Ready to Eat and Shelf Stable Products
Process Familiarization

Many processors combine nonmeat ingredients and raw meat or poultry for further processing into Ready to Eat (RTE) or shelf stable (SS) products. This module reviews important process steps and factors that must be controlled to meet standards for safety and product identity.

Objectives

1. Define Ready to Eat
2. Define Shelf Stable
3. Identify process steps that relate to the safety of fully cooked-not SS, heat treated-SS, and not heat treated-SS products
4. Identify factors requiring control at key process steps to meet standards for safety and product identity

Introduction

This module covers common processing steps for products in the following HACCP processing categories:

1. **Fully Cooked-Not Shelf Stable.** This category applies to establishments that further process products by using primarily a full lethality heat process step (e.g. cooking) to achieve food safety. The finished products are not shelf stable and must be frozen or refrigerated for food safety purposes. These products also **meet the definition of Ready to Eat** as defined in 9 CFR 430.1.

   Ready to Eat (RTE) product is a meat or poultry product that is in a form that is edible without additional preparation to achieve food safety and may receive additional preparation for palatability or aesthetic, epicurean, gastronomic, or culinary purposes. RTE product is not required to bear safe-handling instructions or other labeling that directs that the product must be cooked or otherwise treated for safety, and can include frozen meat and poultry products.

2. **Heat Treated-Shelf Stable.** This category applies to establishments that further process by using a heat treatment processing step to achieve food safety in combination with curing, drying, or fermenting processing step to achieve food safety. The finished products are shelf stable and not required to be frozen or refrigerated for food safety purposes.

Shelf Stable (SS) product is free of microorganisms (pathogens and spoilage) capable of growing in the product at non-refrigerated conditions at which the product is intended to be held during distribution and storage.

3. **Not Heat Treated-Shelf Stable.** This category applies to establishments that further process by curing, drying, or fermenting processing step as the sole means by which product achieves food safety. Establishments in this category may apply a low-level heat treatment as long as the heat treatment is not used as means to achieve food safety. The finished products are shelf stable and not required to be frozen or refrigerated for food safety purposes.

Fully Cooked-Not Shelf Stable Example: Hotdogs

One of the major product groupings under the Fully Cooked-Not Shelf Stable category is cooked sausages. There are many different types of cooked sausages. Some common examples are bologna, cooked salami (a.k.a., cotto salami), polish sausage, and hotdogs. Let's take a closer look at hotdogs as an example of how these products are produced.

The first steps are meat and/or poultry, other ingredients, and packaging materials are received and stored in the establishment until ready to use. Many establishments carefully control the quality of the incoming ingredients through purchasing specifications. Meat ingredients may have quality specifications such as percent fat, moisture, and protein. These are parameters that will affect the final quality of the product.

Raw meat ingredients used in these products will depend on the type of finished product desired. Not long ago, most hotdogs were either a combination of pork and beef, or they were all beef. Today, establishments still make these products, but many more combinations of ingredients are used. Many formulations include at least some ***poultry*** products (turkey or chicken), and some products are made exclusively with poultry.

The first step in the formulation process is weighing or measuring the meat and/or poultry ingredients. They are ground and mixed or blended with the non-meat ingredients. Often establishments will ***pre-blend***, that is, they will grind and mix the meats with water and salt, and sometimes with the nitrite, and let it stand for a period of time in a cooler.

Antimicrobial agents, are substances such as acetates, diacetates, and lactates, added to an RTE product to reduce or eliminate a microorganism, including a pathogen such as *L. monocytogenes*, or suppress or limit growth of *L. monocytogenes* in the product throughout the shelf life of the product.

Binders and extenders, such as dry milk powder, cereal flours, and soy protein, have a number of uses in a sausage formulation. They increase the overall yield, improve binding qualities, and add certain flavor characteristics.

Cure. Meat is cured with the addition of nitrite or nitrate, usually sodium nitrite, often added in a salt and cure mixture. When nitrite is added to the meat mixture it combines with the meat pigment, myoglobin, to form the characteristic pink-red color of cured meat.

Cure accelerators, such as ascorbates and erythorbates, are used to speed up the curing process. They also stabilize the color of the final product.

Phosphates are used to improve the water-binding capacity of the meat, and contribute to the flavor and color of the product.

Spices and flavorings are used to add flavor to the sausage. The wide range of available spices, seasonings, and flavorings is a primary reason for the variety available in sausages in the marketplace.

- **Spices** are any aromatic vegetable substance that is intended to function as contributing flavor to food, rather than as a nutritional substance. The active aromatic or pungent properties of spices that contribute the most to the flavoring effect are present in the volatile oils, resins, or oleoresins of the spice. Spices may be used whole or ground. White pepper, paprika, and nutmeg are common spices used to produce the characteristic flavor of the hotdog. Because paprika also adds color and makes meat look brighter red, it must be listed as “paprika” on labels.
- **Flavorings** are substances that are extracted from a food, and contribute flavoring, such as spice extracts.

After the non-meat ingredients are blended with the ground meats, the mixture is ***emulsified***. This is done in an emulsifier, and further reduces the size of the meat particles to achieve a very fine texture. Fat, protein, salt, and water are mixed and combined into a semi-fluid emulsion. The meat muscle protein, myosin, is ***solubilized***, or released from the muscle fibers. The solubilized protein and water combine and surround the fat globules, and suspend the fat particles within the mixture.

Careful control of the amount of each ingredient is essential to the quality of the final product. The manufacturer must select a mix of raw meat materials with the appropriate binding characteristics. Different meats vary in their ability to bind. Lean beef, for example, bull, cow, and shank meat, has high binding ability. Regular pork or beef trimmings with more fat, and poultry, have medium binding ability. Low binding meats contain high levels of fat, such as jowls and briskets. Organ meats have no binding qualities.

After emulsification, the mixture (or “batter”) is ***stuffed*** into casings, usually artificial plastic casings that allow moisture to cook out and smoke flavors to penetrate. Natural casings such as sheep small intestines may also be used.

