Reducing Process Variation in the Cooking and Smoking Process

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We are lost in the mazes of our ingenuities because, being trained to look at the details rather than the holes, we are confused by the complexity we have created.
– Arnold Pacey, MIT professor

Introduction

Converting meat from non-uniform live animals into uniform-quality meat products is a complex task. To be successful, processors must thoroughly understand the myriad processes that go into manufacturing processed meat products. At every step, variation must be measured and controlled to reduce its impact on product costs and quality.

Once a meat product goes into production, processors generally have the same objective — to manufacture consistent-quality products at the lowest possible cost. For production, the goal is not to change the product quality, but rather to make it the same every time. Reducing variation during manufacturing is essential to control costs and quality.

As scientists, we are trained to identify and solve problems through experimentation. We don't often get the chance to step back and examine the entire manufacturing process to identify the holes that need fixing. To reduce the impact of product variation, however, we must do exactly that — identify the sources of variation and establish methods for measuring and controlling them. Even better, we may find ways of not just controlling variation, but actually eliminating it.

Losses in the Meat Supply Chain

Typical losses in the meat supply chain are shown in Table 1.

Weight losses occur in every step of the meat supply chain for many different reasons. For the processor, the following losses may occur because of variation in the cook/chill process:

- Inability to formulate/pump to regulatory limits
- Cooking losses (cooking shrink)
- Cooling losses (cooling shrink)
- Slicing losses
- Package overfill
- Product defects
- Rework

This paper examines the measurement, control, and reduction of losses related to the cooking, smoking, and chilling processes.

Impact of Process and Product Variation

Process variation during cooking, smoking, and chilling causes variation in the color, weight, and composition of the finished product. This variation results in increased manufacturing costs and variable quality.

Inconsistent color or color defects may result in downgraded product or rework. Variable piece weights cause package weight variation and overfill. Variation in finished-product composition (protein, fat, water) makes it more difficult to formulate or pump to USDA regulatory limits for fat and added-water.

Cook/Chill Variation

During cooking, non-uniform oven temperatures and air velocities cause uneven heating and drying rates, resulting in variable product temperatures, weight, composition, and color.

During chilling, non-uniform cooler temperatures and air velocities cause variable product temperatures, weight, and composition, but do not usually affect color.

Stuffing and Slicing Variation

Cooking and chilling are not the only sources of weight variation. The stuffing process also contributes to piece weight variation.

For linked products, link-weight variation is a combination of stuffer, oven, and cooler variation as follows:

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TABLE 1. Typical Losses in the Meat Supply Chain.[a]

Livestock Producer	Livestock Hauler	Meat Packer	Meat Processor	Distributer & Retailer
Poor feed conversion	Deaths	Yard deaths	Inability to pump/ formulate to regulatory limits	Product damage in transit
Deaths	Crippling	Condemnations	Cooking shrink	Spoiled in code
Disease	Stress	PSE meat	Cooling shrink	Fading
Genetic deficiencies	Injuries	Excessive trim	Slicing losses	Theft
Breed deficiencies		Failure to maximize available cuts	Package overfill	Overage product
Nutrient control		Floor scrap	Product defects	
Timing		Overage product	Rework	
		Poor grading	Packaging defects	
		By-product recovery and sale	Overage distress	
		Poor boning yields	Contamination & foreign objects	
		Failure to use mechanical separation	Raw material shrink	
			Loss of exudate	

[a]*adapted from Thompson (1995)*

Link-weight variation = stuffing variation + oven-shrink variation + cooler-shrink variation (for linked sausages)

For sliced products, most slicers automatically adjust on-the-fly to control slice weights and package weights. Even so, excessive product variation from uneven stuffing, cooking, or cooling makes it harder for the slicer to do its job accurately. Stuffing variation causes non-uniform end-to-end diameters and variable product density. Cooking variation may cause non-uniform product diameters. Cooling variation causes inconsistent slicing temperatures.

Composition Variation

Shrink variation during cooking and cooling causes variable finished-product composition (protein, fat, water). For sausage products such as frankfurters and bologna, the blend-to-blend variation of raw materials also contributes to composition variation. For cured meats such as bacon and ham, uneven injection of curing solutions causes composition variation.

Cost of Finished-Product Variation

Finished-product variation is a huge cost to the meat industry. The primary costs of product variation are —

- Package-overfill giveaway
- Product-composition giveaway
- Quality downgrades

Overfill and composition giveaway are repeated errors that are easily measured and quantified. Quality downgrades occur more sporadically and therefore are difficult to measure accurately.

Cost of Overfill- and Composition-Giveaway in Frankfurter Production

The following example shows the estimated cost of overfill and composition giveaway for a U.S. frankfurter manufacturer.

Overfill Giveaway

Due to stuffing variation and cook/chill shrink variation, not all frankfurter links are exactly the same weight. This link-to-link weight variation causes variable package weights. To avoid underweight packages, processors usually set the target package weight slightly higher than the marked weight. The difference between the average package weight and the marked weight is called the overfill giveaway, and is calculated as follows:

Overfill giveaway = average package weight - marked package weight

The overfill needed to avoid underweight packages depends on the average weight and standard deviation of the individual links (LaBudde, 1991). Increased link-to-link weight variation requires a larger overfill giveaway to avoid underweights.

