CHAPTER 21

EGGS AND EGG PRODUCTS

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ABOUT 69% of the table eggs produced in the United States are sold as shell eggs. The remainder are further processed into liquid, frozen, or dehydrated egg products that are used in food service or as an ingredient in food products. Small amounts of further processed eggs are converted to retail egg products, mainly mayonnaise, salad dressings, and egg substitutes. Shell egg processing includes cleaning, washing, drying, candling for interior and exterior defects, sizing, and packaging. Further processed eggs require shell removal, filtering, blending, pasteurization, and possibly freezing or dehydration.

After processing, shell eggs intended for use within several weeks are stored at 39 to 45°F and relative humidities of 75 to 80%. These conditions reduce the evaporation of water from the egg, which would reduce the egg's weight and hasten breakdown of the albumen (an indicator of quality and grade). Shell eggs are also refrigerated during transportation, during short- and long-term storage, in retail outlets, and at the institutional and consumer levels.

Research has shown that microbial growth can be curtailed by holding eggs at less than 41°F. USDA regulations require eggs to be kept in an ambient temperature below 45°F until they reach the consumer, to prevent the growth of *Salmonella* (see October 27, 1992, United States Federal Register). Storage and display areas must be refrigerated and able to maintain ambient temperatures at 45°F.

SHELL EGGS

EGG STRUCTURE AND COMPOSITION

Physical Structure

The parts of an egg are shown in Figure 1, and physical properties of eggs are given in Table 1.

The **shell** is about 11% of the egg weight and is deposited on the exterior of the outer shell membrane. It consists of a mammillary layer and a spongy layer. The shell contains large numbers of pores (approximately 17,000) that allow water, gases, and small particles (e.g., microorganisms) to move through the shell. A thin, clear film (cuticle) on the exterior of the shell covers the pores. This material is thought to retard the passage of microbes through the shell and serves to prevent moisture loss from the egg's interior. The shape and structure of the shell provide enormous resistance to pressure stress, but very little resistance to breakage caused by impact.

Tough **fibrous shell membranes** surround the albumen. As the egg ages, cools, and loses moisture, an air cell develops on the large end of the egg between these two membranes. The size of the air cell is an indirect measure of the egg's age and is used to evaluate interior quality.

The **white** (albumen) constitutes about 58% of the egg weight. The white consists of a thin, inner chalaziferous layer of firm protein containing fibers that twist into chalazae on the polar ends of the yolk. These structures (Figure 1) anchor the yolk in the center of the egg, also known as the inner thick. The albumen consists of inner thin, outer thick, and outer thin layers.

The **yolk** constitutes approximately 31% of the egg weight. It consists of a yolk (vitelline) membrane and concentric rings of six yellow layers and narrow white layers (Figure 1). In the intact egg, these layers are not visible. Most of the egg's lipids and cholesterol are bounded into a lipoprotein complex that is found more in the white layers. The yolk contains the germinal disc, which consists of about 20,000 cells if the egg is fertile. However, eggs produced for human consumption are not fertile because the hens are raised without roosters.

Table 1 Physical Properties of Chicken Eggs

Property	Whole Egg	Albumen	Yolk
Solids, %	26.4	11.5	52.5
pH (fresh eggs)		7.6	6.0
Density, lb/ft^3	67.5	64.7	64.7
Surface tension, psi			6.38×10^{-4}
Freezing point, °F		31.2	31.0
Specific heat, Btu/lb·°F	0.772		
Viscosity, centipoise			
Thick white		164	
Thin white		4	
Electrical conductivity, mho/cm × 10^{-4}		8.25	0.07
Water activity, % relative humidity		97.8	98.1

Source: Burley and Vadehra (1989).

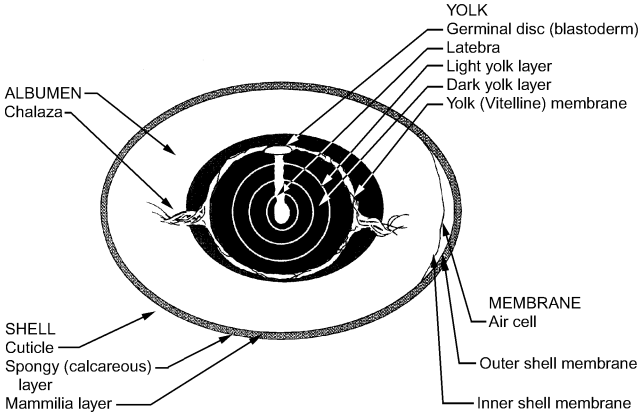


Fig. 1 Structure of an Egg

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

Chemical Composition

The weight of the chicken egg varies from 35 to 80 g or more. The main factors affecting weight and size are the bird's age, breed, and strain. Nutritional adequacy of the ration and ambient temperature of the laying house also influence egg size. Size affects the egg's composition, because the proportion of the parts changes as egg weight increases. For example, small eggs laid by young pullets just coming into production will have relatively more yolk and less albumen than eggs laid by older hens. Table 2 presents the general composition of a typical egg weighing 60 g.

The shell is low in water content and high in inorganic solids, mainly calcium carbonate as calcite crystals plus small amounts of phosphorus and magnesium and some trace minerals. Most of the shell's organic matter is protein. It is found in the matrix fibers closely associated with the calcite crystals and in the cuticle layer covering the shell surface. Protein fibers are also present in the pore canals extending through the shell structures to the cuticle, and in the two shell membranes. The membranes contain keratin, a protein that makes the membranes tough even though they are very thin.

Egg albumen, or egg white, is a gel-like substance consisting of ovomucin fibers and globular-type proteins in an aqueous solution. Ovalbumin is the most abundant protein in egg white. When heated to about 140°F, coagulation occurs and the albumen becomes firm. Several fractions of ovoglobulins have been identified by electrophoretic and chromatographic analyses. These proteins impart excellent foaming and beating qualities to egg white when making cakes, meringues, candies, etc. Ovomucin is partly responsible for the viscous characteristic of raw albumen and also has a stabilizing effect on egg-white foams, an important property in cakes and candy.

Egg white contains a small amount of carbohydrates. About half is present as free glucose and half as glycoproteins containing mannose and galactose units. In dried egg products, glucose interacts with other egg components to produce off-colors and off-flavors during storage; therefore, glucose is enzymatically digested before drying.

The yolk comprises one third of the edible portion of the egg. Its major components are water (48 to 52%), lipids (33%), and proteins (17%). The yolk contains all of the fatty material of the egg. The lipids are very closely associated with the proteins. These very complex lipoproteins give yolk special functional properties, such as emulsifying power in mayonnaise and foaming and coagulating powers in sponge cakes and doughnuts.

Nutritive Value

Eggs are a year-round staple in the diet of nearly every culture. The composition and nutritive value of eggs differ among the various avian species. However, only the chicken egg is considered here, as it is the most widely used for human foods.

Eggs contain high-quality protein, which supplies essential amino acids that cannot be produced by the body or that cannot be synthesized at a rate sufficient to meet the body's demands. Eggs are also an important source of minerals and vitamins in the human diet. Although the white and yolk are low in calcium, they contain substantial quantities of phosphorus, iron, and trace minerals. Except for vitamin C, one or two eggs daily can supply a significant portion of the recommended daily allowance for most vitamins, particularly the vitamins A and B_{12}. Eggs are second only to fish liver oils as a natural food source of vitamin D.

Table 2 Composition of Whole Egg

Egg Component	Protein, %	Lipid, %	Carbohydrate, %	Ash, %	Water, %
Albumen	9.7-10.6	0.03	0.4-0.9	0.5-0.6	88.0
Yolk	15.7-16.6	31.8-35.5	0.2-1.0	1.1	51.1
Whole egg	12.8-13.4	10.5-11.8	0.3-1.0	0.8-1.0	75.5

Note: Shell is not included in above percentages.

	Percent of Egg	Calcium Carbonate	Magnesium Carbonate	Calcium Phosphate	Organic Matter
Shell	11	94.0	1.0	1.0	4.0

Source: Stadelman and Cotterill (1990).

Fatty acids in the yolk are divided into saturated and unsaturated in a ratio of 1:1.8, with the latter further subdivided into mono- and polyunsaturated fatty acids in a ratio of 1:0.3. Eggs are a source of oleic acid, a monounsaturated fatty acid; they also contain polyunsaturated linoleic acid, an essential fatty acid. The fatty acid composition of eggs and the balance of saturated to unsaturated fatty acids can be changed by modifying the hen's diet. Several commercial egg products with modified lipids have been marketed.

EGG QUALITY AND SAFETY

Quality Grades and Weight Classes

In the United States, the Egg Products Inspection Act of 1970 requires that all eggs moving in interstate commerce be graded for size and quality. USDA standards for quality of individual shell eggs are shown in Table 3. The quality of shell eggs begins to decline immediately after the egg is laid. Aging of the egg thins the albumen and increases the size of the air cell. Carbon dioxide migration from the egg increases albumen pH and decreases vitelline membrane strength.

Classes for shell eggs are shown in Table 4. The average weight of shell eggs from commercial flocks varies with age, strain, diet, and environment. Practically all eggs produced on commercial poultry farms are processed mechanically. They are washed, candled, sized, then packed. Eggs are oiled at times to extend internal quality when they are to be transported long distances over a number of days. Although eggs are sold by units of 6, 12, 18, or 30 per package, the packaged eggs must maintain a minimum weight that relates to the egg size.

