Related Commercial Resources

CHAPTER 18

POULTRY PRODUCTS

POULTRY, and broilers in particular, are the most widely grown farm animal on earth. Two major challenges face the poultry industry: (1) keeping food safe from human pathogens carried by poultry in small numbers that could multiply, sometimes to dangerous levels, during processing, handling, and meal preparation; and (2) developing environmentally sound, economical waste management facilities. Innovative engineering and refrigeration are a part of the solutions for these issues.

PROCESSING

Processing is composed of three major segments:

- **Dressing**, where the birds are placed on moving line, killed, and defeathered.
- **Eviscerating**, where the viscera are removed, the carcass is chilled, and the birds are inspected and graded.
- **Further processing**, where the largest portion of the carcasses are cut up, deboned, and processed into various products. The products are packaged and stored chilled or frozen.

A schematic processing flowsheet is described in Figure 1; equipment layout for the dressing area is given in Figure 2 and for the eviscerating area in Figure 3. The space needed in the production area for the various activities is shown in Figure 4. A modern, highly automated poultry processing plant processes 1 to 3 million birds per week. In the 1970s, a standard U.S. plant was processing 1500 birds per hour (2 shifts, 5 days), or close to 120,000 birds per week. Barbut (2000) describes processing in detail.

CHILLING

Poultry products in the United States may be chilled to 26°F or frozen to lower than 26°F. Means of refrigeration include ice, mechanically cooled water or air, dry ice (carbon dioxide sprays), and liquid nitrogen sprays. Continuous chilling and freezing systems, with various means for conveying the product, are common. According to USDA regulations (1990), poultry carcasses weighing less than 4 lb should be chilled to 40°F or below in less than 4 h, carcasses of 4 to 8 lb in less than 6 h, and carcasses of more than 8 lb in less than 8 h. In air-chilling ready-to-cook poultry, the carcasses' internal temperature should reach 40°F or less within 16 hours (9CFR381.66).

Slow air chilling was considered adequate for semiscalded, uneviscerated poultry in the past. But with the transformation to eviscerated, ready-to-cook, sometimes subscalded, poultry, air chilling was replaced by chilling in tanks of slush ice. Immersion chilling is more rapid than air chilling, prevents dehydration, and effects a net absorption of water of 4 to 12%. Per U.S. regulations (9CFR441.10), water retention in raw carcasses and parts must be shown to be an unavoidable consequence of processing, to the specifications of the Food Safety and Inspection Service (FSIS). Additionally, water-retaining poultry must carry a label stating the maximum percentage of water retained. Objections to this weight gain from external water, a concern that water chillers can be recontamination points, and the high cost of disposing of waste water in an environmentally sound manner have encouraged some operators to consider returning to air chillers.

Continuous-immersion slush ice chillers, which are fed automatically from the end of the evisceration conveyer line, have replaced slush ice tank chilling, a batch process. In general, tanks are only used to hold iced, chilled carcasses before cutting up, or to age before freezing.

The following types of continuous chillers are used:

- **Continuous drag chillers.** Suspended carcasses are pulled through troughs containing agitated cool water and ice slush.

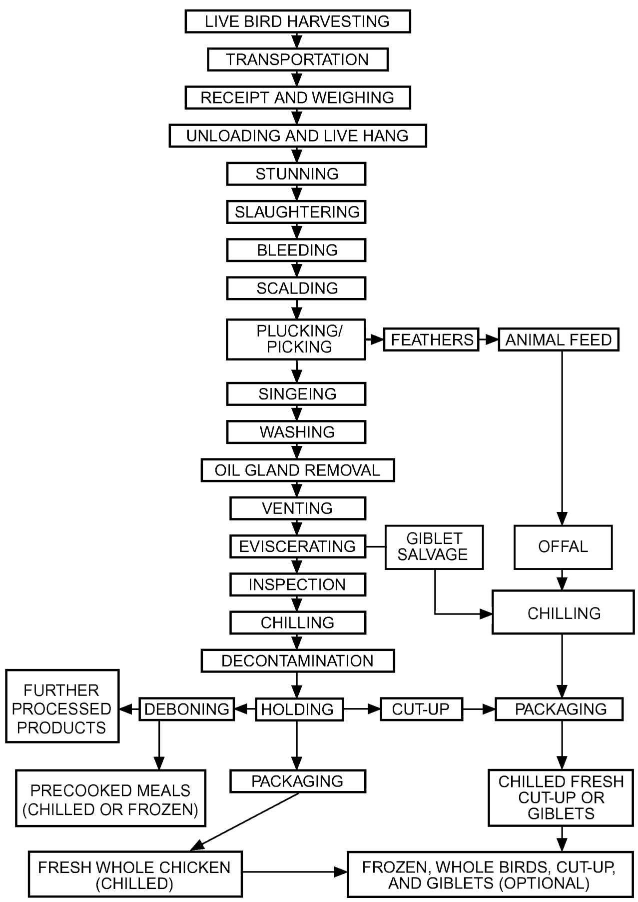


Fig. 1 Processing Sequence of Fresh Poultry

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

- **Slush ice chillers.** Carcasses are pushed by a continuous series of power-driven rakes.
- **Concurrent tumble systems.** Free-floating carcasses pass through horizontally rotating drums suspended in tanks of, successively, cool water and ice slush. Movement of the carcasses is regulated by the flow rate of recirculated water in each tank.
- **Counterflow tumble chillers.** Carcasses are carried through tanks of cool water and ice slush by horizontally rotating drums with helical flights on the inner surface of the drums
- **Rocker vat systems.** Carcasses are conveyed by the recirculating water flow and agitated by an oscillating, longitudinally oriented paddle. Carcasses are removed automatically from the tanks by continuous elevators.

These chillers can reduce the internal temperature of broilers from 90 to 40°F in 20 to 40 min, at processing speeds of 5000 to 10,000 birds/h (Figure 5). Chillers must meet food safety requirements (see, e.g., 9CFR381.66) and the facility's Hazard Analysis of Critical Control Points (HACCP) plan (see Chapter 12).

Adjuncts and replacements for continuous-immersion chilling should be used, if available, because immersion chilling is believed to be a major cause of bacterial contamination. Water spray chilling, air blast chilling, carbon dioxide snow, or liquid nitrogen spray are alternatives, but with the following limitations:

- Liquid water has a much higher heat transfer coefficient than any gas at the same temperature of cooling medium, so water immersion chilling is more rapid and efficient than gas chilling.
- Water spray chilling, without recirculation, requires much greater amounts of water than immersion chilling.
- Product appearance should be equivalent for water immersion or spray chilling, but inferior for air blast, carbon dioxide, or nitrogen chilling, because of surface dehydration.
- Air chilling without packaging could cause a 1 to 2% loss of moisture, whereas water immersion chilling allows from 4 to 15% moisture uptake, and water spray chilling up to 4% moisture uptake. Salt-brine chilling is the fastest chilling medium, but has little use in fresh poultry chilling.

Coolant temperature and degree of contact between coolant and product are most important in transferring heat from the carcass surface to the cooling water. The heat transfer coefficient between the carcass and the water can be as high as 630 Btu/h·ft²·°F. Mechanical agitation, injection of air, or both can improve the heat transfer rate (Veerkamp 1995). Veerkamp and Hofmans (1974) expressed heat removed from poultry carcasses by the following empirical relationship.

$$\frac{\Delta Q}{\Delta Q_i} = (-0.009 \log h + 0.73) \log \theta - (0.194 \log h - 0.187) \log m + 0.564 \log h - 2.219 \tag{1}$$

where

h = apparent heat transfer coefficient, Btu/h·ft²·°F
m = mass of the carcass, lb
θ = cooling time, s
ΔQ_i = maximum heat removal, Btu

Figure 5 shows time-temperature curves in a commercial counterflow chiller and compares calculated and measured values.

With adequately washed carcasses and adequate chiller overflow in counterflow to the carcasses, the bacterial count on carcasses should be reduced by continuous water-immersion chilling. However, incidence of a particular low-level contaminant, such as *Salmonella*, may increase during continuous water-immersion chilling; this can be controlled by chlorinating the chill water. However, for chlorine to be effective, the water's pH should be <7.0.