For example, suppose the marked package weight is 1.0 lb/package for a U.S. product. Depending on the link-weight variation, the processor might target the average package weight at 1.02 lb/package to avoid underweights. The overfill giveaway, then, is 0.02 lb/package or 2.0%. If the product cost into the package is $0.75/lb, the annual overfill cost for a processor that manufactures 60 million lb/yr of frankfurters would be calculated as follows:

Overfill giveaway cost = 60 million lb/yr x .02 lb over fill/lb product x $0.75/lb
= **$900,000/year**

To cut the cost of overfill giveaway, the variation in stuffed weights and cook/chill shrinks must be reduced to decrease the link-to-link weight variation. The target average weight can then be moved closer to the marked package weight to reduce overfill giveaway.

Composition Giveaway

Composition giveaway for frankfurters is caused by undershooting the USDA limits for fat and added-water in the final product. To avoid compliance violations, processors typically set targets for fat and added-water content slightly under the USDA limits. Variation in blend-to-blend raw material composition and uneven cook/chill shrinks create variation in the final-product composition, making it harder to target the compliance limits accurately.

The composition giveaway needed to avoid compliance violations depends on the average undershoot and standard deviation of the final-product composition (LaBudde, 1991). Increased variation in the final-product composition requires a larger composition giveaway to avoid compliance violations.

The cost of composition giveaway depends on the average undershoot and the penalty cost for undershooting (LaBudde, 1991). For example, the USDA limits for a full-fat frankfurter formula are 30% fat + 10% added-water for a total of 40%. To avoid compliance violations, a processor might target an average composition of 38.5% for fat plus added-water — 1.5% under the 40% limit. If the penalty cost for this product was $0.005 /lb/% undershoot, the composition giveaway would be calculated as follows:

Composition giveaway cost = 60 million lb/yr x ($0.005/lb/% x 1.5%)
= **$450,000/yr**

To cut the cost of composition giveaway, variation in raw material blends and cook/chill shrinks must be reduced to decrease the variation in final-product composition. The targets for fat and added-water can then be moved closer to the USDA limits to reduce composition giveaway.

Total Giveaway Cost

The total costs of overfill plus composition giveaway for this example are calculated as follows:

Total giveaway cost = overfill-giveaway cost + composition-giveaway cost
= $900,000/yr overfill cost + $450,000/yr composition cost
= **$1.35 million/yr**

The LaBudde (1991) reference includes further examples explaining the cost of product variation.

Influence of Cooking Equipment and Processes

Equipment design, cooking processes, and heating media all have a strong effect on process and product variation. The influence of these factors must be understood to evaluate their importance in reducing variation.

Cooking Equipment

The meat industry uses many different types of production cooking systems in both batch and continuous designs. Although equipment designs vary widely, only the following four heating media are commonly used:

- Air (free- and forced-convection)
- Steam
- Hot water
- Microwave

A countless variety of meat products are cooked using forced-air convection ovens (smokehouses), steam cabinets, and hot-water cookers. Microwave cooking, however, has gained only limited industry acceptance because of the shallow penetration depth and uneven heating of microwaves. Industrial microwave ovens have generally been confined to applications for thin products such as the continuous cooking of sliced bacon.

Steam and Hot-Water Cooking

For steam and hot-water cooking, products are usually stuffed in plastic casings or stainless steel molds and then cooked in steam cabinets, hot-water tanks, or continuous systems.

Steam and hot-water cooking are simple processes with only two variables — cooking time and cooking temperature. Because condensing steam and hot water are both extremely effective at transferring heat to the product surface, products cooked at the same temperature in either steam or hot water will have approximately the same cooking time (Heldman, 1975). Steam and hot-water temperatures within a steam cabinet or water-cook tank are typically very uniform, and therefore product temperatures are also very uniform.

Forced-Air Convection Cooking

In forced-air convection ovens (smokehouses), products are heated using fan-driven air. Batch oven capacities range widely from small ovens that hold 100–200 kg/batch to large ones that hold up to 25,000 kg/batch. For continuous systems, production capacities commonly range from 200 kg/

TABLE 2. Potential Sources of Temperature, Shrink, and Color Variation for Meat Products Cooked in Batch Ovens.

Variation within oven
- Top-to-bottom
- Side-to-side
- Front-to-back

Batch-to-batch variation among ovens
- Multiple ovens
- Different height, width, and length
- Different designs
- Different ages
- Different operators for different ovens over multiple shifts
- Inconsistent loading practices
- Variable lag times between cooking and cooling

Oven maintenance
- Out-of-balance airflow
- Control system out of calibration
- Inadequate maintenance of major components (eg. main fan, exhaust fan, gas burner or steam coil, fresh-air and exhaust dampers, control system, rotating dampers)

Differences in operator training and experience
- Different levels of training, experience, and capabilities among operators and supervisors

Poor optimization of cooking processes
- Processes designed for "worst-case" ovens
- Processes are drier than necessary to "be on the safe side"

hr for beef-jerky systems to 7,000 kg/hr for wiener systems to 10,000 kg/hr for bacon systems.

