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FSIS DIRECTIVE

7110.3
Rev. 1

2/10
1-24-89

TIME/TEMPERATURE GUIDELINES FOR COOLING HEATED PRODUCTS

I. PURPOSE

This directive clarifies the intent of the time and temperature guidelines for cooling heated products distributed in May 1988.

II. CANCELLATION

Page 1 of FSIS Directive 7110.3, which transmitted Time/Temperature Guidelines for Cooling Heated Product, dated 5/12/88.

III. REASON FOR REISSUANCE

To clarify that the intent of the recently issued Attachment to FSIS Directive 7110.3 concerning time/temperature controls for the cooling of heated products is to provide guidance for producing wholesome, unadulterated product, not to institute mandatory processing controls.

II. REFERENCE

FSIS Directive 5400.1, Inspection System Guide (ISG), dated 9/21/88

III. POLICY

A. FSIS Directive 7110.3 conveyed guidelines which describe time/temperature controls that the inspector and inspected establishments may rely on to ensure that the procedures used by the plant for that purpose will not cause or contribute to the adulteration of product. However, establishments may elect to adhere to such guidelines, or they may choose an alternative means to the same end. The cooling of heated products if not properly done may result in bacterial growth that can adulterate the product. Adherence to

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an agency guideline effectively removes any concerns the inspector might otherwise have as to the adequacy of these cooling procedures. Non-adherence to the guideline alone does not mean the procedure is inadequate. However, unless some routine procedure which the program already has found to be adequate is used, the inspector must make an independent determination of whether the process being used adequately precludes production of adulterated product.

B. The Inspection System Guide is a compilation of existing inspection requirements coupled with the inspection tasks that are applied by the program to determine compliance. It is described in FSIS Directive 5400.1, reference B above, but to date only has had limited distribution -- outside the Directive system as part of FSIS's Performance Based Inspection System (PBIS) training program. The ISG is the key document to be used to help make FSIS inspection more efficient and more effective. However, it is also intended to help inspected establishments be informed of inspection procedures applicable to their plant so they may take measures to ensure the plant will be found in compliance when it is inspected.

1. With regard to ISG provisions concerning the cooling of heated product, the specifications recited in the following sections are intended to be guidelines:

Page 6-12: 06C05a1; 06C05a2

Page 6-48: 06N12a2

Page 6-57: 06Q10a1; 06Q10a2

2. Those who have copies of the ISG are advised that changes to the above-noted sections will be made in the next edition of the ISG; but, should make the following pen and ink changes in their copy of the ISG to remove any confusion on this point:

a. In column two on pages 6-12, 6-48, and 6-57, substitute the following narrative:

Plant meets Agency's Guidelines for Cooling Heated Product or can demonstrate adherence to an alternate cooling procedure shown to maintain such product in a wholesome and unadulterated state.

b. In column three on pages 6-12, 6-48, and 6-57, delete "318.17"

c. In column four on pages 6-12, 6-48, and 6-57, substitute the following narrative:

Compare the plant's product cooling practices to those that the Agency will recognize as safe practice as covered in the Time/Temperature Guidelines for Cooling Heated Products. For cooling practices which are significantly different from those in the Guidelines and are not alternative cooling procedures developed by a processing authority, report to headquarters through supervisory channels, for evaluation on a case-by-case basis.

If results are not comparable, initiate appropriate action.

Compare internal temperature, cold storage temperature, intermediate holding temperature of one or more units of cooked product with plant results.

If results are not comparable, initiate appropriate action.

Administrator



NOTE: Please file this revision with the attachment to FSIS Directive 7110.3 dated 5/12/88.

TIME/TEMPERATURE GUIDELINES FOR COOLING HEATED PRODUCTS

THE SHORT VERSION

I. COVERAGE

A. COVERED PRODUCTS

Processors should use these cooling guidelines for all heated, perishable meat and poultry products and their ingredients except for those listed in Section B below. These guidelines cover ingredients such as cooked beans, noodles, or rice which may either become a part of the product or be packed in a separate container. Examples are the beans to be added to a burrito, the noodles for a stroganoff, the peas for a frozen dinner, and the rice for a jambalaya.