Spray chilling without recirculation has reduced bacterial surface counts 85 to 90% (Peric et al. 1971). Microbe transfer by spray chilling is unlikely. Chilling with air, carbon dioxide, or nitrogen presents no obvious microbiological hazards, although good sanitary practices

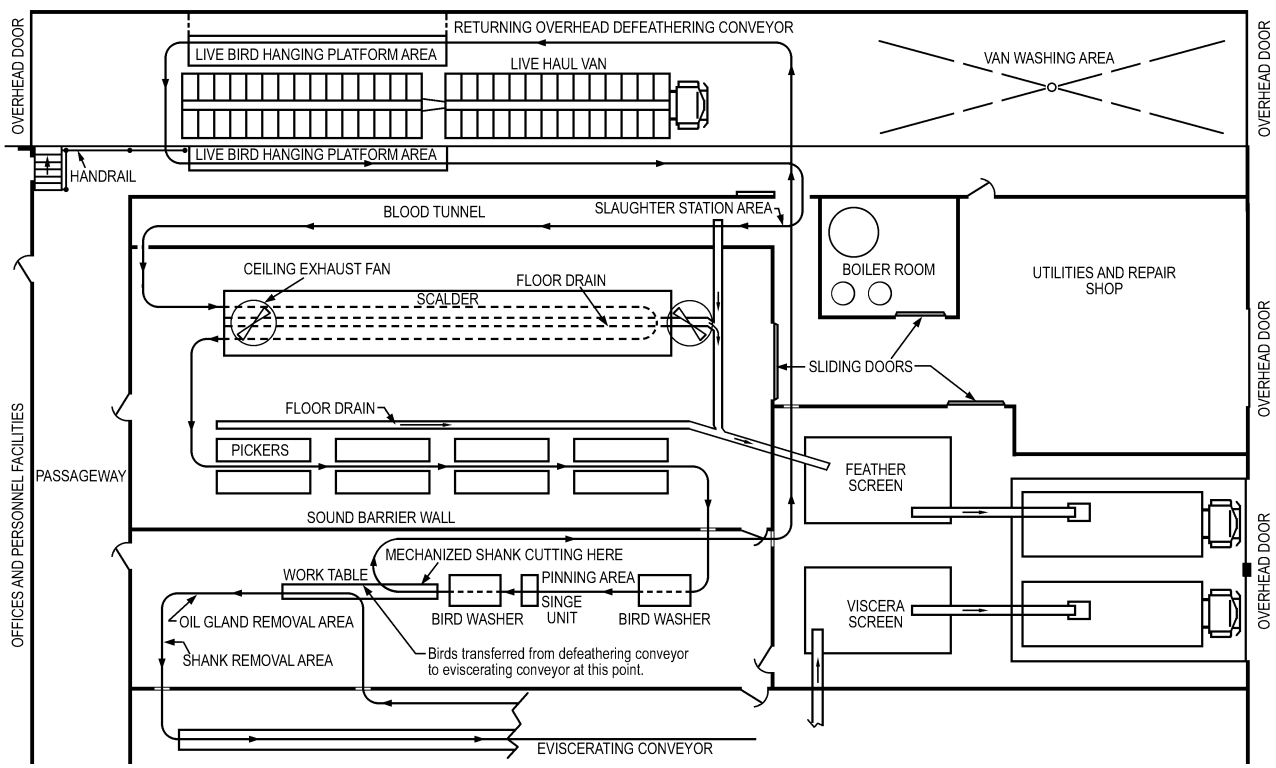


Fig. 2 Typical Equipment Layout for Live Bird Receiving, Slaughtering, and Defeathering Areas

are essential. If the surface of the carcass freezes as a part of the chilling process, the bacterial load may be reduced as much as 90%.

Air or **gas chilling** is commonly used in Europe. In air-blast and evaporative chilling, heat is conducted partly by the air-to-carcass contact and partly by evaporation of moisture from the carcass surface. The amount of water removed by evaporation depends on the carcass temperature, but even at 14°F it is about 1%. The apparent heat transfer coefficient ranges from 16 to 63 Btu/h·ft^2·°F. Major disadvantages of air chilling are slow cooling, dripping from one bird to another in multitiered chillers, and weight loss during chilling. A diagram of a one-tiered evaporative air chiller is given in Figure 6. To reduce contamination, it is very important that birds do not touch or drip on each other if multiple layers are used.

Cryogenic gases are generally used in long insulated tunnels through which the product is conveyed on an endless belt. Some freezing of the outer layer (crust freezing) usually occurs, and the temperature is allowed to equilibrate to the final, intended chill temperature. Some plants use a combination of continuous water immersion chilling to reach 35 to 40°F and a cryogenic gas tunnel to reach 28°F. The water-chilled poultry, either whole or cut up, is generally packaged before gas chilling to prevent dehydration.

