - length of time the straight line takes to pass through one log cycle

Heating Factors (2)

- f_2 value
  - the slope of second straight line
    - length of time the straight line takes to pass through one log cycle
- x_{bh} value
  - time at which the break in a broken heating curve occurs
- f_c value
  - the slope of cooling curve (rate of product cooling)

Ball Formula Calculation Requirements

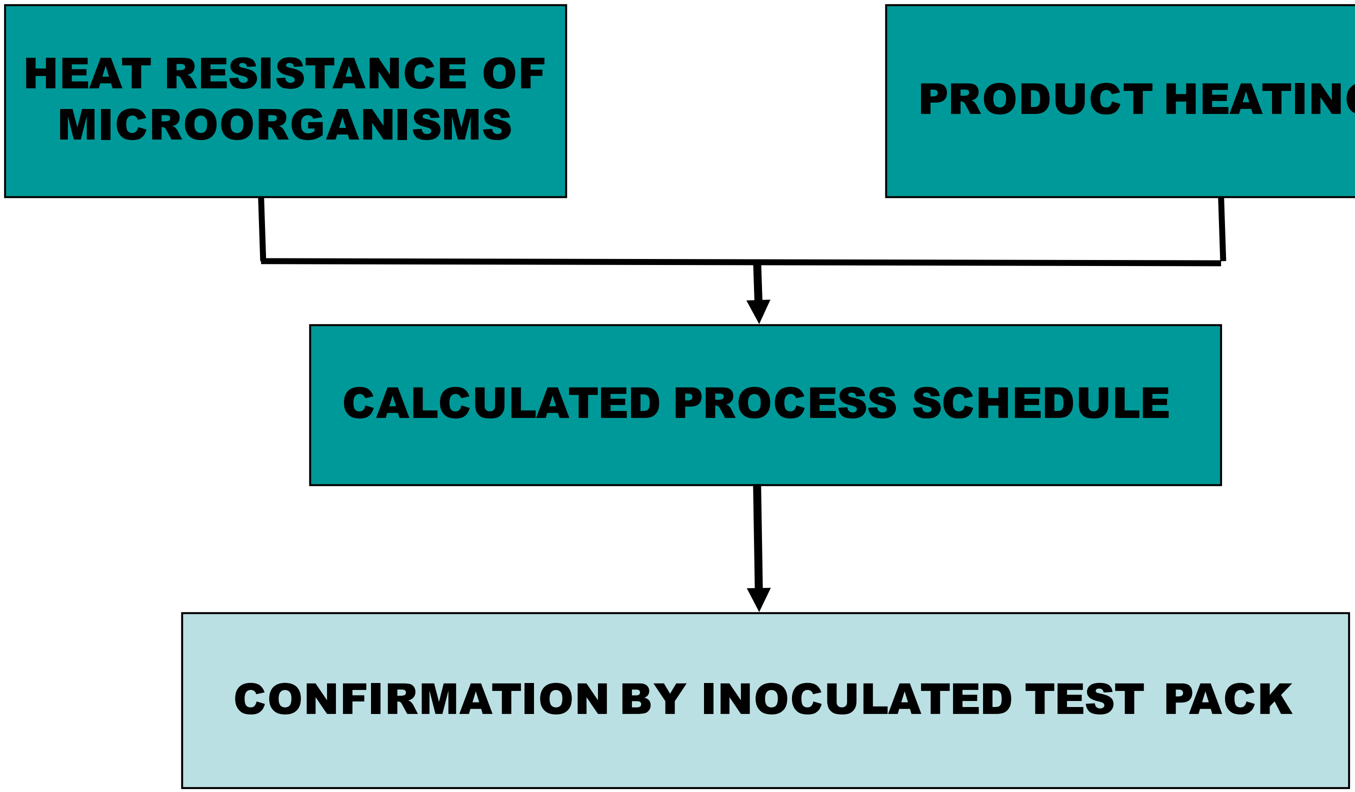
- Initial temperature (IT)
- Retort temperature (RT)
- Heating factors (f_h, j_h, x_{bh}, f_2, f_C)
- Cooling water temperature
- Required sterilization (F_o) value for the product or process time (B_b)