Following stuffing, the product is ***linked*** by pinching and twisting the casing to form separate units of sausage. The sausages are still held together by the casing. These lengths of casings are then placed on racks or trees, and are ready to be loaded into the smokehouse. Some establishments load trees into individual smokehouses, however, some large volume establishments use continuous smokehouses.

The smokehouse parameters that must be controlled are temperature, time, and humidity. Although other documentation can be used to support the adequacy of the cook step, many processors follow the parameters in Appendix A. The product must be exposed to a high enough temperature in order to produce a fully cooked, ready-to-eat product. The temperature inside the smokehouse, and the internal temperature of the sausage, may be monitored by the establishment in order to verify that the critical limits are met. Cooking is a very important step, because it is here that any pathogens (e.g., *Salmonella*) that may be in the product will be eliminated and the numbers of spoilage bacteria will be lowered to an acceptable level. This is called a ***lethality*** treatment.

After product has reached the final temperature desired, the cooling process begins. Many processors use Appendix B to support that their cooling process will prevent pathogen growth. This product is often showered with cold water inside the smokehouse. This removes some of the heat from the product, and immediately halts the cooking process. The shower is usually not sufficient to complete the cooling process. Usually product is moved to another chiller or cooler to finish cooling. Some establishments use very cold water as a chilling medium, sometimes with salt added to lower the temperature below the normal freezing point of water. This is called a ***brine chiller***. Other establishments may use cold air, and some use a combination of methods.

The cooling process is also known as ***stabilization***. There are two types of bacterial contamination that must be addressed by the stabilization process.

- **Spore-forming bacteria** (*Clostridium perfringens* and *Clostridium botulinum*) **can survive cooking** when in the heat-resistant spore form, and these organisms need to be considered as the products are chilled. Growth (sometimes referred to as **“*outgrowth*”**) of these bacteria is slowed by rapid cooling. Cooling rates, or time/temperature relationships, must be carefully controlled in order to ensure that product does not remain at warm temperatures that would support the outgrowth. Excessive dwell time in the range of 130° to 80°F is especially hazardous, as this is the range of most rapid growth for the Clostridia. Therefore cooling between these temperature control points should be as rapid as possible.

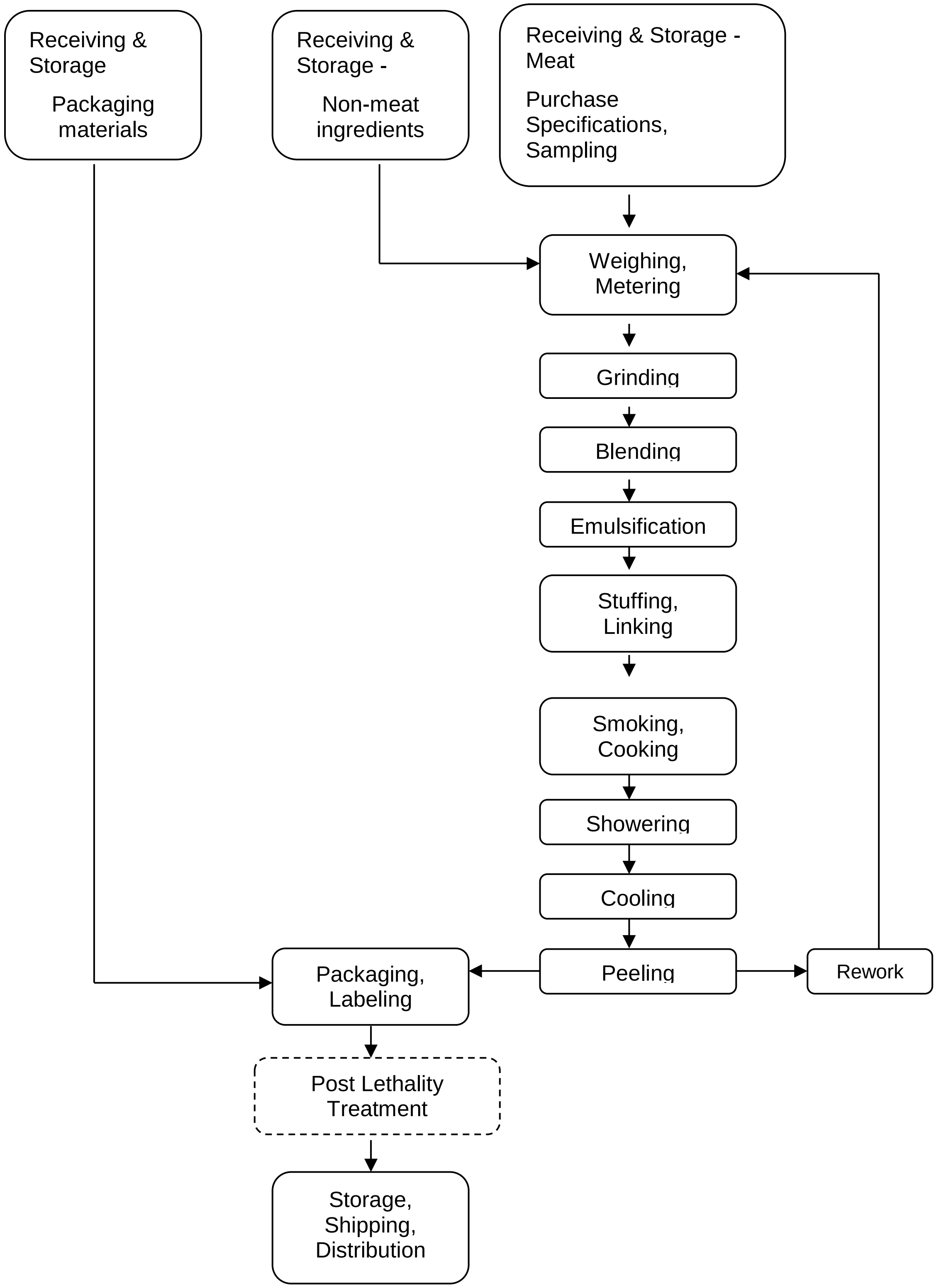
- **Recontamination with bacteria** must be considered as cooked products are exposed to the environment, food contact surfaces, or cross-contamination with raw product prior to final packaging. Proper chilling and cold storage temperatures limit the growth of most pathogens. However, *Listeria monocytogenes* can grow at temperatures above 31°F. Therefore, establishments must follow effective sanitation programs in the post-lethality processing environment to prevent contamination. Some establishments include a validated, post lethality treatment (e.g. steam pasteurization) in their process to eliminate Listeria should contamination occur.