B. PRODUCTS NOT COVERED

These guidelines are not intended for the following products:

1. **Products covered by cooling regulations, e.g.,** those specified in Section 318.17 of the Meat Inspection Regulations, such as roast beef and cooked corned beef, and in Section 381.149 of the Poultry Products Inspection Regulations, such as canned poultry.
2. **Shelf stable products, i.e.,** products which after processing, do not require special cooling instructions, such as fully retorted products, shelf-stable semidry sausages, and dry cured hams.
3. **Cooked products shipped hot, i.e.,** products heated to an internal temperature of 155 °F or more, and conspicuously labeled with a statement such as "This product must either be maintained at no less than 140 °F during shipment or discarded."

II. RECOMMENDED COOLING RATES FOR HEATED PRODUCTS

A. RAPID COOLING.

To avoid product adulteration, processors should rapidly and continuously cool all products not included in Section B below. To rapidly cool, processors should meet the cooling rates below.

1. During cooling, the product's maximum internal temperature should not remain between 130 °F and 80 °F for more than 1.5 hours nor between 80 °F and 40 °F for more than 5 hours, except for product described in paragraph II. A. below.

2. Product consisting of pieces of intact muscle, such as turkey breast or pork loin, may be cooled according to the requirements of Section 318.17(h)(10) of the Meat Inspection Regulations.

B. SLOW COOLING FOR SOME CURED PRODUCTS.

Processors may slowly cool cured products if the product satisfies condition 1, one of the two choices in condition 2, and one of the three choices in condition 3 below.

1. The internal temperature does not remain between 120 °F and 40 °F for more than 20 hours; and

2. the cooling process:

a. causes a continuous drop in product temperature; or

b. controls the product's surface temperature so that it does not stay between 120 °F and 80 °F for more than 2 hours; and

3. the product is formulated:

a. with no less than 120 ppm of sodium nitrite or its equivalent (e.g. 148 ppm KNO_2) and a brine concentration of 3.5 percent or more; or

b. with no less than 40 ppm of sodium nitrite or its equivalent (e.g. 148 ppm KNO_2) and a brine concentration of 6 percent or more; or

c. with or without nitrite (such as salt cured product), but with a maximum water activity of 0.92.

III. HOLDING TEMPERATURES

A. COLD STORAGE TEMPERATURES

35 °F rather than 40 °F should be used to store uncured processed product for any period of time longer than one week.

B. INTERMEDIATE HOLDING TEMPERATURES

These time and temperature guidelines apply to the holding of heated products before cooling them to 40 °F. Products heated above 155 °F then cooled from 130 °F to 60 °F within 2 hours may be held for up to 4 hours if they are:

1. kept below 60 °F during the 4 hours,
2. protected from post-cooking contamination, and
3. cooled to 40 °F within 2 hours, at the end of the 4 hour holding period.

C. HOT HOLDING TEMPERATURES

Uncured cooked products may be safely held for up to 4 hours if kept above 130 °F, or for an extended period if kept above 140 °F. If product drops below 130 °F for over 30 minutes, the processor should either continuously cool it to meet the times and temperatures in II. B. above, immediately reheat it to 160 °F, or discard it.

CAUTION: Processors should hold product above 140 °F unless they have established excellent temperature control over every portion of the product. Thus, processors should definitely keep product above 140 °F when it is in transit, in containers without temperature monitoring, and in similar cases where excellent control is not established and maintained.

THE LONG VERSION, INCLUDING

INTRODUCTION
SIGNIFICANT FOOD SAFETY TEMPERATURES
PREMISES FOR COOLING GUIDELINES
COVERAGE
COOLING RATES
HOLDING TEMPERATURES
MONITORING
VARIANCES IN COOLING RATES
ALTERNATE COOLING PROCEDURES
IMPROVING PRESENT COOLING

INTRODUCTION

This Processing Policy Memo contains guidelines for cooling cooked or heated products in a manner that FSIS recognizes as good practice. It also describes how to develop an acceptable alternative cooling control program and how to improve cooling efficiency.