Formula Methods

- Advantages
  - Can use different initial temperatures and retort temperature to calculate new process times and alternate process schedules
  - Can be used to evaluate process time, retort temperature and initial temperature deviations
- Disadvantages
  - Thermal processes are more conservative than general method

THERMAL PROCESSING
TRAINING

Process Establishment: Confirmation by Inoculated Test Pack

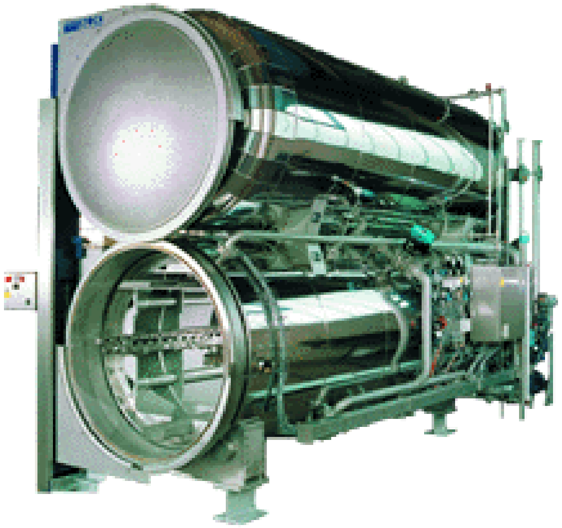


Source: FDA STATE TRAINING BRANCH COURSE MANUAL FOR LOW ACID CANNED FOODS, 1988

Inoculated Pack Study

- Rarely necessary
- Used to confirm thermal processes
- Used when other methods cannot be used
- Inoculate product with microorganisms
- Determine and quantify microorganism survival

HEAT/TEMPERATURE DISTRIBUTION TESTS



For Retort Systems

Purpose of Heat/Temperature Distribution Tests

- HD/TD tests determine temperatures around containers in retort systems
- PAs/equipment manufacturers use HD/TD tests to develop retort operating procedures
  - Steam Retorts: HD tests determine the “Venting Schedule”
  - Other Systems: HD tests determine a “Defined Come Up Profile”

Heat/Temperature Distribution Test Data

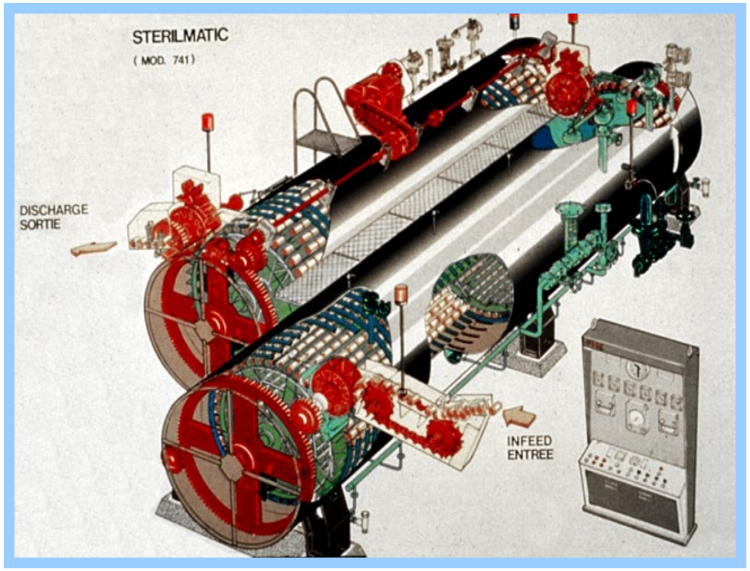
- HD/TD data must be kept on file at the establishment and available to IPP
- Designed to provide uniform HD/TD within the retort
- Accomplished during retort come-up time (CUT)

Retort Come Up Time (CUT)

- Come-up-time is the elapsed time between the introduction of the heating medium into a closed retort and the start of process timing.
- For pure steam retorts this will include the "venting time" from the venting schedule

Retort Come Up Time (CUT)

- Batch operations: CUT occurs every time a batch is processed
- Continuous operations: CUT occurs before containers enter the retort



Process Timing

- **Must** not start until the retort temperature in the process schedule is achieved ***and*** required retort operating procedures are completed

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Heat/Temperature Distribution Tests

- For all retort systems, a large number thermocouples or self-contained data loggers are located throughout the retort baskets or racks filled with containers and the temperature is monitored as the retort is operated