After product has been chilled to the desired temperature, it is removed from the artificial casings in a machine called a **peeler**. This equipment quickly runs the sausage through a tunnel that has a tiny blade that slices the casing. Steam or air is then used to blow the casing away from the sausage. The sausage links are now separate. If you closely examine the outside of a hotdog, you might see where the casing had been cut. This blade is a potential source of contamination, since it contacts every hotdog!

Sometimes a product that has partially or fully completed the production cycle is not salable but is still wholesome, and can be used for food. For example, the casing of some sausages may split during the cooking or smoking cycle. Manufacturers may reuse these edible but unsalable products by removing the casing and adding the contents to the grinder to include in another run of the same product. This is called ***rework***. Since the proteins are coagulated from cooking, rework has no bind capabilities. Of course, the ingredients of the rework must be compatible with the ingredients of the batch to which they are added for labeling purposes.

The final steps are packaging, labeling, and storage. The product is ready for distribution to retail stores, restaurants, or institutions.

Fully Cooked-Not Shelf Stable Flow Chart: Hotdogs



Heat Treated-Shelf Stable Dried Whole Muscle Meat Snacks Example: Jerky

This product category consists mainly of sliced whole muscle beef jerky and similar whole muscle meat snacks such as beef nuggets, steak tenders, or other such named products that consist of predominantly whole muscle tissue. FSIS published updated jerky compliance guidelines in 2012. The new guidelines replace all previous versions.

A variety of other meat snacks such as meat sticks, kippered beef, and assorted chopped and formed or ground and formed products are manufactured similar to sausage-type products. These can be considered a type of dried fermented or non-fermented sausages where manufacturing differences are particle size and final product form (round, flat, etc.).

Shelf stable dried meat snacks have a low moisture content (22-24%) and low water activity. A water activity limit of ≤0.85 should control growth of all bacterial pathogens of concern as well as mold for products stored in the presence of oxygen; however, if the product is vacuum packaged in an oxygen impervious packaging (anaerobic environment), the water activity limit could be ≤0.91. These limits are based on the growth and toxin production limits for *Staphylococcus aureus.* Product labeled as "jerky" must meet the standard of identity which specifies a moisture protein ratio of 0.75:1 or less.

Vacuum packaged products with a water activity level > 0.85 and ≤ 0.91 should be kept refrigerated once the package is opened because the product would no longer be considered shelf-stable once it is exposed to oxygen. Unless the establishment has support that the product is likely to be consumed in a single serving, these products should be labeled with a statement such as "Refrigerate After Opening"

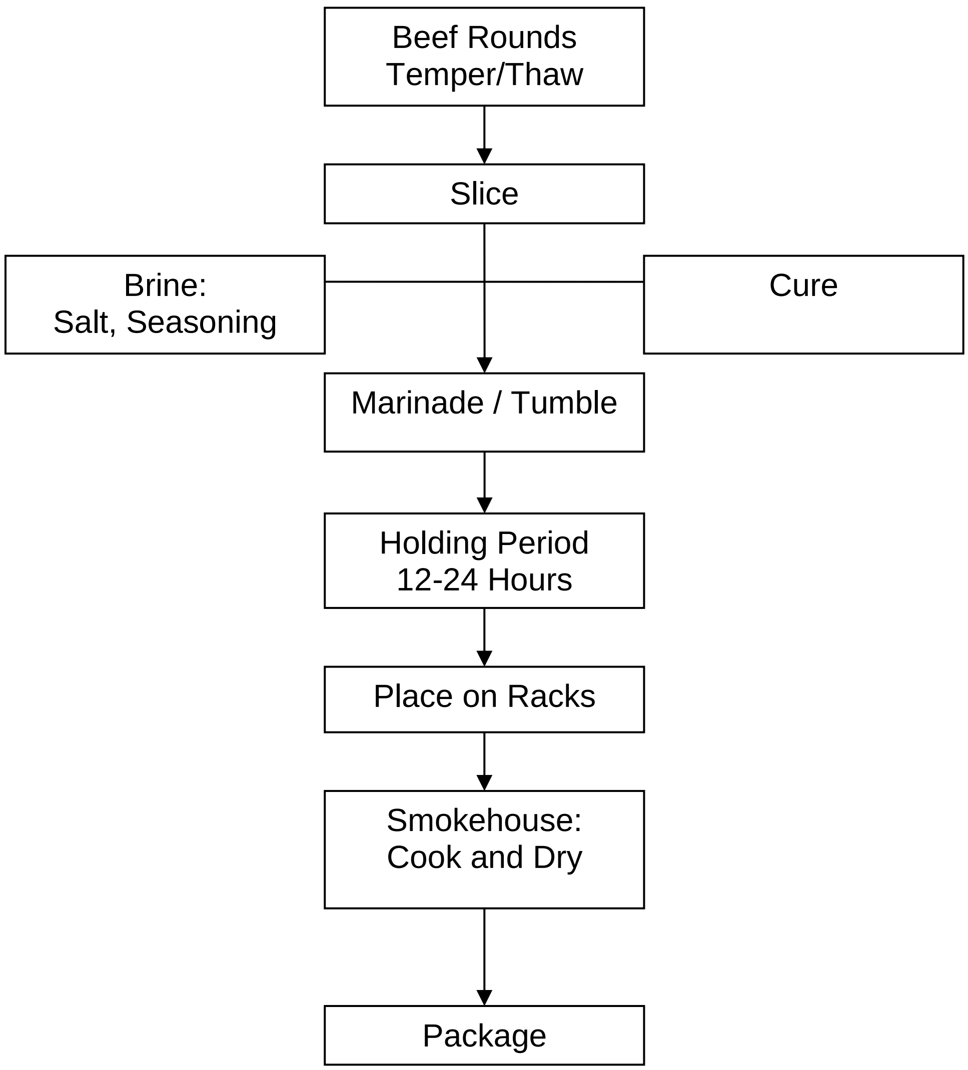
Whole muscle beef jerky products are manufactured by pickle curing the meat in either the whole original piece (e.g., beef rounds) or first slicing, and then curing/marinating the individual slices. For that latter case, the raw beef round is first sliced, the slices then tumbled with the brine, cure and spices (optionally marinated slices are held overnight), and placed on screens for subsequent smoking, cooking and drying. This process is used more often with smaller jerky producers.

