PROCESSED MEATS

THIRD EDITION

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Curing

Although salt was used for preserving fish as far back as 3500 B.C., the origin of its use in curing meat is lost in antiquity. Homer in the *Odyssey,* written about the eighth century B.C., describes sausage made by adding salt to meat. By the fifth century B.C., production of salted meat products had become commonplace. Ancient humans were well aware of the preservative action of salt, which was probably discovered by accident. It is also probable the color-preserving properties of saltpeter (nitrate) were discovered as a result of its presence as an impurity in salt.

Early dry cured meat products were extremely variable in quality, often being too salty and lacking in uniformity of cure. Scientific principles were not applied to meat curing until the latter half of the nineteenth century, when the growing meatpacking industry began to find ways of improving quality. Present rapid curing methods, such as brine injection procedures, are of more recent origin. They were not used commonly until the 1940s. Many innovations have occurred in meat curing during the past 55 years, which have been made possible by advances in equipment design and greater mechanization.

Meat curing was used originally almost entirely as a means of preserving meat during times of plenty to carry over to times of scarcity. Until the successful advent of refrigeration and its availability in the home, curing continued to be designed solely as a means of preservation. The almost universal availability of home refrigerators has, however, greatly altered the reasons for curing. Today, cured meat products are generally mild-cured and must be stored under refrigeration. This chapter deals primarily with the curing of primal meat cuts; but the cure ingredients, together with the discussion of cured meat color development, apply to sausage and cured canned meats as well.

INGREDIENTS UTILIZED IN MEAT CURING

Although a variety of compounds can be used in curing meat, the basic curing ingredients are salt, sugar or some other sweetener, and nitrite.

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Although nitrate has the same effects as nitrite, it acts slowly and is seldom used today. In addition, phosphates are commonly added to pickle cures in commercial operations. A number of other compounds are sometimes used in curing mixtures, such as various spices, baking soda, sodium erythorbate, hydrolyzed vegetable proteins, and monosodium glutamate.

Salt

Salt (NaCl) is basic to all curing mixtures and is the only ingredient necessary for curing. Salt acts by dehydration and altering of the osmotic pressure so that it inhibits bacterial growth and subsequent spoilage. Salt also increases the gel strength of sausage batters. Use of salt alone, however, gives a harsh, dry, salty product that is not very palatable. In addition, salt alone results in a dark, undesirable colored lean that is unattractive and objectionable to consumers.

As a consequence of undesirable effects of salt on flavor and appearance, it is generally used in combination with both sugar and nitrite and/or nitrate. A limited number of products still are sometimes cured with salt alone. Cuts cured in this way are strictly fatty cuts containing little if any lean tissue. Cuts such as clear plates, fat backs, jowls, or heavy bellies that are intended for seasoning of other food products, including pork and beans, may occasionally be cured with salt alone. Even in the case of such fatty cuts, nitrite and/or nitrate is sometimes used. When salt is used alone, it is added in excess since the extreme saltiness is commonly modified by cooking with other food products. Impurities in salt can affect the solubility of the proteins and interfere with the water holding capacity and emulsifying properties of the meats.

Only food-grade salt should be used in curing, since impure salt can cause flavor and color problems. Although dry salt curing utilizes salt in excess, the amount used in other dry-curing methods and pickles is variable, depending upon the end product desired. Pickle cures vary from 50° to 85°, 65° pickles being most common. An acceptable level of salt has been reported to be about 2–3%. Of course, higher and lower salt levels are common and are a matter of personal preference.

Recently, emphasis has been placed on reducing levels of salt in meat products in view of its relationship to hypertension in about 20% of the population. Thus, processors are attempting to decrease salt in most meat products. Since sodium is the element in salt that causes hypertension, substitution of potassium chloride (KCl) for part of the NaCl has been successfully used for producing sodium-reduced meat products. Sodium-reduced products must contain one-third less sodium than those produced conventionally with NaCl. This can be achieved by using a NaCl–KCl mix-

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ture, in which the portion of KCl should not exceed 50% of the mixture because of a strong and objectionable flavor at higher levels. A 60% NaCl and 40% KCl mixture is quite acceptable to most consumers. Normally, this will reduce the sodium content by 34–35%, and allow product labeling as a reduced sodium item. Government regulations for labeling require a one-third reduction in sodium before it can be labeled as a reduced sodium product.

Lite Salt,® which is a 50-50 mixture of NaCl and KCl, is produced by Morton Salt International. Because of Morton's production capacity and analytical capability, their product is generally lower in price than can be achieved by mixing of purified KCl with NaCl by the processor. In addition to the benefits derived by reducing the amount of sodium, the addition of potassium to the diet may also be beneficial in reducing blood pressure even in normal individuals.

When substituting KCl for NaCl, processors should be aware that KCl has a lower ionic strength and a slightly higher water activity than NaCl. Therefore, when mixing NaCl and KCl, the combined mixture should always be added at the same level as when using NaCl alone. Thus, if one is using NaCl at 2 or 2½% the same level of the NaCl–KCl mixture should be used. The addition of KCl to the salt mix may reduce the taste sensation of saltiness. In fact, the first sensation in mixtures will probably be that reduced sodium products are less salty.

Sugar, Corn Syrup Solids, and Honey

The addition of sugar to cures is primarily for flavor. Sugar softens the products by counteracting the harsh hardening effects of salt by preventing some of the moisture removal and by a direct moderating action on flavor. Sugar also interacts with the amino groups of the proteins and, when cooked, forms browning products that enhance the flavor of cured meats. In some instances, the browning reaction may become too pronounced and burned flavors result. Sugar substitutes have been used in bacon cures to prevent excessive browning during cooking. Corn syrup, molasses, and other natural sugar substitutes are sometimes used in place of sugar. The extent of substitution is largely a matter of cost after determining the relative effects on flavor and color. Dextrose is often added to cured products. It is one half as sweet as sucrose and more can be added without affecting the flavor. It also increases the water holding capacity of the products.

Sugar, also, is an effective preservative and will retard bacterial growth. However, the level used in meat curing is so low it is doubtful that sugar has any major influence on the bacteria. Some people have claimed that

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sugar supports the growth of desirable flavor-producing bacteria, but there is little evidence to support this viewpoint.

The proportion of sugar used in curing varies widely in commercial operations. Most processors use only 20–30 lb per 100 gal of brine. At this level, sugar probably plays only a minor role in flavor development. Carefully controlled studies have suggested that consumers prefer about 2% sugar in cured hams. This would require about 160 lb sugar per 100 gal brine. Unfortunately, similar data are not available for other products.

Corn syrup or corn syrup solids are frequently substituted for sugar. As the names imply, corn syrup solids consist of corn syrup from which most of the water has been removed, while corn syrup contains a higher level of moisture. Either corn syrup or corn syrup solids may be purchased in bulk quantities. Since they differ only in the amount of moisture, they will be considered together without differentiation.