Table 3 United States Standards for Quality of Shell Eggs

Quality Factor	AA Quality	A Quality	B Quality
Shell	Clean	Clean	Clean to slightly stained[a]
	Unbroken	Unbroken	Unbroken
	Practically normal	Practically normal	Abnormal
Air cell	1/8 in. or less in depth	3/16 in. or less in depth	Over 3/16 in. in depth
	Unlimited movement and free or bubbly	Unlimited movement and free or bubbly	Unlimited movement and free or bubbly
White	Clear	Clear	Weak and watery
	Firm	Reasonably firm	Small blood and meat spots present[b]
Yolk	Outline slightly defined	Outline fairly well defined	Outline plainly visible
	Practically free from defects	Practically free from defects	Enlarged and flattened
			Clearly visible germ development but no blood
			Other serious defects

For eggs with dirty or broken shells, the standards of quality provide two additional qualities. These are:

Dirty	Check
Unbroken. Adhering dirt or foreign material, prominent stains, moderate stained areas in excess of B quality.	Broken or cracked shell but membranes intact, not leaking.[c]

[a] Moderately stained areas permitted (1/32 of surface if localized, or 1/16 if scattered).

[b] If they are small (aggregating not more than 1/8 in. in diameter).

[c] Leaker has broken or cracked shell and membranes, and contents are leaking or free to leak.

Source: *Federal Register*, 7CFR56, May 1, 1991. USDA *Agriculture Handbook* No. 75, p. 18.

Table 4 United States Egg Weight Classes for Consumer Grades

Size or Weight Class	Minimum Net Weight per Dozen, oz	Minimum Net Weight per 30-Dozen Case, lb	Minimum Weight for Individual Eggs, oz
Jumbo	30	56.0	2.42
Extra Large	27	50.5	2.17
Large	24	45.0	1.92
Medium	21	39.5	1.67
Small	18	34.0	1.42
Peewee	15	28.0	

Quality Factors

Besides legal requirements, egg quality encompasses all the characteristics that affect an egg's acceptability to a particular user. The specific meaning of quality may vary. To a producer, it might mean the number of cracked or loss eggs that cannot be sold, or the percentage of undergrades on the grade-out slip. Processors associate quality with prominence of yolk shadow under the candling light and resistance of the shell to damage on the automated grading and packing lines. The consumer looks critically at shell texture and cleanliness and the appearance of the broken-out egg and considers these factors in their relationship to a microbially safe product.

Shell Quality. Strength, texture, porosity, shape, cleanliness, soundness, and color are factors determining shell quality. Of these, shell soundness is the most important. It is estimated that about 10% of all eggs produced are cracked or broken between oviposition and retail sale. Eggs that have only shell damage can be salvaged only for their liquid content, but eggs that have both shell and shell membrane ruptured are regarded as a loss and cannot be used for human consumption. Shell strength is highly dependent on shell thickness and crystalline structure, which is affected by genetics, nutrition, length of continuous lay, disease, and environmental factors.

Eggs with smooth shells are preferred over those with a sandy texture or prominent nodules that detract from the egg's appearance. Eggs with rough or thin shells or other defects are often weaker than those with smooth shells. Although shell texture and thickness deteriorate as the laying cycle progresses, the exact causes of these changes are not fully understood. Some research suggests that debris in the oviduct collects on the shell membrane surface, resulting in rough texture formation (nodules).

The number and structure of pores are factors in microbial penetration and loss of carbon dioxide and water. Eggs without a cuticle or with a damaged cuticle are not as resistant to water loss, water penetration, and microbial growth as those with this outer proteinaceous covering. External oiling of the shell provides additional protection.

Eggs have an oval shape with shape indexes (breadth/length × 100) ranging from 70 to 74. Eggs that deviate excessively from this norm are considered less attractive and break more readily in packaging and in transit. Egg shape is changing to a more rounded shape, which is resulting in a stronger shell.

Shells with visible soil or deep stains are not allowed in a high-quality pack of eggs. Furthermore, soil usually contains a heavy load of microorganisms that may penetrate the shell, get into the contents, and cause spoilage.

Shell color is a breed characteristic. Brown shells owe their color to a reddish-brown pigment, ooporphyrin, which is derived from hemoglobin. The highest content of the pigment is near the surface of the shell. White shells contain a small amount of ooporphyrin, too, but it degrades soon after laying by exposure to light. Brown-shelled eggs tend to vary in color.

Albumen Quality. Egg white viscosity differs in various areas of the egg. A dense layer of albumen is centered in the middle and is most visible when the egg is broken out onto a flat surface. Raw albumen has a yellowish-green cast. In high-quality eggs, the white should stand up high around the yolk with minimum spreading of the outer thin layer of the albumen. The quality of thick albumen in the freshly laid egg is affected by genetics, duration of continuous production, and environmental factors. Albumen quality generally declines with age, especially in the last part of the laying cycle. Breakdown of thick white is a continuing process in eggs held for food marketing or consumption. The rate of quality loss depends on holding conditions and the length of time required to cool the egg.

Intensity of color is associated with the amount of riboflavin in the ration. The albumen of top-quality eggs should be free of any blood or meat spots. Incidence of non-meat spots such as blood spots and related problems has been reduced to such a low level by genetic selection that it is no longer a serious concern.

The chalazae may be very prominent in some eggs and can create a negative reaction from consumers who are unfamiliar with these structures (see Figure 1). The twisted, rope-like cords are merely extensions of the chalaziferous layer surrounding the yolk and are a normal part of the egg. The chalazae stabilize the yolk in the center of the egg.

Yolk Quality. Shape and color are the principal characteristics of yolk quality. In a freshly laid egg, the yolk is nearly spherical, and when the egg is broken out onto a flat surface, the yolk stands high with little change in shape. Shell and albumen tend to decline in quality as the hen ages. However, yolk quality, as measured by shape, remains relatively constant throughout the laying cycle.

Yolk shape depends on the strength of the vitelline membrane and the chalaziferous albumen layer surrounding the yolk. After oviposition, these structures gradually undergo physical and chemical changes that decrease their ability to keep the yolk's spherical shape. These changes alter the integrity of the vitelline membrane so that water passes from the white into the yolk, increasing the yolk's size and weakening the membrane.

Color as a quality factor of yolk depends on the desires of the user. Most consumers of table eggs favor a light to medium yellow color, but some prefer a deeper yellowish orange hue. Processors of liquid, frozen, and dried egg products generally desire a darker yolk color than users of table eggs because these products are used in making mayonnaise, doughnuts, noodles, pasta, and other foods that depend on eggs for their yellowish color. If laying hens are confined, yolk color is easily regulated by adjusting the number of carotenoid pigments supplied in the hen's diet. Birds with access to growing grasses and other plants usually produce deep-colored yolks of varying hues.

Yolk defects that detract from their quality include blood spots, embryonic development, and mottling. Blood on the yolk can be from (1) hemorrhages occurring in the follicle at the time of ovulation, or (2) embryonic development that has reached the blood-forming stage. The second source is a possibility only in breeding flocks where males are present.

Yolk surface mottling or discoloration can be present in the fresh egg or may develop during storage and marketing. Very light mottling, resulting from an uneven distribution of moisture under the surface of the vitelline membrane, can often be detected on close examination, but this slight defect usually passes unnoticed and is of little concern. Certain coccidiostats (nicarbazin) and wormers (piperazine citrate and dibutylin dilaurate) have been reported to cause mottled yolks and should not be used above recommended levels in layer rations. More serious are the olive-brown mottled yolks produced by rations containing cottonseed products with excessive amounts of free gossypol. This fat-soluble compound reacts with iron in the yolk to give the discoloration. Cottonseed meal may also have cyclopropanoid compounds that increase vitelline membrane permeability. When iron from the yolk passes through the membrane and reacts with the conalbumen of the white, a pink pigment is formed in the albumen. Cyclopropanoid compounds also cause yolks to have a higher proportion of saturated fats than normal, giving the yolks a pasty, custard-like consistency when they are cooled.

Flavors and Odors. When birds are confined and fed a standard ration, eggs have a uniform and mild flavor. Off-flavors can be caused by rations with poor-quality fish meal containing rancid oil or by birds having access to garlic, certain wild seeds, or other materials foreign to normal poultry rations. Off-flavors or odors from rations are frequently found in the yolk, because many compounds imparting off-flavors are fat-soluble. Once eggs acquire off-flavor during storage, their quality is unacceptable to consumers. Eggs have a great capacity to absorb odors from the surrounding atmosphere (Carter 1968). Storage should be free from odor sources such as apples, oranges, decaying vegetable matter, gasoline, and organic solvents (Stadelman and Cotterill 1990). If this cannot be avoided, odors can be controlled with charcoal absorbers or periodic ventilation.

Control and Preservation of Quality

Egg quality is evaluated by shell appearance, air-cell size, and the apparent thickness of the yolk and white. Some changes that occur during storage are caused by chemical reaction and temperature effects. As the egg ages, the pH of the white increases, the thick white thins, and the yolk membrane thins. Ultimately, the white becomes quite watery, although total protein content changes very little. Some coincidental loss in flavor usually occurs, although it develops more slowly. A low storage temperature and shell oiling slow down the escape of carbon dioxide and moisture and prevent shrinkage and thinning of the white. Clear white mineral oil sprayed on the shell after washing partially protects the egg, but its use in commercial operations is diminishing. Rapid cooling will also reduce moisture loss.

