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Factors Affecting Temperature Changes in Dressed Poultry During Refrigeration

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I. INTRODUCTION

Since refrigeration is the prevailing method employed in the preservation of poultry meats the problems involved in cooling, freezing, and thawing of dressed poultry are of utmost interest to those engaged in the preparation, storing, and retailing of dressed poultry. According to the Bureau of Agricultural Economics (U.S.D.A.) on February 1, 1940 the cold storage holdings of poultry was estimated at 166,962,000 pounds. This represents 4.4 per cent of the poultry produced in the United States in 1939. Because of the importance of cold storage in the production and merchandising of poultry meats; cooling, freezing, and thawing time curves should be of invaluable interest and aid to those engaged in the preparation and storage of dressed poultry, to those engaged in the distribution of dressed poultry, to the consumer, and to those engaged in research pertaining to problems of refrigeration.

Considerable experimental work, relative to cooling and freezing of vegetables, certain meats, and fish, has been published. Information regarding the cooling and freezing of poultry meats, however, is quite limited.

There is little information on the subject of thawing frozen poultry meat. While experimental results on the process of thawing other perishable foods have been published, similar data on the thawing of poultry meat are limited and indefinite.

Cooling refers to the process, generally used in most packing plants, of placing dressed birds in a room where a temperature from 30° F. to 35° F. is maintained, and allowing them to remain until the temperature of the birds approach that of the room. Cooling usually takes place immediately following the dressing operation. After cooling the dressed birds are packed in boxes, each containing twelve birds, and exposed to low temperatures (-10° F to -25° F) until they are frozen. Thawing is the reversal of the freezing operation.

Dressed poultry is poultry that has been killed, bled and plucked; the feet, head, and internal organs remaining as part of the dressed bird. A fowl is any female chicken that has reached maturity* regardless of age or weight. A mature male of any weight, with darkened or toughened flesh is known as a

*The domestic fowl is considered mature when the posterior end of the keel bone has become hardened.

cock. Broilers are young chickens between the ages of 8 and 12 weeks, of either sex, not weighing more than 2½ pounds, and sufficiently soft meated to be cooked tender by broiling*. Young chickens between the ages of 14 and 20 weeks, weighing from 2½ to 3½ pounds, and sufficiently soft meated to be cooked tender by frying are termed fryers†.

II. REVIEW OF LITERATURE

A. Cooling and Freezing

The operation involved in the cooling or freezing of an object is that of heat removal. Heat, according to King[1] and Stiles[2] may be extracted by employing one or all of the three following methods; convection, conduction, or radiation. In convection the vibratory motions of heat are transferred to the surrounding medium and removed by circulation or mixing of this medium. In conduction the vibratory motion of heat is transmitted progressively from molecule to molecule by impacts. In radiation heat is transferred from the surface by the emission of heat rays. Whenever the surrounding medium is cooler than the object being cooled heat is being radiated from the surface of the object. Conduction and convection are prevailing methods employed in mechanical cooling of dressed poultry.

The rate at which heat can be extracted from dressed poultry is influenced by many factors. The literature is here classified and reviewed according to the factors, as outlined by Stiles[3], which influence the rate of cooling and freezing.

(1) The conductivity of the substance of which the body is composed.

Frozen poultry meat containing 80 per cent water, according to Stiles[4], will cool 6.4 times as fast as the same meat in the unfrozen state, ice being a more effective conductor of heat than water. Stiles[5] also reports that when the poultry carcass is covered with a layer of fat it will lose heat less rapidly than a carcass of the same weight not covered with fat because of the fact the thermal conductivity of fat is considerably less than that of lean meat.

*Broiling—refers to rapid cooking at high temperatures.

†Frying—refers to cooking in hot fat.

[1]King, W. J., The Basic Laws and Data of Heat Transmission, Mechanical Engineering, LIV (1932), pp. 190-194, 296, 347.

[2]Stiles, Walter, The Preservation of Food by Freezing, with Special Reference to Fish and Meat, British Department of Scientific and Industrial Res. Food Investigation Board, Spec. Report, VIII, (1922) p. 186.

[3 4 5]Stiles, Walter, The Presenvation of Food by Freezing, With Special Reference to Fish and Meat, British Department of Scientific and Industrial Research, Food Investigation Board, Special Report VII, (1922), p. 186.

(2) The specific heat and density of the substance.

Stiles[6] states that the greater the specific heat and density the slower must be the rate of cooling.

(3) The degree of agitation of the body being cooled and of the external medium.

Mandeville[7] has reported that if meat is placed in an open cold storage room at zero degrees Fahrenheit, and the meat is at 70° F., there will be a film of humid air, immediately surrounding the meat, which is the same temperature as that of the meat. This ring is again superimposed by a ring formation of successive overlapping layers of air the temperature of each being relatively lower than the ring nearest the meat until the outer ring is the same temperature as that of the storage room. The air surrounding the meat insulates it from the cooling effects of the room. The slightest movement of air in the room will tend to remove the various bands of humid air although they will rapidly re-form. The faster these higher temperature bands are removed the more rapidly the product will be cooled. Zarotschenzeff and Conn[8] state that velocity of circulating air is an important factor affecting the rate of cooling. On the other hand, Finnegan[9] reports that air distribution is far more important than air velocity. In other words, an air velocity of 100 feet, properly and effectively distributed, will produce much better results than a 1000 foot air velocity that is largely short-circuited and by-passed. Plank[10] reports that freezing in moving liquid is more rapid than freezing in still liquid.

(4) The surface of the body. The greater the surface per unit of weight the more rapid the rate of heat removal.

Cook[11] and Peterson[12] have found that size and shape of the article greatly influence the rate of heat extraction. Peterson also states that the amount of evaporation taking place during freezing will influence the rate of freezing. Stiles[13] has reported that as the diameter of the object increases the freezing time becomes more and more proportional to the square of the diameter.

[6]Loc. Cit.

[7]Mandeville, Paul, The Quick Freezing of Poultry (Part II), U. S. Egg and Poultry Magazine, XLIII (1937), pp. 526-529, 560-570.

[8]Zarotschenzeff, M. T., and Conn, C. J., Quick Freezing and Marketing of Ducks, Ice and Refrigeration, XCI (1936) pp. 51-7.

[9]Finnegan, W. J., Food Freezing Engineered for Quality and Economy, U. S. Egg and Poul. Mag., XLV (1939), pp. 338-343.

[10]Plank, R., Theories Concerning the Changes Taking Place in the Cell Membranes of Animal Flesh During the Process of Refrigeration, Ice and Cold Storage, XXXVIII (1925), pp. 234-35, 261-3.

[11]Cook, W. H., Precooling of Poultry, Food Research, IV (1939), p. 245.

[12]Peterson, P. W., Food Freezing Temperatures, Refrigerating Engineering, XXI (1931), pp. 422-23, 463.

[13]Stiles, Walter, The Preservation of Food by Freezing, With Special Reference to Fish and Meat, British Department of Industrial and Scientific Research, Food Investigation Board, Special Report, VII (1922), p. 186.

(5) The temperature of the external medium.

Cook[14] and Kolbe[15] have reported that the temperature of the cooling medium influences the time required for cooling. Peterson[16] implies that freezing time can be reduced by lowering the temperature of the external medium.

Birdseye[17] relates that water begins to freeze out of flesh at 31° F. Mandeville [18] has also reported that poultry freezes at 30° F. and that a temperature of 0° F. to -10° F. is satisfactory for slow freezing. Peterson[19] states the belief that no article can be completely frozen until it has been drawn to or below its eutectic point, the eutectic point being the temperature at which the article is theoretically completely frozen. He also states that the term, "temperature range", may well be used to cover the temperature field lying between the initial formation of ice crystals in an article (its freezing point) and the point at which the article is theoretically completely frozen (its eutectic point). Many meat and fish products, according to Peterson[20], are comparatively quickly 85 per cent frozen but are only 95 per cent frozen after having passed through a drop of twice as many degrees of their freezing range, and a drop of several times as many degrees must be effected before the object is actually 100 per cent frozen. The optimum freezing temperature of flesh is at its eutectic point. Low temperatures and highly efficient heat extraction will not make the center of a large chunk of meat freeze.

The above statements are confirmed by Birdseye[21]. He states that all animal matter, whether fish, meat, or poultry, is composed of a multitude of tiny elastic walled cells filled with jelly-like fluid containing a solution of various salts, among which may be mentioned sodium and calcium. This jelly-like cell material, because of its salt content, does not freeze homogeneously. Instead, fresh water ice crystals begin to form throughout the cell substance and in the moisture of the intercellular spaces as soon as the temperature gets down to about 31° F. As the temperature is further lowered, more and more

[14]Cook, W. H., Precooling, Freezing, and Storage of Dressed Poultry, Proceedings of 7th World's Poultry Congress, (1939), p. 512.

[15]Kolbe, Carl T., Why Quick Freeze, Food Industries, II (1930), pp. 165-8.

[16]Peterson, P. W., Food Freezing Temperatures, Refrigerating Engineering, XXI (1931), pp. 422-423, 463.

[17]Birdseye, Clarence, Packaging Flesh Products for Quick Freezing, Industrial and Engineering Chemistry, XXI (1929), pp. 414-17.

[18]Mandeville, Paul, The Quick Freezing of Poultry (Part I), U. S. Egg & Poultry Mag. XLIII (Sept. 1937), pp. 464-467.

[19 20]Peterson, P. W., Food Freezing Temperatures, Refrigerating Engineering, XXI (1931), pp. 422-23, 463.

[21]Birdseye, Clarence, The Quick Freezing of Perishable Foods, Ice and Refrig., LXXXIV (1930), pp. 547, 563.

liquid is frozen in the form of fresh water ice, leaving behind an even more concentrated solution of the various salts. The entire fluid content of haddock (fish), for instance, does not freeze until the temperature has been lowered to approximately -68° F., but 75 per cent of the moisture is frozen when the temperature reaches 25° F. above zero.

(6) The conductivity of the external medium.

Stiles[22] has found that the more efficient the conductivity of the external medium the faster will be the rate of heat extraction. Mandeville[23] reports that air has the disadvantage of being a slow conductor of heat and the advantage of being most easily circulated. Greene[24] states that the basic idea of modern quick-freezing apparatus is to replace air freezing, which is known to be a very poor conductor of heat, by surface conduction. Merriman[25] has found the heat conductivity of water to be 25 times that of air, and that brine is also a more efficient conductor of heat than air.

(7) The specific heat and density of the external medium.

According to Stiles[26] the rate of cooling will be more rapid the less the specific heat and density of the external medium

(8) The latent heat of solidification of the substance.

Stiles[27] explains that in the actual freezing process alone is involved 72.7 per cent of the total heat which the substance must part with on cooling from 20° C. to -20° C. Birdseye[28] reports that the latent heat which must be absorbed from a given area of meat during the solidifying of most of the liquids is so much greater than at any other time during the freezing process that the time curve tends to flatten out, in slow freezing, to several hours. The temperature zone where the time curve flattens out is known at the zone of maximum crystal formation. Birdseye[29] has published data that show the zone of maximum crystal formation for haddock (fish) to range from 31° F. to 25° F.

Other factors that influence the rate of cooling and freezing in poultry have been reported. Mandeville[30] states that the age

[22]Stiles, Walter, The Preservation of Food by Freezing, With Special Reference to Fish and Meat, British Department of Scientific and Industrial Research, Food Investigation Board, Spec. Report, VII, (1922), p. 186.