Regardless of the size, shape, design, or age of an oven, all forced-air cooking processes have the same four cooking variables —

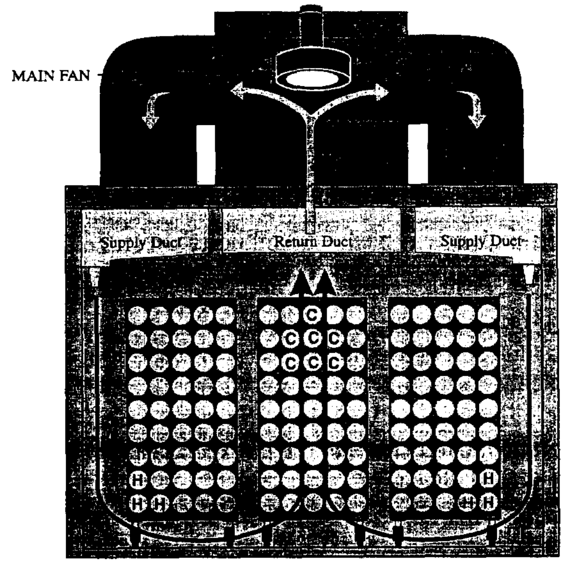
- Cooking time
- Dry-bulb temperature
- Wet-bulb temperature
- Air velocity

When meat products in moisture-permeable casings or without casings are cooked in forced-air convection ovens, heat transfers from the air to the product while, at the same time, moisture evaporates from the product to the air (Bengtsson et al., 1976). This process is known as simultaneous heat and mass transfer. Moisture evaporating from the product surface causes evaporative cooling, and this evaporative cooling strongly influences product drying rates and cooking times (Godsalve et al., 1977; Hanson, 1988; Skjöldebrand, 1980).

A typical air-handling system and airflow pattern for batch meat-processing ovens is shown in Figure 1.

As shown in the diagram, the recirculated air is supplied to the oven cabinet through the supply ducts, driven through the product zone, and then drawn back through the return duct into the fan cabinet. The air is reheated in the fan cabinet and recirculated through the oven. Although the airflow patterns are very turbulent, the air is driven through the product zone in a generally bottom-to-top direction. The supply air is the hottest air in the oven. The return air, having been drawn through the cold product, is the coolest air in the oven.

FIGURE 1.



Batch Oven Airflow.

Sources of Shrink Variation in Batch Ovens

Potential sources of shrink, temperature, and color variation in batch ovens are shown in Table 2.

Meat products are stationary in batch ovens, and therefore have temperature and shrink variation in all three dimensions of the oven as follows:

- Side-to-side
- Top-to-bottom
- Front-to-back

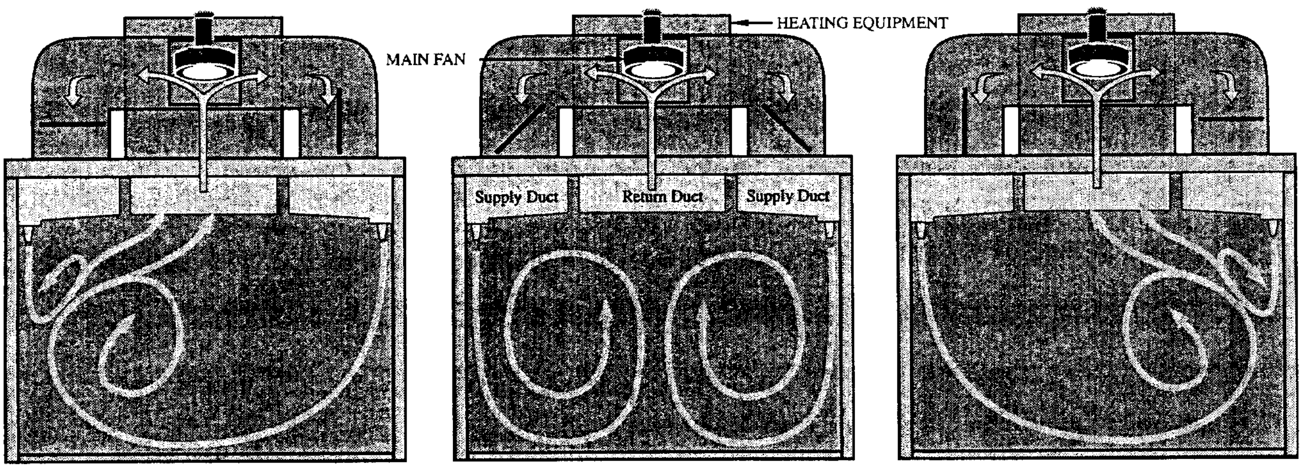
Although product variation can be reduced by adjusting and balancing the airflow, some variation will always exist.