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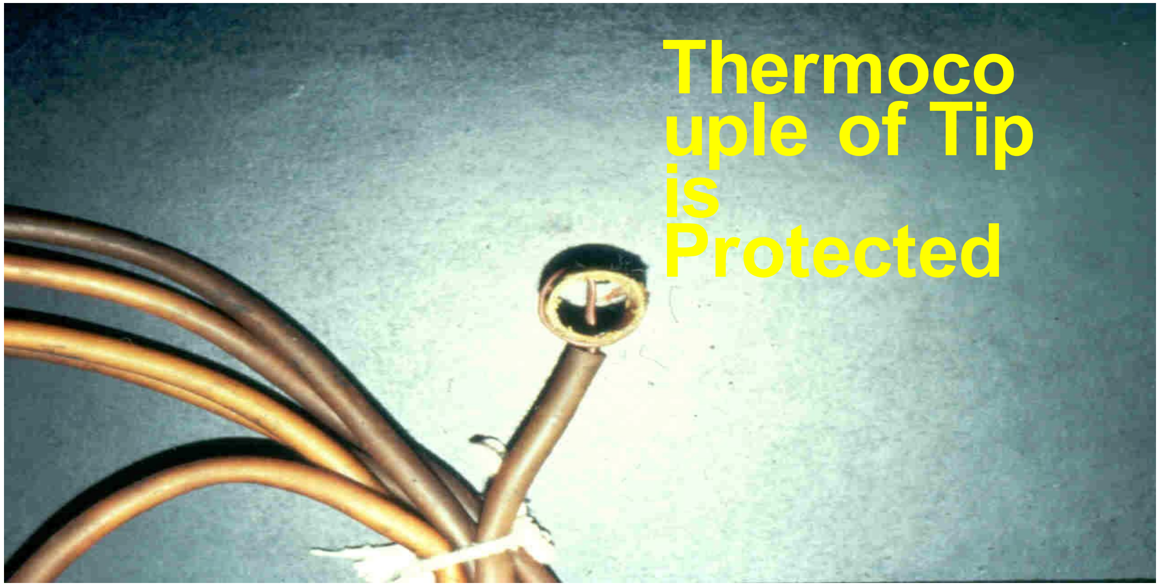
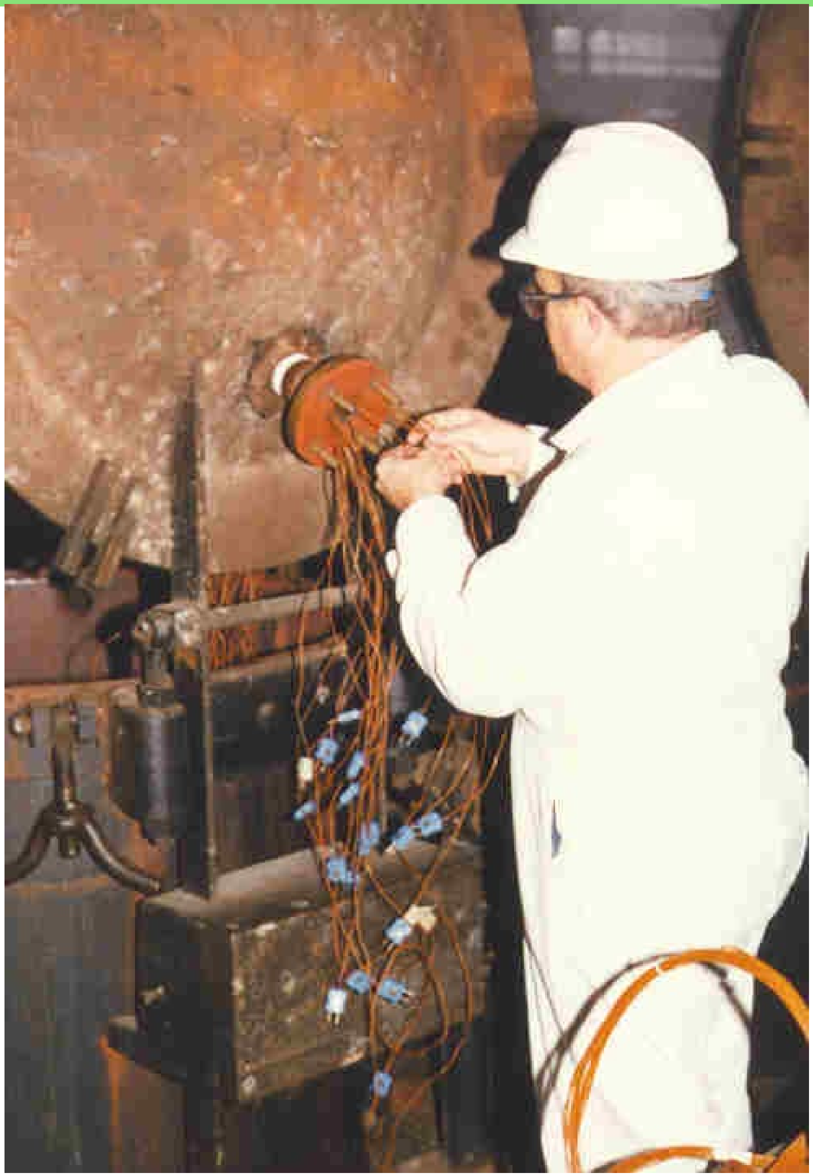
Heat/Temperature Distribution Tests (2)