Most cooked foods are not sterile; many spores will survive an hour or more of boiling. In addition to the heat-resistant bacteria which survive cooking, post-cooking contamination is possible even in an environment which appears entirely sanitary. Therefore, processors must cool heated products rapidly if they are to prevent these bacteria from growing and causing problems.

FOOTNOTE^{1 and 2}:

USDA research¹ has provided new information on cooling rates that will minimize growth of pathogenic bacteria that generally cause problems in slowly cooled foods. The cooling rates are based on that research. However, to safely use these cooling rates, processors need to consistently control the cooling of their products. Lack of control will erode the safety margin in these cooling rates. Maintaining control requires efficient, knowledgeable employees who use the cooling facility and monitor the process carefully. The guidelines thus recommend not only cooling rates, but also processor control.

1) Blankenship, L. R. et. al. (1986) Growth of Clostridium perfringens in chili during post cook chilling. ASM Annual Meeting. Abstract P-28.

2) Blankenship, L. R. et. al. (1988) Applied and Environmental Microbiology. In Press.

Significant Food Safety Temperatures

To help the processor understand the basis of these cooling guidelines, FSIS has developed this list of current and traditionally cited temperatures.

- 35 °F FSIS recommended storage temperature for periods exceeding one week. This storage temperature will greatly reduce the growth of psychrotrophic spoilage bacteria as well as psychrotrophic pathogens such as Listeria and Clostridium botulinum type B.
- 40 °F Traditional FSIS recommended maximum storage temperature and control point.
- 45 °F FDA recommended temperature cooling control point and maximum storage temperature for retail establishments.
- 55 °F FSIS poultry and roast beef cooling control point.
- 80 °F Approximate transition between rapid growth and slower growth of many food-borne pathogenic bacteria; little or no growth of Clostridium perfringens below this point.
- 100 °F Rapid growth of most food poisoning bacteria.
- 120 °F FSIS cooling control point for roast beef; traditional USDA cooling control point; rapid germination and growth of C. perfringens; minimal to no growth of Staphylococcus aureus, C. botulinum; minimum trichina treatment temperature for cured pork products.
- 125 °F Upper growth limit for C. perfringens.
- 130 °F FSIS recommended control point; recommended holding temperature for up to 4 hours, minimum cooking temperature for roast beef.
- 140 °F FDA recommended holding temperature and cooling control point for retail establishments; USDA recommended minimum holding temperature for extended periods, minimum shipping temperature.
- 155 °F FSIS recommended minimum cooking temperature for a product which is to be shipped hot.

FSIS has based these cooling guidelines on several premises:

1. Heat-resistant food-poisoning bacteria can grow from 38°F up to approximately 125°F; however, their range of rapid growth is from approximately 80°F to 125°F. Thus, cooling product quickly through the rapid growth range is more important than cooling through the slow growth range.

2. The rate of heat transfer (cooling rate) from the product's center to its surface is directly proportional to the difference in temperature (dT or ΔT) between those two points. Thus, as the product temperature approaches the coolant temperature, the cooling rate diminishes.

3. Traditional cured products, containing high amounts of salt and nitrite, together with low moisture content are more resistant to bacterial growth than similar newer products; some are even shelf-stable. Thus, rapid cooling of these traditional products is not always necessary. However, manufacturers are making fewer products of this type today. Instead, to meet present consumer tastes, most of their cured products contain less salt and more moisture. These changes minimize the inhibitory effect of added nitrite and increase the need to rapidly cool these products.

4. If the cause of a small problem, such as a cooling variance, is not traced and corrected when first noticed, the problem will probably recur and grow more severe, until it becomes a disaster resulting in widespread illness among the public and large financial losses for the manufacturer.

5. Clearly written employee instructions are valuable in themselves and as an educational tool for management.

6. A temperature measurement probably represents neither the minimum nor the maximum temperature of a product lot because (a) the temperature is not the same throughout the lot, and (b) the temperature measuring device conducts heat better than the product. Processors can minimize these errors by (a) measuring more than one piece of product and (b) using thin temperature probes and shielding or insulating the part exposed to the coolant.

7. The more closely processors operate to the known limits of safety, the more important it is that they control the product temperature well; this in turn requires them to accurately monitor the critical parameters.