Larger producers of whole muscle beef jerky generally inject whole beef rounds with brine containing the salt, cure, spices, any preservatives, and often some percentage of ground meat. Ground meat injection is permitted up to a certain percentage and requires special equipment. The ground beef is less expensive and also serves for better bind and more desirable final meat texture (i.e., softer). After injection, the injected rounds (often 35-50% injection) are tumbled and held for a defined period before slicing and placing on screens for smokehouse smoking, cooking and drying.

A typical beef jerky process would consist of first preparing the brine solution with salt, ground beef, seasoning, and cure, followed by injection, tumbling, slicing and smokehouse processing (with 90% relative humidity) as follows:

135°F (57.2°C)	0.5 hour
150°F (65.6°C)	0.5 hour
170°F (76.7°C)	Time to reach a 160°F (71.1°C) internal temperature and water activity of 0.85 (or other validated a_w)

Heat Treated-Shelf Stable Process Flow: Whole Muscle Jerky



Heat Treated/Not Heat Treated-Shelf Stable
Example: Dried Whole Muscle Products

Dried whole muscle products are mostly dry cured. This product category includes the familiar dried hams, such as prosciutto, Parma and country ham, but also other dried intact pieces of meat such as dried pork bellies (Pancetta), dried pork shoulders (coppa), and dried beef rounds (bresaola, beef prosciutto, basturma). The primary considerations in producing these products are that

- Larger pieces of meat result in slower salt and cure penetration.
- It is preferable to use raw meat materials with pH < 5.8.
- Meat final pH is generally higher than with fermented products.
- Salt extraction at the surface should be minimized.
- Microbial action occurs at the surface only, as the internal tissue is sterile.
- Starter cultures are sometimes added to enhance color, flavor, and preservation, and are mostly non-fermentative.
- Distribution of non-meat ingredients into the meat tissue is through osmosis.

An initial process for manufacturing whole muscle products consists of dry mixing the non-meat ingredients with the meat, pickle curing by immersing the meat pieces in concentrated brine, or injection curing by injecting the brine. Injection curing is less common since the water in the brine must be later removed during drying. After the initial salting, the product is held for some period of time at refrigeration temperatures for salt and cure penetration (“burning” period). The product undergoes a maturation period, air drying and smoking (if desired), and storage. The final product is either then sliced and packaged for sale, or sold in the whole piece form for slicing by the final customer.

►Dry Curing

The most common salting/curing process for dried whole muscle meats is dry curing; often this class of products is referred to as “dry cured” whole muscle meats. The first step in the dry curing process is mixing the meat pieces with the salt and the other curing mixture. Sometimes spices, sugars and starter cultures are added at this initial step or they can be added later in the re-salting process or immediately prior to the forming. In the very traditional Italian Prosciutto products, no cure (nitrate or nitrite) is added. More modern processes – particularly “American style” products – use nitrate and nitrite. During this initial salting of the product, it is critical to completely cover all the surface area with salt, because the high salt level and the colder temperatures are the only measures protecting against the growth of spoilage and pathogenic microorganisms. Sometimes the salting process for smaller, more uniform, meat pieces is completed with mechanical agitation. For larger hams the salting is done by hand to prevent product tissue damage. For some products the bone is removed prior to salting, while for others it is not. If tumbling is utilized, only a minimal schedule is employed to minimize excessive protein extraction. For most "American style" Prosciutto, the bone is removed and the product is tumbled for the salting process.

During dry curing, moisture migrates from inside the tissue to the surface due to osmotic pressure with the higher salt concentration at the surface. The salt and cure migrate into the tissue due to osmotic pressure. This is a relatively slow process and temperatures must be below 40°F (4.4°C) to minimize microbial growth until the salt percentage is high enough to inhibit many of the spoilage and pathogenic microbes. The salted meat pieces are packed in curing containers that allow draining of the meat juices as the moisture migrates out of the tissues. Some products are shaped or formed at this stage, but generally this shaping takes place after the later salting occurs. During the salting process, the products may be re-salted several times as the added salt migrates into the tissue. Generally, the addition of spices occurs after the last re-salting has been completed.

►Pickle Curing

Although most hams are dry cured as above, some products referred to as "dry cured" do employ a concentrated liquid brine (10-20% salt) in which the meat pieces are immersed for some time to allow for uniform salt distribution in the tissue. This brine can also contain the cure, spices and, possibly, a starter culture, or these ingredients are added after the salting stage. The principles of pickle curing are the same as with dry curing, except that liquid brine is used. The product cannot be shaped or formed, although this is not necessary at this stage for some products. Products such as pancetta, when brine cured instead of dry cured, are rolled as whole pork bellies after the brining step.

►Injection Curing

Although not common for whole muscle shelf-stable meat products, this process injects the curing ingredients directly into the meat muscle by random injection or artery injection directly into the blood vessels. This artery injection process is most often used on very large bone-in hams. Obviously, the injection curing is a faster, shorter process allowing for rapid salt and cure diffusion throughout the tissue; however the water for the injection medium must be removed during the drying cycle.