Egg quality loss is slowed by maintaining egg temperatures near the freezing point. Albumen freezes at 31.2°F, and the yolk freezes at 31°F. Stadelman et al. (1954) and Tarver (1964) found that eggs stored for 15 or 16 days at 45 to 50°F had significantly better quality than eggs stored at 57 to 61°F.

Stadelman and Cotterill (1990) recommend that storage humidity be maintained between 75 and 80%. As a rule, eggs lose about 1% of their weight per week in storage. When large amounts of eggs are palletized, humidity in the center of the pallet may be higher than that of the surrounding air. Therefore, airflow through the eggs is needed to remove excess humidity above 95% to prevent mold growth and decay.

Albumen quality loss is associated with carbon dioxide loss from the egg. Quality losses can be reduced by increasing carbon dioxide levels around the eggs. Controlled-atmosphere storage and modified-atmosphere packaging have been studied, but they are not used commercially because eggs typically do not need long-term storage. Oiling also helps retard carbon dioxide and moisture loss.

Egg Spoilage and Safety

Microbiological Spoilage. Shell eggs deteriorate in three distinct ways: (1) decomposition by bacteria and molds, (2) changes from chemical reactions, and (3) changes because of absorption of flavors and odors from the environment. Dirty or improperly cleaned eggs are the most common source of bacterial spoilage. Dirty eggs are contaminated with bacteria. Improper washing by immersing the egg in water colder than the eggs or water with high iron content increases the possibility of contamination, although it removes evidence of dirt. Most improperly cleaned eggs spoil during long-term storage. Therefore, extremely high sanitary standards are required when washing eggs that will go into long-term storage.

Eggs contaminated with certain microorganisms spoil quickly, resulting in black, red, or green rot, crusted yolks, mold, etc. However, eggs occasionally become heavily contaminated without any outward manifestations of spoilage. Clean, fresh eggs are seldom contaminated internally. It has been shown that egg sweating caused by fluctuations in environmental temperatures or humidity does not result in increased bacteria and/or mold spoilage (Ernst et al. 1998).

Preventing Microbial Spoilage. Egg quality can be severely jeopardized by invasion of microorganisms that cause off-odors and off-flavors. With frequent gathering, proper cleaning, and refrigeration, sound-shell eggs that move quickly through market channels have few spoilage problems.

Sound-shell eggs have a number of mechanical and chemical defenses against microbial attack. Although most of the shell pores are too large to impede bacterial movement, the cuticle layer, and possibly materials within the pores, offer some protection, especially if the shell surface remains dry. Bacteria that successfully penetrate the shell are next confronted by a second set of physical barriers, the shell membranes.

Microorganisms reaching the albumen find it unfavorable for growth. Movement is retarded by the egg white’s viscosity. Also, most bacteria prefer a pH near neutral, but the pH of egg white, initially at 7.6 when newly laid, increases to 9.0 or more after several days, providing a deterring alkaline condition.

Conalbumen, which is believed to be the main microbial defense system of albumen, complexes with iron, zinc, and copper, thus making these elements unavailable to the bacteria and restricting their growth. The chelating potential increases with the rise in albumen pH.

Eggs can ward off a limited quantity of organisms, but should be handled in a manner that minimizes contamination. Egg washing must be done with care. Proper overflow, maintenance of a minimum water temperature of 90°F (as required by USDA regulations), and use of a sufficient quantity of approved detergent-sanitizer are important for effective cleaning. The wash water should be at least 20°F warmer than the internal temperature of the eggs to be washed. Likewise, the rinse water should be a few degrees higher than the wash water. Under these conditions, the contents of the eggs expand to create a positive pressure, which tends to repel penetrations of the shell by microorganisms.

Regular changes of the wash water, as well as thorough daily cleaning of the washing machine, are very important. When the wash water temperature exceeds the egg temperature by more than 50°F, an inordinate number of cracks in the shells, called thermal cracks, occur. Excessive shell damage also occurs if the washer and its brushes are not properly adjusted. Most egg processors use wash waters at temperatures of 110 to 125°F.

In-Shell Egg Pasteurization

In-shell egg pasteurization is a process of reducing the potential pathogenic organisms in intact shell eggs. These would be used in institutional settings where susceptible human populations want to eat eggs cooked in their intact state. This process is covered by the 1997 USDA/FDA joint published initial standards for the processing and labeling of pasteurized shell eggs. The FDA defined the target shell egg pasteurization criterion as a “5-log reduction in *Salmonella* count” per egg.

The supply of eggs for this process are USDA Grade AA eggs which contain 0% checks. These eggs must go through traditional egg processing before diversion to the pasteurization process. Typically, because of the increased costs of the process, only large and extra-large eggs are used. This process takes graded shell eggs through a series of baths that raise the internal temperature of the egg to destroy *Salmonella* and other potential pathogens. During heating, the eggs are agitated by air bubbles created by air injection at the bottom of the tanks. The eggs are then rapidly cooled in water baths to an internal temperature of 45°F. The chilling process stops the pasteurization process, after which a protective seal is applied to the shell surface to preserve the safety and quality of the egg.

HACCP Plan for Shell Eggs

Many of the procedures for the control of microorganisms are managed by the Hazard Analysis for Critical Control Points (HACCP), which is currently implemented in U.S. egg farms, egg packaging sites, egg processing facilities, and the distribution system. Information on the fundamentals of the HACCP system can be found in Chapter 12.

HACCP systems in the egg industry focus mainly on the prevention of *Salmonella* food poisoning. In the past, *S. typhimurium* was the leading strain in food poisoning related to eggs. However, since 1985 *S. enteritidis* has taken the leading role in egg-related salmonellosis illnesses (about 25%).

Salmonella is found naturally in the intestines of mice, rats, snakes, and wild birds and not in domesticated chickens. Chicken feed, which attracts rodents and birds, is the main source of chicken intestine contamination. Unfortunately, *S. enteritidis* can invade the hen ovaries and contaminate the developing yolks, thus being transferred into the egg interior. There it is unreachable by sanitizing agents. Pasteurization of eggs in the shell is one method of dealing with this internal contamination. Fortunately, only a very small portion of eggs are internally contaminated. Because the number of internal bacteria is very small, immediate cooling to 45°F and preferably to 41°F will suppress bacterial growth to below the hazard level until the egg is consumed, normally 10 to 30 days after being laid.

SHELL EGG PROCESSING

Off-Line and In-Line Processing

Poultry farms either send eggs to a processing plant or package them themselves. On commercial farms, the hens reside in cages with sloped floors. Eggs immediately roll onto a gathering tray or conveyor, where they are either gathered by hand, packed on flats, and stored for transport to an processing line (off-line); or the eggs are conveyed directly from the poultry house to a packing machine (in-line) operation. Machines can package both in-line and off-line eggs, thereby increasing the flexibility of the operation (Figure 2). Off-line operations have coolers both for incoming eggs and for outgoing finished product (Figure 3). An in-line operation has only one cooler for the outgoing finished product (Figure 4).

Figure 5 illustrates material flow during egg packaging in an off-line facility. Egg packaging machines wash the eggs by brushing with warm detergent solution followed by rinsing with warm water and sanitizing with an approved sanitizing agent. Sodium hydrochloride is most commonly used.

The eggs are then dried by air and moved by conveyor, which rotates the egg as they enter the candling booth. There, a strong light source under the conveyor illuminates the eggs' internal and shell defects. Two operators (candlers) remove defective eggs. The eggs are then weighed and sized automatically and the different sizes are packaged into cartons (12 eggs) or flats (20 or 30 eggs).

Automated candling can now detect and remove eggs with cracks, dirt, and internal defects, with little human intervention. This has raised the limit of 250 cases per hour (with manual candling) to 500 to 800 cases per hour. However, only very large facilities and egg-breaking operations tend to use automated candling; many others still operate at 250 to 300 cases an hour. In shell egg packaging, speed is limited by case and pallet packaging, which are not automated.

Kuney et al. (1992) demonstrated the high cost of good eggs overpulled in error by candlers. Machine speed was the major factor related to overpulling. Packaging is another area that could be automated because feeding packaging materials, packaging cartons or flats into cases, and palletizing are still largely manual operations.

EFFECT OF REFRIGERATION ON EGG QUALITY AND SAFETY

Refrigeration is the most effective and practical means for preserving quality of shell eggs. It is widely used in farm holding rooms, processing plants, and in marketing channels. Refrigeration conditions for shell eggs to prevent quality loss during short- and long-term storage are as follows:

Temperature, °F	Relative Humidity, %	Storage Period
45	75 to 80	2 to 3 weeks
39 to 45	75 to 80	2 to 4 weeks
29 to 31	85 to 92	5 to 6 months

A relative humidity of 75 to 80% in egg storage rooms must be maintained to prevent moisture loss with a subsequent loss of egg weight. Too high a relative humidity causes mold growth,