FSIS DIRECTIVE 7110.3
ATTACHMENT

To incorporate these principles into a practical guideline, FSIS has:

1. Emphasized the need to quickly cool past the rapid growth range.
2. Acknowledged the relationship between the recommended temperature and the time periods involved,
3. Identified those products that may be cooled more slowly,
4. Listed the responsibilities of processors who wish to use the more liberal cooling rates, and
5. Added safety margins to compensate for inherent errors.

I. COVERAGE

A. COVERED PRODUCTS

Processors should use these cooling guidelines for all heated, perishable meat and poultry products, and their ingredients, except for those listed in Section B below. These guidelines cover ingredients such as cooked beans, noodles, or rice which may either become a part of the product or be packed in a separate container. Examples are the beans to be added to a burrito, the noodles for a stroganoff, the peas for a frozen dinner, and the rice for a jambalaya.

B. PRODUCTS NOT COVERED

These guidelines are not intended for the following products:

1. **Products covered by cooling regulations, i.e.,** those specified in Section 318.17 of the Meat Inspection Regulations, such as roast beef and cooked corned beef, and in Section 381.149 of the Poultry Products Inspection Regulations, such as canned poultry.

2. **Shelf stable products, i.e.,** products which after processing, do not require special cooling instructions, such as fully retorted products, shelf-stable semidry sausages, and dry cured hams.

3. **Cooked products shipped hot, i.e.,** products heated to an internal temperature of 155 °F or more, and conspicuously labeled with a statement such as "This product must either be maintained at no less than 140 °F during shipment or discarded."

II. RECOMMENDED COOLING RATES FOR HEATED PRODUCTS

A. RAPID COOLING.

To avoid product adulteration, processors should rapidly and continuously cool all products not included in Section B below. To rapidly cool, processors should meet the cooling rates below.

1. During cooling, the product's maximum internal temperature should not remain between 130 °F and 80 °F for more than 1.5 hours nor between 80 °F and 40 °F for more than 5 hours, except for product described in paragraph 2 below.

2. Product consisting of pieces of intact muscle, such as turkey breast or pork loin, may be cooled according to the requirements of Section 318.17(h)(10) of the Meat Inspection Regulations.

B. SLOW COOLING FOR SOME CURED PRODUCTS.

Processors may slowly cool cured products if the product satisfies condition 1, one of the two choices in condition 2, and one of the three choices in condition 3 below.

1. the internal temperature does not remain between 120 °F and 40 °F for more than 20 hours

2. the cooling process

a. causes a continuous drop in product temperature

b. controls the product's surface temperature so that it does not stay between 120 °F and 80 °F for more than 2 hours

3. the product is formulated

a. with no less than 120 ppm of sodium nitrite or its equivalent and a brine concentration of 3.5 percent or more

b. with no less than 40 ppm of sodium nitrite or its equivalent and a brine concentration of 6 percent or more

c. with or without nitrite (such as salt cured product), but with a maximum water activity of 0.92.

III. HOLDING TEMPERATURES

A. COLD STORAGE TEMPERATURES

35 °F rather than 40 °F should be used to store uncured processed product for any period of time longer than one week.

B. INTERMEDIATE HOLDING TEMPERATURES

These time and temperature guidelines apply to the holding of heated products before cooling them to 40 °F. Products heated above 155 °F then cooled from 130 °F to 60 °F within 2 hours should remain unadulterated for up to 4 hours if they are:

1. kept below 60 °F during the 4 hours,
2. protected from post-cooking contamination, and
3. cooled to 40 °F within 2 hours, at the end of the 4 hour holding period.

C. HOT HOLDING TEMPERATURES

Uncured cooked products may be safely held for up to 4 hours if kept above 130 °F, or for an extended period if kept above 140 °F. If product drops below 130 °F for over 30 minutes, the processor should either continuously cool it to meet the times and temperatures in II. B. above, immediately reheat it to 160 °F, or condemn it. **CAUTION:** Processors should not attempt to hold product below 140 °F unless they have established good temperature control over all portions of the product. Thus, processors should keep product above 140 °F when it is in transit, in containers without temperature monitoring, or in similar cases where good control is not established and maintained.