[23]Mandeville, Paul, The Quick Freezing of Poultry (Part II) U. S. Egg & Poul. Mag., XLII (Sept. '37), pp. 526-29, 560-570.

[24]Greene, V. R. H., Quick Freezing of Poultry, Quick Frozen Foods, I (1938), p. 31.

[25]Merriman, H., Brine Fog Quick Freezing, Without Extreme Temperatures, Food Industries, IV (1932), pp. 396-398.

[26] [27]Loc. Cit.

[28]Birdseye, Clarence, The Quick Freezing of Perishable Foods, Ice and Refrigeration, LXXXIV (1930), pp. 547, 563.

[29]Loc. Cit.

[30]Loc. Cit.

of the bird when killed determines in part the effect of freezing and thawing; the greater the age the more unfavorable the effect. He also reports that evidence indicates that a bird properly conditioned before killing behaves differently from one not properly conditioned.

Moulton[31] believes that pre-treatment, the temperature conditions within the carcass at the time of freezing together with the time interval that has elapsed between slaughter and freezing will account for changes taking place during freezing and thawing.

"Very probably", quoting from Birdseye[32], "the quality of frozen products is affected both by breed of animal and by method of feeding prior to killing".

Cook[33] has found that by immersing the dressed birds in water at 32° F. for two hours prior to cooling he could reduce the time required for cooling in air alone by approximately one-half.

B. Thawing and Dechilling

Kallert[34] states that a reversal of the changes due to freezing in muscle occurs when it is thawed. He also states that with slow thawing the reversal progresses farther than with rapid thawing.

In various experiments Cook[35] has found that with air temperatures of 60° F. to 70° F. periods of 48 to 50 hours are required to raise the average temperature to 45° F. With air at 50° F. and poultry at 28° F., 60 hours were required to raise the temperature to 40° F. In dechilling poultry meat at 32° F. it required 7 hours to dechill in air at 75° F. and 17 hours at 50° F. In explaining the causes for slowness in thawing Mandeville[36] reports that the defrosting process is slower than that of freezing because of the fact that water has only one-half the conductivity of ice. The outer flesh first to thaw surrounds the still frozen portions thus reducing the rate at which they are defrosted.

[31]Moulton, C. R., Meat Through the Microscope, University of Chicago Press, (1929), pp. 11-38.

[32]Birdseye, Clarence, The Preservation of Foods by New Quick Freezing Method, Refrigerating Engineering, XXV (1933), pp. 185-8, 201.

[33]Loc. Cit.

[34]Kallert, E., The Nature of the Modification Produced in the Muscular Tissue of Frozen Meat During Thawing, Zietschrift fir die Gesamte Kolte-Industrie, XXX (1923, pp. 77-81.

[35]Cook, W. H., Defrosting and Dechilling of Poultry and Eggs, Conference of the Associate Committee on Market Poultry, (1936), pp. 98-99.

[36]Loc. Cit.

III. THE NATURE OF THE EXPERIMENT

Object of the Investigation

The object of this investigation was to study the effects of various factors on the rate of cooling, freezing, and thawing in dressed poultry.

1. To compare the rate of cooling, freezing, and thawing in different sections of the same bird.
2. To study the influence of weight of bird on the time required for cooling, freezing, and thawing.
3. To provide time-curves for the rate of cooling, freezing, and thawing in various market classes of dressed poultry.
4. To compare the effect of circulating air with still air on the rate of cooling, freezing, and thawing.
5. To establish the limits of the zone of maximum crystal formation for dressed poultry.
6. To compare the effect of external temperature on the rate of freezing.
7. To compare the rate of freezing with the rate of thawing when exposed to the same difference of temperature.

Materials and Methods

The assembling of these data was effected with the aid of an electrical resistance thermometer. Metal points, containing wire coils for measuring resistance to an electrical current, were inserted into various sections of the dressed bird. These points were connected by insulated wires to the recording apparatus. An instrument of this type affords one the advantage of being able to record the temperature changes without entering or opening the refrigerator. The temperature can also be taken at various depths within the flesh, an accomplishment that cannot be satisfactorily attained with the usual type thermometer.

The poultry was from the station flock at the University Poultry Farm. Each bird was selected on the basis of age, weight, sex, degree of fleshing,* and body measurements.** Housing, feeding, and care, prior to killing, was approximately the same in all cases.

After starving for 12 to 20 hours the birds were killed by sticking,*** bled, semi-scalded,**** and plucked by hand. In order to have the entire carcass at approximately the same temperature and to have all birds of a uniform initial temperature, the dressed birds were placed in a water bath at 100° F. to 105° F. until they approached that temperature. The metal points, used in determining the temperature, were inserted

*Degree of Fleshing—refers to degree of fatness.
**Measurements—the length, width, and depth of each bird was recorded.
***Sticking—refers to puncturing the posterior lobe of the brain.
****Semi-scald—scalding in water at 128°F.

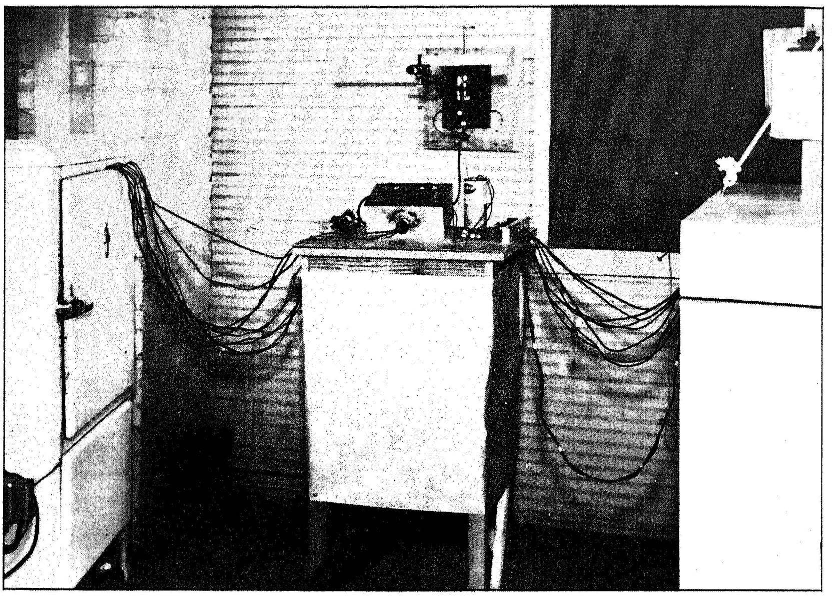

Fig. 1.—The apparatus and equipment used in the collection of these data. Note the temperature control device in the lower left hand corner.

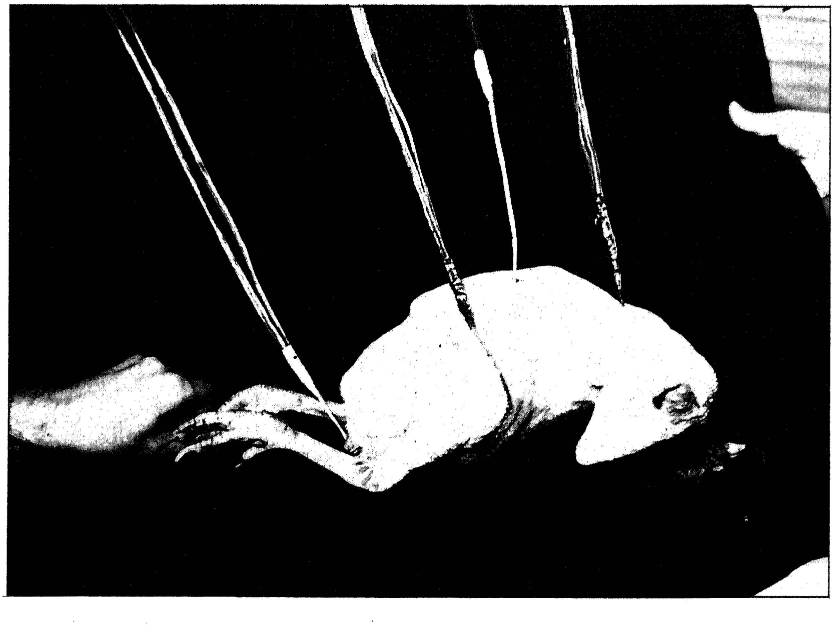

Fig. 2.—Electrical resistance thermometer connections by which temperatures were taken in different parts of the dressed birds.

before the dressed bird was placed in the water. The flesh was pressed firmly around the wires in order to prevent water from entering the opening made by the insertion. On reaching the desired temperature, the birds were taken from the water, the excess moisture removed with a dry cloth, and they were placed in a refrigerator for cooling.

The refrigerator used for cooling was of the usual household type equipped with a device for controlling the temperature. A refrigerator especially designed to provide low temperatures was also used in the freezing work. Thawing was effected in the same machine in which the dressed birds were cooled. Both refrigerators were equipped with wire shelves which allowed the air free access to all sides of the dressed bird.

Each set of data was duplicated before it was considered as representative. In other words, for each determination the data were not used unless it could be duplicated on another bird of approximately the same age, weight, sex, degree of fleshing, and exposed to the same conditions. As no two of the individuals were exact duplicates it was impossible to obtain data, on different birds, that would check exactly; but unless they closely approached each other such data were discarded.

The temperature was taken at four places in the dressed bird; (1) at one-half inch depth in the breast meat (2) at one-half inch depth in the meat of the thigh, (3) in the body cavity at the approximate region of the ovary, the insertion being made through the vent, and (4) in the body cavity making the insertion through the thoracic inlet and taking the temperature in the region adjacent to the lungs. As the abdominal region required the longest time to approach the temperature* of the external medium, the temperature recordings taken at this point were used in making most of the charts.

IV. RESULTS

A. The Rate of Cooling

In order to obtain results applicable to the poultry packing industry, a procedure similar to that followed by packers was used in this investigation. Certain deviations were necessary because of limitations in equipment and materials, but they were not considered great enough to significantly alter the final results. After dressing† the birds were placed in a refrigerator which maintained a temperature of 35° F. and a relative humidity of 70 per cent. The temperatures were recorded at intervals of one-half hour, and comparisons were made between the time

*By approaching the temperature of the external medium is meant for the temperature of the bird to come within 2°F to 4°F. of it.

†Dressed birds—Birds are killed and feathers and blood are removed. Grade refers to degree of fleshing. A. Very well fleshed, B. Well fleshed, C. Poorly fleshed.

required for various birds to cool from the initial temperature to within 2° F. to 4° F. of the external medium.

The Rate of Cooling in Different Sections of the Same Bird.—The birds used for this determination were six-pound grade A fowl, one year of age. The temperatures were recorded from the four different sections discussed in Section III. From Figure 3 it may be observed that an initial difference of 2° F. to 6° F. existed between the temperature within the body cavity and at one-half inch depth in the flesh of the breast and thigh. This may be expected, however, as the cooling effect of a lower external temperature will cause the temperature of the outside of the dressed bird to be reduced quickly, whereas, the internal temperature is not affected in the short interval between killing and placing in the refrigerator.