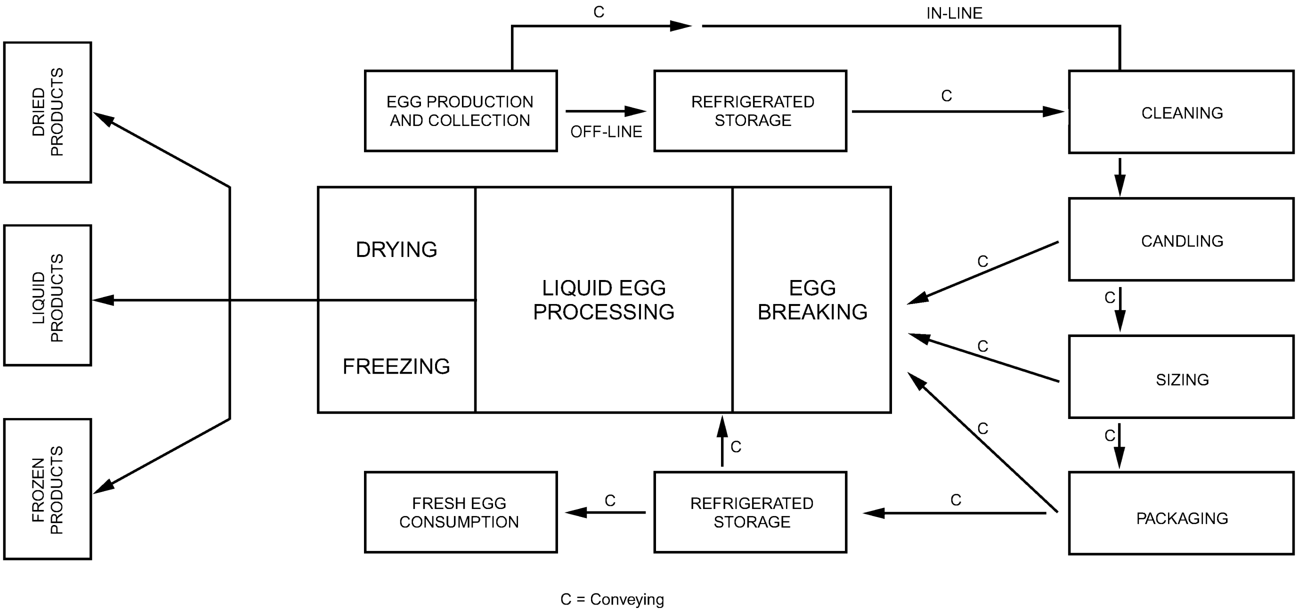


Fig. 2 Unit Operations in Off-Line and In-Line Egg Packaging

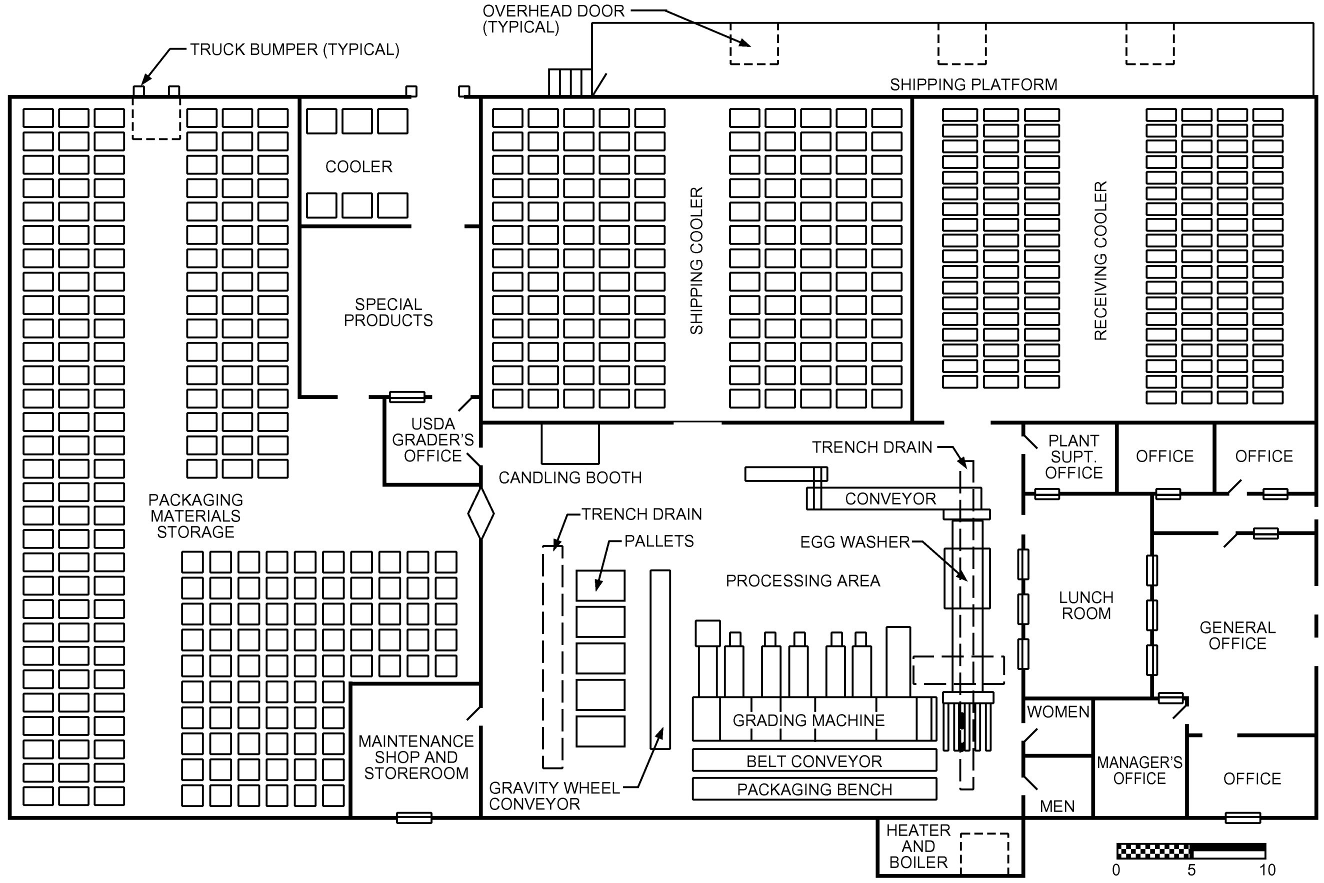
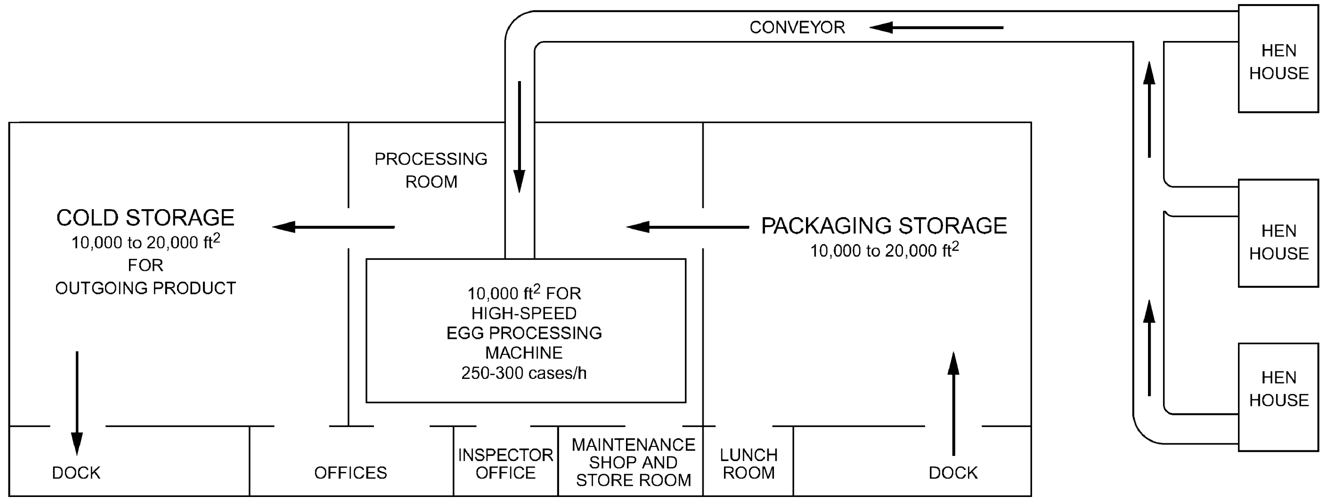


Fig. 3 Off-Line Egg Processing Operation
(Goble 1980)



Building is 30,000 ft^2 equally divided to packaging storage, processing room, and cold storage with possible expansion from cold storage side to 50,000 ft^2.

Fig. 4 Typical In-Line Processing Operation
(Zeidler and Riley 1993)

which can penetrate the pores of the shell and contaminate the egg contents. Mold will grow on eggs when the relative humidity is above 90%.

For long-term storage, eggs should be kept just above their freezing point, 31°F. However, long-term storage is seldom used because most eggs are consumed within a short period. Low temperatures can cause sweating (i.e., condensation of moisture on the shell).