►Burning

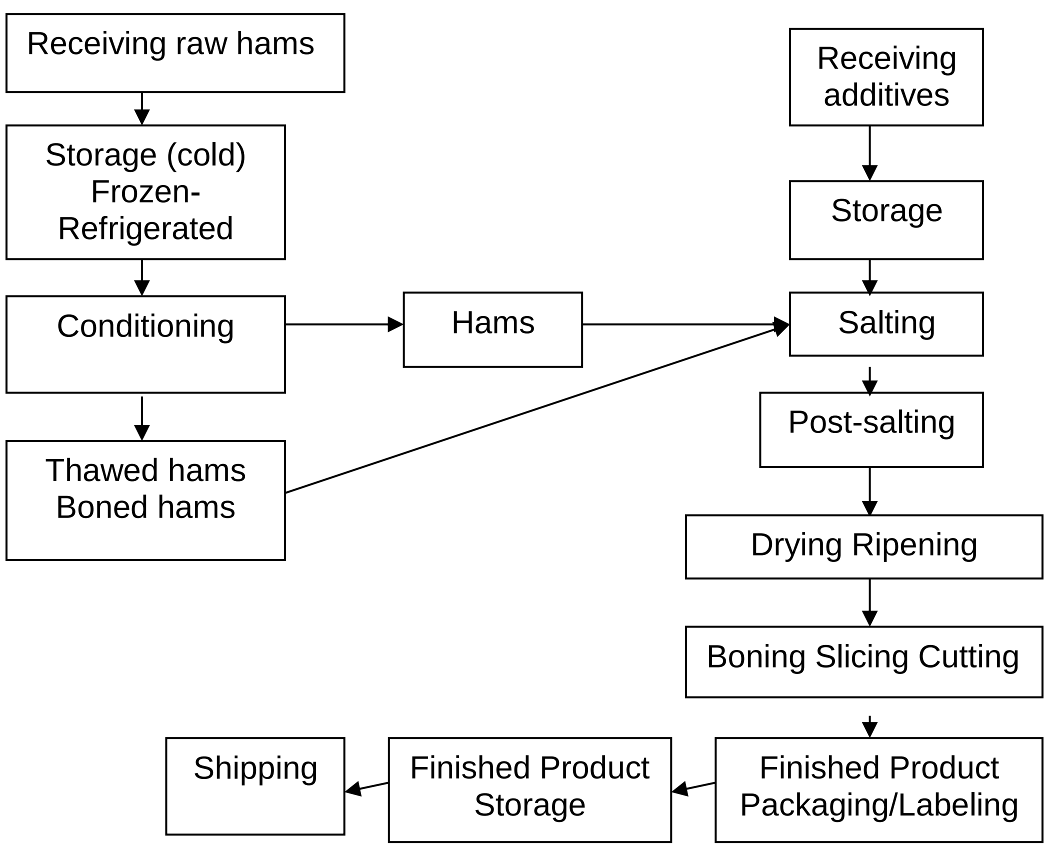
After the salting stage, the product enters the "burning" stage. At this stage the product is held at low temperatures (<40°F (4.4°C)) for many days to allow for sufficient salt penetration and equilibration. The goal is to eventually lower the water activity sufficiently to inhibit microorganisms to a point at which the temperature can be elevated. This period often takes many weeks to achieve uniform salt distribution to greater than 4.5% with a water activity below 0.96.

Excess surface salt may be removed during this period and only moderate air circulation is desired to avoid surface drying. Some processors may apply a soft fat to the cut surface of the lean tissue to avoid this drying.

►Ripening

At this stage in the process, the whole muscle product should be microbiologically stable due to salt content and lower water activity. The ripening stage varies widely in terms of temperature, time and optional smoking cycles. During this stage, the products are held at elevated temperatures for drying and flavor development. Long matured hams are held at 59-65°F (15-18.3°C), while short matured hams can be held at 75°F (23.9°C) or higher for shorter periods. During these periods at higher temperatures, the humidity and air circulation is lowered, with further moisture loss. This final step in the process can be from 3 to 12 months in duration.

Not Heat Treated-Shelf Stable Whole Muscle Flow Diagram: Dry Cured Ham



Heat Treated/ Not Heat Treated-Shelf Stable Example: Fermented Dry Sausage

Dry and semi-dry sausages are possibly the largest category of dried meats, particularly in the United States. These products can be further categorized as fermented, acidified with chemical acidulants, or non-acidified. They are, with a few exceptions, generally cooked.

►Fermented Dry Sausage

Fermented dry sausage basically is manufactured by tempering and breaking the raw meat materials; formulating the meat with added cure, starter culture, salt and seasoning mixture; stuffing the product into casings, fermenting, heating, smoking (optional), and drying.

The key considerations for manufacturing fermented dry sausage are as follows:

- Sausage will require 30-40% moisture loss.
- Fat smearing over lean tissue should be minimized to enhance moisture loss and product definition.
- Raw meat mix should be approximately 25-28°F (-3.9 to -2.2°C) when combined.
- Meat mix temperature at stuffing should be 25-30°F (-3.9 to -1.1°C).
- Meat visual defects (e.g., blood clots) should be minimized, since they are magnified with drying.

Formulation and Blending

During formulation, it is important to form a “meat matrix” consisting of lean and fat particles bound together by salt soluble meat proteins. Initially, the meat mixture consists of soft particles, but with the addition of salt, the salt soluble proteins dissolve and provide the “binding” material necessary. When the product is stuffed and fermented, the resulting acid denatures the mixture, which results in increased firmness. If further heating occurs after fermentation, the added heat adds to the firmness and initially accelerates the drying process. If not heated above fermentation temperatures, the product proceeds to the drying stage, which increases firmness with the corresponding moisture loss. The acid coagulation is an irreversible process, thus the product needs to be in the final shape desired prior to this denaturation. For dry sausages, this initial matrix formation needs to occur to some limited extent, but excessive matrix formation (excessive protein extraction) leads to fat and protein smearing. If insufficient matrix formation occurs due to premature acidification, lack of salt, too low temperatures and/or insufficient mixing, the resulting product will be “shorted” (insufficient bind, mushy texture).

In dried, fermented sausages the first steps in production are the size reduction of the meat tissue and the preparation of the non-meat ingredients. The raw meat materials often are frozen, so the meat blocks must be tempered to the desired temperature, and then reduced in size by frozen block grinders, hydraflakers and/or chopping in a silent cutter. Fresh meats must also be chilled to lower the temperature prior to size reduction; they are often used in combination with frozen materials (or addition of carbon dioxide) to control meat mix temperature.