Corn syrup is composed of a mixture of sugars formed by breakdown of starch and contains dextrose, maltose, higher sugars, dextrins, and polysaccharides. Corn syrup is not as sweet and is less soluble than sugar. However, both corn syrup solids and corn syrup are used widely in curing meat because they cost considerably less. The amount of corn syrup solids is limited to 50 lb per 100 gal brine under federal inspection regulations. Furthermore, the amount of corn syrup or sugars present in any seasonings added to the cure must also be considered in the total.

Honey can also be used in curing meats. It imparts a sweet taste and is used primarily in honey-glazed or honey cured hams and in similar poultry products. Although it costs more than the other sweeteners, some consumers prefer its flavor and will pay a premium for honey cured products.

Nitrite and/or Nitrate

The function of nitrite in meat curing is fourfold: (1) to stabilize the color of the lean tissues, (2) to contribute to the characteristic flavor of cured meat, (3) to inhibit growth of a number of food poisoning and spoilage microorganisms, and (4) to retard development of rancidity. Although color stabilization was originally the primary purpose of adding nitrite to curing mixtures, its effects on flavor and inhibition of bacterial growth are even more important. Nevertheless, the attractive pink-red color of cured meat adds to its desirability. The effect of nitrite on the flavor of cured meat has been demonstrated. However, the most important reason for adding nitrite to meat cures appears to be its effect on microbial growth. It has been clearly demonstrated that nitrite is effective in preventing the growth of the *Clostridium botulinum* organism. Evidence also suggests the

TABLE 3.1. Levels of Nitrite and/or Nitrate Allowed in Curing Different Meat and Poultry Products[a]

Product	Maximum levels		
	Ingoing level as $NaNO_2$ (ppm)	Ingoing level as $NaNO_3$ (ppm)	Residual levels allowed as $NaNO_2$ (ppm)
Bacon—pumped	120[b]	None	40
Bacon—immersion cured	200[c]	None	40
Cooked sausage	156[e]	None	100
Dry and semidry sausage	625[g]	1719[f]	100
Dry cured cuts	156[e]	2188[h]	100
Pickle cured cuts (canned and uncanned)	200[i]	700[d]	100
Shelf stable, sterile canned comminuted products	156[e]	1719[f]	120
Baby foods: Junior and Toddler meats	None	None	None

[a] Table gives maximum ingoing levels of nitrite and nitrate and maximum residual levels as sodium nitrite in various type meat products in USDA regulations as of 1985.
[b] 550 ppm ascorbate or erythorbate is also required.
[c] The regulation actually reads "2 lbs. to 100 gal. pickle."
[d] The regulation actually reads "7 lbs. to 100 gal. pickle."
[e] The regulation actually reads "¼ oz. to 100 lbs. chopped meat and/or meat by-product."
[f] The regulation actually reads "2¾ oz. to 100 lbs. chopped meats." Most processors have discontinued use of nitrate in these products, except in Lebanon bologna.
[g] The regulation actually reads "1 oz. to 100 lbs. meat (dry cured)."
[h] The regulation actually reads "2 lbs. to 100 gal. pickle at 10 percent pump level." It assumes 10 lbs./gal.
[i] The regulation actually reads "3½ oz. to 100 lbs. chopped meat (dry cured)." Nitrate is used in these products to a greater extent than in comminuted products required to have the "Keep Refrigerated" statement on the label.

levels of nitrite found in cured meat may also aid in preventing the growth of other spoilage and food poisoning organisms.

Nitrate serves principally as a source of nitrite. Although nitrate was originally approved for color fixation in cured meats, it has largely been replaced by nitrite. It is now only used in a few products, such as country cured hams and Lebanon bologna.

The maximum levels of nitrite and nitrate allowed in different types of cured meat products are given in Table 3.1, as are the maximum allowable levels of nitrite in the finished products. The latter includes nitrate but is calculated in terms of total sodium nitrite. Although nitrates are allowed in a considerable number of products, in practice sodium nitrate is commonly used only in country hams, Lebanon bologna, and shelf-stable sterile

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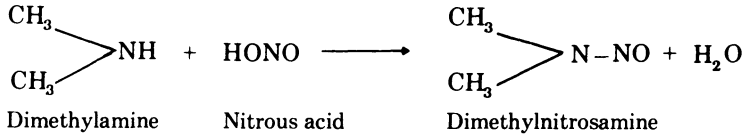
canned comminuted products. It is significant, however, that use of both nitrite and nitrate is prohibited in canned baby meats.

Nitrosamines The reaction of nitrous acid (which is formed by the breakdown of nitrite) with secondary amines to produce nitrosamines is a well-known reaction in organic chemistry. The reaction of nitrous acid with dimethylamine is:



Nitrosamines have been isolated in small amounts from nearly all cured meat products, apparently as a result of the interaction of nitrite with secondary amines during curing and/or cooking. Since nitrosamines have been shown to be carcinogenic, their presence in meat products comes under the Delaney Amendment of the Pure Food and Drug Act, which clearly states that any food additive causing cancer must be removed from the food supply. The Food and Drug Administration has worked closely with the meat industry to develop processing procedures that would eliminate nitrosamines from cured meats, but would still permit retention of nitrite in view of its action in preventing the growth of *Clostridium botulinum* and other food-poisoning organisms. It has generally been conceded that the risks from low levels of nitrosamines are less than those from botulism poisoning, which may occur if nitrites were removed from the cure. It has been shown that combining nitrite with the other curing agents and seasoning ingredients can result in nitrosamine formation in meat curing premixes. The FDA has taken steps to eliminate this problem by requiring that nitrite be package separately from the seasoning ingredients.[1] Formation of *N*-nitrosopyrrolidine during the frying of bacon has been the major problem from nitrosamines in processed meats. However, it has been reported that the problem can be largely eliminated by using α-tocopherol-coated salt in the cure. Erythorbate or ascorbic acid also reduces the forma-

[1] The FDA ordered on July 19, 1973, manufacturers of meat curing premixes which combine nitrite curing agents with seasoning to package the nitrite and seasoning separately to eliminate the possibility of nitrosamine formation in premixes. The FDA action will not affect manufacturers who use a chemical "buffer" to separate the nitrite and the seasoning in a premix. Nitrosamines have not been found in such premixes, which constitute a majority of such products now in use. As a safety precaution, however, FDA is requiring any manufacturer who wishes to market such premixes to submit a food additive petition as further assurance that the premixes are free of nitrosamines.

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tion of *N*-nitrosamines when added to the pickle; thus, it is normally added to all brines.

Nitrite per se has been reported to be carcinogenic above and beyond its possible role in the formation of nitrosamines. The FDA proposed reducing and eliminating nitrite in meat curing as a consequence of these studies. A thorough review of the evidence was undertaken by a Committee of the National Academy of Sciences, which suggested more research was needed on the role of nitrite in meat curing in view of its beneficial effects in cured meats.