- Use copper-constantan thermocouples with welded tip protected in some way (e.g. shrink wrap) so it does not contact containers or stacking equipment surfaces



Heat/Temperature Distribution Tests (4)



Thermocouple wires (leads) are fed into retort through steam tight gasket.

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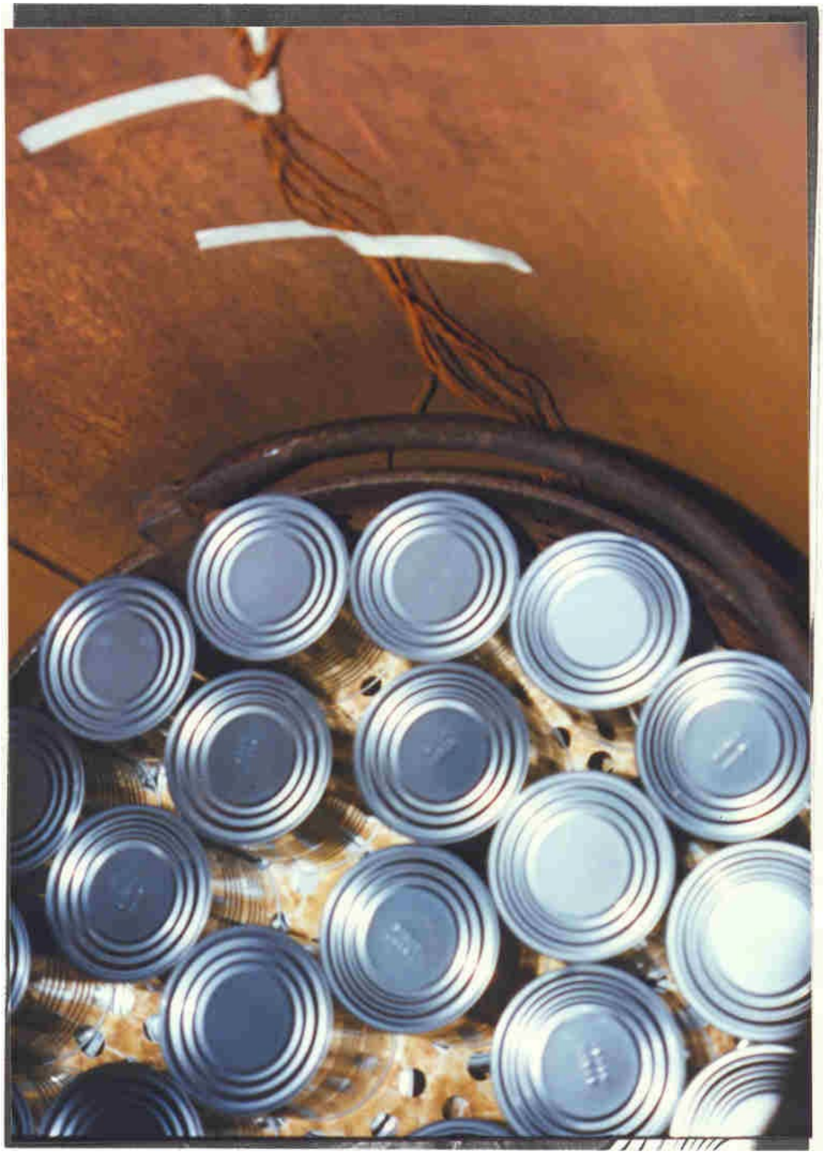
Heat/Temperature Distribution Tests (5)