Non-meat ingredients such as the cure mix, seasoning mix (with or without salt), and starter culture are either weighed according to the batch size or are provided by the vendor in unit packs corresponding to the batch size. The starter culture is either added directly, if using a dry culture, or diluted in water first to afford good distribution of a frozen culture. The sausage casings are also hydrated to afford flexibility, if provided in flat stock, or are added to the stuffing horn directly if shirred. Often potassium sorbate is added to inhibit mold growth.

The initial size reduction is very coarse to afford uniform mixing or chopping with the other ingredients, but after formulation the product is re-ground to achieve the final fat particle size for visibility. This product definition is also dependent upon the equipment used and meat mix temperature. Sometimes the product is final ground prior to formulating with the other ingredients.

Generally, prior to the addition of non-meat ingredients, the meat blend is analyzed for fat, and possibly moisture and protein content, to allow for adjusting the blend to the desired formulation. The meat mix may contain various meat types at various temperatures to afford the desired characteristics of the final product and to afford the desired temperature of the total mix prior to stuffing.

If a mixer is utilized, a paddle type mixer is preferred due to less smearing of the meat mix. After the meats are formulated, the non-meat ingredients are typically added in the following order: the cure mix, seasoning mix, and the starter culture. Minimal mixing time is recommended to uniformly mix the ingredients but not to over work the mix. Vacuum mixing is optimal but not necessary if using a vacuum stuffer. Some smaller processors historically use a silent cutter or chopper for both size reduction and mixing, but this type of equipment is very operator dependent. After mixing, the product is transferred to the stuffing apparatus. Any product transfer should minimize piping and pumping, with a conveyor system preferred, again to minimize “working” the product. After mixing, some processors may final grind the product prior to stuffing, which also allows use of a bone collector device.

Stuffing

The stuffing apparatus is usually a screw type, piston, or chamber device. During the stuffing phase, it is important to maintain cold temperatures and avoid fat and protein smearing. This is accomplished also by minimizing resistance to the meat mix flow; for example, using the largest stuffing horn possible to fit the casing and using flat stock casing instead of shirred casings. Usually, a vacuum stuffer is employed, which removes oxygen, providing for better curing and concentrating the product going into the casing. For most dried fermented sausages, fibrous, collagen or natural casings are utilized.

At this point, the meat mix is in the casing. Excessive fat smearing will breakdown fat, enhance oxidation and retard drying. Oxidative rancidity is degradation associated with oxygen in the air. Oxidation occurs primarily with unsaturated fats. Degradation of fatty acids produces volatile compounds that cause off-odors and flavor changes. Inadequate drying may result in high water activity in the finished product. Fat smearing is usually visible under the casing. Excessive dissolved protein smear results in meat fiber orientation and is the major cause of "cupping" in pepperoni on a pizza.

Fermentation

During the slaughter process, the sterile tissue is often contaminated with Gram-negative (*Enterobacteriaceae*, *E. coli, Salmonella,* and *Pseudomonas)* and Gram-positive (lactic acid bacteria, staphylococci, and micrococci) bacteria. Uncontrolled, fresh meat spoilage is usually caused by Gram-negative, proteolytic bacteria that decompose the protein and produce offensive odors (putrid, rotten egg) and flavors.

Salting, curing, and drying the fresh meat are effective ways to control the fresh meat microflora and preserve the meat. Curing salts (sodium chloride, sodium nitrite, sodium nitrate) and proper handling methods favor the growth of Gram-positive bacteria while inhibiting the growth of Gram-negative bacteria. This change in the typical microflora that allows Gram-positive bacteria to prevail is called "microbial inversion."

Today, over 95% of fermented meat processors use commercial starter cultures. A wide variety of starter cultures may be selected for flavor and color development and for stability (nitrate reduction, oxygen scavenger). Starter cultures may come in several forms including: frozen liquid or pellets, dry (freeze-dried) cultures, or frozen "syrup." Meat cultures are alive and need to be handled appropriately to ensure they do not lose viability and activity.

After stuffing, fermentation can be accomplished in an environment that provides the necessary temperature and humidity (e.g., smokehouse, fermentation chamber). At the proper temperature, the lactic acid bacteria in the starter culture metabolize or ferment a source of sugar (usually dextrose) and produce lactic acid. This controlled method of spoilage results in a “tangy” flavor that many consumers find pleasant to the palate. The lactic acid also lowers the pH which helps with drying the meat.

Growth of *Staphylococcus aureus* during fermentation is a hazard in dry, fermented sausage. It is critically important to monitor the fermentation for the proper conditions and product pH. The fermentation process must be controlled such that a pH of 5.3 or less is reached within a time temperature combination that controls growth of *S. aureus* and development of its heat stabile enterotoxin. Depending on the room temperature maintained during the fermentation process (64-100°F), the time it takes to achieve a pH of 5.3 varies (36-7 hours). As fermentation progresses, staphylococci gradually die off and lactic acid bacteria prevail. This change in the microbial flora is called “microbial succession.” Any monitoring of coagulase positive staphylococci should be done on product at the end of the fermentation cycle and before heating. If done following heating, the Staph organisms may be killed, but the heat stabile enterotoxin may still be present.

Note: In order for *S. aureus* to cause food poisoning, it must be allowed to grow to the level of 1 million cells per gram of meat and then produce the heat stable enterotoxin. Proper temperature and sanitation controls prevent the growth of *S. aureus* to this level. Once the pH reaches 5.3 or lower, *S. aureus* growth is inhibited.

Relative humidity is extremely important to all dried meat processing because of its impact on the quality of the product. Relative humidity expresses the degree of saturation of the air by vapor, expressed as a percentage. Relative humidity describes the relation of the existing vapor pressure at a given temperature to the maximum vapor pressure at that temperature. Air at a given temperature can absorb water (vapor) until its saturation (100%). Although now we have humidity monitoring devices that give a direct readout of relative humidity, historically processors used dry and wet bulb devices. The dry bulb temperature is the direct temperature readout, while wet bulb is a dry bulb surrounded by a wet sock, providing a lower temperature. The difference between the two readings is used to calculate the relative humidity at that temperature. Charts and on-line calculators are available for determining the relative humidity given the wet and dry bulb temperatures.