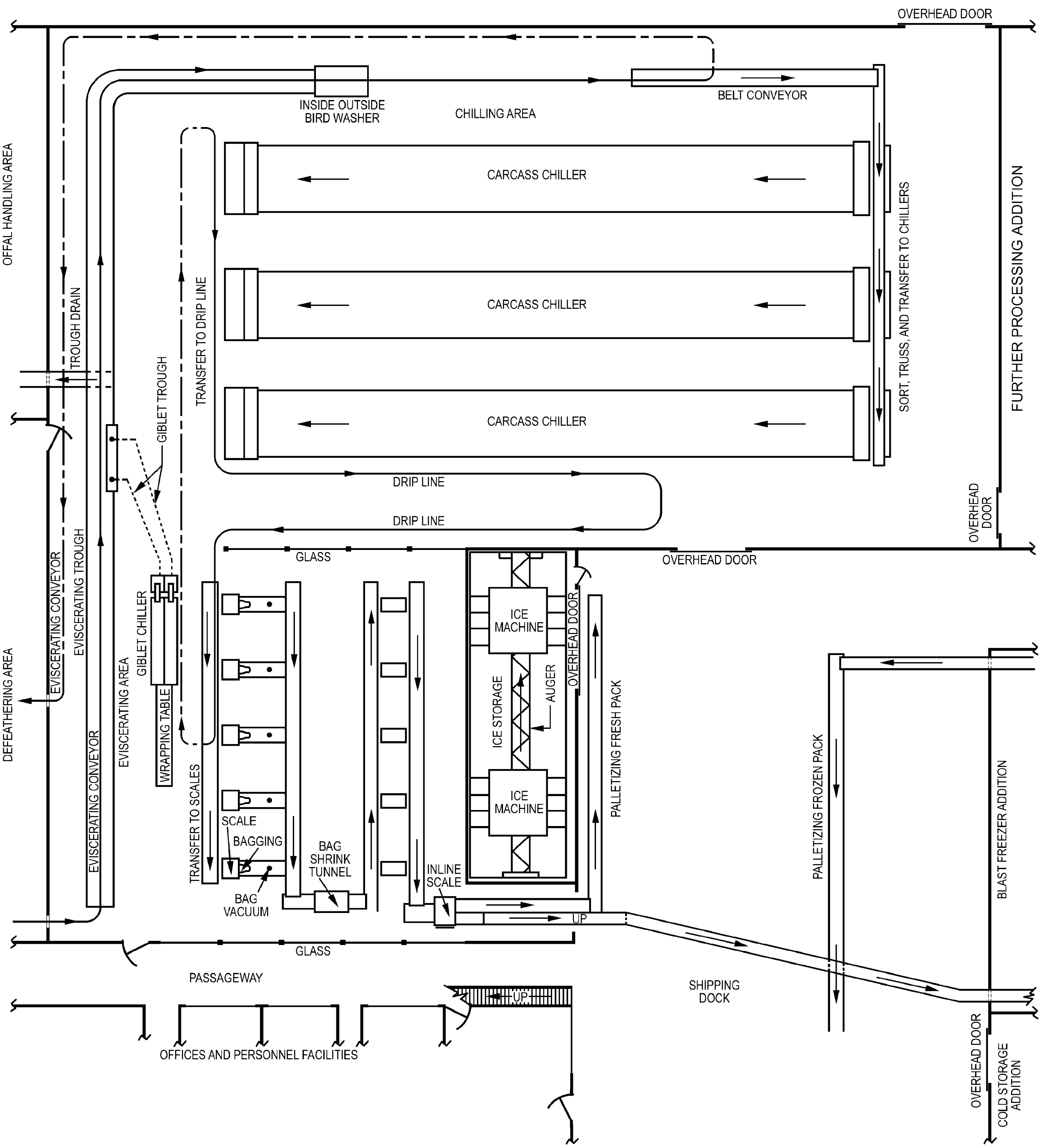


Fig. 3 Typical Equipment Layout for Eviscerating, Chilling, and Packaging Areas

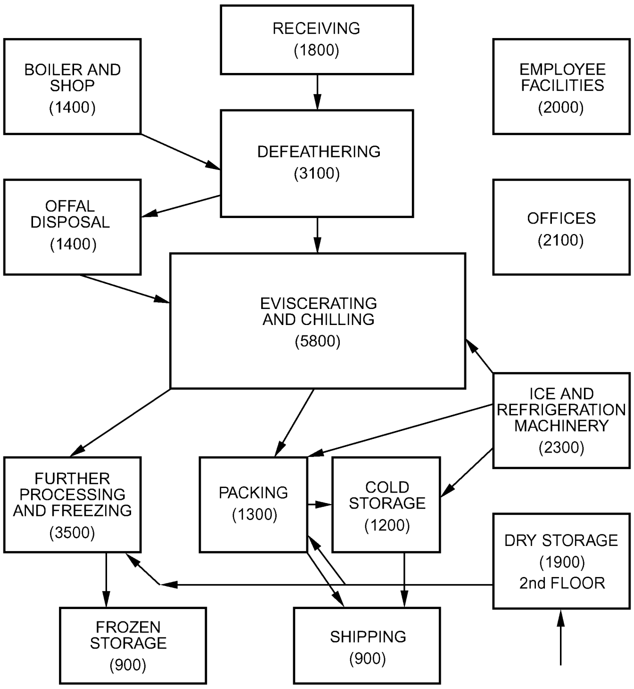


Fig. 4 Space-Relationship-Flow Diagram for Poultry Processing Plant
(Square feet of floor space needed)

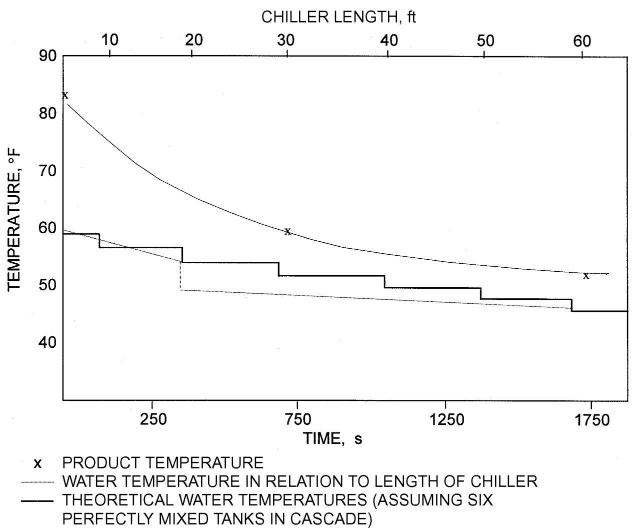


Fig. 5 Broiler and Coolant Temperatures in Countercurrent Immersion Chiller

Ice requirements per bird for continuous immersion chilling depend on entering carcass temperatures and weight, entering water temperature, and exit water and carcass temperature. For a counterflow system, 60°F entering water and 65°F exit water, 0.25 lb of ice per pound of carcass is a reasonable estimate. This may be compared to a requirement of 0.5 to 1 lb of ice per pound of poultry for static ice slush chilling in tanks. For continuous counterflow water-immersion chillers, if plant water temperature is considerably above 65°F, it may be economical to use a heat exchanger between incoming plant water and exiting (overflow) chill water.

Ice production for chilling is usually a complete in-plant operation, with large piping and pumps to convey small crystalline ice or

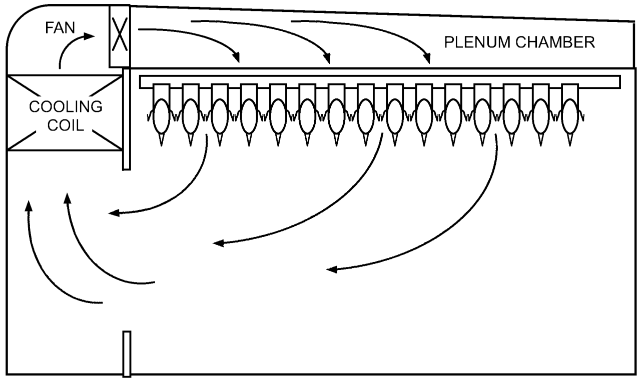


Fig. 6 One-Tier Evaporative Air Chiller
(Source: Bishop 1980)

ice slush to the point of use. To reduce ice consumption, some immersion chillers are double-walled and depend on circulating refrigerant to chill the water in the chiller. The chiller has an ammonia or refrigerant lubricant between the outer and inner jacket, with the inner jacket serving as the heat transfer medium. Agitation or a defrost cycle must be provided during periods of slack production to prevent the chiller from freezing up.

Chilling and holding to about 28°F, the point of incipient freezing, gives the product a much longer shelf life compared with a product held at ice-pack temperatures (Stadelman 1970).

DECONTAMINATION OF CARCASSES

Contamination of poultry meat by foodborne pathogens during processing can be potentially dangerous if microbes multiply to critical numbers and/or produce poisonous toxins (Zeidler 1996, 1997). The Hazard Analysis of Critical Control Points (HACCP) system (see Chapter 12 and the section on HACCP Systems in Poultry Processing) was specifically developed for each food to eliminate or keep pathogen levels very low so food-related illnesses cannot break out. Appropriate refrigeration and strict temperature control throughout the food channel is vital to suppress microbial growth in high-moisture perishable foods and meats in particular.

Decontamination steps are now being added just before chilling. Numerous methods have been developed (Bolder 1997; Mulder 1995), including **lactic acid** (1%), **hydrogen peroxide** (0.5%), and **trisodium phosphate (TSP) sprays**. **Ozone** (O_3) is a strong oxidizer and can be used to decontaminate chiller and scalding water; however, it is very corrosive.

Gamma irradiation of poultry is approved in many countries, including the United States; products are available for sale in a few outlets. The public's fear of this technique limits sales. However, the threat of food poisoning is reducing objections to irradiated foods because irradiation is very effective, and can kill 95.5% of non-spore-forming pathogens (Stone 1995). A dose of 250 krad is the most suitable for poultry.

Steam under vacuum effectively kills 99% of the surface bacteria on beef and pork carcasses and is used commercially. In this continuous system, the carcass is carried on a rail to a chamber. A vacuum is pulled and steam at 290°F is applied for 25 ms. Upon breaking the vacuum, the carcass surface is cooled to prevent the surface from cooking. USDA engineers developed steam equipment for poultry in 1996.

FURTHER PROCESSING

Most chickens and turkeys, for both chilled and frozen distribution, are cut up in the processing plant. More than 90% of the broilers in the United States are sold as cut-up products produced at the processing plant. The cutting procedure is almost fully automatic.

Backs and necks are often mechanically deboned, giving a comminuted slurry that is frozen in rectangular flat cartons containing about 60 lb. Turkey breasts, legs, and drumsticks are available as separate film-packaged parts, and turkey thigh meat is marketed as a ground product resembling hamburger. Partial cooking and breading and battering of broiler parts is done in poultry processing plants.

Unit Operations

The following types of equipment used for further processing of poultry products are also used in red meat facilities.

Size Reduction and Mixing Machines. Several types of size-reduction and mixing equipment are available.