More careful control of processing parameters and the level of nitrite in the cure have lowered the levels of nitrosamines until they are absent or barely detectable (a few parts per billion) in most cured products. Bacon has been the one product in which nitrosamines have been most difficult to eliminate. This is because they are formed during the cooking process, with a combination of high temperatures during cooking and the presence of nitrite and secondary amines contributing to their formation. Research has demonstrated that sodium ascorbate at a level of 550 ppm in combination with 120 ppm of sodium nitrite will materially reduce nitrosamines in cured, cooked bacon. It has also been suggested that addition of potassium sorbate to the cure may be used to further reduce formation of nitrosamines. These studies suggest that it should be possible to further reduce nitrosamine formation in processed meats.

Levels of Nitrite and/or Nitrate Nitrates were used as the only color-stabilizing element for meat curing until 1925. At that time, the U.S. Department of Agriculture also approved the use of sodium nitrite.

Federal meat inspection regulations permit the use of the following quantities of nitrate: 7 lb to 100 gal pickle, 3½ oz to 100 lb meat (dry cure), and 2¾ oz to 100 lb chopped meat. The same regulations permit use of nitrite at the following levels: 2 lb to 100 gal pickle at 10% pump level, 1 oz to 100 lb meat (dry cure), ¼ oz to 100 lb chopped meat. The regulations further state that the use of nitrite or nitrate, or a combination of both, shall not result in more than 200 ppm nitrite in finished products. The legal level permitted is sometimes less than the residual level allowed. This is evident in the case of the ¼ oz nitrite permitted in 100 lb chopped meat, which is only 156 ppm at the time of formulation.

Nitrite levels in curing of bacon have been reduced to an in-going level of 120 ppm of nitrite in combination with 550 ppm of sodium ascorbate. This level of ascorbate in combination with α-tocopherol-coated salt has been shown to greatly reduce *N*-nitrosamine formation during frying of bacon. However, low residual nitrite levels can cause problems with fading of cured meat color.

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Phosphates

Phosphates are added to the cure to increase the water-binding capacity and thereby the yield of finished product. The action of phosphates in improving water retention appears to be twofold: (1) raising the pH and (2) causing an unfolding of the muscle proteins, thereby making more sites available for water binding. Only alkaline phosphates are effective for improving water binding since acid phosphates may lower the pH and cause greater shrinkage. However, it may be advantageous to use a mixture of acid and alkaline phosphates, thereby achieving a pH near neutral.

Phosphates will improve the retention of brine, and improvements in yields have been noted. With addition of phosphates to pumping brines, it is not difficult to obtain finished yields for intact hams and shoulders of over 100%.

Phosphates also chelate trace metal ions and retard development of rancidity in meat products. The effects of phosphates in sausage products are covered in greater detail in Chapter 11.

Because of the corrosive nature of phosphates, the equipment utilized must be made of stainless steel or plastic. Canned hams pumped with phosphates should always be placed in anodized cans, where an aluminum insert is selectively corroded and the can per se is protected, or wrapped in polyethylene film. Another problem sometimes encountered in utilizing phosphates has been the occurrence of crystals on the surface of the cured products. Such crystals have been identified as disodium phosphates. The excess salt appears to be due to hydrolysis of the polyphosphates by the natural phosphatase in meat. Prevention of the condition can be achieved by reducing the level of phosphate in the cure and maintaining a high relative humidity in the product environment.

Phosphates are used in most pumped meats, such as ham, bacon, roast beef, cooked corned beef, pastrami, and some similar poultry products. Advantages include a reduction in cookout, improvement in sliceability, retention of flavor, and greater juiciness. In sausages, phosphates serve the same purposes but also improve emulsification and protein extraction. Addition of phosphates to sausages reduces the viscosity of the batter and makes stuffing more uniform and easier.

For emulsion products, pyrophosphates or diphosphates are best, as the phosphates are only active in the diphosphate form. Thus, tripolyphosphates must be hydrolyzed to diphosphate before they are active. No one phosphate can do everything, but combinations work best. Although tetrasodium pyrophosphate produces the best bind, it is highly caustic at its pH of about 11. This results in production of soap in meat containing any fat. Sodium acid pyrophosphate has an acid pH, and if used alone results in greatly reduced yields. The acid nature of this phosphate results in rapid

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development of cure color and avoids development of a green core in rapidly cooked sausages, especially those containing alkaline phosphates. A combination of tetrasodium pyrophosphate and sodium acid pyrophosphate produces a pH of about 7 and is useful in sausages. Commercially available mixtures are available and have been used successfully. More complex polyphosphates may be used in the mixtures in order to chelate metal ions, especially calcium and iron. The binding of calcium ions aids in restoring the meat to prerigor state by breaking the bonds between actin and myosin. Chelation of iron, on the other hand, aids in prevention of oxidation, since iron is a prooxidant. Thus, combinations of tetrasodium polyphosphate and sodium acid pyrophosphate along with some other complex polyphosphates are used in sausages.

For curing brines, a mixture of tripolyphosphate and sodium hexametaphosphate are used. They are dissolved in water and injected into hams and bacons, where they are slowly hydrolyzed to diphosphate and become active more slowly. Too high a temperature may result in faster hydrolysis and cause rapid formation of the monophosphate, which is inactive in the tissues. Thus, low temperature pumping (about 32°F) is recommended. The low temperature inhibits microbial growth and extends the shelf life.

Sodium acid pyrophosphate produces the best bind, but its acid pH results in reduced yields. On the other hand, pyrophosphate (diphosphate) increases the water-binding capacity of the muscle proteins by causing swelling. Tripolyphosphate-sodium hexametaphosphate blends are commonly used in curing brines but are not normally utilized in sausage emulsion-type products. Thus, mixtures of phosphates are utilized for specific products.

Sodium Ascorbate and Erythorbate

Ascorbate and erythorbate are isomers, with ascorbate being the L-form and erythorbate the R-isomer. Both compounds have the same functions, although erythorbate is more stable than ascorbate. Thus, erythorbate is the preferred compound for use in meat curing, although the two terms are used interchangeably in this discussion.

The salts of ascorbic acid and erythorbic acid are commonly used to hasten development and stabilize the color of cured meat. In practice, only sodium erythorbate or sodium ascorbate are used in curing pickles, since ascorbic or erythorbic acid reacts with the nitrite to form nitrous oxide. Since nitrous oxide is dangerous in confined spaces and the nitrite is destroyed, ascorbates or erythorbates are always used under practical conditions. This group of compounds, which will be referred to as ascorbates during the remainder of this discussion, serves three main functions: (1) ascorbates take part in the reduction of metmyoglobin to myoglobin,

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thereby accelerating the rate of curing; (2) ascorbates react chemically with nitrite to increase the yield of nitric oxide from nitrous acid; (3) excess ascorbate acts as an antioxidant, thereby stabilizing both color and flavor; and (4) under certain conditions ascorbates have been shown to reduce nitrosamine formation.