IV. MONITORING

To safely use these more flexible cooling rates, processors must accurately monitor the product's internal temperature. FSIS suggests that temperature recorders are generally the best and most economical means. Additional recommendations for temperature monitoring follow:

A. THE MONITORING DEVICE

1. **Accuracy:** The temperature recording devices should be both readable and accurate to 2 °F and 5 minutes within the critical range. The processor should check the manufacturer's accuracy specifications before purchasing a unit, e.g., a unit accurate within 1 percent of range and a range of 0 °F to 250 °F is not accurate enough. However, a processor can verify that some of these instruments are in fact sufficiently accurate by careful calibration at two temperatures within the critical temperature range. (See subparagraph 2. below.)

2. **Calibration:** Processors should check each new instrument for accuracy regardless of the manufacturer's claims; rough handling during shipping can undo the factory calibration. Although electronic instruments are resistant to rough handling, they too should be checked. The processors should calibrate both time and temperature accuracy against known standards.

a. **Temperature calibration standards:** The most practical and reliable temperature standard for this purpose is a mercury-in-glass thermometer which conforms to the standards of the American Society for Testing Materials (ASTM). In most cases ASTM requires that thermometers bearing their initials be accurate within one scale division.

A review of ASTM Standard E-1, Standard Specification for ASTM Thermometers, will present the processor with a choice of several ASTM thermometers having a maximum scale error of less than 20 °F. The ASTM 64 F thermometer would be an excellent choice for calibrating in the range of 80 to 130 °F. The ice point at 32 °F is a reference point for temperature calibration and is used to detect changes in the reading of the standard mercury-in-glass thermometer due to changes in the volume of the bulb with time.

b. **Calibration procedure:** Immerse the probe and standard into a substance with a uniform temperature; FSIS recommends a stirring water bath within 20 °F of the critical temperature the measuring device will have to monitor. For these cooling guidelines, a water bath at 105 °F would suffice, however, calibrating the device at two temperatures within the 130 °F and 80 °F range is better.

c. Verifying the accuracy of uncertified thermometers: A processor with a thermometer that the manufacturer does not certify to be accurate within 2 °F and 5 minutes may be able to verify that it is adequate by checking it at several standard temperatures within the critical temperature range. For these cooling guidelines, FSIS recommends verifying that the measured temperatures at 130 °F, 80 °F, and 40 °F are accurate.

B. TEMPERATURE MEASUREMENT

1. **Number of probes:** The number of probes or temperature sensing devices needed varies with the circumstances. Processors should depend on their QC resources to determine the appropriate number and placement.

2. **Frequency of monitoring:** Initially the plant should monitor every lot. However, if the plant builds a history of excellent compliance, reduced monitoring should not add unacceptable risk. Processors should consult with their QC specialists for applications to their specific plant.

C. RECORDS

Processors should keep records of all time and temperature checks for at least 1 year, even though the product may have a shelf-life of only 60 days. A record of good manufacturing practice is valuable insurance, and an invaluable reference for improving future performance.

V. VARIANCES IN COOLING RATES

These guidelines contain a safety margin; therefore, a small lapse in and of itself will probably not cause a problem in every instance. However, a large variance or continual small ones constitute unacceptable risk. In addition, the processor should consider an occasional small variance an opportunity to find and correct a control problem.

A. UNACCEPTABLE VARIANCES

If the number of minutes of product cooling time exceeds the minutes of guideline time by more than 25 percent, the processor should take the following actions:

1. Notify the inspector, the QC unit, and other concerned units such as refrigeration maintenance and production.
2. Hold the involved product and examine it for potential adulteration by bacteria, particularly clostridial pathogens. If it is adulterated, inform the inspector.
3. Postpone further product manufacturing utilizing that chill facility until the processor has:
 - a. determined the cause of the variance;
 - b. completed adjustments to assure that the variance will not recur; and
 - c. informed the inspector and the production units of the determinations and adjustments and made any needed amendments in the written processing procedures.