Thermocouple leads must be placed so they are not damaged during the test

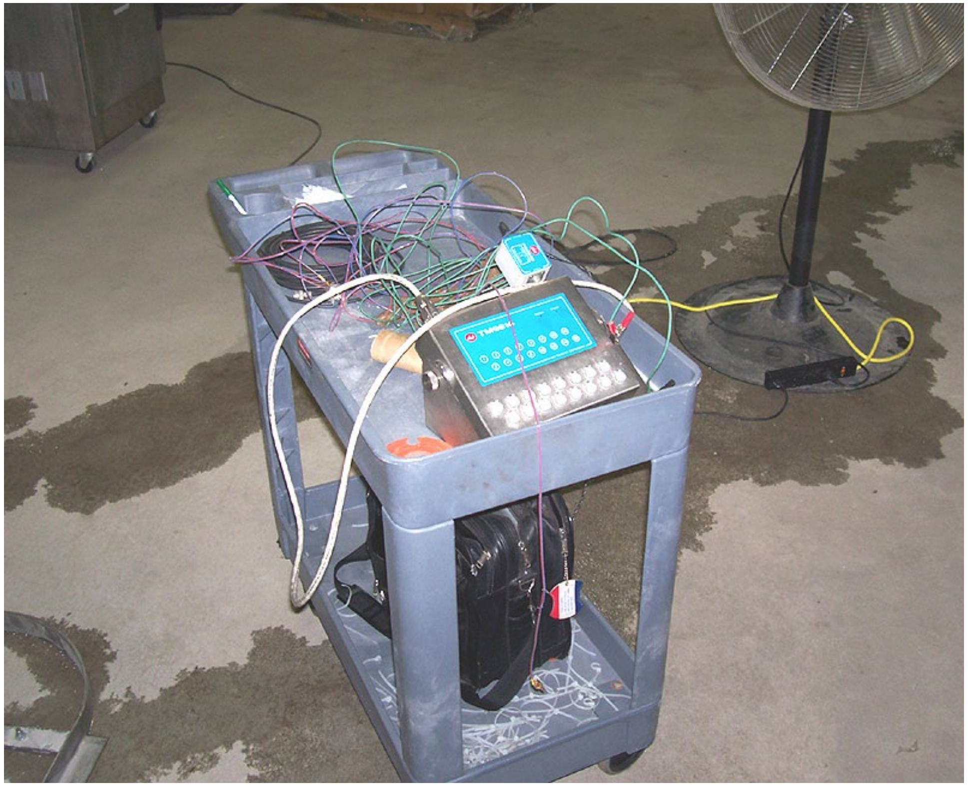
Heat/Temperature Distribution Tests (6)

THERMAL PROCESSING TRAINING

Leads are held in place to ensure they do not contact metal.

Heat/Temperature Distribution Tests (2)