A relatively high humidity (85-90%) is preferred to keep the product surface slightly moist, or “tacky,” during fermentation and prior to subsequent drying. This avoids premature and uneven drying at the surface and the humidity enhances the fermentation.

Heating and Drying

As previously mentioned, after fermentation the product can be heated prior to drying, or go directly into drying. If heated, the product can be heated to a variety of temperatures depending upon specific validation parameters or desired final product characteristics. Intermediate heating (120-140°F, 48.9-60°C) or fully cooking (155-160°F, 68.3-71.1°C) both provide a means of destroying pathogens potentially present in meat to achieve the desired destruction. Applying heat to fermented products is not always desirable due to the resulting flavor and texture changes; so many processors have arrived at intermediate heating schedules (time/temperature) that meet both objectives for destroying potential pathogens while preserving desired product characteristics. U.S. processors now must validate their own process for the specific destruction of the relevant pathogens (trichinae, *Salmonella*, *E. coli* O157:H7, *S. aureus*, *Listeria monocytogenes*), either by use of literature studies, by conducting a challenge study, or by relying on FSIS Appendix A: Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products.

The variables during cooking and drying are cooking time, dry bulb temperature (generated by gas, steam coil, or electric heat), wet bulb temperature (natural humidity/fresh air/exhaust, steam injection, atomized water and/or refrigeration), and air velocity. It is very important to maintain uniform conditions during cooking and drying. This is dependent on cooking and drying room design, product loading, product shape and the drying process.

Uniform and balanced air flow is critical. Typical values for fermentation rooms are 4-6 air changes per minute, and less than 2 air changes per minute for drying chambers. Processing ovens should initially be balanced by the manufacturer and periodically checked for uniformity. Ovens with constant airflow from the supply ducts to the return may have temperature variations from top to bottom, side to side, or front to back. Temperature distribution can be determined by placing temperature indicating devices throughout the equipment to locate cold spots and hot spots. Processors must determine the location of cold and hot spots to support product or equipment monitoring procedures. For example, monitoring internal product temperature at the cold spots in the oven could support that all product in the batch was adequately cooked. Not monitoring internal product temperature at the cold spots may result in failure to identify underprocessed product. Some ovens are designed with oscillating airflow to provide more uniform temperature distribution.

Uneven temperature distribution in fermentation equipment may result in some product pieces not achieving a pH low enough to prevent *Staphylococcus aureus* growth and toxin production. Fermentation rates may be slower at the equipment cold spots. Elevated temperatures at hot spots may inhibit or destroy the fermentation bacteria also resulting in failure to achieve a desired pH.

Temperature variation in drying equipment could result in the failure to achieve the target water activity for the finished product.

Product loading is also important to achieve uniform airflow. Uneven loading will result in uneven conditions around the product, regardless of the design of the heating and drying rooms. Improper loading can affect the adequacy of cooking, fermenting, and drying.

Product shape will affect uniform heat transfer. Heat is transferred along the shortest dimension, so naturally shaped products like bacon and bone-in hams will inherently have more temperature variation compared to casing products. Product should be monitored for minimum internal temperature at a predetermined “coldest” spot in the product.

The final drying process is influenced by the previous fermentation and heating processes. Adequate carbohydrate source, the chemical environment, processing temperatures and humidity are the influencing factors during fermentation. During heating after fermentation, the product initially shows fast drying, but subsequently can actually dry more slowly if cooked, due to surface drying and “skin” formation. Finished core temperatures also affect final product texture and appearance, going from more of a “raw” taste and firm bite with definite fat and lean differentiation (final core temperature < 90°F, 32.2°C) to a cooked taste, hard bite, and little fat and lean definition with a fully cooked product (final core temperature > 137°F, 58.3°C).

A cooling step may or may not be employed. A hot shower rinses any residual fat from the surface and can tighten casing onto the product. A following cold shower will quickly reduce surface temperature. Meeting the cooling (stabilization) performance standard to control *C. perfringens* is not needed for this cooling step – the pH of the products is too low for growth at this point. The pH is close to the limit for germination and growth by other sporeformers as well – very limited growth could occur at this point and as the water activity drops in the drying step, sporeformers will be fully controlled.

During the drying process in a dry room, it is very important that the rate of moisture migration from the product center to the surface equal the rate of moisture migration from the surface to the atmosphere. This is more difficult with larger diameter products, and most dry sausages exhibit greater moisture loss at the surface. The controlling factors for drying are temperature, relative humidity, air velocity, and air distribution and direction. If product is dried too fast, case hardening occurs. Case hardening results in voids or pockets in the interior which could lead to bacterial degradation/spoilage. Case hardening also impedes moisture migration so the product may not dry to the required water activity. If product is dried too slowly, mold growth can be a problem. Mold growth is desirable in some products (e.g., Italian salami) for flavor and appearance, but for most processors, mold growth is a problem. In addition to being visibly undesirable, mold growth can increase surface pH, alter flavor and restrict moisture loss. If only sporadic mold growth occurs, it generally is removed at peeling of the casing and slicing.

Smoking

Smoking of the product, whether using either natural smoke or liquid smoke, can produce desirable effects for specific products. Generally, dried meats are characteristically smoked (hard salami) or not smoked (Genoa salami). Smoking provides color (carbonyls + amines + dry heat) and flavor (phenols), as well as antioxidant (phenols) and antimicrobial (phenols + acids) properties to the product. Smoking should not be done while the product surface is still wet due to the resulting dark brown or “muddy” color and potential “streaking” of the color. Generally, smoking is done toward the end of fermentation. Excessive smoke application in the beginning of the fermentation cycle on small diameter product can inhibit the fermentation activity of the starter culture.