- In **grinding**, meat is conveyed by an auger and forced through a grinding plate.
- **Flaking** is done by cutting blades locked at a specific angle on a rotating drum. Flaking does not extensively break muscle cells, as in grinding, and moisture loss and dripping are limited. Product texture resembles muscle texture.
- **Chopping** is generally conducted with silent cutter equipment. Meat is placed in a rotating bowl with ice, which is used to keep the temperature low, and vertical rotating blades chop the moving meat. The length of chopping time determines the particle size. The end product is used in hot dogs and sausages.
- **Mixing, tumbling, and injecting machines** produce a uniform product out of various meats and nonmeat ingredients such as salt, sugar, dairy or egg proteins, spices, and flavorings. Together with salt, mixing also helps extract myosin, which acts likes a glue in holding the product together.
- **Injection machines** insert an accurate and repeatable volume of liquid that contains salt and flavorings into large chunks of muscle meats such as turkey breasts or whole turkeys. The procedure disperses these ingredients better and faster than soaking in brine and marinade. It also protects the meat from drying during cooking, especially at home.
- **Automated** systems consist of conveyor belts that pass meat into a channel where a cross head assembly of needles is lowered into the product. The hollow needles pierce the meat and marinade is pumped in through a small orifice in the side of each needle. Each needle is independently suspended so bones are not penetrated (Smith and Acton 2001). Production line speeds are fast, averaging up to 10,000 lb/h or greater.
- **Tumblers** shaped like concrete mixers tumble injected large meat chunks mostly under vacuum. The tumbling helps distribute injected brine and spices throughout the meat. Tumbling is a widespread method of commercial marination.

Shaping Forms and Dimension. These machines establish the form, size, and desired weight of size-reduced meats.

- **Stuffing machines** make hot dogs and sausages by stuffing meat emulsion into the casing. Modern stuffing machines operate under vacuum to eliminate bubbles and other textural defects. Dough products or muscle meats are also stuffed with other meats, fruit or vegetable pieces, etc., using equipment that was originally designed to stuff doughnuts with jelly.
- **Forming machines** make hamburgers and nuggets. They are basically presses that force the meat through a plate with holes of various sizes and shapes.
- **Metal molds.** Many products such as turkey rolls and luncheon meats are made from meat chunks, which are placed into metal molds and cooked to produce a restructured log. The meat is chilled in the molds before being released.
- **Coating.** Batter and breading give the product a uniform shape as well as higher palatability and weight. Products are carried on belts through ingredients that coat the products, which are fried immediately after.

Cooking Techniques. Many meat products are produced as ready-to-eat meals that need warming only or are eaten cold. These products are fully cooked in the plant by various methods. Other products are produced as ready-to-cook and skip the cooking step.

- **Smoking/cooking** is a popular method, in which smoke from slow-burning wood outside the cooking chamber flows over the hanging product. To eliminate some smoke carcinogenic compounds and to accelerate the process, liquid smoke is used to treat the product before cooking (Lazar 1997). Smoking is done best on a dry, uncooked surface, which better absorbs the smoke ingredients. Smokehouses are generally the bottleneck of the process, and their high capital cost and large size limits the number of units in the plant. Every product is cooked to a specific internal temperature, commonly between 145 and 175°F, followed by immediate chilling by water showers from sprinklers located in the cooking chamber.
- **Continuous hot-air ovens** cook hamburgers and chicken breast products. These ovens accelerate cooking and reduce labor compared to batch-type equipment. Wireless, solid-state temperature monitoring devices that travel with the product optimize and record the cooking process. Indirect heat sources are used to prevent pink or red discoloration of some poultry products exposed to gases from the direct-heat gas jet (Smith and Acton 2001).
- **Cooking in water bath** is a fast and low-cost way to cook meats because of better heat transfer than in air cooking. Product is protected from the water by waterproof plastic packaging. Most operations are batch-type.
- **Frying** provides higher palatability at the cost of increasing fat content. Frying provides crispness as the hot oil above 212°F replaces the water in the skin, batter, and breading. Frying is a fast method of cooking because of oil's high heat transfer capacity. Oil quality is critical to good product quality; oil problems translate into poor appearance, flavor, and odor of finished product.

There are three basic types of poultry meat products:

- **Whole-muscle products**, such as nuggets, rolls, Buffalo wings, and schnitzels
- **Coarsely ground products**, such as ground poultry meat, loaves, and meatballs
- **Emulsified products**, such as hot dogs and bologna

Figure 7 gives a flow chart for preparing these product groups; batch and continuous heat processing (i.e., cooking and chilling) are illustrated in Figures 8 and 9.

FREEZING

Effect on Product Quality

Generally, lower temperature and protection from atmospheric oxygen reduces oxidation rancidity and extends storage life. At ≤0°F, most microbial growth and enzymatic activity drop to almost zero because most of the cellular water molecules are fixed in a crystalline structure, but reactions may continue slowly down to –80°F. Most commercial holding freezers range from –4 to –20°F, whereas air-blast individual quick freeze (IQF) freezers use high air velocity (2500 ft/min at ≤20°F) to rapidly remove heat. Powdered carbon dioxide (CO_2 "snow") may be added to product before closing the box container to accelerate freezing. In any freezing application, raw or finished products must be packaged to exclude air and protect the surface from excessive drying (freezer burn). Poultry muscle that is frozen and held at –4 to –20°F should retain its quality for 6 to 10 months. The least desirable temperature range for holding products is –12 to –14°F, at which the phase transition between intercellular crystalline ice and a combination of ice and water occurs. Frequent

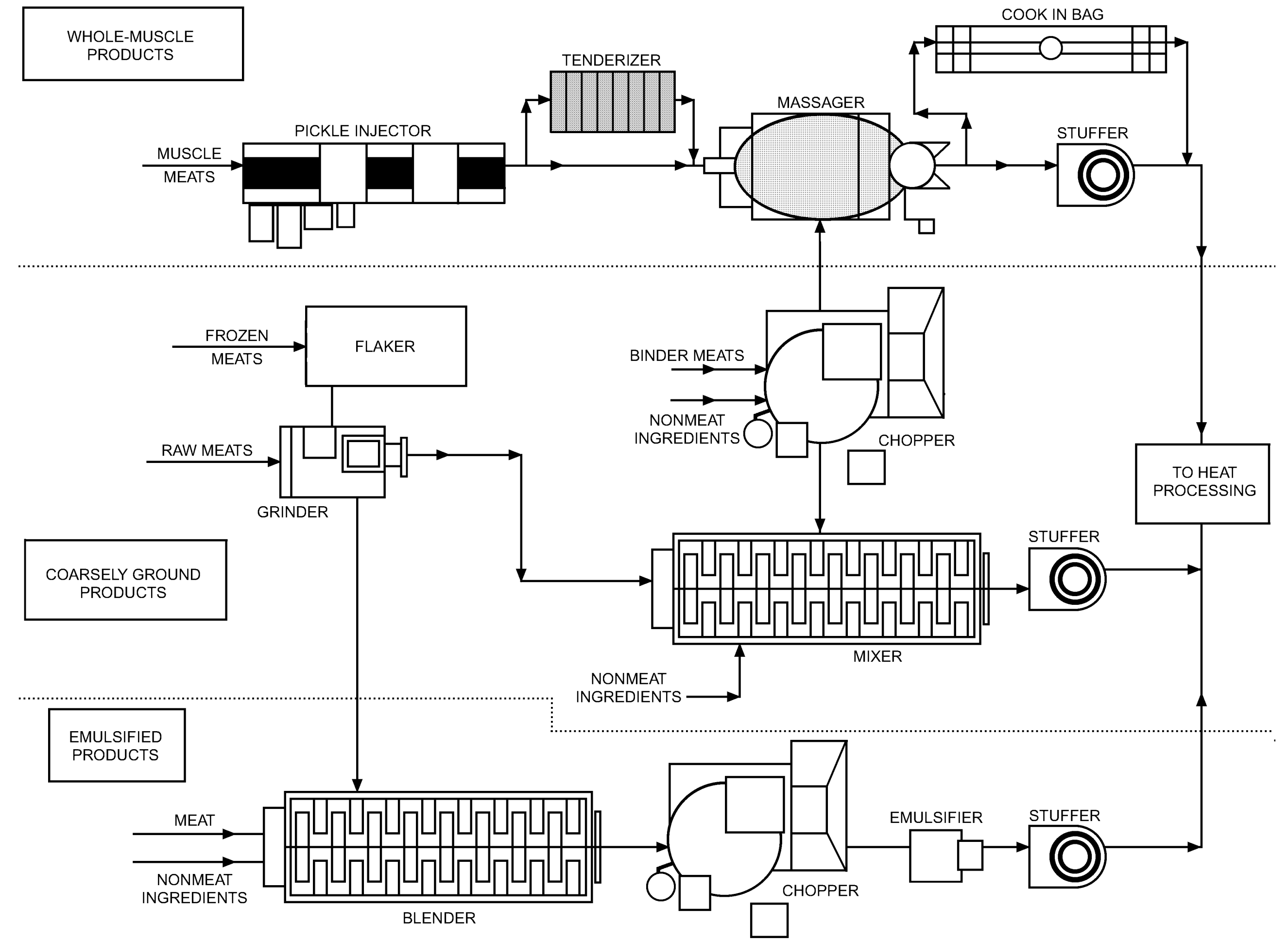


Fig. 7 Meat Products Processing Flow Chart

cycling of the refrigeration system through this temperature zone causes large ice crystal formation in muscle cells and excessive purge (water loss) when thawed (Keeton 2001).