Refrigeration Requirement Issues

Temperature has a profound effect on *Salmonella enteritidis* on and in eggs. Research has shown that the growth rate of *S. enteritidis* in eggs is directly proportional to the temperature at which the eggs were stored. Holding eggs at 39 to 46°F reduced the heat resistance of *S. enteritidis* and suggested that not only does refrigeration

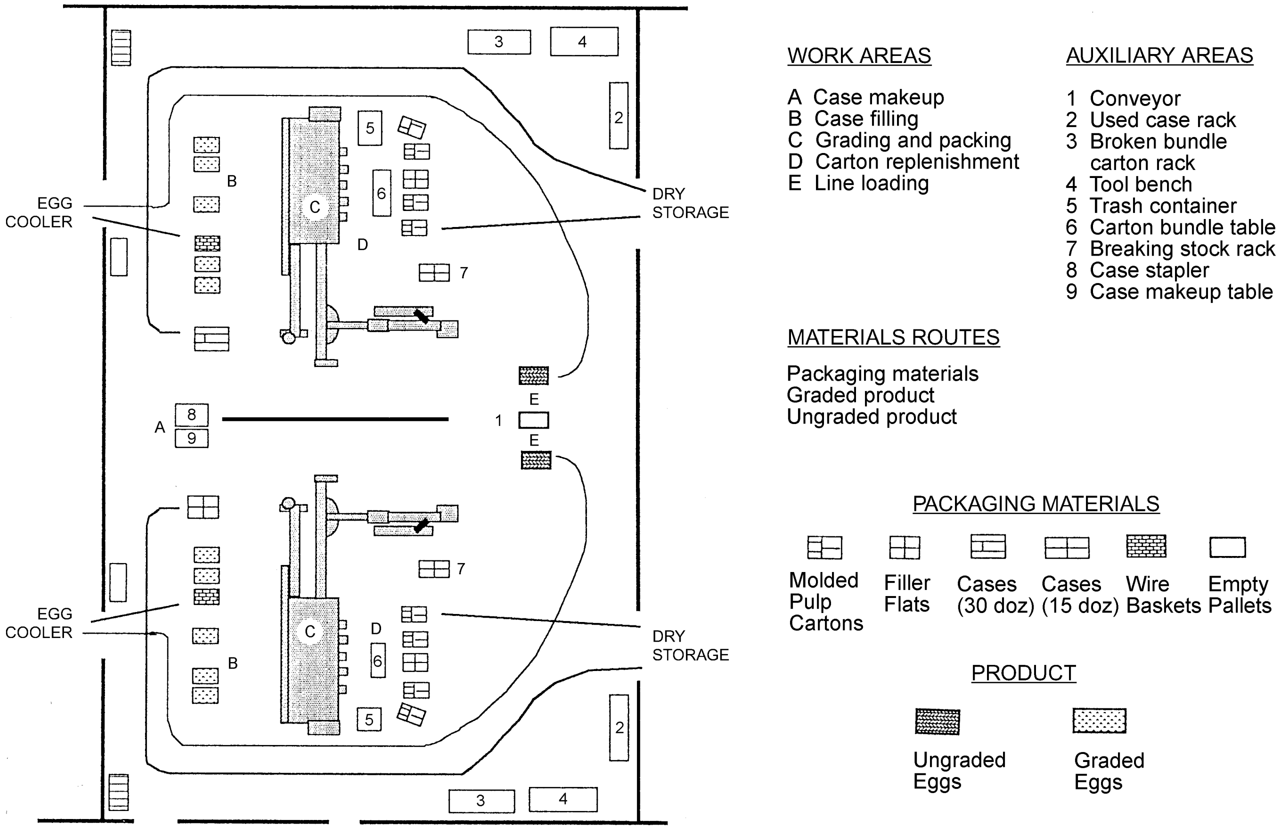


Fig. 5 Material Flow in Off-Line Operation
(Hamann et al. 1978)

reduce the level of microbial multiplication in shell eggs, but it lowers the temperature at which the organism is killed during cooking.

At present, most shell eggs in the United States are refrigerated to 45°F after processing. Commonly, they are transported in refrigerated trucks and displayed in refrigerated retail displays.

Condensation on Eggs

Moisture often condenses on the shell surface when cold eggs are moved from cool storage into hot and humid outside conditions or if the temperature varies widely inside the cooler. Sweating results in a wet egg, and the egg may adhere to the packaging material. The ability of any microbes present on the shell to penetrate the shell is not increased (Ernst et al. 1998). However, wet eggs are more likely to become stained when handled.

Plastic wrapped around the pallets to stabilize the load for shipping can also prevent moisture loss and increase humidity in the load, which can cause mold problems when eggs are held too long in this condition.

Condensation or sweating can be predicted from a psychrometric chart. Table 5 lists typical conditions in which sweating may occur.

Initial Egg Temperatures

Cooling requirements for shell eggs obviously vary with the weight of eggs to be cooled and their initial temperature. Anderson et al. (1992) showed that incoming egg temperature depends on the type of processing operation and time of year. In off-line plants, eggs typically arrive at the plant with internal temperatures ranging from 62 to 68°F. Before processing, the eggs are placed in a cooler, which is held between 50 and 60°F. In in-line plants, eggs are conveyed directly from poultry houses to the packing area. Anderson et al. measured incoming egg temperatures ranging from 88 to 96°F. Czarick and Savage (1992) reported that incoming egg temperature in an in-line system reached equilibrium with the layer house temperature. House temperatures are often maintained at 75 to 80°F; however, 90°F sometimes occurs.

Table 5 Ambient Conditions When Moisture Condenses on Cold Eggs

Outside Temperature, °F	Outside Relative Humidity, % Egg Temperature 45°F	 55°F
55	70	—
60	60	85
65	50	70
70	40	60
75	35	50
80	30	43
85	25	36
90	21	31

Egg Temperatures After Processing

Experience has shown that quality defects are more readily detected when eggs are allowed to age. Thus, in off-line processing, eggs from production units are usually stored overnight at 55 to 60°F before processing. With present cooling methods, eggs require about 48 h in cold storage to cool completely.

Cooling eggs before processing is limited by the temperature rise the shells can tolerate without cracking, which is about 62°F. Most processors wash eggs in warm water ranging from 115 to 125°F (Anderson et al. 1992). This wash temperature could cause shell cracking if eggs are initially cooled to the minimum temperature prescribed by USDA (41°F). Therefore, the lowest egg temperature acceptable before processing is about 60°F. In contrast, eggs in in-line operations are commonly processed while still warm from the house and are packaged warm.

Hillerman (1955) reported that wash water kept at 115°F increases internal egg temperature by 0.4°F per second. Anderson (1993) showed that the internal temperature of eggs rose because of the high temperatures during washing, resulting in an 8 to 12°F internal temperature increase above their starting temperature. As a result, egg temperature after washing and packing in in-line systems can typically reach 75 to 85°F, and in rare cases may reach nearly 100°F.

Cooling Rates

Henderson (1957) showed that air rates of 105 to 600 fpm flowing past an individual egg caused it to cool within one hour by 90% of the difference between the initial egg temperature and the temperature of the cooling air. Eggs packed in filler flats required 4 to 5 h to achieve 90% of total possible temperature drop. Bell and Curley (1966) reported that 55°F air forced around fiber flats in vented corrugated fiberboard boxes cooled eggs from 90 to 60°F in 2 to 5 h. Unvented cartons with the same pack required more than 30 h to cool.

Czarick and Savage (1992) placed eggs with an internal temperature of 81 to 100°F either on fiber flats and stacked six high or in egg flats placed in 6-flat (15 dozen) fiber cases. The eggs were then placed in a 50°F cooler. Eggs in the outermost cells of the cased flats cooled to 50°F in 9 h and all eggs in the fiber flats cooled to 50°F in 24 h. However, eggs at the center of the cases had not reached 50°F after 36 h. They found that it took more than 5 days for a pallet of eggs in cases to cool from 85 or 90°F to 45°F in a 45°F cold room.

Egg moisture loss is not increased by rapid cooling. Funk (1935) found that weight loss was the same for eggs in wire baskets cooled in 1 h with circulating air or 15 h with still air.

Cooling for Storage

With current handling practices, packed eggs require more than one week of storage before they reach the temperature of the storage room. This slow cooling results in egg temperatures in the optimal growth range for *S. enteritidis* from 24 to 72 h after processing. Packaging materials effectively insulate the eggs from the surrounding environment, especially in the center of the pallet. In addition, pallets are often stacked touching each other and may be wrapped in plastic, which further insulates the inner cases and reduces airflow. Also, most eggs are moved from storage within hours of processing, so they are barely cooled. But delaying shipment to allow the eggs to cool results in less-than-fresh products being delivered to the consumer, and interior quality suffers.

Adequate air flow through a box requires that the box be vented. In a study done for fruits and vegetables, Baird et al. (1988) showed that cooling cost increases rapidly when carton face vent area decreased below 4% of the total area. Other packing materials, such as liners, wraps, flats, or cartons, must not prevent air that enters the box from contacting the eggs. Also, cases must be stacked to allow air to circulate freely around the pallets.

Because of the inefficiency of cooling eggs in containers, it would seem best to cool them before packing. Eggs could be cooled between washing and packing just before being placed into cartons and then cases. A cooler has been developed specifically for in-line cooling to capitalize on the cooling rate of individual shell eggs. This would allow the use of current packaging. However, existing equipment is not designed to incorporate this procedure.

Accelerated Cooling Methods

Forced-Air Cooling. Henderson (1957) showed that forced ventilation of palletized eggs produced cooling times close to that of cooling individual eggs. Thompson et al. (2000) arranged a 30-case pallet of eggs so that a 1000 cfm fan drew 40°F air through openings in the cases. The eggs were cooled to less than 45°F within 1 to 3 h. This cooling method can be used in an existing refrigerated storage room with little additional investment.

Cryogenic. Curtis et al. (1995) showed that eggs exposed to a –60°F carbon dioxide environment for 3 min continued to cool after packaging and 15 min later were at 45°F. The process maintained egg quality and did not increase the incidence of shell cracking. This process has been refined to allow the cooling process to occur in an –70°F environment for 80 sec.

PACKAGING

Shell eggs are packaged for the individual consumer or the institutional user. Consumer packs are usually a one dozen carton or variations of it. The institutional user usually receives shell eggs in 30 dozen cases on twelve 30-egg filler-flats.