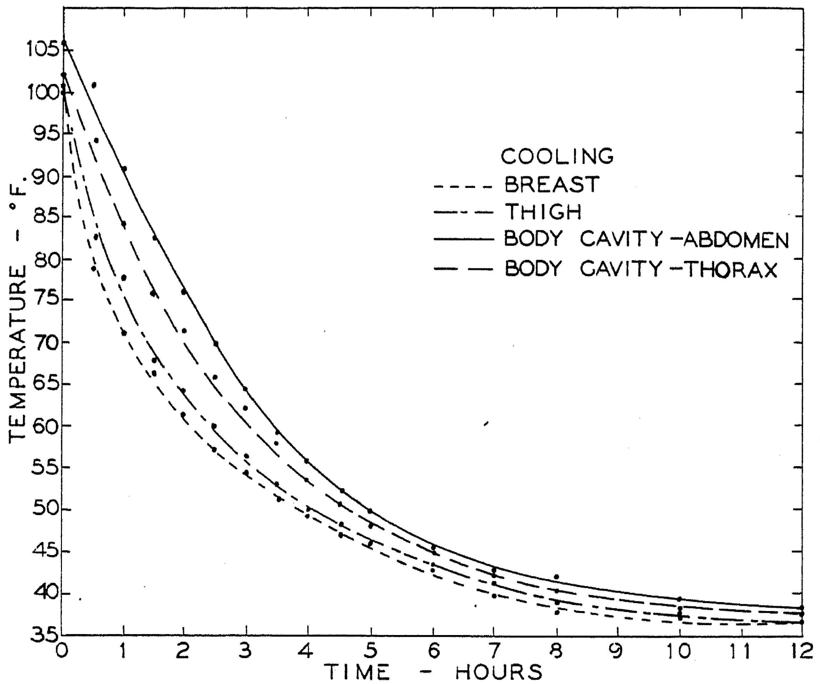

Fig. 3.—The rate of cooling in different sections of the same bird. The temperature of the external medium was 35° F.

When first exposed to the cooling effects of the refrigerator, the meat of the thigh and breast registered a very rapid drop in temperature, while the temperature inside the body cavity decreased slowly. The breast meat apparently loses heat at a more rapid rate than does the meat of the thigh. According to Maw and Puddington,[37] the thigh meat of White Leghorn cockerels contains two to four times as much fat as does the breast meat. Stiles[38] has reported that the thermal conductivity of fat is considerably less than that of lean meat. The difference in the cooling rate of the breast and thigh meat is probably due to their fat content. The variation in the cooling rate in the thoracic and abdominal regions is doubtless due to the thickness of the dressed bird in these particular regions. Stiles[39] relates that as the diameter of an object increases the time required for cooling becomes more and more proportional to the square of the diameter. The thickness of the bird in the lung region is slightly more than one-half that in the section adjacent to the ovary, therefore, the logical expectation would be for the abdominal region to lose heat less rapidly.

The Rate of Cooling in Various Market Classes of Dressed Poultry.—The object of this determination was to compare the rate of cooling of various classes of dressed poultry. All birds were exposed to approximately the same conditions and all possessed approximately the same degree of fleshing (Grade B.) The market class includes numerous variables as weight, age, and sex. In Figure 4 it may be observed that broilers cooled very rapidly, closely approaching the temperature of the external medium within six hours. From data reported by Mitchell, Card, and Hamilton[40] it is observed that chickens of the same weight as those used in this experiment contain more surface per unit of weight than do older birds. The greater the surface according to Stiles,[41] the more rapid will be the rate of heat removal. Cook[42] and Petersen[43] also relate that size and shape of an article greatly influences the rate at which heat may be extracted therefrom. Chatfield and Adams[44] have published data which show that broilers and fryers contain more water and less fat than do older members of the species. A higher content of water would reduce the comparative density of the younger birds. Stiles[45] reports that the rate of cooling varies inversely with the density of a substance. He also reports that when the poultry carcass is covered with a layer of fat it loses heat less

[37]Maw and Puddington, The Determination of the Effect of Fattening on the Carcass of the Chicken, Scientific Agr. Reprint, 17:9 (1937).

[38 39]Loc. Cit.

[40]Mitchell, H. H., Card, L. E. and Hamilton, T. S., The Growth of White Plymouth Rock Chickens, Illinois Agr. Exp. Sta. Bulletin 278 (June, 1926).

[41]Loc. Cit.

[42]Cook, W. H., Precooling of Poultry, Food Research, IV (1939), p. 245.

[43]Peterson, P. W., Food Freezing Temperatures, Refrigerating Engineering, XXI (1931, pp. 422-423, 463.

[44]Chatfield, Charlotte, and Adams, Georgian, Proximate Composition of American Food Materials, U.S.D.9. Circular 549 (1940).

[45]Loc. Cit.

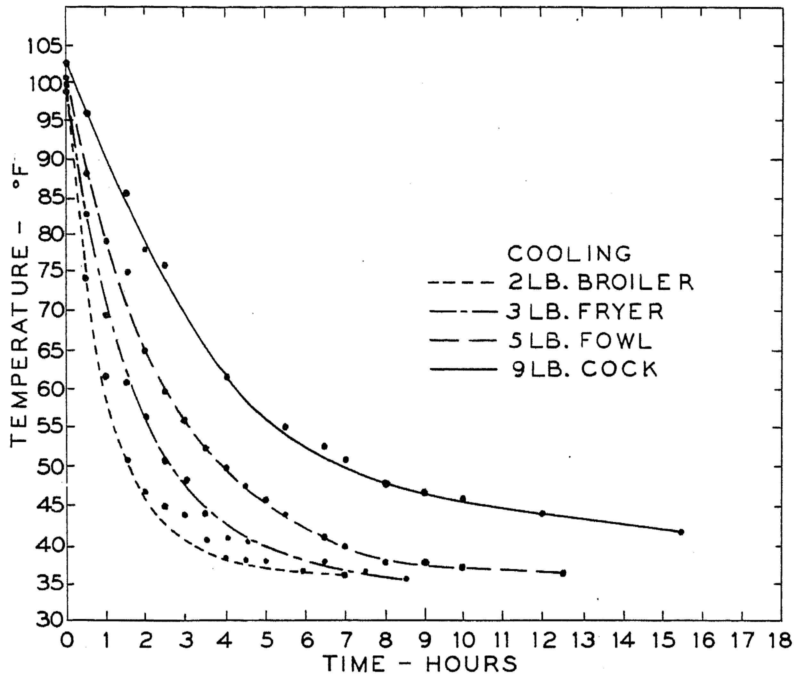

Fig. 4.—A comparison of the rate of cooling in various market classes of dressed poultry. The temperature of the external medium was 35° F.

rapidly. In view of the fact that broilers have a larger amount of exposed surface per unit of weight, and that they contain more water and less fat than do older birds, it would be expected that they would lose heat rapidly. Fryers being heavier and according to Chatfield and Adams,[46] containing slightly more fat and less moisture require a somewhat longer period of time for cooling. It required four to five hours longer for five pound fowl to cool than was required for fryers and broilers. From the data of Mitchell, Card and Hamilton[67] it is observed that five pound White Plymouth Rock females contain less surface per unit of weight than do younger birds. It has also been reported by Chatfield, and Adams that adult birds contain considerably less moisture and more fat than broilers or fryers. The cock birds being heavier and containing a relatively low content of water and a high content of fat required much longer to cool than did the other classes of dressed birds.

[46]Loc. Cit.
[47]Loc. Cit.

The Rate of Cooling in Dressed Birds at Different Weight.—The object of this test was to determine the effect of weight on the rate of cooling in dressed poultry. Only one year old Grade B birds were used. From figure 5 it is apparent that weight is an important factor in the rate of heat removal from dressed birds. The effect of weight, however, is probably dependent on such factors as the amount of exposed surface per unit and the thickness of the bird.

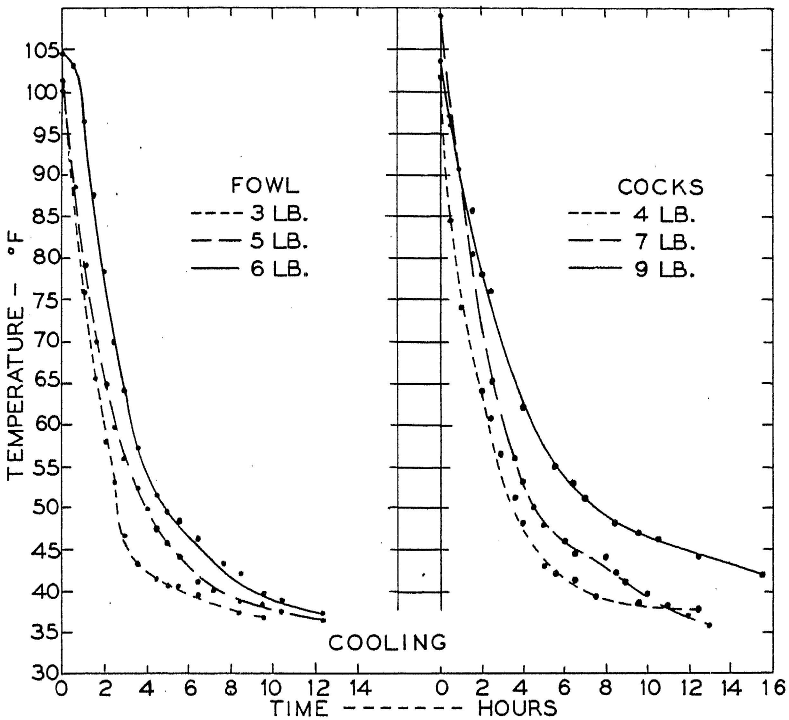

Fig. 5.—The rate of cooling in dressed birds of different weight. The temperature of the external medium was 35° F.

The time required for different weight birds to cool to 39° F. is as follows: six and one-half hours for three pound fowl, eight hours for five pound fowl, and ten hours for six pound fowl. Four pound cock birds were cooled to 39° F. after seven hours, seven pound cocks after ten hours, and after fifteen hours the temperature of nine pound cock birds was 44° F.

Although their initial temperature was somewhat higher it will be observed that seven pound cock birds were cooled almost as rapidly as six pound fowl. One may also observe the comparative rate of cooling between three pound fowl and four pound cock birds was only slightly greater in the females. This phenomena is accounted for in a report by Mitchell, Card, and Hamilton. They present data which show the fat content of the meat of White Plymouth Rock females to be approximately twice that of the males. The above investigators have also reported the same results from tests on White Leghorns. Because of the fact that the thermal conductivity of fat is considerably less than that of lean meat[49] the rate of cooling in the females will be slower. From measurements made on birds used in this work it has been determined that the thickness, width across the back, was no greater in the males than in the lighter weight females. The vertical measurements, however, were slightly greater in males. The accelerated rate of cooling per unit of weight in the males is probably due to a lower fat content of the flesh and to the body shape.

A Comparison of the Effect of Circulating and Still Air on the Rate of Cooling.—Mandeville,[50] Stiles,[51] and Zarotschenzeff and Conn[52] have reported that air movement will increase the rate of heat extraction. The object of this test was to determine the time for cooling in circulating air as compared to cooling in still air. The birds used were five pound, one year old, Grade B fowl. A blast of air with a velocity of 8.33 feet per second was directed on the dressed bird. The comparison is presented in Figure 6. Circulating air of the velocity used reduced the time of cooling five pound Grade B fowl by approximately one-half.

[49]Loc. Cit.

[50]Loc. Cit.

[51]Loc. Cit.