To reduce side-to-side and top-to-bottom variation, most batch ovens are equipped with a rotating-damper system that continuously sweeps the air from side-to-side during cooking (Figure 2). This side-to-side sweeping action is known as "moving-front" or "oscillating" airflow. The rotating-dampers can be adjusted to balance the airflow from side-to-side and top-to-bottom.

To reduce front-to-back variation, the oven return ducts usually have adjustable slides that can be opened or closed to balance the airflow from front-to-back.

Although the rotating dampers create a moving front of air, the general direction of the air through the product zone is still from bottom-to-top (Figures 1 and 2). Because the air cools as it travels through the product, the supply air is hotter that the return air. As a result, the product in the top-center of the oven is the coolest and has the lowest cooking shrink, and the product in the bottom corners is the hottest and has the highest cooking shrink.

FIGURE 2.



Oscillating Oven Air Flow.

If an oven is very tall or wide, the air has a longer path from the supply to the return ducts, and therefore it cools down more as it travels through the product zone. For this reason, the dry-bulb temperature drop from the supply to return ducts is generally greater for large ovens than for small ones. As a result, given the same product and process, the product temperature and shrink variation are generally greater in a large oven than in a small one.

In addition to oven design and size, several other factors contribute to shrink variation for products cooked in batch ovens (Table 2). A major cause of batch-to-batch variation among ovens is simply that different employees operate multiple ovens over multiple shifts. Different levels of experience, training, and capabilities among operators will cause inconsistent shrinks and color from batch-to-batch.

Oven maintenance also plays a key role in controlling shrink variation. Components such as control systems, intake and exhaust dampers, rotating dampers, main and exhaust fans, fan belts, gas burners, steam and humidity valves, gaskets and others must be properly calibrated, balanced, and maintained to provide consistent performance among ovens.

Another major factor contributing to shrink variation is poor optimization of batch cooking processes. Processors with many ovens of different ages and designs often develop cooking processes that target their "worst-case" ovens, thus overcooking many loads and creating unnecessary load-to-load shrink variation. Furthermore, meat products are often cooked using overly-conservative processes that are drier than necessary to prevent problems such as fat separation and color streaking. In other words, processes are often designed to "be on the safe side." Because dry cooking processes inherently create more variation than humid ones, this practice contributes to unnecessary shrink and color variation.

Reducing Product Variation

Shrink variation that occurs during cook/chill processes can be reduced in many ways, including the following:

- Upgrading to electronic controls
- Optimizing oven designs
- Using good loading practices
- Optimizing cook/chill processes
- Training operators, supervisors, and maintenance
- Cooling products immediately after cooking
- Using low-shrink cooling methods
- Converting from batch to continuous processing

These methods of reducing product variation are further explained below.

Electronic Controls

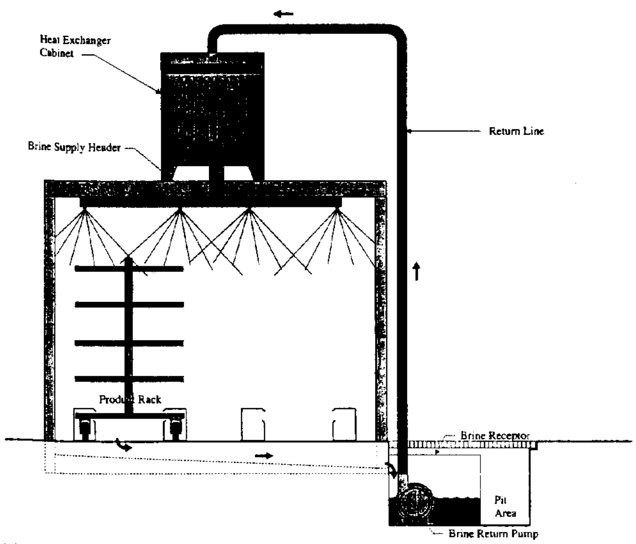
The widespread adoption of electronic controls in place of older-technology pneumatic controls has reduced total shrink and shrink variation in batch ovens. Electronic controls improve the repeatability of cooking processes from batch-to-batch. They are also more accurate and stay in calibration for much longer than pneumatics, thus reducing shrink variation caused by control system miscalibration.

Oven Design & Product Loading

As previously stated, the temperature, shrink, and color variation are generally greater for large ovens than for small ones. In factories with multiple ovens, however, the load-to-load variation *among* ovens is usually greater than the variation *within* ovens (LaBudde, 1989). In processing system layouts, therefore, the installation of fewer, larger ovens of matching design and size will generally reduce batch-to-batch variation.