Consumer cartons are generally made of paper pulp, foam plastic, or clear plastic. Some cartons have openings in the top for viewing the eggs, which also facilitates cooling. Cartons are generally delivered to the retailer in corrugated containers that hold 15 to 30 dozen eggs, in wire or plastic display baskets that hold 15 dozen eggs, or on rolling display carts. Wire baskets and rolling racks allow more rapid cooling, but are also more expensive and take up more space in storage and in transport.

TRANSPORTATION

Shell eggs are transported from the off-line egg production site to egg processing plants, and from there to local or regional retail and food service outlets. Less frequently, eggs are transported from one state to another or overseas. Truck transport is most common and refrigerated trucks capable of maintaining 45°F are mandatory in the United States, with an exemption for small producer-packers with an annual egg production from 3000 or fewer hens.

Cases and baskets are generally stored and transported on pallets in 30-case lots (five cases high with six cases per layer). The common carrier for local and long-distance hauling is the refrigerated tractor/trailer combination. Trailers carry 24 to 26 30-case pallets of eggs, often of one size category. A typical load of 720 to 780 cases weighs about 44,000 lb. Some additional cases may be added when small or medium eggs are being transported. Eggs are not generally stacked above six cases high to allow the cold air to travel to the rear of the trailer and to minimize crushing of lower-level cases.

Interregional shipment of eggs is quite common, with production and consumption areas often 1500 miles apart. Such shipments usually require two to three days using team driving.

Local transportation of eggs may be with similar equipment, especially when delivered to retailer warehouses. Smaller trucks with capacities of 250 to 400 cases are often used when multiple deliveries are required. Local deliveries are commonly made directly to retail or institutional outlets. Individual store deliveries require a variety of egg sizes to be placed on single pallets. This assembly operation in the processing plant is very labor-intensive. Local delivery may involve multiple short stops and considerable opening and closing of the storage compartment, with resultant loss of cooling. Many patented truck designs are available to protect cargo from temperature extremes during local delivery, yet none has been adopted by the egg industry.

A 1993 USDA survey found that over 80% of the trucks used to deliver eggs were unsuitable to maintain 45°F. Damron et al. (1994), in a survey of three egg transport companies in Tampa and Dallas, found the average temperature of trailers during nonstop warehouse deliveries was 46.4°F. The front of the trailer averaged below 45°F 20 to 25% of the time while the back of the trailer was below 45°F 65% of the time. The loads were below 45°F 37% of the time while the reefer discharge was below 40°F.

Trailers used for store-door deliveries had temperatures averaging approximately 45°F at the start of the route; however, some areas only reached a low of 48.5°F. As the deliveries continued and the volume of eggs decreased, temperatures increased and temperature recovery never occurred.

EGG PRODUCTS

Egg products are classified into four groups according to the American Egg Board (www.aeb.org):

1. Refrigerated egg products
2. Frozen egg products
3. Dried egg products
4. Specialty egg products (including hard-cooked eggs, omelets, scrambled eggs, egg substitutes)

Most of these products are not seen at the retail level, but are used as further processed ingredients by the food processing industry for such products as mayonnaise, salad dressing, pasta, quiches, bakery products, and eggnog. Other egg products, such as deviled eggs, Scottish eggs, frozen omelets, egg patties, and scrambled eggs, are prepared for fast food and institutional food establishments, hotels, and restaurants. In recent years, several products such as egg substitutes (which are made from egg whites) and scrambled eggs have appeared. Yet to be developed are large-volume items such as aseptically filled, ultrapasteurized, chilled liquid egg and low-cholesterol chilled liquid eggs.

EGG BREAKING

Egg breaking transforms shell eggs into liquid products: whole egg, egg white, and yolk. Liquid egg products are chilled, frozen, or dried. These items can be used as is or are processed as an ingredient in food products. Only a few products, such as hard-cooked eggs, do not use the breaking operation system. Dried egg powder, which is the oldest processed egg product, lost ground as a proportion of total egg products, whereas chilled egg products are booming because of their superior flavor, aroma, pronounced egg characteristics, and convenience. Most liquid egg products (about 44% of all egg products) must be consumed in a relatively short time because of their short storage life. Frozen or dried egg products may be stored considerably longer.

Surplus, small, and cracked eggs are the major supply source for egg-breaking operations. Those eggs must be cleaned in the same manner as shell eggs. Washing and loading of eggs to be broken must be conducted in a separate room from the breaking operation (Figure 6). Eggs with broken shell membrane (leakers) or blood spots are not allowed to be broken for human consumption. Most breaking operations are close to production areas, and in many cases are merely a separate area of a shell egg processing and packaging facility. An egg-breaking operation usually receives its eggs from several processing plants in the area that do not have breaking equipment. Storage and transport of eggs, and especially of cracked eggs, reduces the quality of the end product.

Two types of egg-breaking equipment are available:

1. **Basket centrifuge.** Shell eggs are dumped into a centrifuge and a whole egg liquid is collected. Several states and some local health authorities ban this equipment for breaking eggs for human consumption because of the high risk of contamination. Similar centrifuges are used to extract liquid egg residue from the discarded egg shells. This inedible product is used mostly for pet food.
2. **Egg breaker and separator.** These machines can process up to 100 cases per hour (36,000 eggs), which is still slow compared to up to 500 cases per hour (180,000 eggs) handled by modern table egg packaging equipment.

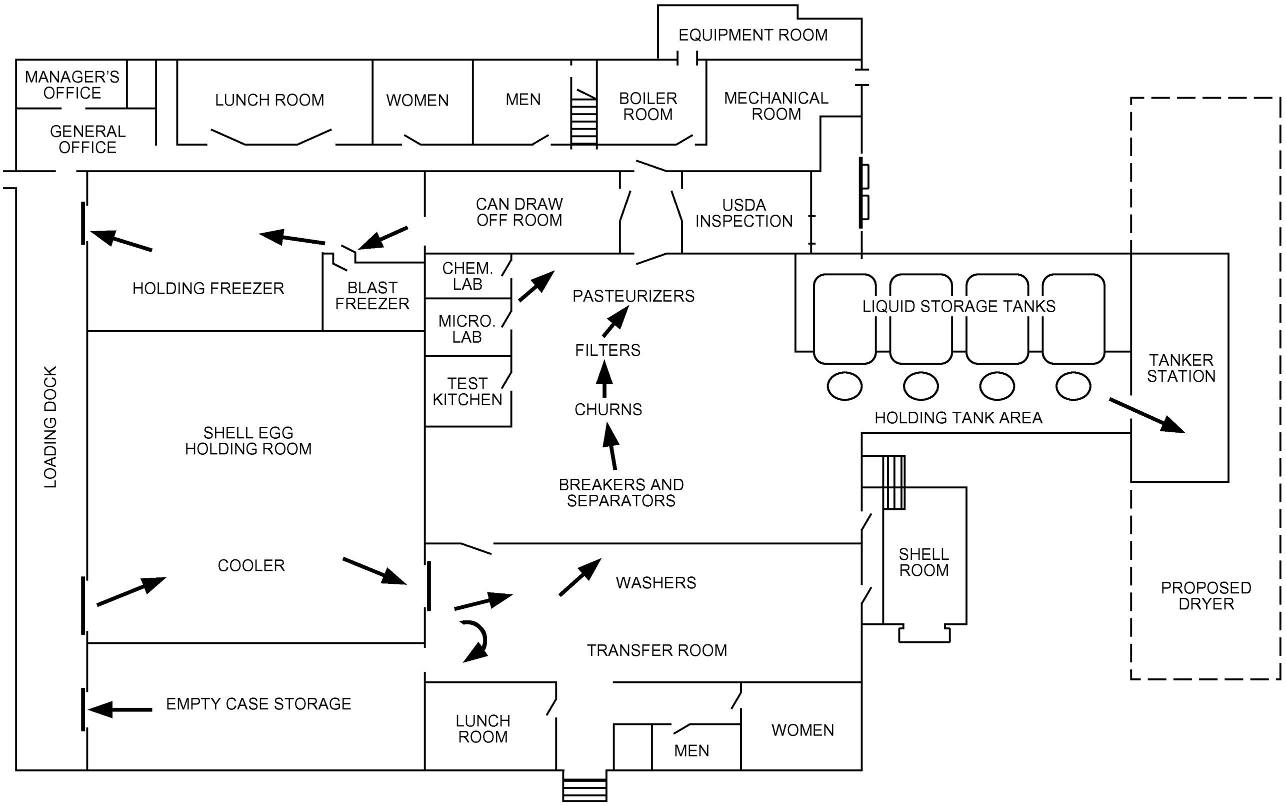


Fig. 6 Floor Plan and Material Flow in Large Egg-Breaking Plant
(Courtesy of Seymour Food)

Table 6 Minimum Cooling and Temperature Requirements for Liquid Egg Products
(Unpasteurized product temperature within 2 h from time of breaking)

Product	Liquid (Other Than Salt Product) Held 8 h or Less	Liquid (Other Than Salt Product) Held in Excess of 8 h	Liquid Salt Product	Temperatures Within 2 h after Pasteurization	Temperatures Within 3 h after Stabilization
Whites (not to be stabilized)	55°F or lower	45°F or lower	—	45°F or lower	—
Whites (to be stabilized)	70°F or lower	55°F or lower	—	55°F or lower	[a]
All other products (except product with 10% or more salt added)	45°F or lower	40°F or lower	If held 8 h or less, 45°F or lower. If held more than 8 h, 40°F or lower.		
Liquid egg product (10% or more salt added)	—	If held 30 h or less, 65°F or lower. If held in excess of 30 h, 45°F or lower.	—	65°F or lower[b]	—

Source: Inspection of eggs (7CFR57), January 1, 2005.