[52]Zarotschenzeff, M. T., and Conn, C. J., Quick Freezing and Marketing of Ducks, Ice and Refrigeration, XCI (1936), pp. 51-57.

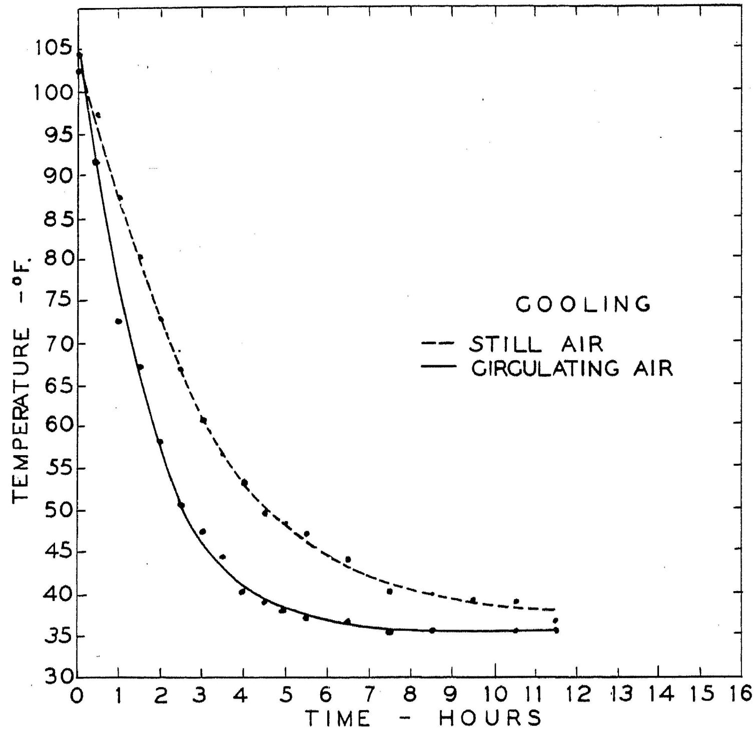

Fig. 6.—The effect of circulatory air on the rate of cooling. The temperature of the external medium was 35° F.

B. Freezing.

After the dressed birds had been cooled to approximately 35° F. they were transferred to a refrigerator that maintained a temperature of -25° F. Apparently there are no definite data available relative to the most desirable temperatures for freezing dressed poultry, however, it is believed that low temperatures (-10° F. to -20° F.) are more satisfactory.* The temperature given above was chosen for this investigation because it could be easily maintained in the refrigerator, and it appeared to be an efficient extractor of heat. All dressed birds, used in this work, were held in the refrigerator until the temperature inside the body cavity approached that of the external medium. Although they were considered frozen after their temperature had dropped below the lower limit of the zone of maximum crystal formation, the time required for the temperature of the various birds to pass through the zone of maximum crystal formation was used as a basis for comparisons.

*According to G. A. Fitzgerald, Chief Chemist, The Birdseye Laboratories, U. S. Egg and Poultry Magazine, XLVVV (1937), p. 561.

The Zone of Maximum Crystal Formation.—During the process of freezing a point is reached where the temperature remains constant for a period of time depending on the object being frozen. Birdseye[53] has observed this phenomena in meats and explains that the latent heat* that must be absorbed from a given area is so much greater than at any other time during the freezing process that the time curve tends to flatten out in slow freezing to several hours. The limits of this zone have not, to the authors' knowledge, been definitely established for dressed poultry. Birdseye[54] has published data that show this zone for haddock (fish) to range from 31° F. to 25° F.

The limits of the zone of maximum crystal formation for dressed poultry, as determined in this investigation, are shown graphically in Figure 7. It may be observed that these limits depend on the section of the dressed bird in which the temperatures are taken. Time curves of temperatures taken in the body tend to level off at a higher temperature than curves of temperatures taken in the flesh. The above results may be explained on the basis of the comparative density of the sections in which the temperatures were taken. A report by Chatfield and Adams[55] shows drawn birds to contain a lower percentage of moisture than undrawn birds. This would indicate that the internal organs contain a higher moisture content than the flesh. The higher average freezing level in the body cavity is probably due to the higher moisture content in that section. Water freezes at 32° F. and the more dense a substance is the lower must be the temperature required for freezing, therefore, the more liquid internal organs would be expected to freeze at a higher temperatur than the comparatively dense flesh.

The results of this investigation, which includes over 80 cases, show the limits of the zone of maximum crystal formation for dressed poultry to range from 32° F. to 25° F. The point within this range at which a particular time curve will level off appears to depend largely on the individuality of the dressed bird in which the temperatures were taken. All the variations obtained in this work are included in the cases presented by the charts.

[53]Birdseye, Clarence, The Quick Freezing of Perishable Foods, Ice and Refrigeration, LXXXIV (1930), p. 547.

[54]Loc. Cit.

[55]Loc. Cit.

*Latent heat. Heat given off by a body without a resulting change in the temperature of that body.

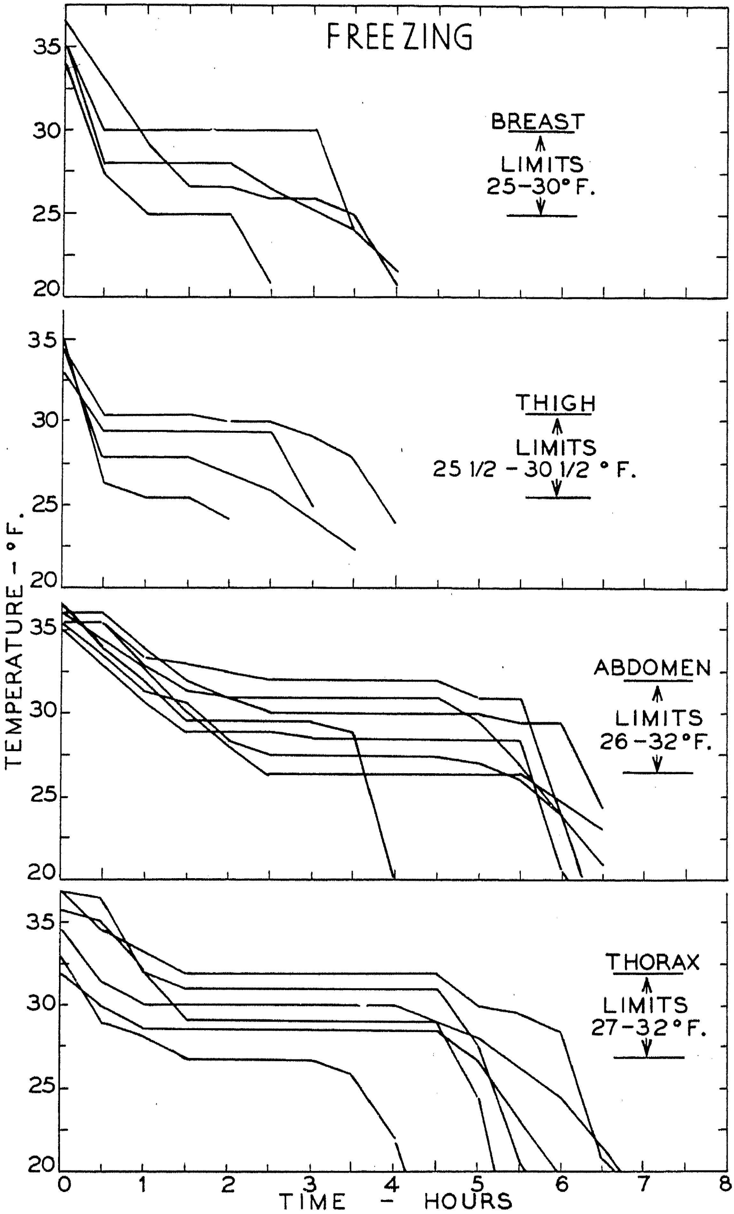

Fig. 7.—The zone of maximum crystal formation in dressed poultry. The temperature of the external medium varied from -5° F. to -35° F.

The Rate of Freezing in Different Sections of the Same Bird.—The birds used in this determination were one year old, Grade A, six pound fowl. The results may be observed in Figure 8.

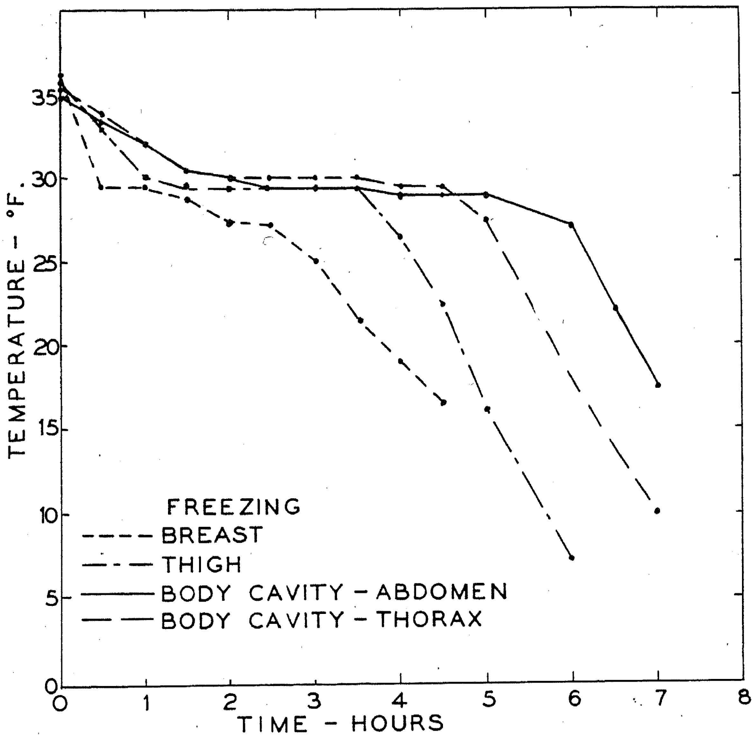

Fig. 8.—The rate of freezing in different sections of the same bird. The temperature of the external medium was -25° F.

The comparative rate of freezing in the different sections is the same as that of cooling. The breast was frozen three hours after the dressed bird was transferred to the freezer. The thigh required four hours, the thoracic region five hours, and the bird was entirely frozen after six hours. As in cooling, freezing is the result of heat removal, therefore, the factors responsible for the rate of cooling in the various sections would also be responsible for the rate of freezing. These factors are discussed in the section devoted to factors affecting the rate of cooling in dresesd birds.

The Rate of Freezing in Various Market Classes of Dressed Poultry.—The birds used in this work were all Grade B. The variable, market class, as explained in the section under cooling, contains certain other variables. The relation between the rate of freezing in the various market classes is the same as in cooling. Two pound broilers were frozen after two hours, three pound fryers after three and one-half hours, and five pound fowl were frozen after five hours of exposure. Nine pound cock birds were frozen after six and one-half hours. The smaller broilers and fryers, containing a large amount of exposed surface per unit of weight, and, according to Chatfield and Adams,[56] a higher percentage of moisture and a lower content of fat would be expected to freeze more rapidly than the older fowl and cocks. The composition of the various market classes of birds which contribute to their behavior during refrigeration is explained in the section on the rate of cooling in various market classes of poultry. Figure 9 presents the results.

