slaughter is arrested by freezing. For birds held at 40 F, complete tenderization occurs for all muscles within 24 hr and for many muscles in much shorter times. Other factors which interfere with normal tenderization are immersion in 140 F water and cutting into the muscle. Until recently birds were held unfrozen for sufficient time in the normal channels of processing and utilization to permit adequate tenderization. Recent trends, particularly shorter chilling periods, more rapid freezing, and cooking without a preliminary thawing period, have shortened the period during which tenderization can occur to such an extent that toughness has become a potential complaint of consumers. Processors should be cognizant of the need for an adequate aging or tenderising period. Unfortunately, because of the extreme variability in rates of tenderization between birds apparently treated the same, it is difficult to recommend the minimum number of hours of aging needed to tenderize all birds in any particular class or lot. However, some observations have been made that may serve as guides.

As early as 1939, Lowe reported[2] that birds chilled for 2 hr were less tender when cooked than those chilled overnight. Stewart et al found,[3] for New York dressed chickens held at 35 F, that tenderness increased rapidly after the passing of rigor. Maximum tenderness was attained within 24 hr at 35 F, but most of the tenderization took place within the first 8 hr. Under about the same conditions, Hanson et al observed[4] a rapid increase in tenderness within the first three hours of holding, and a gradual increase thereafter.

Graf and Stewart found[5] 140 F scalded chickens to be slightly tougher than those scalded at 130 F scalded chickens to be slightly tougher than those scalded at 130 F. Shannon et al, working with hand picked stewing hens, demonstrated[6] an increased toughness due to increased scalding temperature or increased scalding time in the ranges of 120 to 195 F and 5–160 sec. However, the differences in toughness that occurred within the limits of temperature and time that would be necessary or practical in commercial plants were quite small.

Recent work in the U. S. Department of Agriculture has shown[7,8] that in addition to the beneficial effect of increasing holding time above freezing, tenderness is increased by lower scald temperatures, shorter scalding time, and particularly by reducing the extent of beating received by the birds during picking operations. In addition, the data obtained support the following detailed conclusions: chicken fryers and turkey fryers should be held at least 12 hr above freezing in order to develop optimum tenderness. Holding fryers at commercial frozen storage temperatures (0 F) for prolonged periods of 6 months and longer has no tenderizing effect, but holding in a thawed state (35 F) after frozen storage has as much tenderizing effect as an equal period of chilling before freezing. Machine feather picking may result in twice as tough meat as that obtained for a theoretical, hand-picked control. Toughening induced by the beating action of the mechanical feather pickers is not resolved appreciably by otherwise adequate chilling periods. This toughening action is accumulative in that increasing the number of picking machines to which the bird is exposed increases the degree of toughness. Thus optimum tenderness can be attained only through careful attention to chilling (aging) periods, feather picking conditions, and scalding practices.

PACKAGING

Packaging materials and boxes for frozen poultry products have not been standardized to the same extent that they have been for many other foods. Aluminum foil, cellophane, mylar, pliofilm, polyethylene, polyvinylidene chloride, waxed paper and cardboard and various laminated combinations of these materials all have performance characteristics that fit them for certain packaging uses and conditions. The physical and chemical properties of these materials pertinent to their application in poultry packaging have been summarized in Reference 9.

Ideally, packages should possess low moisture-vapor permeability characteristics, and should be strong, protective, attractive, and suitable for rapid freezing and prolonged storage of the product. Packages for precooked frozen poultry products must in addition be adaptable for reheating the product. In general, packaging requirements increase as we go from whole to cut-up to precooked forms.

Packages for frozen, whole, ready-to-cook poultry consist principally of plastic film bags that are relatively transparent, tough and reasonably impermeable to moisture vapor and air. The commonly used polyvinylidene chloride and polyethylene films are sufficiently moisture vapor proof and air proof to give adequate protection for normal commercial times and temperatures. Polyvinylidene chloride is relatively transparent and has form-fitting ability (by heat shrinking), while polyethylene provides a tough and quite pliable film at frozen storage temperatures. Turkeys, ducks, and geese are packaged mainly in the whole, ready-to-cook form, while frozen chickens appear whole and in packaged, cut-up form.