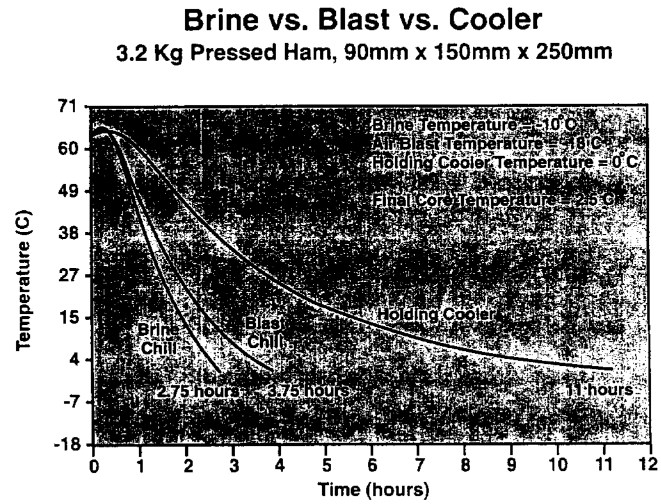
Good loading practices reduce product variation. Ovens should be loaded with adequate clearance between the product and the side walls and floor. For most ovens, adequate

FIGURE 3.



Liquid Brine Chiller.

FIGURE 4.



clearance is 30 cm. This spacing allows the moving front of air to travel unimpeded from side-to-side in the oven. For partial loads, the oven should be loaded evenly from front-to-back to maintain balanced airflow along the length of the oven.

Optimization of Cook/Chill Processes

In a previous RMC paper, I explained the principles of heat and moisture transfer in meat products during cooking (Hanson, 1990). A good understanding of these principles is necessary to develop optimized cooking processes.

As previously stated, the following variables are used to control oven cooking processes: cooking time, dry-bulb temperature, wet-bulb temperature, and air velocity. Typically, the first one-half to three-quarters of a cooking process for smoked meats is used to develop quality characteristics such as smoke color, internal color, skin set, and texture. After the desired quality characteristics are achieved, the product is heated to its target core temperature. Cooking processes must be optimized to balance quality characteristics with cooking time and shrink.

Cooling Methods

After the product is cooked, immediate and rapid chilling helps prevent excessive cooler shrinks and shrink variation. When hot products are removed from an oven, moisture evaporates rapidly from the hot product surfaces. After the surface is cool, the evaporation rate drops off dramatically.

In an air cooler, uneven cooling and drying causes variable cooler shrinks within a batch. If the holding times in the cooler vary widely from batch-to-batch, the variable holding times will cause cooler-shrink variation among batches.

Brine chillers are often used for rapid cooling of meat products (Figure 3). Here, a prechilled sodium-chloride brine solution (usually -4 to -12°C) is showered over the product to cool it. Products that are brine chilled generally have no cooler shrink or shrink variation.

The cooling curves for hams cooled in a brine chiller, blast chiller, and holding cooler are shown in Figure 4. Temperature setpoints for the trials represented cooling temperatures typically used in the industry. The average air velocities were approximately 5 m/s for the blast chiller and 0.5 m/s for the holding cooler.

As shown in Figure 4, to cool the hams to a 2.5°C core, the brine chiller had the shortest cooling time of 2.75 hours, followed by the blast chiller at 3.75 hr and the holding cooler at 11 hr.

Cooler shrinks for hams chilled using the three cooling methods are shown in Figure 5.

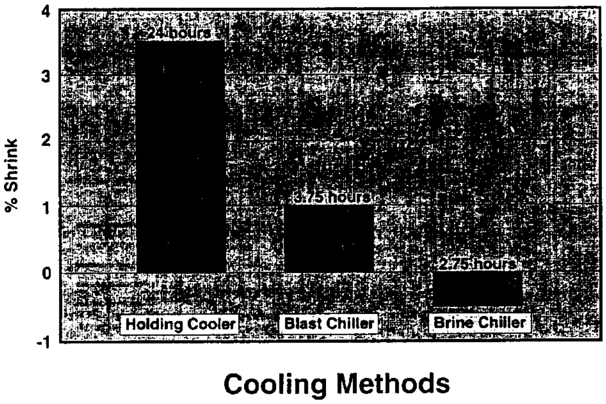
The holding-cooler hams had the highest cooler shrink at 3.5%, followed by the blast-chilled hams at 1%. In the brine chiller, the hams actually gained weight (+0.5%) by absorbing brine. However, most of this absorbed brine was subsequently lost by drip-off and evaporation while tempering in a holding cooler. The net cooler-shrink for the brine-chilled hams was therefore approximately 0%.

Fellows (1988) stated that high-velocity air causes faster drying rates than low-velocity air. Accordingly, since the blast chiller had a higher air velocity that the holding cooler, it theoretically should have caused more drying and a higher cooling shrink. As shown in Figure 5, however, the cooling shrink was lower for the blast-chilled hams than for the holding-cooler hams. The faster cooling of the blast-chilled hams most likely caused this apparent contradiction. As the product surfaces cooled, the moisture would have evaporated less readily from the blast-chilled product. Therefore, the faster cooling of the blast-chilled hams would have made them less prone to evaporation for much of the cooling process, resulting in a lower cooling shrink.

FIGURE 5.

Cooler Shrink Comparisons

Retail Hams, Permeable Casings



Continuous Processing

Converting from batch to continuous processing generally results in major reductions in product variation. Many of the sources of batch oven variation listed in Table 2 are reduced or eliminated in continuous systems.