[a] Stabilized liquid whites should be dried as soon as possible after removal of glucose. Limit storage of stabilized liquid whites to that necessary for continuous operation.

[b] Cooling should be continued to ensure that any salt product held over 24 h is cooled and maintained at 45°F or lower.

Table 7 Pasteurization Requirements of Various Egg Products

Liquid Egg Products	Minimum Temperature, °F	Minimum Holding Time, minutes
Albumen (without use of chemicals)	134 132	3.5 6.2
Whole egg	140	3.5
Whole egg blends (less than 2% added non-egg ingredients)	142 140	3.5 6.2
Fortified whole eggs and blends (24 to 38% egg solids, 2 to 12% non-egg ingredients)	144 142	3.5 6.2
Salt whole egg (2% salt added)	146 144	3.5 6.2
Sugar whole egg (2 to 12% sugar added)	142 140	3.5 6.2
Plain yolk	142 140	3.5 6.2
Sugar yolk (2% or more sugar added)	146 144	3.5 6.2
Salt yolk (2 to 12% salt added)	146 144	3.5 6.2

Source: Regulations governing the inspection of eggs and egg products (9CFR590).

Holding Temperatures

Prepasteurization holding temperatures required by the USDA for out-of-shell liquid egg products are listed in Table 6.

Pasteurization

In the United States, the USDA requires all egg products made by the breaking process to be pasteurized and free of salmonella and requires all plants to be inspected. The minimum required temperatures and holding times for pasteurization of each type of egg product are listed in Table 7.

Plate heat exchangers, commonly used for pasteurization of milk and dairy products, are also commonly used for liquid egg products. Before entering the heat exchanger, the liquid egg is moved through a clarifier that removes solid particles such as vitelline (the yolk membrane) and shell pieces.

Egg white solids may be made *Salmonellae*-negative by heat treatments. Spray-dried albumen is heated in closed containers so that the temperature throughout the product is not less than 130°F for not less than 7 days, until it is free of *Salmonellae*. For pan-dried albumen, the requirement is 125°F for 5 days until it is free of *Salmonellae*. For the dried whites to be labeled pasteurized, the USDA requires that each lot be sampled, cultured, and found to contain no viable *Salmonellae*.

Table 8 Minimum Pasteurization Requirements in Various Countries

Country	Temperature, °F	Time, minutes
Great Britain	148	2.5
Poland	151-154	3
China (PRC)	146	2.5
Australia	144.5	2.5
Denmark	149-156.5	1.5-3
United States	140	3.5

Source: Stadelman et al. (1988).

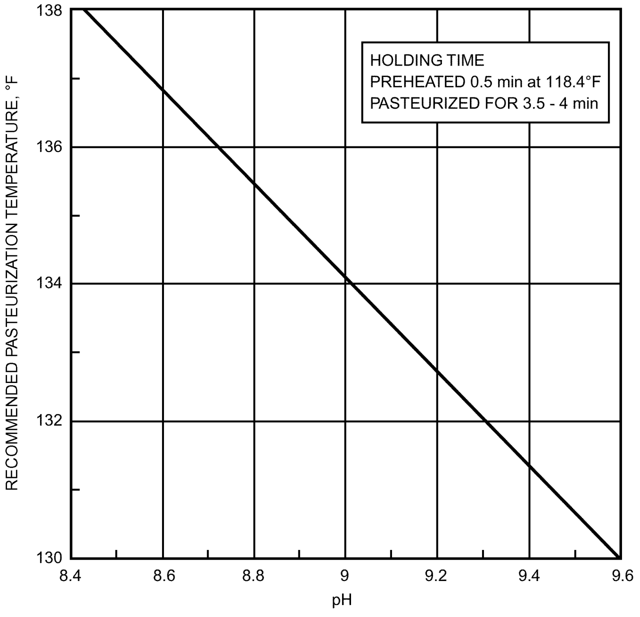


Fig. 7 Effect of pH on Pasteurization Temperature of Egg White

Temperature, time, and pH affect the pasteurization of liquid eggs. Various countries specify different pasteurization time, temperature, and pH, but all specifications provide the same pasteurization effects (Table 8). Higher pH requires lower pasteurization temperature, and pH 9.0 is most commonly used for egg whites (Figure 7). Various egg products demonstrate different destruction curves (Figure 8); therefore, different pasteurization conditions were set for these products (Table 8).

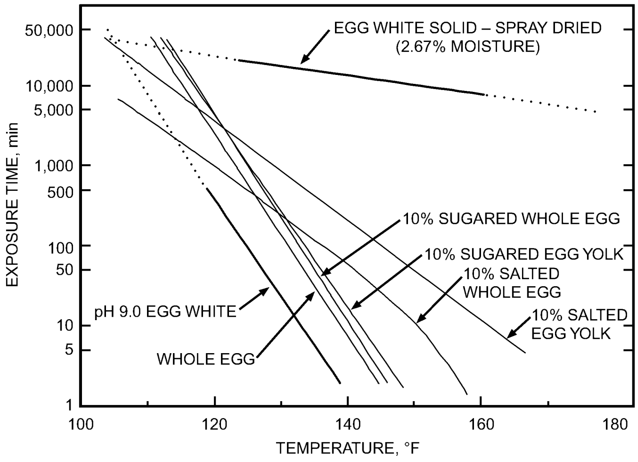


Fig. 8 Thermal Destruction Curves of Several Egg Products
(Stadelman and Cotterill 1990)

Table 9 Liquid and Solid Yields From Shell Eggs

	Liquid (% by weight)		
Constituent	**Mean**	**Range**	**Solids, %**
Shell	10.5	7.8 to 13.6	99.0
Whites	58.5	53.1 to 68.9	11.5
Yolk	31.0	24.8 to 35.5	52.5
Edible whole egg	89.5	86.4 to 92.2	24.5

Source: Shenstone (1968).

Egg whites are more sensitive to higher temperatures than whole eggs or yolk, and therefore will coagulate. Thus, lactic acid is added to adjust the pH to 7.0 to allow the egg whites to withstand 141 to 143°F. Egg whites can be pasteurized at 125 to 127°F for 1.5 min if, after the heat treatment, 0.075 to 0.1% hydrogen peroxide is added for 2 min, followed by its elimination with the enzyme catalase. Liquid yolk, on the other hand, requires higher temperatures for pasteurization than liquid whole eggs (144°F for 3.5 min).

Yields

The ratios of white, yolk, and shell vary with the size of the egg. During the laying cycle, the hens lay small, medium, and large eggs, which have different proportions of yolk and white. Therefore, the distribution of egg sizes that the breaking plant receives during the year varies with season, breed, egg prices, and surplus sizes. As a result, processing yields of white, yolk, and shell vary accordingly (Table 9).

REFRIGERATED LIQUID EGG PRODUCTS

Liquid egg products are extremely perishable and should be cooled immediately after pasteurization to below 40°F and kept cool at 34 to 40°F during storage. Refrigerated liquid egg products are convenient to use, do not need defrosting, and can be delivered in bulk tank trucks, totes, or pails, which reduces packaging costs. However, shelf life at 34 to 30°F is about 2 to 3 weeks; therefore, this product is used mostly as an ingredient in further food processing and manufacturing.

Extending the shelf life of liquid egg products is difficult because egg proteins are much more heat-sensitive than dairy proteins. As a result, ultrapasteurized liquid eggs must be kept under refrigeration whereas ultrapasteurized milk can be kept at room temperature. Ball et al. (1987) used ultrapasteurization and aseptic packaging to extend the shelf life of refrigerated whole eggs to 24 weeks.

Chilled Egg Products

Chilled or Frozen Liquid. Whole egg, yolk, and whites are the major high-volume products.

Stabilized Egg Products. Additives in yolk products to be frozen prevent coagulation during thawing. Ten percent salt is added to yolks used in mayonnaise and salad dressings, and 10% sugar is added to yolks used in baking, ice cream, and confectionery manufacturing. Whole egg products are also fortified with salt or sugar according to finished product specifications. However, egg whites are not fortified, because they do not have gelation problems during defrosting.

UHT Products. High-temperature processing (UHT) was initially aimed at producing sterile milk with superior palatability and shelf life by replacing conventional sterilization at 250°F for about 12 to 20 min with 275°F for 2 to 5 s. UHT treatment of liquid eggs is more complicated, because egg proteins are more sensitive to heat treatment; therefore, UHT liquid eggs must be kept under refrigeration.

In one study, researchers applied aseptic processing and packaging technology to extend the shelf life of liquid egg products to several months under refrigerated (40°F) conditions. According to the USDA, the process condition for extended-shelf-life liquid whole egg is about 147°F for 3.5 min. Ultrapasteurized, aseptically filled, chilled, whole liquid egg product is now limited to institutional food establishments in the United States, although retail products are available in some European countries.

Egg Substitutes. Substitutes are made from egg whites, which do not contain cholesterol or fat. The yolk is replaced with vegetable oil, food coloring, gums, and nonfat dry milk. Recent formulations have reduced the fat content to almost zero. These products are packaged in cardboard containers and sold frozen or chilled in numerous formula variations. Aseptic packaging extends the shelf life of the refrigerated product.

Low-Cholesterol Eggs. Many techniques have been developed to remove cholesterol from eggs, yet no commercial product is currently available.