Although ascorbate or erythorbate has been used by meat processors to speed up processing and to prevent fading, an even more important use may be its effect in reducing nitrosamine formation. At a level of 550 ppm, ascorbate has been shown to reduce or eliminate nitrosamine formation. The exact mechanism is not known, but current meat inspection regulations specify that all bacon be produced using no more than 120 ppm of nitrite in combination with 550 ppm of ascorbate/erythorbate.

Ascorbate may be used in both intact cuts and sausages, but the greatest advantage of its use is in sausages, where the time of processing can be greatly reduced; in processing frankfurters, the time can be reduced by one-third if ascorbates/erythorbates are added. This eliminates the waiting period normally needed for breakdown of nitrite and formation of the stable pink pigment in the absence of ascorbate/erythorbate. If ascorbate is added to the cure, emulsion-type products can go directly into the smokehouse after stuffing, without waiting for color development.

The antioxidant properties of ascorbate or erythorbate not only prevent development of rancidity, but also prevent fading of sliced meats when exposed to light. Protection is closely associated with prevention of heme-catalyzed lipid oxidation, which results in both pigment degradation and development of rancidity. As long as excess ascorbate is present, the pigments are protected against breakdown. When ascorbate is depleted, however, the heme pigments are degraded and apparently catalyze lipid oxidation.

Federal regulations permit addition of 0.75 oz ascorbic acid or erythorbic acid (0.875 oz sodium ascorbate or erythorbate) per 100 lb sausage emulsion, or addition of 75 oz (87.5 oz of sodium salts) per 100 gal pickle for curing primal cuts. Pickles containing both sodium nitrite and sodium ascorbate are stable for at least 24 hr when maintained at 50°F and pH 6.0 or higher. However, longer periods of storage are not advisable, and if the pickle is to be stored for extended periods, it should be analyzed and the necessary levels of nitrite and ascorbate added to bring it back to the original concentration.

Potassium Sorbate

Sorbic acid and its potassium salt, potassium sorbate, are antimicrobial agents that have been widely used as food preservatives. These compounds

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are particularly effective in inhibiting mold growth and have been extensively utilized for this purpose in fish, dairy, and bakery products. Potassium sorbate is generally preferred in food systems because of its greater solubility in water. Sorbate is on the GRAS list since it is readily metabolized and relatively nontoxic.

The only presently approved use of sorbate in meat products is as a 2.5% solution of potassium sorbate for dipping of stuffed dry sausages, where it inhibits mold growth on the casings. Sorbate has also been shown to be a potent inhibitor of *Clostridium botulinum,* especially when used in combination with low levels of nitrite. In 1979, USDA meat inspection regulations were proposed that would have allowed the use of 0.26% of potassium sorbate in combination with 40 ppm of sodium nitrite for production of cured bacon. The proposed regulation was withdrawn since allergenic reactions were reported by some individuals during sensory evaluation of bacon prepared using sorbate. Although the effectiveness of the nitrite and sorbate combination in controlling botulism has been verified in many studies, the question as to its possible allergenic reactions still remains unresolved. Should sorbate be cleared of causing allergies, it will no doubt be widely utilized for reducing the levels of nitrite in cured meat.

Monosodium Glutamate

Monosodium glutamate (MSG) has been used in a number of products to enhance the flavor. It has not, however, been widely used in the meat industry as there is little advantage in its use in good meat products, although mixed meat dishes may profit from its meat flavor-enhancing properties.

Hydrolyzed Vegetable Proteins

Addition of hydrolyzed vegetable proteins (HVP) to sausages and other meat products has been utilized by some processors. HVP is said to improve flavor and effectively increase the protein content. Its use in meat products has, however, gained little acceptance by the processing industry. It is used most commonly in kosher sausage products. Some smaller processors have also used HVP in cured hams.

Sodium and Potassium Lactate

Sodium or potassium lactate may be added to fresh or cured meats to prevent spoilage and extend storage life. Generally, sodium lactate is preferred over potassium lactate because the latter product has a bitter taste.

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However, the potassium salt can be substituted in producing low sodium products. Sodium and potassium lactate come as a USP 60% solution, with a pH 7.0 and a specific weight 11 lbs per gallon. It is usually added at a level of 2.5–3.3% of product, depending on the specific product. Too much lactate may result in a "chemical" taste.

Since sodium lactate has a slightly acid taste, salt levels in all formulations should be reduced by 0.25–0.50%. This may require some seasoning or flavor adjustment. In curing whole muscle cuts (hams, picnics, and bacon), sodium lactate may be added directly to the pickle at a level of 5% of the 60% solution. For meat emulsions, sodium lactate can be added to the chopper at 2.5–3.3% or 2.25–3.0 gal per 1,000 lbs of product. For fresh meat and poultry products, 1.25 to 2.50% or 1.0–2.25 gal of sodium lactate should be added per 1,000 lbs of finished product.

CURED MEAT COLOR

In order to understand color development during meat curing, it is necessary to have knowledge of the pigments in muscle and the chemical reactions they undergo during curing. Color develops as a result of the interaction of nitrites with the muscle pigments. Thus, the structure and importance of the pigments will be discussed in light of their reactions and their effects on meat color.

Muscle Pigments

There are a number of muscle pigments in meat, including myoglobin, hemoglobin, the cytochromes, catalase, the flavins, and other colored substances. Quantitatively, the first two listed, myoglobin and hemoglobin, are by far the most abundant. Although the lesser pigments could play key roles in color development and stabilization, most of our knowledge about meat color deals with myoglobin and hemoglobin.

Myoglobin and hemoglobin are both complex proteins that undergo similar reactions in meat. However, their roles in living tissue are quite different. Hemoglobin is the red pigment found in blood and acts as the carrier for oxygen to the tissues. Myoglobin is the predominant pigment in muscle and serves as the storage mechanism for oxygen at the cellular level. Because of the differences in function, myoglobin has a greater affinity for oxygen. This can be shown by exposing a freshly cut surface of meat to air, as manifested by the rapid brightening in color as the myoglobin takes up oxygen.

Although hemoglobin is the predominant pigment in the living animal, after slaughter by bleeding, myoglobin becomes the major pigment. Myoglobin accounts for only 10% of the total iron in the live animal, but after

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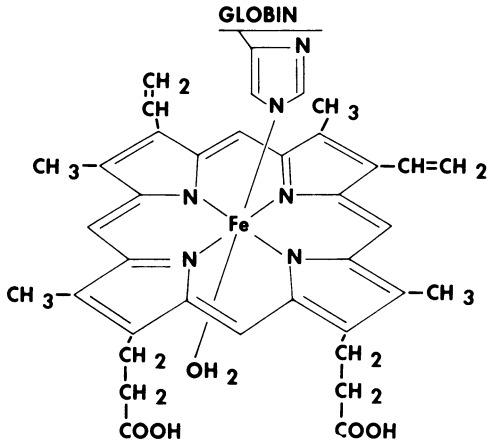
bleeding, may account for as much as 95% of the iron in beef skeletal muscle. Nevertheless, hemoglobin is still present in appreciable quantities and may play an important part in meat color.