The conveyer designs in continuous systems inherently eliminate variation in one or more of the batch oven dimensions — front-to-back, side-to-side, or top-to-bottom.

For example, a "tunnel" continuous system for small sausages is shown in Figure 6. In this system, a chain conveyer carries sausages through the oven from front-to-back — eliminating front-to-back variation.

A "horizontal-serpentine" continuous oven for small sausages is shown in Figure 7. In this system the conveyer turns back on itself as it carries the product through the oven — eliminating front-to-back and side-to-side variation.

A "vertical-serpentine" continuous oven is shown in Figure 8. The conveyer in this system carries the product up and down through the oven — eliminating front-to-back and top-to-bottom variation.

Continuous systems reduce or eliminate many other sources of variation found in batch ovens and coolers. The following sources of batch oven variation (Table 2) are reduced or eliminated by continuous systems:

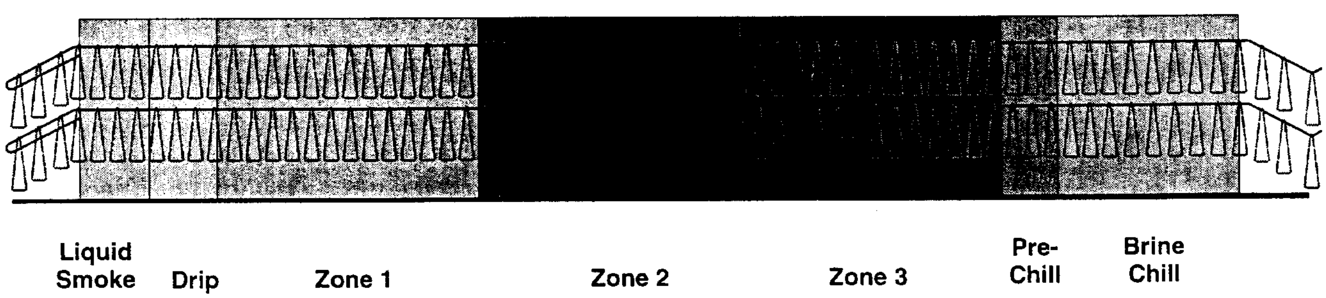
- Differences among multiple ovens of different designs, dimensions, and ages
- Differences among operators for different ovens over multiple shifts
- Differences in operator training and experience
  - For these first three bullets, continuous processing reduces variation because similar products all go through the same continuous oven, eliminating variation due to multiple ovens and operators.
- Inconsistent loading practices
  - Fixed loading positions on continuous conveyers reduce variation by forcing proper and consistent product spacing.
- Variable lag times between cooking and cooling
  - In continuous systems, variable lag times are eliminated because products are chilled immediately after cooking.
- Oven maintenance
  - Maintenance is generally better for continuous systems than for batch equipment.
- Optimization of cooking processes
  - Continuous systems are generally designed around optimized processes.
  - Similar products all go through the same continuous process, creating consistent shrinks and quality characteristics.

Because continuous systems inherently reduce or eliminate many sources of variation that exist for batch ovens, product variation is generally much lower for continuous systems than for batch equipment.

Reducing Variation by Eliminating Processes

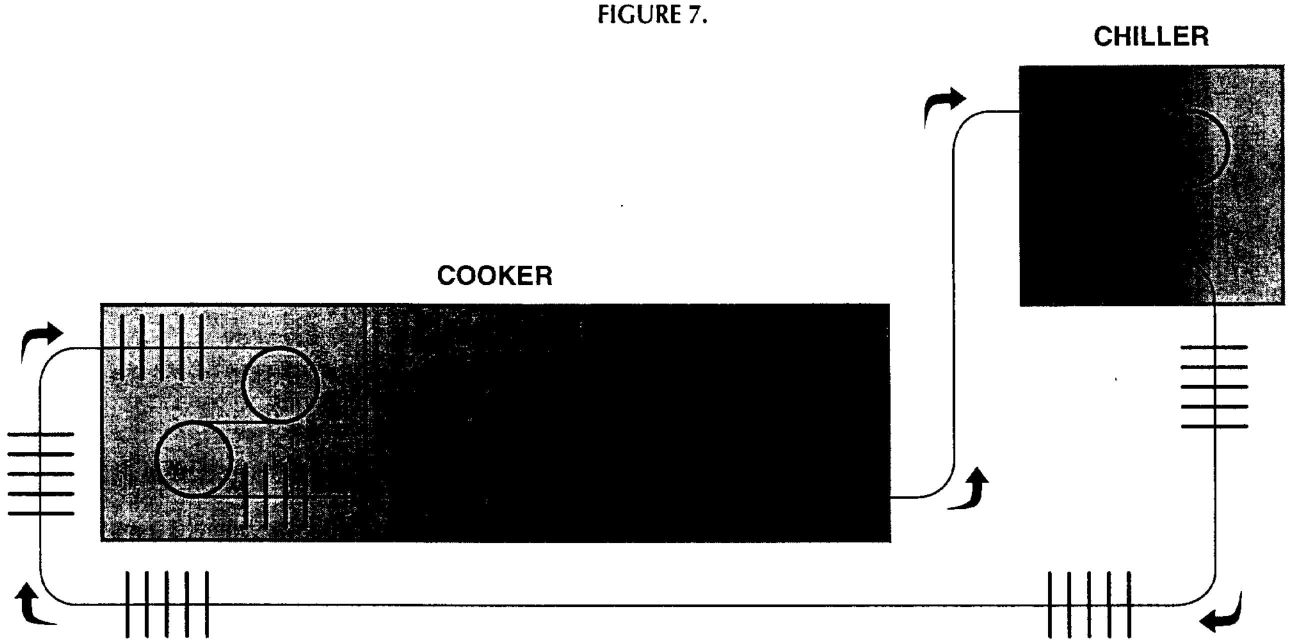
Reducing variation through process improvements is not the only way to reduce product variation. Another method is to eliminate steps within a process or even entire processes. In this way, the variation within a process or process step is not just reduced, it is completely eliminated. This method also simplifies the manufacturing process, making it more consistent and repeatable.