USDA regulations define frozen poultry as cooled to 26°F or lower. This rule prevents the practice of cooling meat to above 0°F, thawing it in destination, and selling it as fresh. Poultry that is frozen to less than 0°F is now called deep frozen.

The freezing rate of diced cooked chicken meat does affect the quality of the frozen meat. Hamre and Stadelman (1967a) reported that cryogenic freezing procedures were desirable because the resulting color was lighter, but too rapid a freezing rate resulted in the meat cubes shattering. The freeze-drying rates for rapidly frozen material were slower than for products frozen by slower methods. Hamre and Stadelman (1967b) indicated that tenderness of freeze-dried chicken after rehydration was affected by freezing rate prior to drying. Liquid nitrogen spray or carbon dioxide snow freezing were selected as preferred methods for overall quality of diced cooked chicken meat to be freeze-dried.

Freezing Methods

Air Blast Tunnel Freezers. Air blast tunnel freezers use air temperatures of –20°F and air velocities of 2500 ft/min. To obtain high air velocity over the product, the blast tunnel should be completely loaded across its cross section, with product units properly spaced to ensure airflow around all sides and no large openings that might allow bypassing of the airstream.

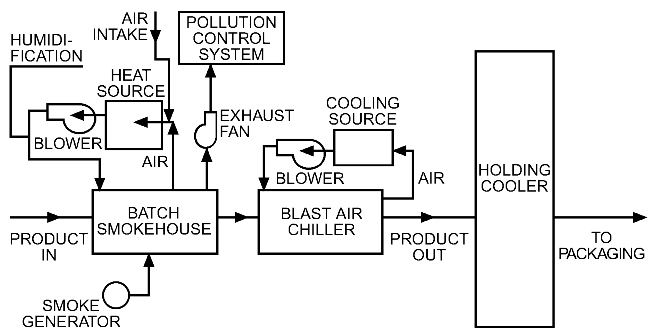


Fig. 8 Heat Processing of Meat Products by Batch Smoker/Cooker

Individual Quick Frozen (IQF) Products. This method creates a crust on the bottom of the product, which moves on thin, disposable plastic sheets. IQF works well for marinated bones, chicken breast, and chicken tenders because they are moist and softer than other parts and tend to stick to freezer belts. The plastic sheet keeps the product from sticking.

Freezer Conveyors. Automated units may be designed to handle packages, cartons, or unwrapped pieces of chicken or turkey. The product may be transported through the freezing chamber on belts or trays. One such system adapts to all sizes of whole birds.

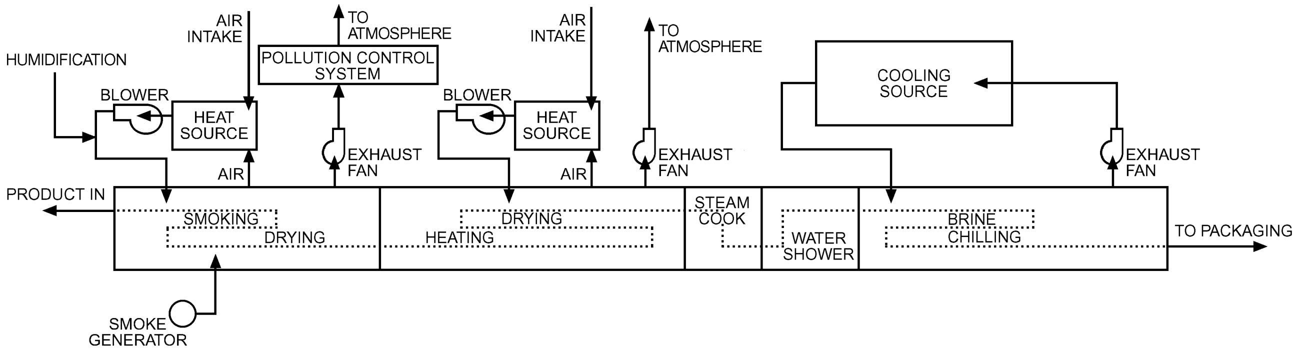


Fig. 9 Heat Processing of Meat Products by Continuous Smoker/Cooker

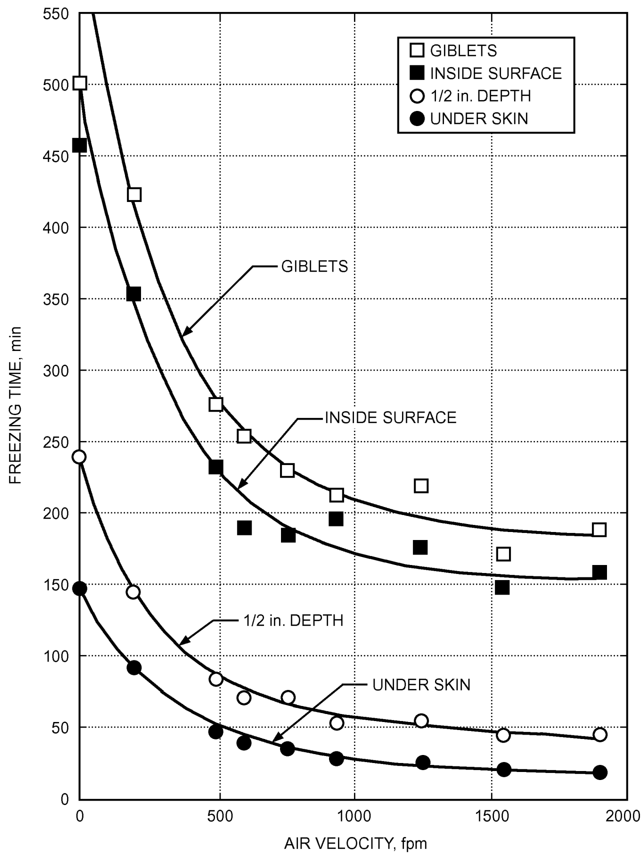
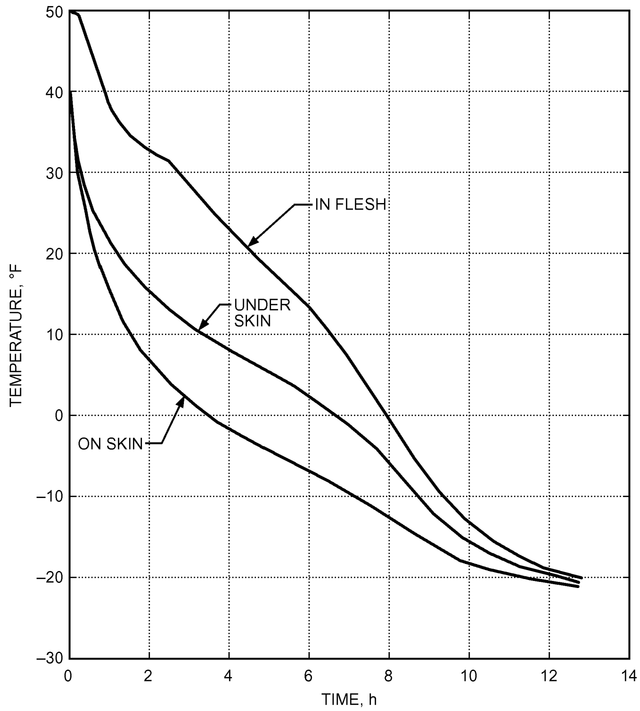


Fig. 10 Relation Between Freezing Time and Air Velocity
(van den Berg and Lentz 1958)



Note: For 21 lb, bronze tom turkeys on shelves in air blast.