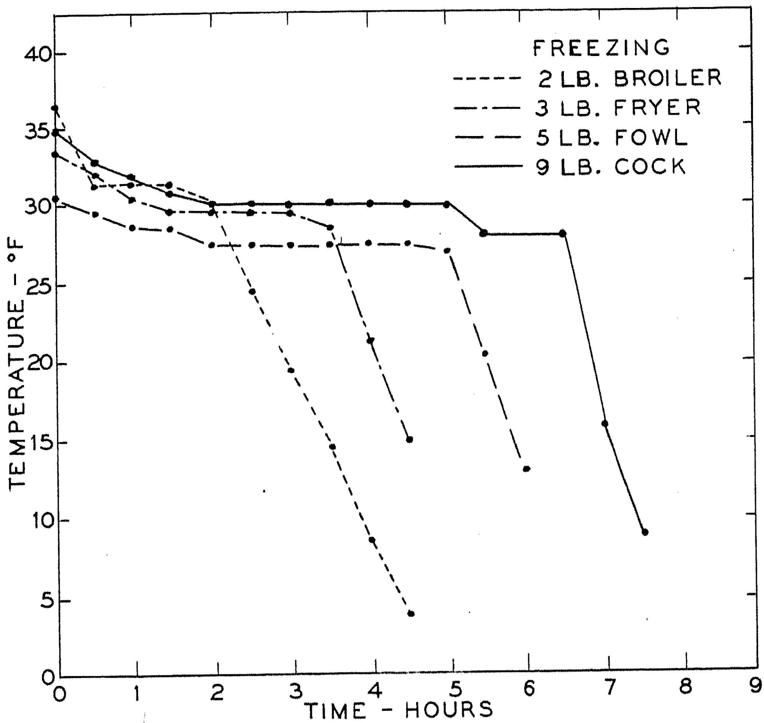

Fig. 9.—The rate of freezing in various market classes of dressed poultry. The temperature of the external medium was -25° F.

The Rate of Freezing in Dressed Birds of Different Weight. —As in cooling weight appears to play a major role in affecting the rate of freezing in dressed poultry. The effect of weight, however, appears to be limited by the size and shape of the bird. All birds used were one year old, Grade B, individuals. In the females three pound fowl required four hours for freezing, five pound fowl required five hours, and six pound fowl were frozen after six hours. In the males four pound cocks were

[56]Loc. Cit.

frozen in four hours, seven pound cocks in five and one-half hours, and nine pound cocks in six and one-half hours. In Fig. 10 it will be observed that seven pound cocks were frozen more rapidly than six pound fowl, and that four pound cocks required no longer time for freezing than three pound fowl. Size and

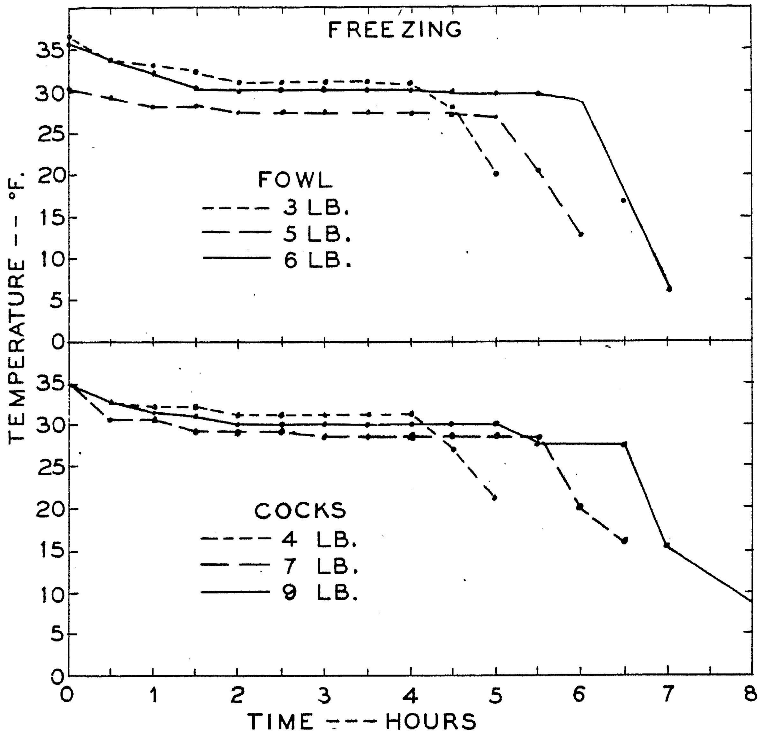

Fig. 10.—The effect of weight on the rate of freezing in dressed poultry. The temperature of the external medium was -25° F.

shape of the body, according to Cook[57] and Peterson[58] greatly influence the rate of heat extraction. The shape of the male carcass is somewhat more rectangular than that of the female having less width per unit of length and depth than the females. Mitchell, Card, and Hamilton,[59] have found that the flesh of females contains approximately twice as much fat as does that of males. Fat, as reported by Stiles[60] acts as an insulator and retards the rate of heat extraction. He also states that a greater amount of surface per unit of weight will accelerate the rate of freezing. The variation in the rate of freezing, as exhibited by

[57]Cook, W. H., Precooling Poultry, Food Research, IV (1939), p. 245.

[58]Peterson, P. W., Food Freezing Temperatures, Refrigerating Engineering, XXI (1931), pp. 422-23, 463.

[59]Loc. Cit.

[60]Loc. Cit.

birds used in this investigation, is probably due not only to weight, but also to the amount of surface area and the fat content of the meat of the individuals being frozen.

A Comparison of the Effect of Circulating Air and Still Air on the Rate of Freezing.—Movement of air was the only variable in this test. The dressed birds were one year old, Grade B, five pound fowl. The air, agitated by an ordinary type house-hold fan was directed on the dressed bird at the rate of 8.33 feet per second. From Figure 11 one may observe that circulating air of the velocity used reduced the time required for freezing five pound, Grade B, fowl by more than one-half. Stiles[61] reports that the rate at which the external medium is agitated will influence the rate at which heat is extracted.

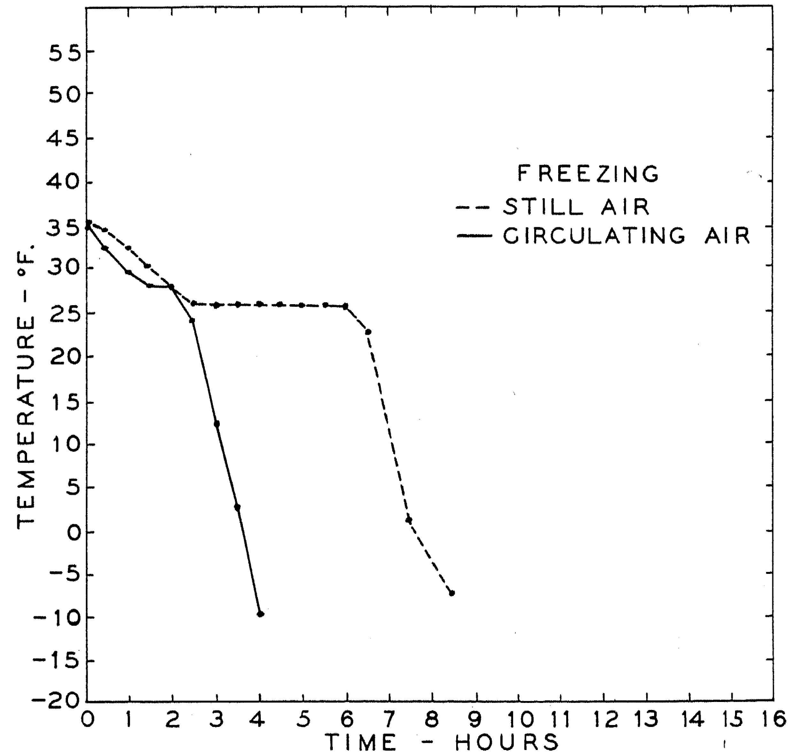

Fig. 11.—The effect of circulating air on the rate of freezing. The temperature of the external medium was -25° F.

The Effect of Various Temperatures on the Rate of Freezing.—Since apparently no definite temperature is recommended for the freezing of dressed poultry it was the object of this part of

[61]Loc. Cit.

the investigation to determine the comparative efficiency of different freezing temperatures. Grade B, 4½ pound heavy fowl were used in this test. The temperatures were -10° F., -20° F., and -30° F. The birds frozen at -30° F. required less than one-half the time necessary to freeze a similar bird at -10° F. The time required for freezing appears to vary directly with the temperature providing all other variables are constant. The results are presented in Fig. 12.

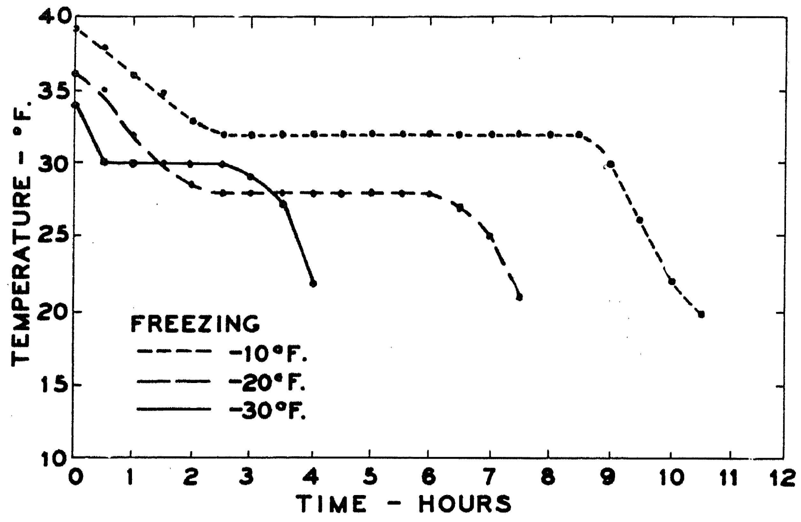

Fig. 12.—The effect of temperature of the external medium on the rate of freezing. Grade B heavy fowl weighting 4½ pounds.

C. Thawing

The author was unable to locate reports of previous work on the factors affecting the rate of thawing in dressed poultry. Cook[62] has recorded the time required for thawing dressed poultry at different temperatures. Stiles[63] has reported that other things being equal, the time required for thawing will be longer than that required for freezing. Kallert[64] has also stated that in thawing the reversal of the changes due to freezing takes place and with slow thawing the reversal progresses farther than with rapid thawing.

[62]Cook, W. H., Defrosting and Dechilling of Poultry and Eggs, Conference of the Associate Committee on Market Poultry, Nat'l. Res. Council of Canada (1936), pp. 98-99.

[63]Loc. Cit.

[64]Kallert, E., The Nature of Modification Produced in the Muscular Tissue of Frozen Meat During Thawing. Zietschrift fur die Gesamte Kaltee-Industrie, XXX (1923), pp. 77-81.

In this work thawing was affected in an ordinary type house-hold refrigerator which maintained a temperature of 50° F. The frozen birds were held at -25° F. until they were transferred to the refrigerator for thawing. As in freezing the time curves tend to flatten out in the temperature zone between 25° F. and 32° F. The defrosting was considered complete when the temperature inside the body cavity had been raised to 33° F. or 1° F. above the temperature at which ice crystals begin to form. The time required for the temperature of frozen birds to reach 33° F. was used as a basis for comparison.