FROZEN EGG PRODUCTS

Egg products are usually frozen in cartons, plastic bags, 30-lb plastic cans, or 55-gal drums (for bulk shipment). Table 3 in Chapter 9 lists thermal properties involved in freezing egg products. Freezing is usually by air blasts at temperatures ranging from –10 to –40°F. Pasteurized products designated for freezing must be frozen solid or cooled to a temperature of at least 10°F within 60 h after pasteurization. Newer freezing techniques for products containing cooked white (e.g., deviled eggs, egg rolls) include individual quick freezing (IQF) at very low temperatures (–4 to –240°F).

Defrosting. Frozen eggs may be defrosted below 45°F in approved metal tanks in 40 to 48 h. If defrosted at higher temperatures (up to 50°F), the time cannot exceed 24 h. Running water can be used for defrosting. When the frozen mass is crushed by crushers, all sanitary precautions must be followed.

DEHYDRATED EGG PRODUCTS

Spray drying is the most common method for egg dehydration. However, other methods are used for specific products such as scrambled eggs, which are made by freeze drying, and egg white products, which are usually made by pan drying to produce a flakelike product. In spray drying (Figure 9), liquid is atomized by nozzles operating at 500 to 600 psi. The centrifugal atomizer, in which a spinning disc or rod rotates at 3500 to 50,000 rpm, creates a hollow cone pattern for the liquid, which enters the drying chamber. The atomized droplets meet a 250 to 450°F hot air cyclone, which is created and driven by a fan blowing in the opposite direction. Because the surface area of the atomized liquid is so large, moisture

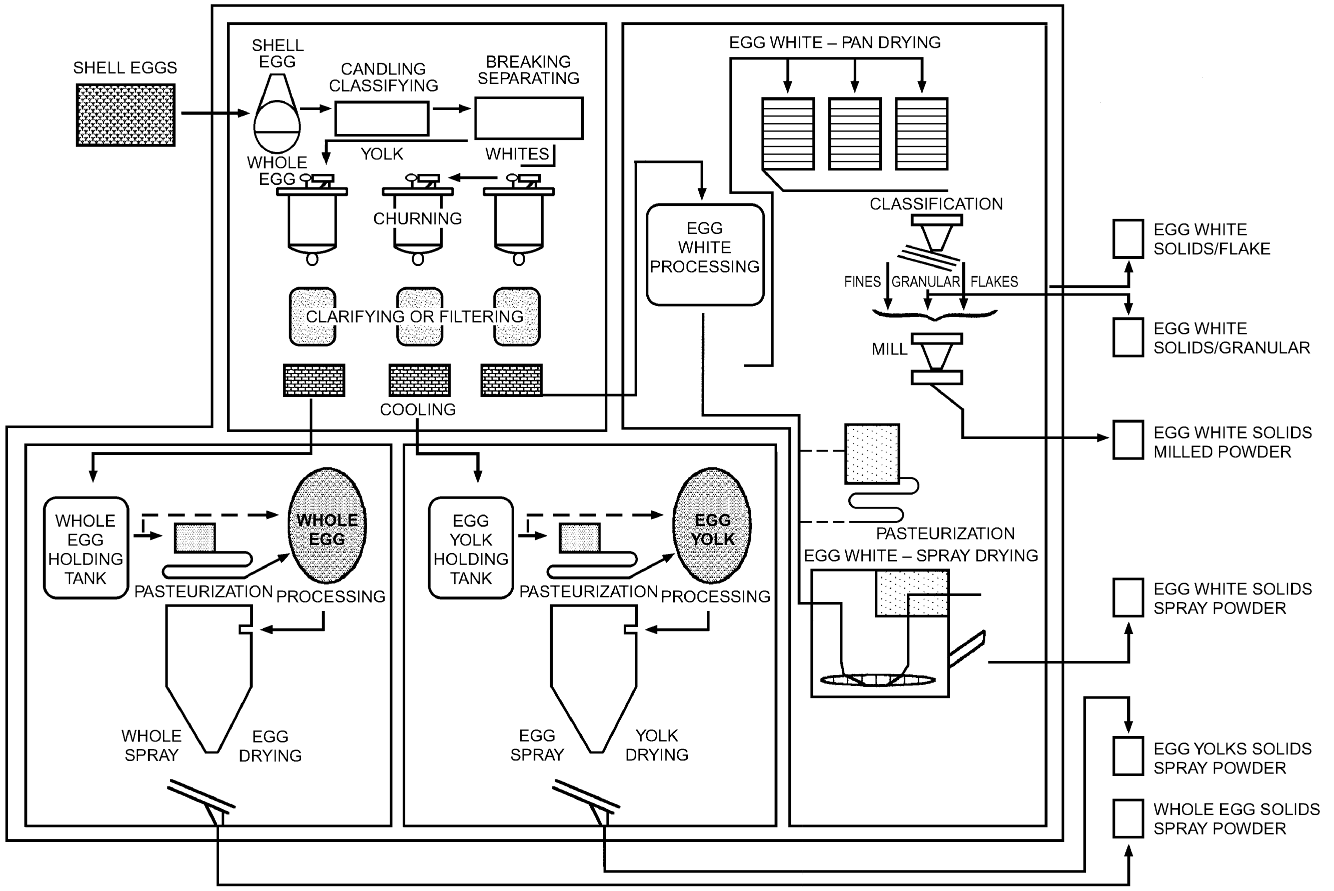


Fig. 9 Steps in Egg Product Drying

evaporates very rapidly. The dry product is separated from the air, cooled, and, in many cases, sifted before being packaged into fiber drums lined with vapor retarder liners. Military specifications usually call for gas-packaging in metal cans. Moisture level in dehydrated products is usually around 5%, whereas in pan dryer products it is around 2%.

Spray dryers are classified as vertical or horizontal. However, there are large variations in methods of atomizing, drying air movement, and powder separation.

Whole egg, egg white, and yolk products naturally contain reduced sugar. To extend shelf life and to prevent color change through browning (Maillard reaction), the glucose in the egg is removed by baker's yeast, which consumes the glucose in 2 to 3 h at 86°F. Many commercial firms replace the baker's yeast method with a glucose oxidase-catalase enzyme process because it is more controllable. The enzyme-treated liquid is then pasteurized in continuous heat exchangers at 142°F for 4 min and dried. Whole egg and yolk powder have excellent emulsifying, binding, and heat coagulating properties, whereas egg white possesses whipping capabilities.

Dry egg products are used in production of baked goods such as sponge cakes, layer cakes, pound cakes, doughnuts, and cookies. Numerous dry products exist because it is possible to dry eggs together with other ingredients such as milk, other dairy products, sucrose, corn syrup, and other carbohydrates.

Common Dried Products. Figure 9 shows processing steps for several dried products. Common dried products include

- Pan-dried egg whites, spray-dried egg white solids, whole egg solids, yolk solids
- Stabilized (desugared) whole egg, stabilized yolk
- Free-flowing (sodium silicoaluminate) whole egg solids, free-flowing yolk solids
- Dry blends (whole egg or yolk with carbohydrates, such as sucrose, corn syrup)
- Dry blends with dairy products, such as scrambled egg mix

EGG PRODUCT QUALITY

Criteria usually used in evaluating egg product quality are odor, yolk color, bacteria count, solids and fat content (for yolk and whole egg), yolk content (for whites), and performance. All users want a wholesome product with a normal odor that performs satisfactorily in the ways it will be used. For noodles, a high solids content and color are important. Bakers are particular about performance: whites do not perform well in angel food cake if excessive yolk is present. They test the foaming performance of whites based on the height and volume of angel food cake and meringue. Performance is also critical for candy (using whites). Salad dressing and mayonnaise are used to evaluate the performance of the yolk as an emulsifier, and emulsion stability is tested.

SANITARY STANDARDS AND PLANT SANITATION

In the United States, *Egg 3-A Sanitary Standards and Accepted Practices* are formulated by the cooperative efforts of the U.S. Public Health Service; the U.S. Department of Agriculture; the Poultry and Egg Institute of America; the Dairy Industry Committee; International Association of Milk, Food, and Environmental Sanitarians; and the Dairy Food Industries Supply Association. The Standards are published by the *Journal of Food Protection* (formerly the *Journal of Milk and Food Technology*).

Egg processing facilities and equipment require daily cleaning and sanitation. Plastic egg flats should be sanitized after each use to avoid microbial contamination of eggs. Chlorine or quaternary-based sanitizers are often used for egg washing and for cleaning equipment, egg flats, floor, walls, etc. Water for egg washing should have low iron content (below 2 ppm) to prevent bacterial growth.

Filters in forced-air egg drying equipment should be cleaned a minimum of once per week. Egg processing rooms should be well ventilated. Inlet air filters should be cleaned weekly. Egg cooling rooms should be kept clean and free from dust or molds.

HACCP Program for Egg Products

Food regulations in the USA require food companies to operate under Current Good Manufacturing Practices (CGMPs, CFR100). Egg products must also be produced under 9CFR590, Egg Products Inspection Act. Many egg companies have chosen to implement Hazard Analysis and Critical Control Point (HACCP) programs to further ensure the safety of their products. HACCP programs rely heavily on CGMPs and other programs (collectively called **prerequisite** programs). Some of these programs include

- Standard sanitation operating procedures (SSOPs)
- Pest control program
- Customer complaint and recall programs
- Maintenance program
- Training programs

When all of the prerequisite programs are properly implemented and satisfied, the HACCP program is used to monitor, control, verify, and record critical points in the process. Critical control points in egg products processing include pasteurization time and temperature, and prevention of post process contamination.

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