Fig. 11 Temperature During Freezing of Packaged, Ready-to-Cook Turkeys
(Klose et al. 1955)

Predicting Freezing or Thawing Times

The following equation can be used to predict freezing and thawing time with an accuracy of about 10% (Calvelo 1981; Cleland and Earle 1984; Cleland et al. 1982).

$$\theta_f = \rho \frac{\Delta H}{\Delta t}\left(\frac{d}{6h} + \frac{d^2}{24k}\right) \qquad (2)$$

where

θ_f = freezing time, h
ρ = product density, lb/ft^3
d = equivalent diameter of product, ft
ΔH = enthalpy difference, Btu/lb
Δt = temperature difference between air and mean freezing temperature, °F
h = heat transfer coefficient, Btu/h·ft^2·°F
k = thermal conductivity at mean freezing temperature, Btu·ft/h·ft^2·°F

PACKAGING

Most packaged poultry is now tray-packed, either for frozen or chilled distribution. All-plastic packages and automated packaging lines using plastic film have been engineered. Changes in packaging methods and materials are so rapid that the best sources of information on this subject are manufacturers and distributors of films and packages. They are listed in the most recent Encyclopedia Issue of *Modern Packaging*.

Packages for frozen, whole, and ready-to-cook poultry consist principally of plastic film bags that are tough and reasonably impermeable to moisture vapor and air. The commonly used polyvinylidene chloride, polyethylene, and polyester films are sufficient barriers to water vapor and air to give adequate protection for normal commercial times and temperatures. Turkeys, ducks, and geese are packaged mostly in the whole, ready-to-cook form; frozen chickens appear whole and in packaged, cut-up form.

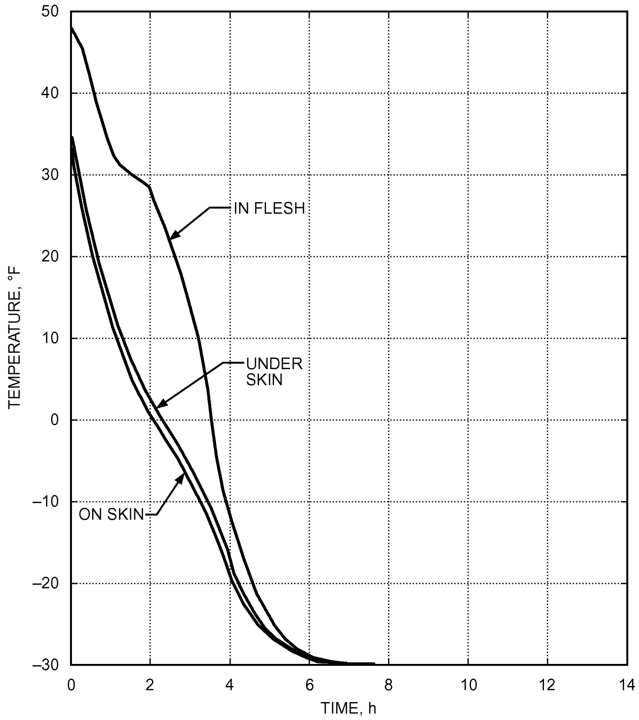


Fig. 12 Temperature During Freezing of Packaged, Ready-to-Cook Turkeys
(Klose et al. 1955)

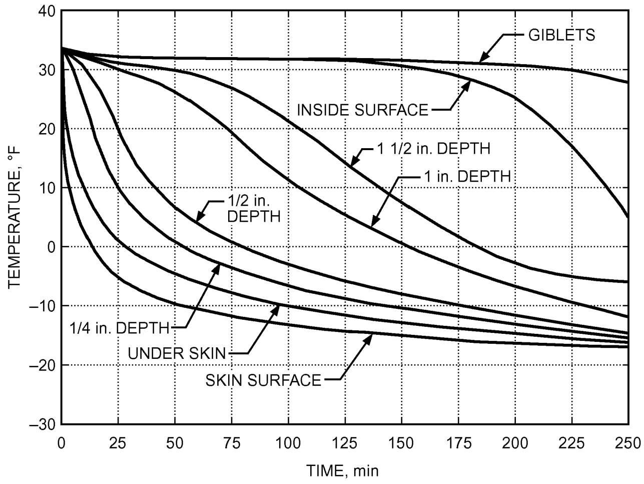


Fig. 13 Temperatures at Various Depths in Breast of 15 lb Turkeys During Immersion Freezing at –20°F
(Lentz and van den Berg 1957)

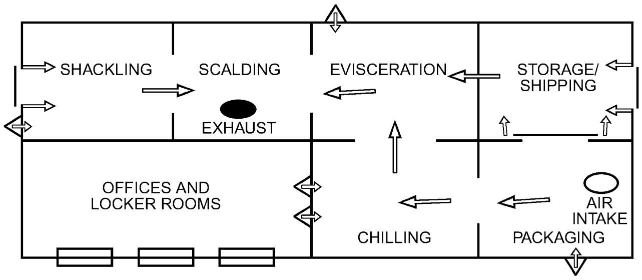


Fig. 14 Air Movement Pattern in Positively Pressurized Poultry Processing Plant
(Further processing is not included)
(*Source*: Keener 2000)

Table 1 Thermal Properties of Ready-to-Cook Poultry

Property	Value	Reference
Specific heat, above freezing	0.70 Btu/lb·°F	Pflug (1957)
Specific heat, below freezing	0.37 Btu/lb·°F	Pflug (1957)
Latent heat of fusion	106 Btu/lb	Pflug (1957)
Freezing point	27°F	Pflug (1957)
Average density		
Poultry muscle	67 lb/ft^3	
Poultry skin	64 lb/ft^3	
Thermal conductivity, Btu/h·ft·°F		
Broiler breast muscle =	0.24 at 80°F	Walters and May (1963)
Broiler breast muscle ⊥	0.29 at 68°F	Sweat et al. (1973)
Broiler breast muscle ⊥	0.80 at –4°F	Sweat et al. (1973)
Broiler breast muscle ⊥	0.87 at –40°F	Sweat et al. (1973)
Broiler dark muscle ⊥	0.90 at –40°F	Sweat et al. (1973)
Turkey breast muscle ⊥	0.73 at –4°F	Sweat et al. (1973)
Turkey breast muscle =	0.93 at –4°F	Sweat et al. (1973)
Turkey leg muscle ⊥	0.83 at –4°F	Lentz (1961)

⊥indicates heat flow perpendicular to the muscle fibers.
= indicates heat flow parallel to the muscle fibers.

Large fiberboard cartons or containers for holding and shipping from 2 to 12 individually packaged birds should be rectangular to facilitate palletizing, and should be strong enough to support 16 ft high stacked loads common in refrigerated warehouses. If rapid freezing is necessary for contents (e.g., fryer turkeys), holes or cutaway sections in the sides and ends are needed to permit rapid airflow across the poultry surfaces in the air-blast freezer.

AIRFLOW SYSTEMS IN POULTRY PROCESSING PLANTS

Appropriate air-handling systems in poultry processing plants are vital for maintaining product quality and safety as well as for employees' health and comfort. Moisture, dust, and microorganisms, some of which are hazardous to human health, become airborne at the beginning of the slaughtering process in the unloading, shackling, killing, scalding, and defeathering areas. This aerosol must be treated to protect finished products and workers from contact. Specific work on airflow systems in poultry processing plants and aerosol handling were conducted by Heber et al. (1997) and Keener (2000). Reviews of articles on airflow systems appear in ACGIH (1995) and Burfoot et al. (2001). A typical arrangement of the airflow system in a poultry processing facility is shown in Figure 14. There, air moves from the cleanest cold-storage and packaging areas to the dirtiest parts (shackling and killing) of the plant. Unfortunately, in many poultry processing plants, airflow systems have had a low priority, and renovations often ignore correcting airflow system deficiencies or adjusting the system to the renovated plant.