Quality versus Safety

In processing dried meats, there are many formulations and processing conditions that can be varied to balance quality and safety. For example, some processors have elected to remove beef from some formulations that contained pork and beef so that *E. coli* O157:H7 is not a consideration. The rate of pH drop and the final pH can affect both the safety and the quality of the final product. In general, a lower pH provides more safety, but the lower pH can adversely impact taste. The degree of heating (none, partial, or fully cooked) is important in safety (more heat provides greater pathogen inactivation) but changes the characteristics of the product. Heat may be needed to obtain appropriate pathogen inactivation. The relative humidity during drying can also impact both product characteristics and safety. Microorganisms have increased heat resistance to dry heat and at lower a_w. A decreased relative humidity may result in pathogens being exposed to a dry heat, which could increase their chance of survival. As noted before, improper air flow can dry the surface too quickly or too slowly, both of which can impact quality of the product.

Fermented Dry Sausage: Pepperoni Formulation and Process

A typical example of a fermented dry sausage formulation and process would be that of U.S.-style pepperoni. The product is formulated to about 28-32% fat (figuring 68-70% final yield) considering a least cost formulation, including predominantly pork with some beef. The maximum amount of beef allowed in product labeled as “pepperoni”, and not “beef pepperoni” is 55%. Generally, most processors use a minimum 60% pork, but can go to as much as 100% pork depending upon market meat prices and if exported. Pork and beef cheek meat is commonly used (lack of bind, high protein) and is allowed as “meat.” Finely textured beef and pork is also allowed and used due to price, but the desired texture and color prevent excessive usage levels.

Non-meat ingredients include:

Salt (bind, flavor, preservative)	2.7-3.5 lb./100 lb. meat
Dextrose (limiting, carbohydrate for starter culture fermentation)	0.5-0.8 lb.
Spices (mustard for flavor)	0.75-1.5 lb.
Natural flavorings (spice extracts for flavor, color)	0.3 lb.
Starter culture (*Pediococcus acidilactici* for high temperature fermentation)	0.5 lb. diluted
Antioxidant (BHA, BHT, citric acid, rosemary)	in flavorings
Cure (nitrite on salt carrier, color, preservative)	0.25 lb.

Typically, the meat is tempered to about 26-28°F (-3.3 to -2.2°C) prior to mixing. The entire meat mix is blended with the cure, flavorings/antioxidants, salt and starter culture. After blending and regrinding, the product is stuffed at temperatures not exceeding 26-28°F (-3.3 to -2.2°C). The stuffed product is fermented at 95-110°F (35-43.3°C), 80-90% RH, to pH < 5.0 (typically 8-12 hours), then heated (to a temperature validated for the appropriate pathogens; e.g., 128°F (53.3°C) internal temperature for 1 hour), cooled and dried (50-55°F (10-12.8°C), 68-72% RH) until moisture/protein ratio reaches 1.6 or less (typically 12 – 14 days). The MPR is used mostly for labeling purposes and has limited use in food safety. A more reliable measure for food safety is the a_w.

►Fermented Semi-Dry Sausages

Summer sausage, Lebanon bologna and Thuringer are examples of fermented semi-dry sausages. These products are manufactured in much the same way as the fermented dry sausages but with a few distinctions. In general, semi-dry sausages, as the name implies, do not lose as much water (10-15% loss) as dry sausages (30-40% loss). The drying occurs during fermenting and cooking, so a specific dry room is not needed. Fat and protein smearing are not as much of an issue due to less moisture loss, so formulation temperatures are higher, in the range of 28-40°F (-2.2 to 4.4°C). Most semi-dry types are cooked following fermentation and exhibit finer grind and lower pH (<4.8). A typical summer sausage process would include a fermentation period of 12-16 hours at 100°F (37.8°C), 98% RH, to a pH < 5.0, followed by a smoking/cooking cycle to a minimum of 140°F (60°C) internal temperature. Many products are shelf-stable, with limiting amounts of added sugars (to prevent secondary fermentation in the vacuum package) and fully cooked to 160-165°F (71.1-73.9°C) internal temperature.

►Chemically Acidified Sausages

Some dried meat products are formulated with chemical acidulants, rather than starter cultures, which accelerate the process by eliminating the fermentation period. These chemical acidulants provide a slower release of the specific acid (as opposed to addition of the straight acid) into the meat mix in order not to result in premature acidulation before the meat matrix is established. These types of acidified, product processes are direct heated and cooked following formulation.

Chemical acidulants can be encapsulated acids or the slow release acid glucono-delta-lactone (GDL). With encapsulated acidulants, the active acid ingredient (e.g., lactic, citric, fumaric, GDL/gluconic acid) generally is encapsulated with fat material that melts at varying temperatures releasing the acid. Thus, acidification occurs during the cooking process after the meat matrix has been established. The rate of acid release is dependent upon the specific particle size, fat coating, temperature, other fats in the formulation, physical processing, and processing temperature.

GDL is a cyclic compound that releases gluconic acid slowly when the GDL is hydrated with the meat moisture. When GDL is added to the meat mix, the product must be stuffed and processed immediately, before significant acid formation. The rate of acid generation is dependent upon moisture content and temperature.

A typical process for chemically acidified summer sausage would consist of formulation, followed by heating at 115°F (46.1°C), 74% RH, and then cooking to 165°F (73.9°C) internal temperature. The entire process takes 6-7 hours versus a 12-18 hour fermentation process.

►Non-Acidified Dried Sausages

Some dried sausages are not fermented or acidified. This product segment includes a portion of the dried meat snacks (meat sticks) and some larger diameter sausages, particularly those exported to Japan and other markets where acidity or tang is not a popular flavor. These products have the same general formulation process as fermented dried sausages, but no starter cultures or acidulants are added during formulation and no fermentation period is required. Generally, after stuffing, the products are cooked to 146°F (63.3°C) and then dried to a water activity of ≤0.85. Due to the higher pH, these products must be dried to a lower water activity (less moisture) than fermented products to achieve shelf-stability. The higher pH makes the product more difficult to dry and tight control of temperature, humidity and airflow is critical.

Heat Treated/Not Heat Treated-Shelf Stable Flow Chart: Fermented Dry Sausage