The amount of myoglobin and hemoglobin in various tissues varies with (1) amount of muscular activity of the tissue, (2) blood supply, (3) oxygen availability, and (4) age of the animal. Tissues having a high degree of muscular activity tend to have greater proportions of both myoglobin and hemoglobin. For example, the heart is the most active muscle in the body and contains relatively large amounts of both hemoglobin and myoglobin by virtue of its high oxygen requirements. Tissues with a relatively good blood supply tend to have more hemoglobin and relatively less myoglobin than muscles having a poorer oxygen supply. This is evident in the wing muscles of birds where the demands for oxygen are largely supplied by an efficient circulatory system. If the tissues are able to store large quantities of oxygen, the myoglobin content is relatively high and the hemoglobin content relatively low. The whale has the ability to store large quantities of oxygen because of its extremely high myoglobin content, and thus can remain submerged for extended periods of time. In regard to age, the young animal has less myoglobin and relatively more hemoglobin than older animals of the same species. This is shown by the following values for myoglobin for fresh bovine skeletal muscle: veal, 1 to 3 mg/g; beef, 4 to 10 mg/g; and old beef animals, 16 to 20 mg/g. Pork contains 1 to 3 mg/g for young animals of slaughter weight, but may reach 8 to 12 mg/g in old animals. Lamb may vary from 3 to 8 mg/g, but old ewes and rams may reach levels from 12 to 18 mg/g.

Much of the knowledge about myoglobin was derived from earlier work by blood chemists and physiologists studying the structure and functions of hemoglobin. More recently, however, myoglobin has been extensively studied in its own right by protein chemists, who have detailed its exact amino acid sequence. Although myoglobin and hemoglobin undergo essentially the same reactions, they do have significant differences in structure. Both of these important pigments are molecules composed of a protein, known as globin, complexed to a nonprotein moiety containing iron. Although the globin portion of hemoglobin and myoglobin is similar in structure, the exact amino acid sequence is slightly different. Furthermore, there are slight differences between the globin from different species. The iron-containing fraction of the molecule is known as heme and is composed of two parts—an iron atom and a larger planar ring called porphyrin. The porphyrin is made up of four heterocyclic pyrrole rings linked together by methene bridges. When the hemes and globin are complexed together by the side chains and the iron nucleus, the resulting compounds are either myoglobin or hemoglobin. An essential difference in structure between myoglobin and hemoglobin is that myoglobin complexes only one heme

group per molecule, whereas, hemoglobin contains four hemes per molecule. Thus, myoglobin has a molecular weight of 16,000 to 17,000 as compared to approximately 64,000 for hemoglobin.

The central atom does not contribute any electrons but accepts six pairs of electrons from other atoms—five pairs from nitrogen and one pair from oxygen. Four of the nitrogen atoms contributing electrons are in the porphyrin ring, while the other nitrogen atom is from the imidazole group of the histidine molecule in the amino acid chain of globin. The nature of the group attached to the iron atom of the heme at the position shown to be occupied by the OH_2 radical determines the color of the pigment, both of myoglobin and hemoglobin.



Myoglobin

Color of the Pigments In living tissue, myoglobin and hemoglobin exist in equilibrium between the reduced dull purple-red form, myoglobin and hemoglobin, and the bright red oxygenated form, oxymyoglobin and oxyhemoglobin. Upon death, the oxygen in the tissues is rapidly depleted, leaving the pigment in the dull purple-red form of myoglobin or hemoglobin. The iron can exist in the ferrous (Fe^{2+}) or ferric (Fe^{3+}) forms, or as ionic (unwilling sharer of bonds) or covalent (willing sharer of bonds) bonds. The covalent form is of the greatest importance, since all the bright red pigments of both fresh and cured meat belong to this class. On the other hand, the iron in the dull red-black pigment—oxidized myoglobin and hemoglobin—exists in the ferric form. The nucleus of a myoglobin molecule, with changes in the state of the iron and the radical attached to it, affects fresh meat color. The pigment in the oxidized form, metmyoglobin, is an undesirable brown-red and is typical of the color observed on the exposed surface of aged meat. Although the three forms of myoglobin are interconvertible or

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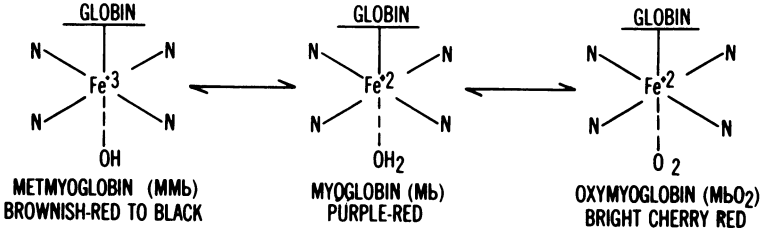
reversible, changes from metmyoglobin to the other forms are slower and require more favorable conditions.



The pigments containing covalent bonds are characterized spectrally by sharp peaks at 535–545 nm (the green portion of the spectrum) and 575–585 nm (blue), which gives them a bright red color. Oxymyoglobin of fresh meat, nitrosomyoglobin of cured meat and carboxymyoglobin, a combination of carbon monoxide with myoglobin, are characterized by peaks in the green and blue portion of the spectrum, and all are bright red pigments. Myoglobin is characterized by a broad diffuse peak of 555 nm, and thus is dull red in color. In metmyoglobin, the peak is shifted to 505 nm in the blue portion of the spectrum, and has a weaker peak at 627 nm in the red part of the spectrum, the two combining to produce a brown-red color. The absorption spectra of myoglobin, metmyoglobin, and oxymyoglobin are shown in Fig. 3.1. This shows schematically the color at different parts of the spectrum, which, when combined, accounts for the color of the various products.

Myoglobin and hemoglobin can be both oxidized and oxygenated, both resulting from the presence of oxygen. The relative proportion of metmyoglobin and oxymyoglobin depends on the partial oxygen pressure. At low oxygen pressures formation of metmyoglobin is favored, whereas high oxygen pressures favor oxymyoglobin formation. Thus, reduced myoglobin is constantly being both oxygenated and oxidized. In living tissues, and to some extent in meat, metmyoglobin is continuously reduced back to myoglobin by the action of the reducing enzymes that are naturally present in the tissues. However, the efficiency of the reducing system gradually decreases and ultimately is depleted following death. Thus there is a gradual buildup of metmyoglobin until it predominates, and the meat color becomes a dull red or brown.