Historically, many processing plants were ventilated using negative-pressure systems in which uncontrolled fresh air entered the plant through doors, windows, and exhaust hoods. Currently, positive-pressure ventilation systems are used, because they better control internal airflow and incoming fresh air. An air pressure gradient prevents contaminated air produced at the beginning of the process from reaching the finished product areas, while exhausting it from already-dirty areas. Air enters the plant through doors and openings in the unloading and shackling sections and through shipping areas. An air intake is also located in the packaging area, and the exhausting outlets are located in the scalding area. Fans are routinely installed in the chilling area to better recirculate the moist air to prevent condensation. Airflow balance within a room depends on the location of openings in the rooms and their size. In a positive-pressure ventilated system, the packaging area (the cleanest area in the processing plant) has the greatest static pressure, and the defeathering and scalding areas are neutral. As a result, air moves away from the finished product area, where incoming air is filtered and controlled.

The demand for poultry meat has dramatically increased since the mid-1970s and is still growing. To accommodate this growth, processing plants are often being renovated and expanded, but frequently, these projects were designed without sufficient consideration for their effect on the plant ventilation system. Often, moist and dusty air migrates from the slaughter area into the further processing area, and condensation on ceilings and structures results in moisture dripping onto the processing lines, floors, and employees.

This type of air movement can recontaminate in-process and finished products, reducing quality and shelf life and creating a potential health hazard to plant workers and consumers. Airborne microorganisms, including several pathogens, are attached to dust and tiny feather particles, which become airborne in the shackling and slaughtering areas and can remain suspended for a long time. For example, one of the most dangerous pathogens in poultry processing plants is *Listeria monocytogenes*, which is well adapted to grow in low temperatures and can survive long periods in evaporators' drip pans, creating a secondary contamination source. Because many cooked poultry products are eaten cold or warm, pathogens such as *Salmonella*, *Campylobacter*, and *Listeria* in recontaminated products are not destroyed before consumption and could result in serious illnesses and fatalities. Outbreaks with fatalities have been recorded in countries around the world, with severe economic losses by the processing companies and growers. The presence of *Listeria* in cooked poultry could result in immediate product recall. In contrast, raw poultry products have lower risk because they are fully cooked before consumption, destroying all pathogens in the process.

Airflow System Consideration During Renovation

During structural changes, such as providing new doors or wall openings or increasing or altering processing capacity, airflow pattern will probably be affected. Therefore, before renovations take place, the ideal and practical parameters of the airflow system should be reestablished. The evaluation should be conducted by qualified HVAC practitioners and consider all areas of the plant, not just the renovation area. Parameters should include airflow patterns, static pressures, air speed, air temperature, and relative humidity. A follow-up evaluation should be conducted to determine the deviation from the ideal pattern to minimize changes in airflow patterns and production of stagnant areas, and to prevent movement of contaminated air into the finished product areas. In addition, serious attention should be paid to moisture-producing parameters: for example, processing an additional 100,000 chickens per day adds about 150 to 160 lb of water vapor per hour, adding 10 employees generates 3 to 10 lb of water vapor per hour, and sanitation with hot water increases plant humidity. Proper consideration and evaluation of these parameters can help provide safe products and a healthy atmosphere for workers.

PLANT SANITATION

Poultry meat is highly perishable because it composed of nutrients that are ideal for microbial growth. During processing, excessive amounts of meat and drippings soil equipment and floors. If not thoroughly cleaned and sanitized, it becomes a source of bacterial growth that can recontaminate incoming new meats. Therefore, specific cleaning teams clean the plant at the end of the working day using steam, soap, and sanitizing agents. In many instances, work is stopped and certain equipment is cleaned every few hours.

In January 1997, the rules for meat inspection changed dramatically (USDA/FSIS 1996). Processing plants are required to (1) inspect their own processes by writing and implementing their own sanitation standard operation procedures (SSOP), (2) monitor the processes, and (3) take corrective action when necessary. Precise records should be kept in a format ready for instant review by purchasers.

Proper sanitation should be addressed when the structure, processing equipment, and refrigeration systems are designed. The plant structure should be designed to prevent pests such as mice, rats, cockroaches, and birds from entering the facility and finding places to hide that cannot be reached. This includes drainage, sewage, windows, vents, etc. Equipment should be designed for easy cleaning and easy assembly and disassembly. It should not have any areas on which product particles can accumulate. Refrigeration systems should be designed to restrict airflow from raw to cooked meat areas and to eliminate possible condensation and dripping into the product or into drip pans that cannot be reached for easy cleaning.

Clearly written procedures, constant training of employees, and adequate numbers of employees are essential for successful implementation of the program. Also, constant management commitment is vital.

HACCP Systems in Poultry Processing

Hazard Analysis of Critical Control Points (HACCP) is a logical process of preventative measures that can control food safety problems. HACCP is a process control system designed to identify and prevent and microbial and other hazards in food production. It is designed to prevent problems before they occur and to correct deviations as soon as they are detected. This method of control emphasizes a preventative approach rather than a reactive approach, which can reduce the dependence on final product testing. The fundamentals of HACCP are described in Chapter 12.

HACCP systems are used in poultry processing to improve the safety of fresh meats and their products. HACCP programs are required by the USDA in all plants.

Poultry is associated with numerous microbial pathogens that occur naturally in wild birds, rats, mice, and cockroaches. Poultry is contaminated by feed containing feces of these pests. They are potentially transferred to the meat during processing from unclean equipment, processing water, air, and human hands, hair, or clothing. Strict temperature control throughout the system will strongly suppress microbial growth, keeping pathogen levels too low to generate foodborne illness outbreaks**. In most outbreaks, temperature control breakdown or temperature abuse is involved** (Zeidler 1996).

The major pathogens associated with raw poultry are various types of *Salmonella* and *Campylobacter jejuni*, which recently became the leading pathogen in poultry meat. HACCP programs cover production farms, processing plant, and shipping trucks. Water baths (as in chilling and scalding areas) could easily spread pathogens, and the circulating water must be treated. The aerosol, places where condensation may accumulate, backup of sewage, and used processing water are also potential contamination risk areas. Reducing human touch, bird-to-bird contact, and dripping from bird to bird during air chilling, as well as increased automation, help reduce contamination. Appropriate temperature control throughout the system is vital as foodborne disease outbreaks always involve temperature abuse.

TENDERNESS CONTROL

Texture is considered the most important characteristic of poultry meat and is most affected by the bird's age and by processing procedures.

Tenderness in cooked poultry meat is a prerequisite to acceptability. Relative tenderness decreases as birds mature, and this toughness has always been considered in the recommendations for cooking birds of various ages. However, another type of toughness depends primarily on the length of time that the carcass is held unfrozen before cooking. Birds cooked before they have time to pass through rigor are very tough. Normal tenderization after slaughter is arrested by freezing. For birds held at 40°F, complete tenderization occurs for all muscles within 24 h and for many muscles in a much shorter time.

Other factors that interfere with normal tenderization are immersion in 140°F water and cutting into the muscle. Formerly, birds were held unfrozen for enough time in the normal channels of processing and use to allow adequate tenderization. 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 consumer complaint.

Hanson et al. (1942) observed a rapid increase in tenderness within the first 3 h of holding and a gradual increase thereafter. Shannon et al. (1957), working with hand-picked stewing hens, found increased toughness because of increased scalding temperature or time, in the ranges of 120 to 195°F and 5 to 160 s. However, the differences in toughness that occurred within the limits of temperature and time, necessary or practical in commercial plants, were quite small.

Tenderness is also increased by reducing the extent of beating received by the birds during picking operations. Turkey fryers should be held at least 12 h above freezing to develop optimum tenderness. Holding fryers at 0°F for 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. Turkeys frozen 1 h after slaughter are adequately tenderized by holding for 3 days at 28°F, a temperature at which the carcass is firm and no important quality loss occurs for the period involved. Behnke et al. (1973) confirmed this effect for Leghorn hens.

Overall processing efficiency is improved by cutting up the carcass directly from the end of the eviscerating line, packaging the parts, and then chilling the still-warm packaged product in a low-temperature air blast or cryogenic gas tunnel. Webb and Brunson (1972) reported that cutting the breast muscle and removing a wing at the shoulder joint before chilling significantly decreased tenderness of treated muscles, though cut carcasses were aged in ice slush before cooking. Klose et al. (1972) found that, under commercial plant conditions, making an eight-piece hot-cut before chilling and aging significantly reduced tenderness of breast and thigh muscles, compared to cutting after chilling. Smith et al. (1966) indicated that too-rapid chilling of poultry might have a toughening effect, similar to cold shortening observed in red meats.