If the number of minutes of product cooling time exceeds the minutes of guideline time by any percentage twice or more in any consecutive 20-day-period of production, the processor should take the following actions:

1. Notify the inspector, the QC unit, and other concerned units such as refrigeration maintenance and production.
2. Postpone further product manufacturing utilizing that chill facility until the processor has:
 - a. determined the cause of the variance;
 - b. completed adjustments to assure that the variance will not recur; and
 - c. informed the inspector and the production units or the determination and adjustments and made any needed amendments in the written procedures.

B. OTHER VARIANCES

If the actual cooling time exceeds a guideline time by less than 25 percent once during any 20-consecutive-day period of production, the processor should:

1. Notify the inspector, the QC unit, and other concerned units such as refrigeration maintenance and production;
2. Investigate and determine the cause of the variance;
3. Complete any needed adjustments to assure that the variance will not recur;
4. Inform the inspector and production unit of the determinations and adjustments; and
5. Make any needed amendments in the written processing procedures.

VI. ALTERNATE COOLING PROCEDURES

Processed Products Inspection Division based these guidelines on the best available information and is providing them for general application. We will modify the general guidelines if we have additional information to warrant it. In addition, Processed Products Inspection Division will consider alternate cooling procedures which processors may propose for their specific products and processes.

A. BASIS FOR ACCEPTABLE ALTERNATE PROCEDURES Acceptable alternate procedures should be based on reliable information that assures the safety of the procedure. Either:

1. **Original scientific research**, developed from a previously accepted research protocol, which establishes the safety of the alternate procedure with respect to the probable pathogens concerned and identifies the critical factors; or

2. **A letter or report by a processing authority** that the proposed procedure is appropriate for the product proposed, considering the processing method, the packaging method, the handling involved, and the pathogens considered. This should be supported by an appropriate review of the relevant scientific literature and any original data.

B. CONTENT OF ACCEPTABLE ALTERNATE PROCEDURES Acceptable alternate cooling procedures should include:

1. A description of the cooling procedure, including:

- a. The critical control points
- b. A map of the cooling facility and the product arrangement within it
- c. A description of the cooling facility's refrigeration capacity and coolant flow

2. An explanation of how the plant will control the procedure, including:

- a. A product temperature monitoring program that is at least equal to that in Division IV of this guideline
- b. The product processing procedure including controls over product formulation and composition
- c. How the critical control points will be controlled
- d. Written employee instructions as to how cooling is to be done, how monitoring is to be done, and how variances should be handled.

VII. IMPROVING PRESENT COOLING

We have added this Division to the Guidelines to help processors consistently satisfy our recommended cooling rates, thus producing higher quality products and also saving energy and the money that energy represents. We have based the following information on our experience with solving cooling problems and the scientific expertise of the USDA's Agricultural Research Service.

A. COMMONLY KNOWN FACTS ABOUT COOLING

Some of the means for improving product cooling are commonly known because we all are continually exposed to some form of cooling; winter winds, metal stadium seats, or cold swimming pools are some of the examples. We have also learned to minimize the chilling effects of these factors by standing out of the wind, sitting on cardboard, or wearing a wetsuit. But we don't always apply what we know in one context to another. Thus, we have devised this Division to stimulate processors to apply their present knowledge to improving food cooling. We have also included two simplified formulas to aid in quantifying the effect of different cooling practices and added a cooling practice checklist.

B. HEAT FLOW

Processors planning cooling improvements should consider how heat moves from the product's center to its surface and ultimately to the exterior of the plant. A simplified diagram would be:

[PRODUCT] [PRODUCT] [REFRIGERATOR] [REFRIGERATOR]
[CENTER]->[SURFACE]->[COOLANT]->[EVAPORATOR]->[CONDENSER]->[AIR]
[COIL] [COIL]

The rate at which heat flows between these preceding steps is governed by the laws of heat transfer. By understanding the gist of these laws, and applying them to cooling procedures, the processor can improve cooling efficiency.

C. ~~PHYSICAL LAWS OF HEAT TRANSFER~~

1. **Fourier's and Newton's Laws** describe the factors affecting heat transfer from the food product until it is ultimately transferred to the outside environment. Understanding these laws will help you understand how to improve your cooling rate.