Role of Nitrite and/or Nitrate in Meat Color

Nitrite and/or nitrate are used in curing meat to counteract the undesirable effects of salt on color. Not only is the color of fresh meat protected from

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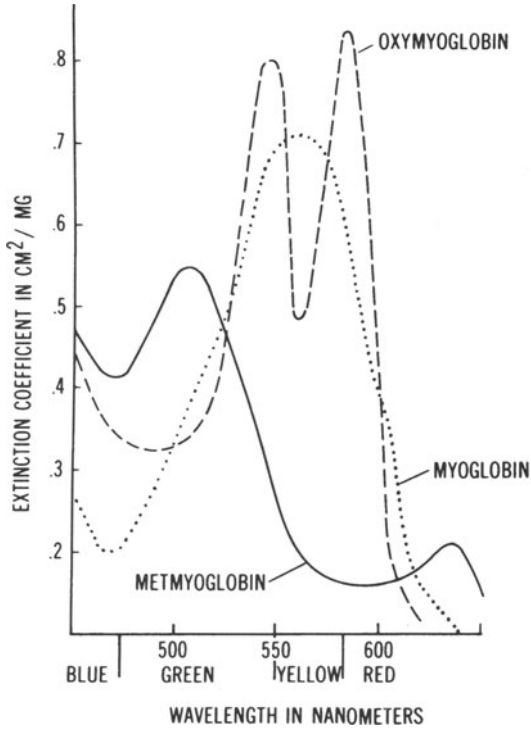

Fig. 3.1. Absorption spectra of myoglobin, oxymyoglobin, and metmyoglobin from fresh meat in which wavelengths of maximum absorption and the primary color spectrum are displayed.

degradation, but the pigments react with nitric oxide to produce the stable pigments characteristic of cured meat. These pink pigments are important to the acceptability of most processed meat products.

As indicated, both nitrite and/or nitrate are used in meat curing for color stabilization. The end result is the same in either case, although the pathway for stabilization of color by nitrite is more direct. Nitrite requires one less step in stabilization of color, as shown in the series of reactions below:

$$\text{Nitrate} \xrightarrow[\text{organisms}]{\text{nitrate reducing}} \text{Nitrite} \tag{1}$$

$$\text{Nitrite} \xrightarrow[\text{absence of light and air}]{\text{favorable conditions}} \underset{\text{nitric oxide}}{NO} + \underset{\text{water}}{H_2O} \tag{2}$$

$$\underset{\text{nitric oxide}}{NO} + \underset{\text{myoglobin}}{Mb} \xrightarrow[\text{conditions}]{\text{favorable}} \underset{\text{nitric oxide metmyoglobin}}{NOMMb} \tag{3}$$

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$$\text{NOMMb} \xrightarrow[\text{conditions}]{\text{favorable}} \underset{\text{nitric oxide myoglobin}}{\text{NOMb}} \quad (4)$$

$$\text{NOMb} + \text{Heat} + \text{Smoke} \longrightarrow \underset{\substack{\text{Nitroso-hemochromogen} \\ \text{Stable pink pigment}}}{\text{NO—hemochromogen}} \quad (5)$$

Since nitrite reacts quicker and less is required for color stabilization, it is being widely used in place of nitrate. Many processors prefer to use a combination of nitrite and nitrate, which gives a source of additional nitric oxide should the nitrite be depleted during curing. They believe the slower release of nitric oxide from nitrate gives them an additional safety factor over nitrite alone. Nevertheless, many highly successful operators use nitrite alone with excellent results. Trends have been toward decreased use of nitrate by the industry.

As shown by the series of reactions, nitric oxide is the active ingredient that combines with meat pigments. Although step 3 has not been proven conclusively, all evidence suggests that the original combination of nitric oxide is with the oxidized pigments, metmyoglobin and methemoglobin. The best proof for this is the fact that the pigments in sausage becomes characteristically brown after adding the cure, but after heating have the characteristic pink color of cured meat, as shown in step 5. An alternate pathway for production of the stable pink pigment is possible, in which nitric oxide metmyoglobin is not formed. In this case, myoglobin is oxidized to metmyoglobin, which is reduced back to myoglobin before combining to form nitric oxide myoglobin. The end result is the same regardless of the pathway; nitric oxide reacts to produce the desirable and stable pink pigment of cured meat. Any hemoglobin remaining in the meat would undergo essentially the same series of reactions and also give a stable pink pigment.

Figure 3.2 shows how the various forms of myoglobin or hemoglobin fit into the total scheme to produce cured meat pigments, both desirable and undesirable.

CURING METHODS

Although there are a number of methods of curing primal or subprimal cuts of meat, they are all modifications or combinations of two fundamental procedures: (1) dry curing and (2) pickle curing. In dry curing, the curing ingredients—usually salt, sugar, and nitrite and/or nitrate—are added to meat without additional water. In this method, the curing ingredients draw enough moisture from the meat to form a brine, which serves to transport the ingredients into the meat by diffusion. In pickle curing, the ingredients are dissolved in water, which forms a brine that acts in the same general

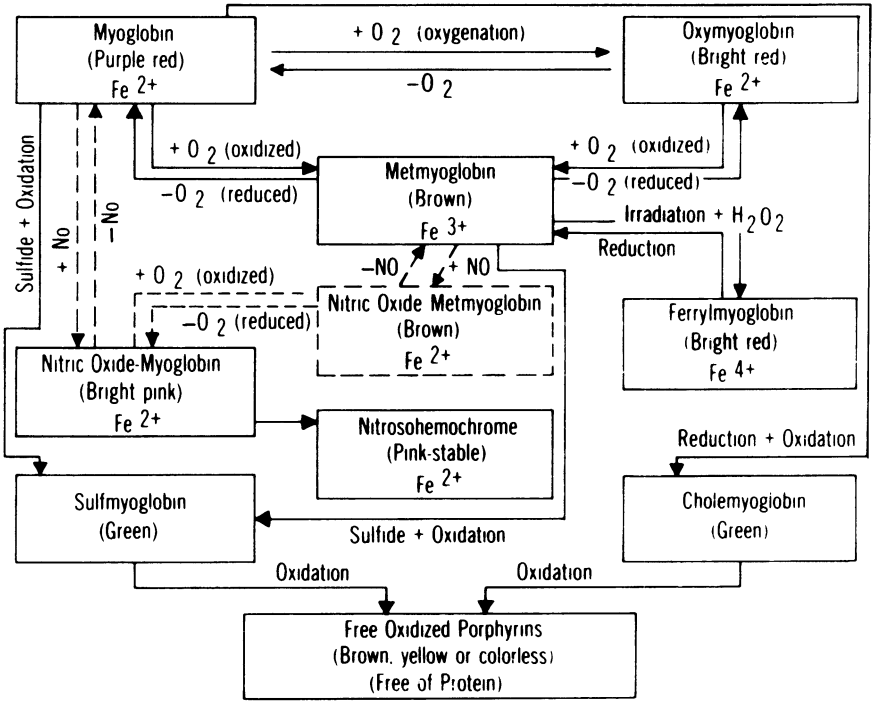

Fig. 3.2. Heme pigments in muscle in relationship to fresh and cured meats. Broken lines indicate reactions and compounds possible but not definitely proven. Sulfmyoglobin and cholemyoglobin most frequently occur as a result of bacterial action.

manner as that formed by the natural meat juices and the curing ingredients.