FIGURE 6.



Tunnel Continuous System.

FIGURE 7.



Horizontal Serpentine Continuous System.

Eliminating Processes or Steps in a Process

In evaluating opportunities for eliminating processes, we must ask the question, "Is the process necessary to satisfy a consumer preference, or is it just the way we have always done it?" In other words, do consumers actually want it, or is it just industry tradition?

One commonplace example of a process that was successfully eliminated many years ago is the smoking process for bologna. Although it was once a smoked product, most processors no longer smoke bologna, and consumers no longer expect it to be smoked. Eliminating this process simplified bologna manufacturing and eliminated any variation associated with uneven or inconsistent smoke color.

Another example of eliminating a process is the replacement of conventional smoking methods with pre-smoked fibrous casings. Using pre-smoked casings, the product absorbs liquid smoke from the casings instead of from an external application of traditional or liquid smoke. This method eliminates conventional smoking processes and any smoke color variation associated with those processes.

Microwave Bacon Processing

Newer products such as microwave bacon may hold opportunities for changing or eliminating processes or process steps. Although microwave bacon is manufactured many different ways in the U.S., most processors follow some form of the following procedure:

U.S. Bacon Manufacturing Process

1. Inject bellies
   - Usually pump to 110–115% of green weight
2. Smoke and partially-cook bacon in smokehouse
   - Cook to 52–54°C core temperature
   - Shrink to 100–102% of green weight
3. Cool and temper
4. Press
5. Slice
6. Fully-cook slices in continuous microwave

American meat processors often specify a mahogany-red smoke color for bacon after cooking and smoking. If the bacon is to be sliced and microwave-cooked later in the manufacturing process, however, the surface color is less important. Strict adherence to a traditional mahogany-red smoke color is probably unnecessary for microwave bacon, and therefore the color specifications could be relaxed. To eliminate the smoking process altogether, liquid smoke could be injected into the product.

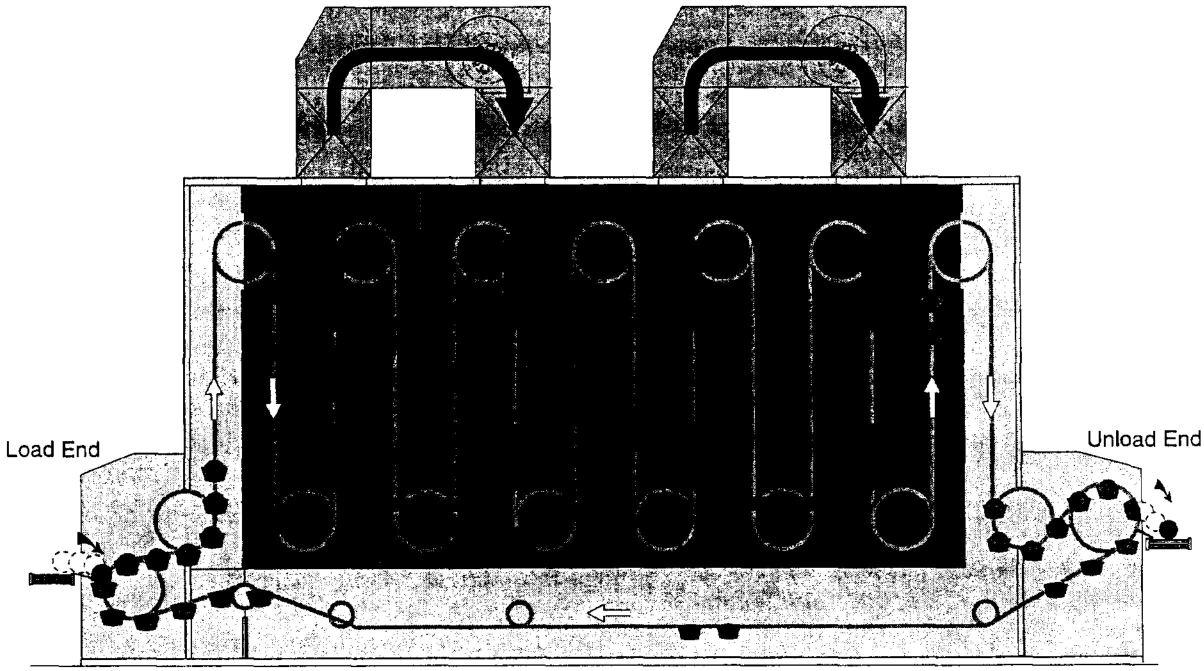
The following example is a microwave bacon production process used in the U.K. that eliminates conventional smoking:

U.K. Bacon Manufacturing Process

1. Inject bellies
   - Inject liquid smoke with brine
2. Steam cook
3. Cool/Temper
4. Press
5. Slice
6. Fully-cook in continuous microwave

For the U.K. process, instead of conventionally smoking the bacon, liquid smoke is injected into the product. Elimi-

FIGURE 8.



Vertical Serpentine Continuous System.

nating the smoking process simplifies the overall process and eliminates any smoke color variation. The bacon is steam cooked instead of ovencooked, thereby reducing shrink variation. Finally, because the new process is much shorter than a conventional one, it would be more readily converted from a batch to a continuous process. Continuous processing would further reduce product variation.

This U.K. bacon process is a useful example of reducing variation through process changes and improvements. Nevertheless, process changes for U.S. meat products must always be evaluated as to product conformance to USDA regulations and labeling standards. The effects of process changes on product quality must also be evaluated.

Rapid Smoking of Precooked Meat Products

The conventional smoking processes commonly used for precooked products such as molded hams and turkey breast could be simplified to save time and reduce variation. For example, in a conventional process for smoked turkey breast, the deli-breast is steam cooked and then smoked using the following procedure:

Conventional Smoking Procedure for Precooked Turkey Deli-Breast (3.5–4.0 kg)

1. Steam cook turkey breast in plastic film
2. Strip fully-cooked products out of plastic film and place on racks
3. Load racks into batch ovens
4. Smoke using a traditional- or liquid-smoke process
   - Process time = 2–6 hours
5. Move racks from oven to air cooler
6. Cool to less than 4°C core temperature
7. Package

This conventional smoking process is necessary to produce smoked turkey breast, but it also causes cooking and cooling shrink along with color and shrink variation.

Replacing this conventional batch process with a continuous rapid-smoking process would eliminate several process steps, reduce shrink and shrink variation, and improve color uniformity. The following rapid-smoking procedure has been used for precooked turkey breast:

Rapid-Smoking Procedure for Precooked Turkey Deli-Breast

1. Steam cook turkey breast in plastic film
2. Strip fully-cooked products out of plastic film and load onto continuous oven conveyer
   - Shower product with liquid smoke at entrance to oven
   - Dry product in oven for 10–15 minutes using high-velocity air at 65°C to develop smoke color
   - Product automatically unloaded
3. Package
4. Cool to less that 4°C core temperature

The rapid-smoking process is shorter, simpler, and more consistent than a conventional process. The continuous process reduces the shrink and shrink variation inherent in batch processes. Color uniformity is improved because all product is run through the same continuous oven instead of multiple batch ovens. Finally, packaging the product before cooling eliminates cooler shrink and shrink variation.

Key Points for Reducing Process Variation

The key points for reducing process variation are summarized as follows:

- Eliminate processes and process steps where possible
  - Consumer preferences, not industry tradition, should guide the evaluation of process changes and improvements
- Replace existing processes with less variable ones
  - Use steam or hot-water cooking where possible
  - Replace conventional smoking with new pocess innovations such as rapid- smoking or pre-smoked casings
- Optimize cooking, smoking, and cooling processes to reduce variation
- Train operators and production supervisors to understand the sources and cost of product variation, and how to reduce it
  - Uneven operator experience and training often cause load-to-load variation among ovens
- Conduct regular oven maintenance and calibration
  - Out-of-calibration control systems and irregular oven maintenance commonly cause product variation
- Evaluate new equipment options
  - Understand how oven and cooler designs can be used to reduce variation
  - Convert from pneumatic to electronic oven controls
  - Convert from batch to continuous ovens wherever justifiable
- Consider cooling as part of the process
  - Rapidly cool products after cooking
  - Water shower products before moving into air coolers
  - Use non-shrink cooling methods such as brine chilling when possible

Conclusion

Product variation is a huge cost to the meat industry. Reducing variation is therefore essential to achieve our common goal of manufacturing consistent-quality meat products at the lowest possible cost.

To reduce variation, we must first identify the sources of variation within manufacturing processes — in other words, find the holes that need fixing. Process improvements and changes can then be evaluated and implemented. New manufacturing techniques can also be used to simplify processes and to eliminate some sources of variation altogether. In the end, reducing variation will enable us to drive down costs and make it easier to manufacture products right the first time and every time.

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