The Rate of Thawing in Different Sections of the Same Bird. —The time curves presented in Figure 13 show graphically the comparative rate of thawing in the different sections of six pound, Grade A, one year old fowl. It is apparent that the various

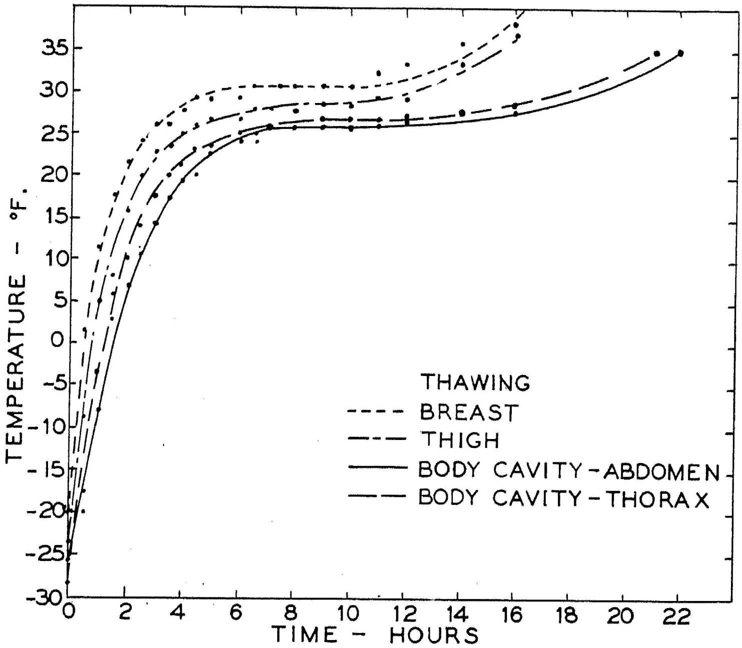

Fig. 13.—The rate of thawing in different sections of the same bird. The temperature of the external medium was 50° F.

sections in which the temperatures were taken behave in relation to each other the same as in cooling or freezing. The temperatures taken at one-half inch depth in the flesh of the breast and thigh increase at a more rapid rate than those taken inside the body cavity. It may also be observed that the various sections thaw in the same order as that in which they cooled and were frozen. Although there is no experimental work, to the authors' knowledge, to confirm the following statement it is their conclusion that because of the fact that the various sections thaw in the same order as that in which they cooled and were frozen the factors responsible for the rate and order of cooling and freezing are also responsible for the rate and order of thawing. The above conclusions are also applied to the following discussions of factors affecting the rate of thawing, therefore, for detailed discussions the reader is referred to the corresponding section under cooling.

The rate at which the different sections of six pound, Grade A, fowl were thawed is as follows: the breast meat required thirteen hours, the thigh meat approximately fourteen hours, the thoracic region twenty hours, and the fowl was completely thawed after twenty-one hours exposure at 50° F.

The Rate of Thawing in Various Market Classes of Dressed Poultry.—Only Grade B birds were used in this test. The variations in moisture content, fat content, and exposed surface per unit of weight were discussed in the corresponding section under cooling. Two pound broilers requiring the least amount of time

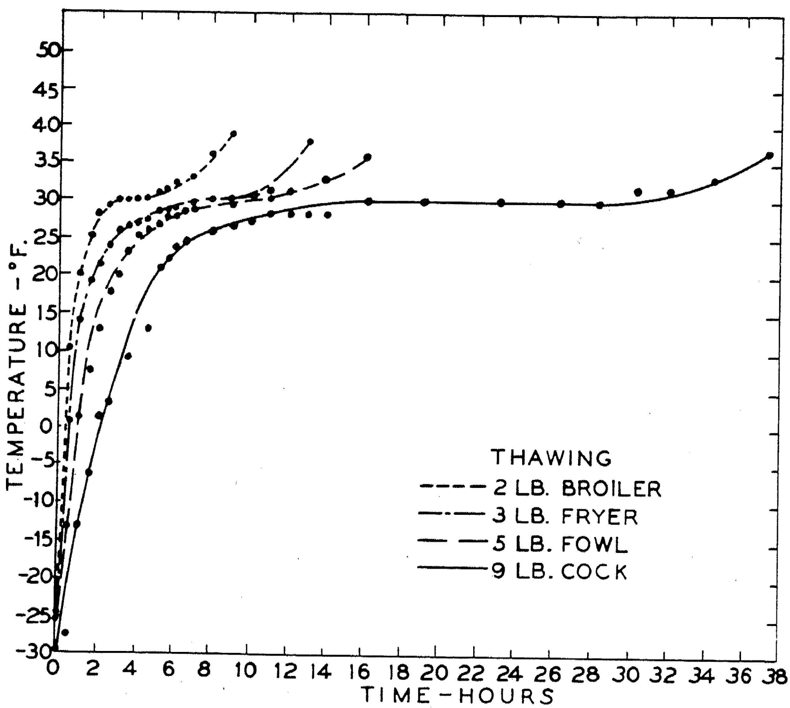

Fig. 14.—The rate of thawing in various market classes of dressed poultry. The temperature of the external medium was 50° F.

were thawed after six and one-half hours, three pound fryers required eleven hours, and five pound fowl were thawed after fifteen hours of exposure. Nine pound cock birds reached a temperature of 33° F. after being in the refrigerator at 50° F. for thirty-four hours. The various market classes thawed in the same order in which they were cooled and frozen, therefore, it is concluded that the factors affecting the rate of cooling and freezing are also responsible for the rate of thawing.

The Rate of Thawing in Dressed Birds of Different Weight.—Weight and associated factors which affect the rate of cooling and freezing apparently affect the rate of thawing in the same manner. The order in which different weight birds were thawed is the same as that in which they were cooled and frozen. In

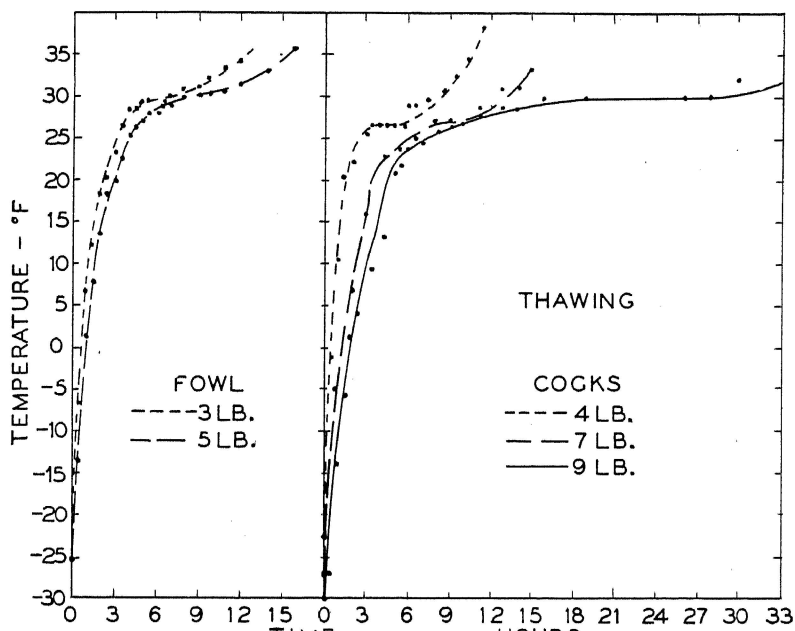

Fig. 15.—The rate of thawing in dressed birds of different weight. The temperature of the external medium was 50° F.

this investigation three pound fowl were defrosted in ten and one-half hours and five pound fowl in fourteen hours. Four pound cock birds were thawed in ten and one-half hours, seven pound cocks in approximately fourteen hours, and nine pound cock birds were not completely defrosted until after thirty-three hours of exposure. As in cooling and freezing male birds were thawed as rapidly as females of less weight. The factors, other than weight, responsible for the above results are discussed in the corresponding section under "Cooling".

The Effect of Circulating Air and Still Air on the Rate of Thawing.—The time required for thawing five pound, one year old, Grade B. fowl was reduced one-half with the aid of circulating air. The moving air was directed on the dressed bird at the rate of 8.33 feet per second. Investigators[65] agree that circulating air will decrease the time required for cooling and freezing. The results of the test are shown in Figure 16.

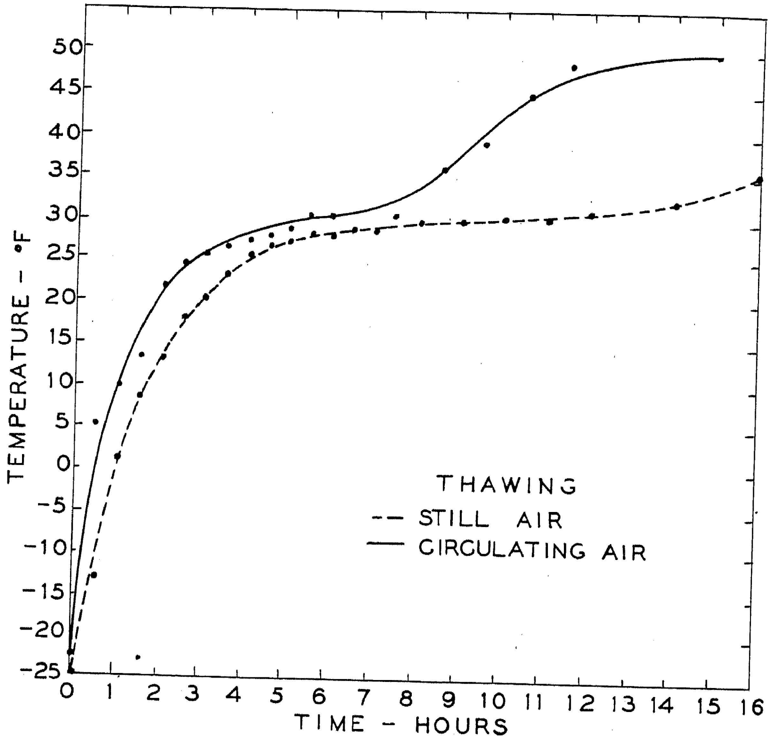

Fig. 16.—The effect of circulating air on the rate of thawing in dressed poultry. The temperature of the external medium was 50° F.

The Time Required for Thawing Compared to That Required For Freezing.—It is a common belief that the time required to thaw a dressed bird will be somewhat longer than that required for freezing. Stiles[66] states that, other things being equal, the time of thawing will be longer than the time of freezing. The

[65]Stiles and Mandeville.
[66]Stiles.

defrosting process, according to Mandeville[67] is slower than that of freezing because of the fact that water has only half the conductivity of ice. The outer flesh first to thaw, surrounds the still frozen portions thus reducing the rate at which they are defrosted.