In actual practice, there are several modifications of the dry and pickle curing procedures, which are a result of combining the two methods. For example, one may start with pickle curing and end with dry curing, or vice versa. Thus, for ease of discussion the methods will not be differentiated solely on principles, but by more specific procedures for curing, such as (1) dry salt curing, (2) conventional dry curing, (3) conventional pickle curing, (4) artery pumping, (5) stitch pumping, (6) thermal or hot cures, and (7) curing of specialty products. Each of these curing procedures will be examined in detail.

Dry Salt Cure

The dry salt cure uses salt alone or salt in combination with nitrite and/or nitrate. As indicated earlier, the cure is primarily used in excess and

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mainly for fatty cuts, such as fat backs, clear plates, jowls, or heavy bellies. The advantages of dry salt curing are (1) it is safe, that is, there is little if any spoilage, and (2) it is easy. Little special care is required to produce dry salt cured cuts. However, dry salt curing has the disadvantages that the end product is too salty and that color is lost. Color degradation can be easily prevented by adding nitrite and/or nitrate to the cure. Since dry salt curing is used almost exclusively for fatty cuts utilized primarily for seasoning, the salty flavor is actually an advantage in practice. However, there is only a restricted and relatively low-priced market for dry salt cured products.

Conventional Dry Curing

Dry curing in the conventional manner, which involves salt, nitrite and/or nitrate, and sugar, is sometimes utilized by the industry. However, dry curing is no longer the predominant method of curing, but is used mainly for specialty products, such as dry-cured bacon and Country-cured hams, both of which command a premium on the market. In addition, some artery-pumped hams are rubbed with a dry cure and held for a short period of time. Cuts cured by this procedure cannot be strictly classified as either dry-cured or artery-pumped, but more correctly as combination-cured. Their final properties are, however, altered by the addition of dry cure.

There are a number of modifications of the dry-curing method itself, but the procedure is essentially the same, since water is not added to the cure. These modifications depend mainly on the container utilized in curing. Originally, much of the curing was carried out in barrels, where the brine was formed by withdrawal of natural juices from the meat by the salt. The resulting brine accumulated in the bottom of the barrel. Barrel curing, which is seldom used today, required periodic overhauling with reversal of the order with which the cuts were placed in cure each time. Use of barrels also involves unusually high space requirements, since their shape is not conducive to tight packing and efficient floor space utilization. In addition, use of space between the floor and ceiling is even less efficient.

More efficient use of space in dry curing has been achieved by using built-in shelves, which are often made of hardwood and can be made watertight. One of the major problems encountered with this type of curing is cleaning and sanitation. Improvements in the method can be obtained by using stainless steel shelves on movable steel racks. The initial investment is high, but ease of cleaning is greatly improved.

Still another modification in the equipment used for dry curing is found in pressure boxes, which are usually made of galvanized iron or stainless steel. The boxes have a lid with a spring to generate pressure. As the pressure in the box is increased, the curing ingredients combine with

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the meat juices to cover the product with brine. Pressure boxes are most commonly used for bacon, jowls, and other cuts of regular shape.

There are a number of other types of equipment such as wooden and concrete vats and boxes as well as other modifications of the containers described here. Regardless of the type of equipment, the principle of curing remains unchanged. Furthermore, the advantages and disadvantages of the procedures, although slightly altered, are essentially the same.

The time required for dry curing is usually 2 to 2½ days per lb for hams and shoulders. Bellies are commonly cured about 7 days per in of thickness. Thus, bacon cured by this method usually requires about 10 to 14 days total time in cure. The cure is applied in two to three stages at the time of overhauling. Bacon cured in pressure boxes does not normally require overhauling, so all the cure is applied at once. The mixture of curing ingredients in dry curing varies somewhat, but a common recipe is 6.0 lb salt, 2.5 lb sugar, and 2.5 oz of nitrate or 0.25 oz nitrite per 100 lb meat, or 1 oz of curing mix per lb meat.

There are three major disadvantages to the dry curing method: (1) high cost due to poor space utilization and the amount of labor required, (2) high inventory due to slowness of curing, and (3) harsh salty flavor of the final product. Even though the salty flavor of dry cured meat is a disadvantage under average conditions, it can also be an advantage, as is found with Country-cured hams.

The advantages of conventional dry curing are (1) a relatively high-priced specialty product is produced, (2) the cuts are less perishable because of their dryness and firmness, and (3) they have more flavor.

Conventional dry curing is a useful procedure, but is not likely to regain any large fraction of the total cured meat market. Nevertheless, it is admirably suited to small operations, where attention can be given to the operation and high-quality products are produced. Some consumers prefer dry cured hams and bacon and are willing to pay a premium for them.

Pickle Cure

The pickle curing procedure uses the same ingredients as dry curing, except the cure is dissolved in water to form a brine or pickle. The cuts are submerged in the pickle until the cure has completely penetrated the meat. Because the meat is packed tightly in the container, it is usually overhauled and repacked to assure uniform penetration of the brine.

All cuts can be cured by the conventional pickle curing procedure. It is used largely by locker plant operators and other small processors. Nevertheless, some larger processors still use conventional pickle curing for certain cuts. This method is used to produce corned beef in a large number of

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TABLE 3.2. Formulas for Preparing Sweet Pickle Cures of Different Salometer Readings

Salt (lb)	Ingredients Sugar (lb)	Nitrite (g)	Cold water[a] (gal)	Cold water[a] (lb)	Salometer reading at 40°F[b]
10	3	28	4	33⅓	95°
9	3	28	4	33⅓	90°
10	3	33	5	41⅔	85°
8	3	28	4	33⅓	80°
8	3	33	5	41⅔	75°
6	3	28	4	33⅓	70°
7	3	33	5	41⅔	65°
6	3	33	5	41⅔	60°

[a] Weight of water—hot = 8.016/gal; cold = 8.3316 gal.
[b] Water temperature must be adjusted to 40°F to obtain an accurate salometer value.

plants. In this case, the method is frequently altered by stitch-pumping the larger pieces of meat to speed up the rate of curing. Since the time required for immersion pickle curing is about the same as for the dry cure, this results in an inventory reduction.

The strength of the brine is expressed in terms of degrees brine, which is essentially a measure of its density. A salometer or salinimeter is used to determine strength of the brine, and its strength is adjusted to the desired level. The water used should have a high degree of purity. It is usually cold when added, although it may be necessary to heat or add hot water to get all the curing ingredients into solution. Table 3.2 gives the necessary ingredients required to prepare brines of different salometer readings.