Frozen, cut-up frying or stewing chickens are usually packaged in rectangular cartons, with considerable variation among processors in materials, shape and construction of carton. Most cartons have a cellophane sheet inner liner which is designed to overlap and provide a continuous film around the contents. This inner liner is designed to give considerable protection against dehydration and other quality deterioration when properly in place. In actual commercial practice, there are many instances of incomplete laps made by careless operators, which almost completely destroy the potential protective value of the liner. A sealed overwrap, either of moisture-proof plastic film, wax paper or aluminum foil laminate is valuable added protection and should be used when frozen storage life in excess of one or two months is needed. Telescoping cartons (with separate cover sliding down over the carton) will naturally give greater protection than cartons with flap-type lids. Any cut-outs in the carton, either to provide a transparent window to view the contents or to view recorded information on the inner carton, tend to reduce the effectiveness of the package as a moisture barrier and should be used for those products having a rapid turnover.

Precooked frozen poultry products are much less stable than the raw products and hence require a much better package. The ideal package should keep moisture in, air (oxygen) out, have a certain amount of structural rigidity and finally serve as a container for reheating the product before serving. Aluminum foils and aluminum foil laminates have been found to be particularly effective for this purpose. Everyone is familiar with the use of heavy aluminum foil for packaging, heating, and serving chicken pies and complete chicken or turkey dinners. Polyethylene when laminated to aluminum foil provides heat sealing ability as well as protection against pinpoint holes or cracks developing in the foil during rough handling. Most plastics are not stable at high enough temperatures to permit their use as a container for reheating frozen precooked products in boiling water or in a hot oven. *Mylar*, a plastic with a melting point above 450 F, is an exception and hence opens up a field for an entirely new type of combined package and cooking container. New types of polyethylene are also being developed that can be used at higher temperatures.

Precooked products having a sauce or gravy enveloping the meat are much more stable than products in which the cooked meat surface is exposed, such as fried frozen chicken. In the latter product, all practical means of excluding oxygen and preventing rancidification should be employed.

Large fiberboard cartons or containers for holding and shipping from 2 to 12 individually packaged birds should be rectangular in shape to facilitate palletizing and strong enough to support 16-ft high stacked loads common in refrigerated warehouses. For material such as fryer turkeys that need to be frozen rapidly, if freezing is to be accomplished in the case, there is need for holes or cut away sections in the sides and ends to permit a rapid air flow across the poultry surfaces in the air blast freezer.

FREEZING THEORIES AND METHODS

Effect of Freezing on Product Quality

The behavior of muscle tissue during freezing represents the combined effects of the soluble constituents that produce a freezing point lowering and a freezing range, the size and location of the ice crystals formed, and the translocation of cellular constituents during the freezing process. It was pointed out by Koons and Ramsbottom[10] that very slowly frozen poultry appears dark, with very large ice crystals of the extra-fiber type. When poultry is frozen at a temperature that insures a natural bloom, the ice crystals are smaller and more numerous, but are still principally of the extra-fiber type. Ice crystals are small and are of the intra-fiber type when freezing is sufficiently rapid to insure a white appearance. Ice crystals become progressively larger in beef steaks as the time between slaughter and freezing is increased. This also is true for poultry.

DuBois, Tressler and Fenton[11] studied cross-sections of chicken muscle after employing different methods and conditions of freezing. Chickens were frozen with the multiplate freezer and in air, with and without air blast at 10, 0, −8 and −25 F. Large ice crystals were found to be present in tissues slowly frozen at 10 F without air blast, whereas the faster methods of freezing effected the formation of a large number of very small crystals.