A simple expression of Fourier's law of heat transfer is:

$$q = \frac{k \times A \times dT}{L}$$

Newton's Law of cooling by convection is:

$$q = h \times A \times dT$$

q is the rate of heat transfer (BTU/hr)

k, for Fourier's Law, is the thermal conductivity constant (ice is 1.28; cold water is .32; meat is .29; stainless steel is 9.4)

h, for Newton's Law of Convection, is the heat transfer coefficient (still air = 0.5 to 5; fanned air = 2 to 20; stirred water = 100 to 1000)

A is area for heat transfer (sq ft)

dT, in Fourier's Law, is the difference in temperature between the surface and center (^oF) or in Newton's Law, the difference in temperature between the food and coolant

L is the distance the heat must move (ft)

2. To better understand what these laws mean to you, imagine what would happen if you tried the following experiments:

a. The effect of "A" & "L": Take two 5 pound warm meatballs and mash one to 1 inch thickness, net both, then hang them in the same cooler. Experience tells you that the mashed meatball will cool faster; so does Fourier. For the mashed meatball, "A" is higher and "L" is lower, thus q, the rate of heat transfer, will be higher.

The factors are multiplied in Newton's and Fourier's laws. Thus, halving any factor (except "L") halves "q", the rate of heat transfer; halving "L", doubles "q".

b. The effect of "A", "L" & "k": Next, take two identical 5 pound meatballs mashed to 1 inch thickness. Put one on a plastic foam tray, the other on a stainless steel tray, and place both in the same area of the cooler. Because the plastic tray conducts very little heat, it effectively reduces "A" by almost half (the 1 inch edge would remain the same). Conversely, the stainless steel tray conducts heat more rapidly than the air and effectively acts as a large fin, thus "dT" will be higher at the bottom surface of the meat than at the top. Experience reinforces this logic; leaning against a steel wall will chill you faster than leaning against a wooden or plastic foam wall.

c. The effect of "h" & "dT": The coefficient of heat transfer (h) for stirred air is approximately 50 times that for still air; kids huddled around each other while waiting for the bus would agree. Moving the air across the surface replenishes the air heated by the food with colder air, thus keeping "dT" at a high value for both Fourier's and Newton's laws. Fans are cheaper than lowering the cooler temperature. If you already have fans, check to see if all pieces are being exposed to the moving air; you may find some pieces huddled in the wind shadow of others, exposed only to preheated slow air. Another example of "h" is cold water and air; putting your hand into 50 °F water chills it much faster than putting it into 50 °F air. This is not surprising since the value of "h" for water is approximately 100 times the value of "h" for air.

d. The effect of "dT": Imagining an experiment for "dT" is hardly necessary since it is common knowledge that the colder the coolant, the quicker the food will cool; you wear heavier coats on colder days. However, consider the magnitude of "dT" and how it affects the cooling rate. A "dT" of 60 °F provides sufficiently rapid cooling for most purposes. Beyond that the limiting factor is the food's heat conductance; instead of cooling faster, the surface freezes. Since lower cooler temperatures cost more, processors might be able to economize by using coolant at ambient temperature (air or water) to bring the product temperature to within 50-60 °F of ambient, then moving the product into the cooler. This would also lessen the heat load on the refrigeration system.

e. The effect of "k", "h", "A", & "L": We can bring several of these factors together by considering the cooling of boxed food. Boxing warm food products slows cooling because of several factors: (1) "h" is low because the food inside is exposed to still air, (2) the box adds an extra layer of insulation, thus decreasing "k", (3) many small pieces in a box become one large thermal mass, thus increasing "L" and decreasing "A". Therefore, it is not surprising to find food remaining above 70 °F a day after putting in into a cooler, if was boxed while still warm. Boxed food can be cooled safely using a sufficiently cold blast freezer; however, removing a BTU of heat with a freezer costs much more than removing it with a cooler. These are factors the plant management should consider.

f. The thermal conductivity constant, "k": This affects both cooling rates and temperature monitoring. One common manifestation of the effect of "k" in food processing is the use of potato nails, aluminum spikes people stick in potatoes to hasten baking time. Because the aluminum conducts heat so much better than the potato, it is almost like cooking the potato from inside and outside at the same time. The principle works on both cooking and cooling and on meat as well as potatoes.