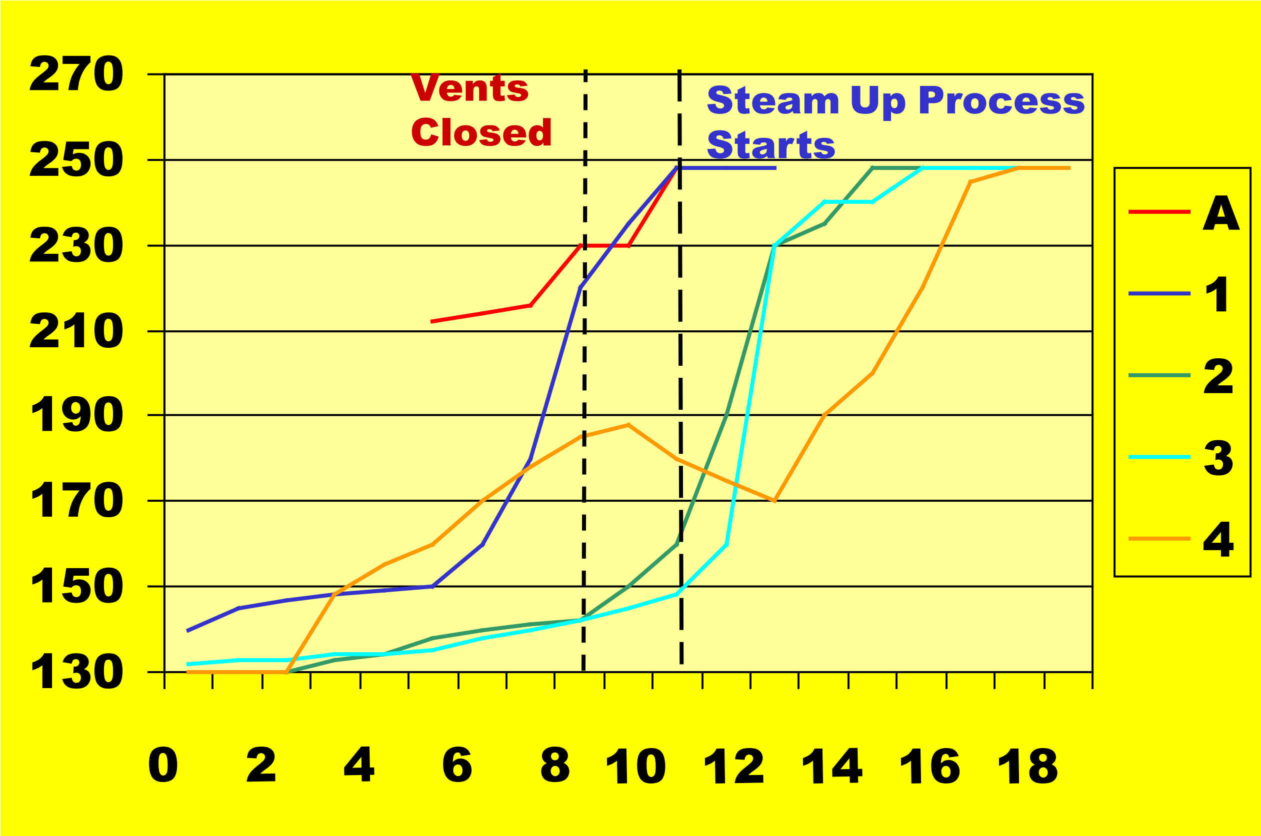
- HD/TD thermocouples are connected to a data logging system



Retort Temperature Distribution Data

THERMAL PROCESSING TRAINING

Temperature



Time in minutes after steam-on

The time the process starts, 3 leads are at temperatures below 190°. It takes several minutes for them to reach operating temperature.

Guidelines for Conducting HD/TD Tests

- The Institute for Thermal Processing Specialists (IFTPS) guidelines for still steam, water retorts, etc., are in your reference manual
- National Food Processors Association Bulletin 26 L

THERMAL PROCESSING TRAINING

Key Points

- Process establishment considerations:
  - Heat resistance of organism in the product
  - Product heating data in the container being used
- Who establishes the process
- Definition of commercial sterility
- What is a scheduled process

THERMAL PROCESSING TRAINING

Key Points (2)

- Critical factors
- Definition of D-value
- Definition of Z-value
- Methods of heat penetration
  - Conduction
  - Convection
  - Combination
- Definition of F-value

Key Points (3)

- GENERAL METHOD:
  - Lethality of the thermal process is derived by summing small increments of time and temperature
    - Very accurate
    - Difficult to determine effect of deviations in the process

Key Points (4)

- FORMULA METHODS:
  - Require heating factors
  - Can be used to calculate deviations in processes
  - Can be used to calculate new processes

Key Points (5)

- INOCULATED PACKS:
  - Used to confirm calculated processes
  - Can be used to establish process when other methods cannot be used

Key Points (6)

- OPERATING PROCEDURES:
  - Need uniform heating medium to deliver the thermal process
  - Determined by heat distribution studies
    - Performed in heating medium on exterior of the container
    - Used to determine operating procedures for thermal processing system (retort)

Process Schedules

- The students should read:
  - 9 CFR 431.3 – Thermal Processing
  - 9 CFR 431.4 – Critical factors and the application of the process schedule

Questions?

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