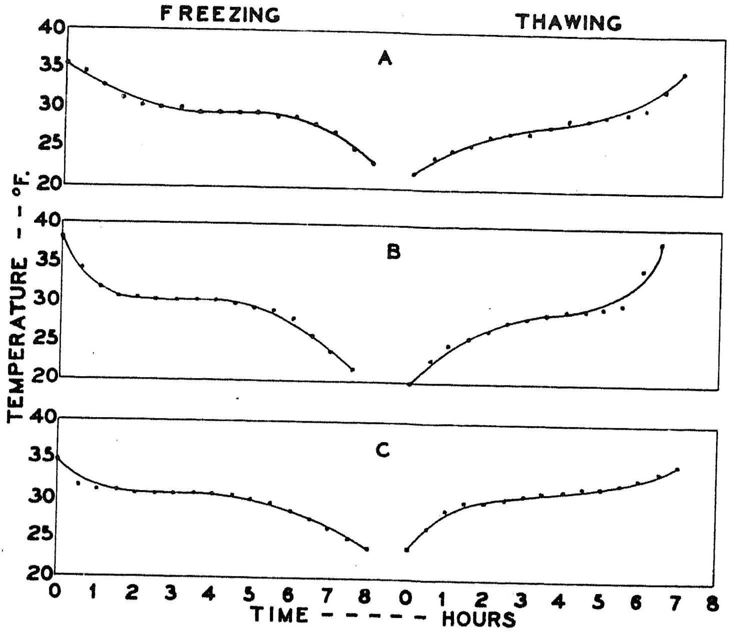

Fig. 17.—The comparative rate of freezing and thawing in the same dressed bird when the same temperature difference exists:
A. 6-pound grade B heavy fowl.
B. 4½-pound grade B heavy fowl.
C. 5-pound grade B heavy fowl.
Temperature of external media: freezing -5° F.; thawing 62° F.

It is impossible to obtain an accurate comparison between the freezing and thawing rate unless the same difference of temperature exists during the tests. In this test freezing was affected at -5° F. and the time required for the temperature to pass through the zone of maximum crystal formation (32° F. to 25° F.) was used as the time required for freezing. The thawing temperature was 62° F. The time required for raising the temperature from 25° F. to 33° F. was used to measure the thawing rate. With these temperatures a difference of 37° F. existed both in the freezing and thawing operation.

In this determination less time was required for thawing than for freezing when both operations were carried out at the same difference of temperature. The time required to freeze a

[67]Mandeville.

6 pound Grade B heavy fowl under the conditions of this experiment was six and one-half hours whereas the time required for thawing was five and one-half hours. Six hours were required to freeze a four and one-half pound Grade B heavy fowl and five hours for thawing the same bird, while a five pound Grade B heavy fowl was frozen in seven hours and thawed after five and one-half hours.

V. CONCLUSIONS.

1. Because of the fact that the order of thawing is the same as that of cooling and freezing, it is concluded that factors responsible for the behavior of poultry meat during cooling and freezing are also responsible for its behavior during the thawing process.

2. The different sections of the same bird cool, freeze, and thaw in the same order. The breast meat containing a lower fat content will respond more rapidly than the thigh meat to the effects of cooling, freezing, and thawing temperatures. In the body cavity the thoracic region responds more readily to the various temperatures than does the abdomen. It is concluded that this behavior is probably due to the difference in the thickness of the poultry carcass in these sections.

3. The factors affecting the rate of cooling, freezing, and thawing in the various market classes of dressed poultry are: size, and shape of bird, weight, moisture content, fat content of the meat, and the amount of exposed surface per unit of weight.

4. The effect of weight appears to depend on such factors as shape of body, sex, and the fat content of the meat. The rate of cooling, freezing, and thawing in birds of the same age and sex varied directly with the weight. The males appeared to cool, freeze, and thaw more rapidly than did the females. It is concluded that body shape and fat content of the flesh are responsible for these sex differences.

5. Circulating air at a velocity of 8.33 feet per second reduced the time required for cooling, freezing, and thawing five pound, Grade B. fowl by approximately one-half.

6. The zone of maximum formation for dressed poultry as determined in this work ranges from 32° F. to 25° F.

7. The rate of freezing in temperatures of -10° F., -20° F. and -30° F. varied directly with the temperature.

8. The time required for thawing was less than that required for freezing when both were effected with the same difference of temperature.

VI. APPENDIX

Table 1. THE COMPARATIVE SIZE OF DRESSED BIRDS OF DIFFERENT WEIGHTS.

	Length from base of neck to preen gland	Width of body across hips.	Maximum depth of body
Fowl (3 lbs.)	168.3	86.3	102.0
Fowl (5 lbs.)	181.8	96.8	116.7
Fowl (6 lbs.)	190.0	111.0	131.5
Cocks (4 lbs.)	193.4	95.3	114.5
Cocks (7 lbs.)	210.0	108.6	137.0

Table 2. THE COMPARATIVE WIDTH OF THE FOWL IN THE THORACIC AND LUMBO-SACRAL REGIONS.

Weight	Width Lumbo-Sacral Region	Width Thoracic Region
Lbs.	mm.	mm.
7.0	116	59
6.4	110	69
5.9	105	55
6.5	118	65
5.8	110	64
5.4	114	63
5.3	115	64
5.0	109	55

(Measurements were made on White Plymouth Rock Hens)

Table 3. A COMPARISON OF CIRCULATING AIR AND STILL AIR FOR COOLING (35°F), FREEZING (-25°F), AND THAWING (50°F), FIVE POUND, GRADE B, FOWL.

Time	Cooling		Freezing		Thawing	
Hours	Still Air	Circulating Air	Still Air	Circulating Air	Still Air	Circulating Air
	°F	°F	°F	°F	°F	°F
0	102.5	104.5	36.0	35.5	-25.0	-22.5
.5	97.5	91.5	35.0	33.0	-13.0	.5
1.0	87.5	73.5	33.0	29.5	1.5	10.0
1.5	80.5	67.5	30.0	28.0	8.0	13.0
2.0	73.5	58.0	28.0	28.0	13.5	22.0
2.5	67.0	51.0	26.5	24.0	18.0	24.0
3.0	61.0	47.5	26.5	12.5	20.0	25.5
3.5	57.0	44.0	26.5	3.0	23.0	26.5
4.0	53.0	40.5	26.5	-9.5	25.5	27.0
4.5	50.0	39.0	26.5	-15.5	26.5	28.0
5.0	48.5	38.5	26.5	-18.0	27.0	29.0
5.5	47.0	37.5	26.5	-20.0	28.0	30.5
6.0	-	-	26.0	-21.5	28.0	30.5
6.5	44.0	36.5	23.0	-21.5	29.0	30.5
7.0	-	-	-3.5	-	29.0	30.5
8.0	40.5	35.5	-	23.5	30.0	-
9.0	39.0	35.5	-7.0	-	30.0	36.0
10.0	39.0	35.5	-	-24.0	30.5	39.5
12.0	36.5	35.5	-	-24.0	31.5	48.5
14.0	-	-	-	-24.0	33.0	-
15.0	-	-	-	-	36.0	50.0

Table 4. THE COMPARATIVE RATE OF COOLING (35°F), FREEZING (-25°F), AND THAWING (50°F) VARIOUS MARKET CLASSES OF DRESSED POULTRY.

Time	Cooling				Freezing				Thawing			
Hours	2 Lb. Broilers	3 Lb. Fryers	5 Lb. Fowl	9 Lb. Cocks	2 Lb. Broilers	3 Lb. Fryers	5 Lb. Fowl	9 Lb. Cocks	2 Lb. Broilers	3 Lb. Fryers	5 Lb. Fowl	9 Lb. Cocks
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
0	99.0	99.5	100.0	103	36.5	33.5	30.5	35.0	-24.5	-24.5	-25.0	-27.0
.5	74.0	83.0	88.0	96	31.5	32.0	29.5	33.0	10.5	1.0	-13.0	-13.0
1.0	62.0	69.5	79.0	-	31.5	30.5	28.5	32.0	20.0	14.0	1.5	- 6.0
1.5	51.0	61.0	70.0	86	31.5	29.5	28.5	31.0	25.0	19.5	8.0	1.5
2.0	47.0	56.5	65.0	78	29.5	29.5	27.5	30.0	28.5	21.5	13.5	4.0
2.5	45.0	51.0	59.5	76	24.5	29.5	27.5	30.0	29.0	24.5	18.0	-
3.0	44.0	48.5	56.0	-	19.5	29.5	27.5	30.0	30.0	26.0	20.0	9.5
3.5	41.0	44.0	52.5	-	14.5	28.5	27.5	30.0	30.0	26.5	23.0	-
4.0	38.5	41.0	50.0	62	8.5	21.5	27.5	30.0	30.0	27.0	25.5	13.0
4.5	38.5	41.0	47.5	-	4.0	15.0	27.5	30.0	30.0	27.5	26.5	21.0
5.0	38.5	-	46.0	-	0	9.5	27.0	30.0	31.0	28.5	27.0	22.0
5.5	-	-	44.0	55	-5.5	3.0	20.5	28.0	31.5	28.5	28.0	24.0
6.0	37.5	-	-	-	-9.0	-5.0	13.0	28.0	32.5	29.0	28.0	24.5
6.5	-	38.5	41.5	53	-	-9.5	-	28.0	-	-	29.0	-
7.0	36.5	37.0	40.0	51	-17.5	-	.5	16.0	33.0	29.5	29.0	26.0
8.0	36.0	36.0	38.5	48	-18.5	-17.0	-8.5	9.0	36.0	-	30.0	27.0
10.0	36.0	-	37.5	46	-20.5	-22.0	-20.0	-	44.5	31.5	30.5	28.5
12.0	-	-	36.5	44	-	-23.5	-25.0	-11.0	-	38.5	31.5	28.5
14.0	-	35.5	-	-	-	-	-	-	46.0	-	33.0	28.5
16.0	36.0	-	-	42	-21.0	-	-	-	-	-	36.0	30.0
30.0	-	-	-	-	-	-	-	-	-	-	-	32.0
34.0	-	-	-	-	-	-	-	-	-	-	-	33.0
38.0	-	-	-	-	-	-	-	-	-	-	-	37.0

Table 5. THE TEMPERATURE CHANGES IN COCK BIRDS OF DIFFERENT WEIGHTS DURING THE PROCESS OF COOLING (35°F), FREEZING (-25°F), AND THAWING (50°F).

Time	Cooling			Freezing			Thawing		
Hours	4 Lbs.	7 Lbs.	9 Lbs.	4 Lbs.	7 Lbs.	9 Lbs.	4 Lbs.	7 Lbs.	9 Lbs.
	°F	°F	°F	°F	°F	°F	°F	°F	°F
0	101.5	109.0	103	35.0	35.0	35.0	-22.5	-27.0	-27.0
.5	84.5	97.0	96	33.0	31.0	33.0	- 1.0	-	-13.0
1.0	74.0	91.0		32.5	31.0	32.0	10.5	- 5.0	- 6.0
1.5	-	80.5	86	32.5	29.0	31.0	21.0	-	1.5
2.0	64.0	-	78	31.5	29.0	30.0	22.5	7.0	4.0
2.5	61.0	65.0	76	31.5	29.0	30.0	-	-	-
3.0	56.5	-	-	31.5	28.5	30.0	26.0	16.0	9.5
3.5	51.5	56.0	-	31.5	28.5	30.0	27.0	-	-
4.0	48.5	53.0	62	31.5	28.5	30.0	27.0	-	13.0
4.5	-	50.0	-	27.5	28.5	30.0	27.0	23.0	21.0
5.0	43.0	48.5	-	21.5	28.5	30.0	27.0	-	22.0
5.5	42.5	-	55	12.5	28.5	28.0	27.0	24.0	24.0
6.0	-	46.0	-	- .5	20.5	28.0	29.0	-	24.5
6.5	42.0	-	53	-	16.0	28.0	29.0	25.0	-
7.0	-	-	-	-13.5	5.0	16.0	30.0	-	26.0
8.0	39.5	44.0	48	-19.0	- 7.0	9.0	31.0	27.0	27.0
10.0	38.5	39.5	46	-	-18.5	-	34.5	-	28.5
12.0	-	38.0	44	-	-	-11.0	38.0	27.5	28.5
14.0	38.0	-	-	-21.0	-	-	41.5	31.0	28.5
16.0	-	36.0	42	-	-	-	-	33.0	30.0
30.0	-	-	-	-	-	-	-	-	32.0
34.0	-	-	-	-	-	-	-	-	33.0
38.0	-	-	-	-	-	-	-	-	37.0

Table 6. THE COMPARATIVE RATE OF COOLING (35°F), FREEZING (-25°F), AND THAWING (50°F) FOWL OF DIFFERENT WEIGHTS.