g. The effect of "k" and temperature measurement errors: Ignoring the effect of "k" can induce errors in temperature monitoring if the temperature probe is thick enough to transfer a significant amount of heat. An example of this can be seen by cutting into a roasted piece of meat, longitudinally, through the hole left by a thick temperature probe. The gray area beneath the surface of the meat will follow the hole into the interior of the meat for some distance. The gray area is the meat that has reached approximately 160 - 170 °F. The temperature probe, because it transfers heat much better than meat, raises the meat temperature around the probe to 160 - 170 °F in less time. Errors in temperature monitoring occur when the probe shaft conducts heat to the probe tip and raises the probe tip to the critical temperature faster than the meat an inch or so away. The reverse can happen during cooling when the probe shaft transfers heat from the probe tip and causes an erroneously low reading.

Following is a list of practices that can minimize temperature measuring errors induced by "k"; since they have practical limits we suggest processors use them when practical.

(1) Use probes that are as thin as practical; a 1/8 inch diameter probe carries 4 times the heat that a 1/16 inch diameter probe carries; a 1/4 inch diameter probe carries 16 times the heat that a 1/16 inch probe carries.

(2) Use probes whose exposed metal shaft is thermally (not just electrically) insulated from the cooling (or cooking) medium.

(3) Instead of continuous monitoring, insert the probe only when a temperature reading is needed.

C. A COOLING PROBLEM CHECKLIST

1. The heat transfer coefficient, "h", for the coolant directly affects the rate of heat transfer. Since the value of "h" for forced convection air is approximately 5 times that of still air, the processor should check the following:

- a. Does the cooler/freezer have fans?
- b. Is the product exposed to the air or is it in a protective package?
- c. Is the air circulating fully around the product or are some pieces protected from the wind?
- d. ~~Could the product be cooled by using chilled water or brine? Cold water has an "h" value approximately 50 times that of fanned air.~~

2. Maintaining a large difference in temperature (ΔT) between the product's center and its surface or the product and the coolant will assure rapid cooling. If the coolant warms significantly during the cooling cycle, then the later cooling stages will be slower and the processor should consider the following:

- a. Should additional refrigeration capacity be installed to cool the amount of product being produced?
- b. Is the refrigeration unit running optimally? For instance, are all coils clean, are all compressors properly maintained, are there no impediments to refrigerant flow, and is the refrigerant at optimum pressure?
- c. Is hot product ($>140^{\circ}\text{F}$) entering the cooler, thus overloading its capacity? If so, could the procedure be safely amended to permit the product to cool longer at ambient temperature before moving it into the cooler?
- d. Is the refrigeration space managed effectively: does stacked product divert coolant flow, is the insulation effective, is there excessive traffic through the space, do doors remain open, and could door baffles help?

3. Although the thermal conductivity constant, "k", for meat is not high, it is approximately 30 times that of air and over 10 times the "k" value for many packaging materials. Thus, the processor should consider the following:

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a. Is the product packaged in an insulating material, e.g. cardboard or plastic foam, before entering the cooler?

b. If the product is inside a thin film packaging material, are there significant air pockets acting as insulators?

c. Is the product directly exposed to the coolant or is there a thin tight film of packaging material between the coolant and the product? If so, the cooling problem may be elsewhere.

4. The area of product exposed to the coolant is another controllable factor.

a. Is the product exposed to the coolant on all sides?

b. Is part of the product covered by material with a low thermal conductivity value, e.g. thick plastic lugs or trays? If so, could they be replaced with materials with a higher "k" value, e.g stainless steel trays and lugs?

5. The longer the path the heat has to travel, the more time it takes. Thus, the processor should consider whether the present facilities are adequate for large products.

a. Can the product size be reduced in one or more dimensions?

b. Is the product being packed together so that it acts as one large piece?

If you have questions or want additional information on developing cooling control programs or improving your present program, please contact FSIS's Processed Products Inspection Division at the following address:

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You may contact us directly by telephone at (202) 447-3840 or address general questions through the FSIS Hotline at 800-535-4555.