Hams and shoulders are normally cured from 2 to 2½ days per lb, as in dry curing. However, this will depend on the strength of the pickle and temperature of curing. The usual pickles are 60–70°, 70° brine being most common. As indicated earlier, most pickles contain the usual curing ingredients of salt, sugar, and nitrite and/or nitrate. Those containing sugar are sometimes referred to as sweet pickle cures.

The disadvantages, in common with those of dry curing, include (1) poor utilization of space, and (2) slow turnover of meat inventories. Pickle cure usually gives a product with a milder flavor than dry curing and requires less labor. However, space utilization is even poorer, since the pickle must be in a tight container.

Although pickle curing was widely used in the early part of this century, it is now largely used in combination with artery or stitch pumping, followed by either submerging in a cover pickle or by rubbing with dry cure and

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Fig. 3.3. Artery cure pumping operation. Courtesy of the National Provisioner, Chicago, Illinois.

holding for a short time. However, even combination procedures such as these are declining with emphasis on rapid processing.

Artery Pumping Artery pumping is said to have been developed by a New Zealand undertaker who decided that the principles utilized in embalming the dead could be applied in curing of meat. Thus, the method makes use of pumping a pickle or brine into the cuts through the arterial system. Since the conventional cutting procedures used to disassemble carcasses do not maintain the intact arterial system, the procedure is almost entirely limited to curing hams and, to a lesser extent, picnics. Figure 3.3 shows a modern artery cure pumping operation.

The needle is usually inserted in front of the branch in the femoral artery so that the pickle goes into the entire ham. Some operators insert pickle into each branch and claim more uniformity in cure, although the operation is more time-consuming. The pumping schedule commonly calls for adding 8–10% by weight of the pump pickle. In some cases, one stitch pump (about 3 oz of pickle) is injected into the cushion. Some operators believe this minimizes undercuring and deep-seated spoilage.

The curing ingredients are essentially the same as for dry curing, except the brine is dissolved in water to make a pickle. In addition to water, the

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pickle contains salt, sugar, and nitrite and/or nitrate. It is a common practice to also use phosphates to aid in water retention and increase yields. Nitrite has replaced nitrate, since the hams are frequently held for very short periods before smoking, which requires rapid color development.

Some years ago, hams were pumped and then placed in either brine or dry cure and held for 7 to 14 days before smoking. At present, the holding time before smoking is much shorter, many processors pumping the hams and holding for only a few hours. Some processors go directly into the smokehouse after pumping, but the majority hold them for 1 to 3 days. The use of dry cure is sometimes helpful to bring yields within legal limits. Cover pickles are also used during the holding period to complete the curing process.

The pump pickle is usually a 65–80° brine, 65° being the most common under commercial conditions. Dextrose and/or corn syrup are the most common sweeteners. Nitrite is usually utilized instead of nitrate, and at a level of 150 ppm, or 1.5 oz per 100 gal brine. If cover pickles are used, the strength of the brine is usually 55–60°.

The major advantage of artery pumping is the speed of curing and the resulting reduction of inventories through more rapid turnover. A second advantage is the relatively high yield, which is usually further improved by use of alkaline phosphates. The major disadvantages are (1) it is largely limited to curing of hams and picnics and cannot be readily used for other products; (2) special care is required in cutting to maintain the artery intact; (3) hams cured by this procedure are perishable and require refrigeration. This is not a serious disadvantage because the majority of consumers prefer the mild-cured product.

Single-Needle Stitch Pumping Stitch pumping utilizes a needle having several openings, so it can be adapted to a variety of cuts. It does not depend on the arterial system. Usually, the operator makes three to five stitches per cut of meat, delivering about 3 oz of brine per injection. However, the total amount of pickle injected is based on adding a given weight of pickle, depending on its strength. Generally, 10% by weight of a 65° pickle containing 150 ppm nitrite plus alkaline phosphate is utilized.

Stitch pumping gives a somewhat wetter product than artery pumping and requires special care to produce a good-quality product because the brine often accumulates at the injection site. As a consequence, a longer time is required for cure diffusion by stitch pumping.

Many processors use artery pumping for hams and stitch pumping for curing picnics, shoulders, bellies, and other miscellaneous cuts. The amount of meat cured by stitch pumping and artery pumping has increased greatly in the past 70 years.

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Fig. 3.4. Multineedle pump injecting boneless hams. Courtesy of Townsend Engineering Co., Des Moines, Iowa.

Multiple-Needle Stitch Pumping The regularity in shape and freedom from bone makes bellies ideally suited for curing by injection pumping. Hams, both bone-in and boneless, are also injection-cured. Mechanization of the pumping operation using the same principles as utilized in stitch pumping provided the real impetus for change. The results have been greatly reduced labor costs and time required for production. Pickle injection has also increased yields, all of which have contributed to lower production costs. The quality of the final product is not as high as for dry-cured bacon, since the flavor is less desirable and cooking shrinkage is greater. Nevertheless, it has been estimated that about 80% of U.S. bacon production is produced by injection curing.

There are several models of machines for injecting the cure into bellies and hams. Most injection equipment contains a series of offset needles. Pickle is pumped until the desired weight is obtained. Since the pickle enters through a large number of needles spaced relatively close together, the distribution of pickle is excellent. The spacing of the needles, their size and dwell time are important to good distribution and retention of the pickle. This results in rapid curing. Figure 3.4 shows a stitch pumping machine in operation.

Thermal or Hot Cures

Several groups have experimented with hot cures, which can be either hot dry cures or hot pickles. The hot cures speed up the rate of curing and allow acceleration of the entire processing operation. To achieve maximum advantages from heating, the curing ingredients must be distributed into the tissues rapidly before the cure becomes cold.

Hot pickle cures can best be applied by artery pumping or stitch pumping.

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There are advantages in raising the temperature of the products either before or immediately after injection. This can best be achieved by placing them in the heated pickle. Best results with the hot pickle method have been achieved using a 70° pickle at a temperature of 135°–140°F. Hams should not be held in the hot pickle for periods longer than 1 hr, while 30 min is adequate. Following the heating period, the hams can go directly into the smokehouse. Holding overnight before smoking gives the best results.

Hot dry cure is not well adapted to large cuts but can be used to produce dry-cured bacon. One machine utilizes a series of offset needles similar to those used for injection of brine into bellies, except they are used solely for making perforations in the tissues. The hot dry cure is then applied to the perforated bellies and rapidly penetrates the tissues; 3–5 lb of cure are recommended per 100 lb of bellies. A temperature of curing between 48° and 50°F is recommended, with 3 to 5 days total curing time. This curing procedure is patented. The advantages claimed for hot dry curing are (1) rapid curing with reduction of inventory, (2) greater amounts of smoke flavor, as smoke also penetrates the perforations, (3) increased yields over dry curing, although lower than injection-cured bellies, (4) absence of pickle pockets, and (5) improved flavor. The disadvantages include problems in heating and applying the cure and reduced yields as compared to injection curing. Also, hot dry curing is adapted only to relatively thin cuts.

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