Time	Cooling			Freezing			Thawing	
Hours	3 Lbs.	5 Lbs.	6 Lbs.	3 Lbs.	5 Lbs.	6 Lbs.	3 Lbs.	5 Lbs.
	°F	°F	°F	°F	°F	°F	°F	°F
0	101.5	100.0	104.5	37.0	30.5	36.0	-25.0	-25.0
.5	94.0	88.0	103.0	34.0	29.5	34.0	- 6.5	-13.0
1.0	76.0	79.0	96.5	33.5	28.5	32.5	7.0	1.5
1.5	66.0	70.0	87.5	32.5	28.5	30.5	12.0	8.0
2.0	58.0	65.0	78.5	31.5	27.5	30.5	18.5	13.5
2.5	53.0	59.5	70.0	31.5	27.5	30.5	20.0	18.0
3.0	47.0	56.0	64.5	31.5	27.5	30.5	23.5	20.0
3.5	43.5	52.5	57.5	31.5	27.5	30.5	26.5	23.0
4.0	-	50.0	-	31.0	27.5	30.5	28.5	25.5
4.5	42.0	47.5	51.5	28.5	27.5	30.0	28.5	26.5
5.0	41.0	46.0	49.5	20.0	27.0	30.0	29.5	27.0
5.5	41.0	44.0	48.5	5.0	20.5	30.0	29.5	28.0
6.0	-	-	-	- 1.5	13.0	29.0	-	28.0
6.5	39.5	41.5	46.5	- 5.5	-	17.0	29.5	29.0
7.0	-	40.0	-	-	- .5	6.0	30.0	29.0
8.0	37.5	38.5	42.0	-13.0	- 8.5	- 4.0	31.5	30.0
10.0	37.0	38.5	39.5	-19.0	-20.0	-12.0	32.5	30.5
12.0	-	36.5	37.0	-22.5	-	-	34.0	31.5
14.0	35.0	-	-	-22.5	-25.0	-20.5	35.0	33.0
16.0	-	-	-	-	-	-	-	36.0

Table 7. TEMPERATURE CHANGES IN VARIOUS SECTIONS OF SIX POUND GRADE A FOWL.

Time	Cooling				Freezing				Thawing			
Hours	Breast	Thigh	Thorax	Abdomen	Breast	Thigh	Thorax	Abdomen	Breast	Thigh	Thorax	Abdomen
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
0	101.0	100.0	102.0	106.0	36.5	36.0	35.5	35.0	-20.0	-23.0	-28.5	-26.0
.5	79.0	83.0	94.0	101.0	29.5	33.0	34.0	33.5	1.5	- 8.5	-17.5	-20.0
1.0	71.5	78.0	84.0	91.0	29.5	30.0	32.0	32.0	11.5	5.0	- 3.5	- 8.0
1.5	66.5	68.0	76.0	82.5	29.0	29.5	30.5	30.5	18.0	13.0	6.0	3.0
2.0	62.0	64.5	71.5	76.0	27.5	29.5	30.0	30.0	21.5	16.0	10.0	7.0
2.5	57.5	60.0	66.0	70.0	27.0	29.5	30.0	29.5	24.0	20.0	14.0	10.5
3.0	54.5	56.5	62.5	64.5	25.0	29.5	30.0	29.5	26.0	22.5	17.5	14.5
3.5	51.5	53.0	58.0	59.0	21.5	29.5	30.0	29.5	26.0	23.5	20.0	17.5
4.0	49.0	50.0	53.5	55.5	20.0	26.5	29.5	29.0	27.5	25.0	21.5	19.5
4.5	47.0	48.5	50.5	52.5	16.5	22.5	29.5	29.0	29.0	26.0	23.0	20.0
5.0	46.5	46.5	48.0	50.0	15.0	16.0	27.5	29.0	29.0	27.0	23.5	23.0
5.5	-	-	-	-	-	-	-	-	-	-	-	-
6.0	43.0	43.5	45.0	45.5	5.0	7.5	18.0	27.0	29.5	27.0	25.0	24.0
7.0	40.0	42.0	42.5	43.0	-4.0	3.0	10.0	17.5	30.5	28.0	25.5	25.5
8.0	38.0	39.0	40.5	42.5	-9.5	-2.0	- 1.5	4.5	30.5	28.0	25.5	25.5
10.0	37.5	38.5	38.0	39.5	-15.0	-11.5	-16.0	-11.5	30.5	28.5	26.5	25.5
12.0	36.5	36.5	37.5	39.0	-21.5	-18.5	-21.5	-18.5	33.5	29.5	27.0	27.5
14.0	-	-	-	35.5	-23.0	-21.0	- 25.5	-23.5	36.0	33.5	37.5	37.5
16.0	-	-	-	-	-	-	-	-	38.0	37.0	28.5	28.0
24.0	-	-	-	-	-	-	-	-	40.5	40.5	37.0	36.0

Table 8. THE EFFECT OF STILL AIR TEMPERATURES ON THE RATE OF FREEZING FOUR AND ONE-HALF POUND GRADE B. HEAVY FOWL.

Time	Freezing		
Hours	-10°F.	-20°F.	-30°F.
0	39.0°F.	36.0°F.	34.0°F.
.5	38.0	35.0	30.0
1.0	36.0	32.0	30.0
1.5	35.0	30.0	30.0
2.0	33.0	28.5	30.0
2.5	32.0	28.0	30.0
3.0	32.0	28.0	29.0
3.5	32.0	28.0	27.0
4.0	32.0	28.0	22.0
4.5	32.0	28.0	
5.0	32.0	28.0	
5.5	32.0	28.0	
6.0	32.0	28.0	
6.5	32.0	27.0	
7.0	32.0	25.0	
7.5	32.0	21.0	
8.0	32.0		
8.5	32.0		
9.0	30.0		
9.5	26.0		
10.0	22.0		
10.5	20.0		
11.0			

Table 9. THE DATA USED IN THE CONSTRUCTION OF FIGURE 7 WHICH SHOWS THE LIMITS OF THE ZONE OF MAXIMUM CRYSTAL FORMATION IN DIFFERENT SECTIONS OF DRESSED BIRDS AS DETERMINED IN THIS INVESTIGATION.

Time	Breast				Thigh				Thorax						Abdomen						
	Cases				Cases				Cases						Cases						
	1	2	3	4	1	2	3	4	1	2	3	4	5	6	1	2	3	4	5	6	7
	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
0	35	35.0	36.5	34.0	34.5	33.0	34.5	35.0	37.0	37.0	34.5	36.0	32.0	33.0	35.5	36.0	35.5	36.5	35.0	35.5	36.0
.5	30	28.0	-	27.5	30.5	29.5	28.0	26.5	34.5	36.5	31.5	35.0	30.0	29.0	35.5	36.0	35.5	34.0	-	33.5	35.0
1.0	-	28.0	29.0	25.0	-	29.5	28.0	25.5	-	32.0	30.0	32.0	28.5	28.0	33.5	34.0	33.0	32.0	31.0	31.5	33.0
1.5	30	28.0	26.5	25.0	30.5	29.5	28.0	25.5	32.0	31.0	30.0	29.0	28.5	27.0	33.0	32.0	31.5	29.5	29.0	30.5	30.0
2.0	30	28.0	26.5	25.0	30.0	29.5	27.0	24.0	32.0	31.0	30.0	29.0	28.5	27.0	32.5	31.0	31.0	29.5	29.0	28.5	28.0
2.5	-	26.5	26.0	21.0	30.0	29.5	26.0	-	32.0	31.0	30.0	29.0	28.5	27.0	32.0	31.0	30.0	29.5	29.0	27.5	26.5
3.0	30	-	26.0	-	29.0	25.0	22.5	-	32.0	31.0	30.0	29.0	28.5	27.0	32.0	31:0	30.0	29.5	28.5	27.5	26.5
3.5	24	24.0	25.0	-	28.0	-	-	-	32.0	31.0	30.0	29.0	28.5	26.0	32.0	31.0	30.0	29.0	28.5	27.5	26.5
4.0	-	21.5	21.0	-	24.0	-	-	-	32.0	31.0	30.0	29.0	28.5	22.0	32.0	31.0	30.0	20.0	28.5	27.5	26.5
4.5	-	-	-	-	-	-	-	-	32.0	31.0	29.0	29.0	28.5	14.5	32.0	31.0	30.0	16.0	28.5	27.5	26.5
5.0	-	-	-	-	-	-	-	-	30.0	27.5	28.0	24.5	27.0	11.0	31.0	29.5	30.0	-	28.5	27.0	26.5
5.5	-	-	-	-	-	-	-	-	29.5	20.5	-	13.5	23.0	5.0	31.0	27.0	29.5	-	28.5	26.0	26.5
6.0	-	-	-	-	-	-	-	-	26.0	-	24.5	8.0	19.5	-	-	24.0	29.5	-	20.5	24.0	24.0
6.5	-	-	-	-	-	-	-	-	21.0	8.5	21.5	-	14.0	-	17.5	21.0	24.5	-	16.0	-	-

Table 10. TIME (HRS.) REQUIRED TO FREEZE AND THAW THE GRADE B. HEAVY FOWL WHEN THE SAME TEMPERATURE DIFFERENCE EXISTS.

Time	A. Six Pound Grade B. Fowl.		B. Four and One-Half Pound Grade B. Fowl.		C. Five Pound Grade B. Fowl.	
Hours	Freezing	Thawing	Freezing	Thawing	Freezing	Thawing
0	35.5°F	22.0°F	38.0°F	20.0°F	35.0°F	24.0°F.
.5	34.0	24.0	34.0	23.0	32.0	27.0
1.0	33.0	25.0	32.0	25.0	31.5	29.0
1.5	31.5	25.5	31.0	26.0	31.5	30.0
2.0	30.5	27.0	31.0	27.0	31.0	30.0
2.5	30.0	27.5	30.5	28.0	31.0	30.5
3.0	30.0	27.5	30.5	28.5	31.0	31.0
3.5	29.5	28.0	30.5	29.0	31.0	32.0
4.0	29.5	29.0	30.5	29.5	31.0	32.0
4.5	29.5	29.0	30.0	29.5	30.5	32.5
5.0	29.5	29.5	29.5	30.0	30.0	32.5
5.5	29.0	30.0	29.0	30.5	29.5	33.0
6.0	29.0	30.5	28.0	35.0	28.5	33.0
6.5	28.0	33.0	26.0	38.0	27.5	33.5
7.0	27.0	35.5	24.0	-	26.5	34.0
7.5	25.0	-	22.0	-	25.0	35.0
8.0	23.0	-	-	-	24.0	-
Temperature of external media	-5°F.	62.0°F.	-5°F.	62.0°F.	-5°F.	62.0°F.

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