Rapid freezing is essential to obtain satisfactorily light appearance in certain types of frozen poultry.[12] Birds scalded at relatively high temperatures (140 F and above) completely lose their outer layer of skin during normal machine picking and become particularly susceptible to development of a dark frozen appearance if not frozen rapidly. Also immature fryer-roaster turkeys which have a thin, practically fat-free skin are naturally dark and require a rapid rate of freezing to insure a light, pleasing frozen appearance.

Increased rates of freezing have been provided by use of air blast tunnels operating at air temperatures ranging from −20 to −40 F and at air velocities of 500 fpm or more. It has been found advantageous in many cases to freeze packaged birds on open shelves in the air blast rather than to freeze them after packing the packaged birds in cartons or wire-bound wooden boxes. In an evaluation of various factors contributing to freezing rate and frozen appearance, Klose and Pool found[13] that freezing on open shelves versus freezing in boxes, lower air blast temperature, and higher air blast velocity were important in that order. At an air blast temperature of −20 F or below, increasing air blast velocity beyond 600 fpm had little beneficial effect. Also at 1300 fpm, decreasing air blast temperature from −20 F to −30 F produced little additional improvements in frozen appearance. Birds placed in the blast freezer immediately after evisceration and packaging and while still warm did not develop an appreciably darker frozen appearance than those chilled in ice slush before packaging and blast freezing. However, this procedure has the serious disadvantage that the duration of holding above freezing temperatures may be reduced to an amount inadequate optimum tenderization. Of course, the factor of finish, or amount of fat in the skin layer, can exert a much greater beneficial effect on frozen appearance than any possible changes in processing or freezing practices.

Freezing Methods

Poultry may be frozen between refrigerated double walled plates, in a blast of refrigerated air, or by immersion in a refrigerated liquid. A detailed description of the available commercial equipment is in Chapter 36, Theories and Methods of Freezing.

Considerable quantities of rectangularly packaged, cut-up poultry are frozen in multiplate freezers. Complete freezing can be accomplished within several hours.

The major proportion of whole, ready-to-cook birds are frozen in air blast tunnel freezers, with air temperatures ranging from −10 to −40 F and air velocities of 300–1000 fpm and up. It is desirable to have air temperatures at −30 F or below during operation and air velocities over the product surfaces should be at least 600 fpm. In order to obtain high air velocity over the product, the blast tunnel should be completely loaded across its cross section, with proper spacing of the units of the product to insure air flow around all sides and no large openings that would permit bypassing of the air stream. In some cases, the whole birds may be packed into cartons or boxes, and the cartons stacked on pallets in the blast tunnel, with spacing between layers and between cartons in the same layer to permit adequate air flow and rate of freezing. However, as mentioned above, freezing rates required to give a sufficiently light frozen appearance are so high for high-temperature-scalded birds and immature turkeys that modification of freezing methods are necessary. Boxes may be left open during freezing, or they may be constructed with holes or cut-outs on the ends, or best of all the individual, bagged birds may be frozen on open racks or shelves to provide maximum air flow and freezing rate. Simons proposed[14] an improved, more efficient method of blast freezing in space that could be used alternatively for either freezing or storage. The system involved a combination of high velocity air blasts directed from the ceiling and proper baffles to direct the air flow through the boxes of product. If freezing rates in excess of those possible in air blast tunnels are required, immersion freezing should be considered.

Freezing by direct contact with low temperature brine or other liquids such as glycols has been proposed from time to time and limited commercial applications have been made in Canada and the United States. Esselen et al found[15] that the freezing time per pound of packaged ready-to-cook birds immersed in −20 F brine was in the range of 20–30 min. In −20 F calcium chloride brine, times for the interior to reach 15 F for warm eviscerated, packaged broilers, 12 lb turkeys and 25 lb turkeys were approximately 1½, 5 and 7 hr, respectively. Lents and van den Berg have made comprehensive studies[16,17] of immersion freezing of poultry, in which factors affecting freezing time and frozen appearance were evaluated. Immersion freezing at −20 F produced a lightness of appearance that