Post-mortem electrical stimulation can prevent some toughness while providing some tenderization. In electrical stimulation (which is very different from preslaughter stunning), electricity is pulsed through a recently bled carcass still on the shackles. The electricity enters the head from a charged plate and exits the carcass where the feet contact the metal shackle. The electrical characteristics and timing cause two effects: the pulses excite the muscle and speed onset of rigor mortis, and cause such forceful contractions that the filaments are torn, reducing the integrity of the protein network responsible for toughness (Sams 2001).

DISTRIBUTION AND RETAIL HOLDING REFRIGERATION

Chilled poultry, handled under proper conditions, is an excellent product. However, there are limitations in its marketability because of the relatively short shelf life caused by bacterial deterioration. Bacterial growth on poultry flesh, as on other meats, has a high temperature coefficient. Studies based on total bacterial counts have shown that birds held at 36°F for 14 days are equivalent to those held at 50°F for 5 days or 75°F for 1 day. Spencer and Stadelman (1955) found that birds at 31°F had 8 days of additional shelf life over those at 38°F.

The generation time of psychrophilic organisms isolated from chickens was 10 to 35 h at 32°F, depending on the species studied (Ingraham 1958). Raising the temperature to 36°F reduced generation time to 8 to 14 h, again depending on the species.

Frequent cleaning of processing equipment, as well as thorough washing of the eviscerated carcasses, is essential. Goresline et al. (1951) reported a substantial decrease in bacterial contamination and an increase in shelf life by the use of 20 ppm of chlorine in processing and chilling water. Water is routinely chlorinated in the United States, but chlorine is not allowed to touch poultry meat in some European countries.

Because shelf life is limited considerably by bacterial growth (slime formation) on the skin layer, it is reasonable to assume that drastic changes in the skin surface, such as removal of the epidermal layer by high-temperature scalding, might appreciably affect shelf life. Ziegler and Stadelman (1955) reported approximately 1 day more chilled shelf life for 128°F scalded birds than for 140°F scalded ones.

Chickens, principally broilers, are sold as whole, ready-to-cook; cut-up, ready-to-cook; or boneless, skinless ready-to-cook. Poultry may be shipped in wax-coated corrugated containers, but most is consumer-packaged at the processing plant. A number of precooked poultry meat products are sold in wholesale and retail markets as refrigerated, nonfrozen products. Such items are usually vacuum-packaged or packaged in either a carbon dioxide or nitrogen gas atmosphere. The desired temperature for such products is also 28 to 30°F.

PRESERVING QUALITY IN STORAGE AND MARKETING

Important qualities of frozen poultry include appearance, flavor, and tenderness. Optimum quality requires care in every phase of the marketing sequence, from the frozen storage warehouse, through transportation facilities, wholesaler, retailer, and finally to the frozen food case or refrigerator in the home.

Tissue Darkening. Darkening of the bones occurs in immature chickens and has become more prevalent as broilers are marketed at younger and younger ages. During chilled storage or during freezing and defrosting, some of the pigment normally contained inside the bones of particularly young chickens leaches out and discolors adjacent tissues. This discoloration does not affect the palatability of the product. Brant and Stewart (1950) found that development of dark bones was greatly reduced by a combination of freezing and storage at –30°F and immediate cooking after rapid thawing. Aside from this combination, freezing rate, temperature and length of storage, and temperature fluctuations during storage were not found to have a significant effect.

Further research suggested that freezing and thawing not only liberated hemoglobin from the bone marrow cells but modified the bone structure to allow penetration by the released pigment. Roasting pieces of chicken 0.5 h prior to freezing reduced discoloration of the bone. Ellis and Woodroof (1959) found that heating legs and thighs to 180°F before freezing effectively controlled meat darkening. Methods of preheating, in order of preference, include microwave oven, steam, radiant heat oven, and deep fat frying.

Dehydration. During storage, poultry may become dehydrated, causing a condition known as **freezer burn**. Dehydration can be controlled by humidification, lowering storage temperatures, or packaging the product adequately (Smith et al. 1990).

Rancidity. Poultry fat becomes rancid during very long storage periods or at extremely high storage temperatures. Rancidity in frozen, eviscerated whole poultry stored for 12 months is not a serious problem if the bird is packaged in essentially impermeable film and held at 0°F or below. Danger of rancidification is greatly increased when poultry is cut up before freezing and storage, because of the increased surface exposed to atmospheric oxygen.

Length of Storage. Klose et al. (1959) studied quality losses in frozen, packaged, and cut-up frying chickens over temperatures of –30 to 20°F and storage periods from 1 month to 2 years. All commercial-type samples examined were acceptable after storage at 0°F of at least 6 months, and some were stable for more than a year. In a comparison of a superior (moisture/vaporproof) commercial package with a fair commercial package, increased adequacy of packaging resulted in as much extension in storage life as a decrease in storage temperature of about 20°F. The results indicate that no statement on storage life can have general value unless the packaging condition is accurately specified.

Frozen storage tests by Klose et al. (1960) on commercial packs of ready-to-cook ducklings and ready-to-cook geese established that these products have frozen storage lives similar to other commercial forms of poultry. Ducks and geese should be stored at 0°F or below to maintain their original high quality for 8 to 12 months.

Incorporation of polyphosphates into poultry meat by adding it to the chilling water has been shown to increase shelf life in frozen or refrigerated storage and to control loss of moisture in refrigerated storage and during thawing and cooking.

Storage of Precooked Poultry. Studies on frozen fried chicken indicated that precooking produces a product much less stable than a raw product. Rancidity development is the limiting factor, and is detected in the meat slightly sooner than in the skin and fatty coating of the fried product. The marked beneficial effect of oxygen (air)-free packaging was demonstrated in tests in which detectable off-flavors were observed at 0°F in air-packed samples after 2 months, whereas nitrogen-packed samples developed no off-flavors for periods exceeding 12 months.

Cooling precooked parts in ice water before breading was found to reduce TBA (thiobarbituric acid, a measure of rancidity from fat oxidation) values of precooked parts (Webb and Goodwin 1970). In this study, no difference in rancidity was noted for chicken stored 6, 8, or 10 months. By removing the skin from precooked broilers, TBA values were lower, but yield and tenderness were reduced. No difference was detected in the TBA values of thighs frozen in liquid refrigerant with or without skin. Chicken parts that were blast-frozen without skin were less rancid than those frozen with skin. Precooked frozen chicken parts browned for 120 s at 400°F were less rancid than those parts browned at 300°F (Love and Goodwin 1974).

In contrast to a loosely packed product such as frozen fried chicken, Hanson and Fletcher (1958) reported that a solid-pack product such as chicken and turkey pot pies, in which cooked poultry is surrounded by sauce or gravy, with consequent exclusion of air, had a storage life at 0°F of at least 1 year. As is the case with raw poultry, turkey products have less fat stability than chicken products, but stability can be increased by substituting more stable fats in the sauces or by using antioxidants. A quality defect found in precooked frozen products containing a sauce or gravy is a liquid separation and curdled appearance of the sauce or gravy when thawed for use. This separation is extremely sensitive to storage temperature. Sauces can be stored at least five times as long at 0°F as at 10°F before separation takes place. Hanson et al. (1951) established that flour in the sauce was the cause of the separation, and found, among a large number of alternative thickening agents, that waxy rice flour produced superior stability. Sauces and gravies prepared with waxy rice flour are completely stable for about a year at 0°F.

Because precooked frozen foods are not apt to be sterilized in the reheating process in the home, the processor has an added responsibility to keep bacterial counts in the product well below hazardous levels. Extra precautions should be taken in general plant sanitation, in rapid chilling and freezing of cooked products, and in seeing that products do not reach a temperature that will permit bacterial growth at any time during storage or distribution.

THAWING

Under ordinary conditions, poultry should be kept frozen until shortly before its consumption. The general procedure is to defrost in air or in water. No significant difference has been found in palatability between thawing in oven, refrigerator, room, or water.

For turkeys that have been scalded at high temperatures and fast-frozen to give a light appearance, the temperature in retail storage and display must be kept as low as possible (0°F is reasonable) to prevent darkening. Thawing in the package will minimize darkening.

The safest procedure for thawing poultry to hold the bird in the refrigerator (35 to 40°F) for 2 to 4 days, depending on the size of the bird.

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