# OIL IMMERSION CHILLING OF PORCINE HAM

By

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# CHAPTER I

## INTRODUCTION

Refrigeration in commercial meat processing operations is usually accomplished by a chilled air medium. Chilling in 38 to 40 cubic feet of space per carcass is the usual procedure. This requires approximately 24 hours at 1.11°C to accomplish a satisfactory chill.

The intact carcass contains 16-17% bone and 20-25% fat, most of which could be removed (by high temperature processing) before chilling. Thus, chilling would be more efficient in that waste bone and fat would not be refrigerated nor occupy cooler space.

To develop a more rapid method of chilling which could be used as a companion to "hot processing" of pork carcasses would be of great value. This could mean shorter cooling periods and less total capital being devoted to the chilling facility as well as less total product inventory accumulations.

This study was designed to evaluate oil immersion chilling in terms of cooling time and moisture loss using "high temperature" processed boneless hams.

# CHAPTER II

# REVIEW OF LITERATURE

Meat, as the flesh of animals used for food, is a complex biological material. These complexities not only affect raw and cooked meat products, but also the processing procedures applied to the product. Phases of processing as applied to meat and meat products consist of several steps (fabrication, marketing, etc.). These phases and the method in which they are implemented depend on the material being processed.

The subject matter contained herein will pertain predominantly to the characteristics of meat as related to its cooling rate and the details of the cooling process as it relates to this biological material.

## Heat Flow Through Muscle

Heat flow through muscle is accomplished by conduction. Energy movement by conduction is heat flow from a molecule to an adjacent molecule without gross movement of either. Once the heat energy reaches the surface molecules of the material being cooled, the heat energy is transferred to the coolant medium molecules. The coolant molecules are then moved away from the surface of the material by either free or forced convection.

Boneless meat contains: (1) lean, (2) fat, (3) connective, and (4) nerve

tissues. Each of these tissues has a different thermal conductivity. Thermal conductivity is a relative measure of resistance to heat flow from one point to another within a given material. The greater the thermal conductivity the less the resistance to heat flow. The terminology for thermal conductivity has been designated as K and the unit as Btu/hr.ft.°F. Even though nerve and connective tissue have an effect on thermal conductivity the majority of the influence is received from fat and lean. Therefore, greater emphasis will be given in the review to the thermal effect of the two major tissues lean and fat.

The water content of lean is approximately 72 percent. The greater the moisture content of lean tissues the greater the thermal conductivity (Hill et al. 1967). Lean tissue is composed of muscle fibers which are the characteristic cells. These fibers can vary from 10-100 microns in diameter and several hundred microns in length. The arrangement of muscle fibers may be predominantly parallel or the flow may be intertwined so that there is no one predominant fiber flow direction. The same authors also pointed out that the thermal conductivity of lean tissue varied in the same piece of meat, depending on the direction of heat flow. Thermal conductivity was greatest when the heat flow was parallel to the muscle fibers. This heat flow difference may be as much as 0.800 Btu/hr.ft.°F. at -11°C as opposed to 0.737 Btu/hr.ft.°F at -10.6°C for parallel versus perpendicular heat flow respectively. As indicated, temperature has an effect on thermal conductivity. Differences in freezing temperatures and the frozen versus the non-frozen state of lean tissue both affect thermal conductivity. As lean was frozen, the thermal conductivity appeared to increase as the freezing temperature decreased (Cherneeva, 1956). This may not be a firm conclusion because differences in the freezing rate,

which affected ice crystal structure, had an influence on thermal conductivity values (Hill et al. 1967).

Fat tissue contains less moisture than lean; therefore, the thermal conductivity is less than that of lean at the same temperature. As reported by Hill et al. 1967, beef fat which was approximately seven percent moisture had a thermal conductivity of .118 Btu/hr.ft.°F at 0°C, while beef lean at the same temperature had a value of .277 Btu/hr.ft.°F. The thermal conductivity of meat and meat products is dependent on the relative amounts of lean and fat contained within the product, and whether heat flow is parallel or perpendicular to the muscle fiber flow.

## Evaluation of Fluid Environments Used in Chilling

The efficiency of a fluid as a coolant can be evaluated by using the Prandtl number as the criterion. Each cooling medium has a Prandtl number which is a relative measure of the rate at which heat is transported from the surface of the object being cooled to the moving cooling medium used as the coolant (Clary et al. 1968). The larger the Prandtl number the more efficient that the cooling medium is as a coolant.

$$Pr = \mu C_p / KNe$$

Where:

Pr = Prandtl number

$\mu$ = Viscosity of the cooling medium - $lb_f$-sec/$ft^2$

$C_p$ = Specific heat of the cooling medium - Btu/$lb_m$°F

K = Thermal conductivity of the cooling medium - Btu/hr.ft.°F

The prandtl number of air at -1.1°C was 0.72 (Scott, 1959). Air is easily cir-

culated, often by free convection, but it did not provide the efficient interface for cooling as did water which had a Prandtl number of 13.0 (Scott, 1959). Scott also reported, that alcohols had a Prandtl number near 35.0, but it is a known fact that alcohols are often toxic and impart objectionable odors and flavors to food products.

Cryogenic gases have to be evaluated in the liquid and gaseous forms. The Prandtl number of nitrogen as a liquid is heat dependent and will range from 4.30 to 1.86; the Prandtl number decreased as the liquid reached its boiling point (Barron, 1966). The interface which occurs between nitrogen in the liquid state and the product being frozen is unique. As the liquid strikes the surface of the warmer object, it immediately vaporizes, causing a gaseous environment to surround the object rather than a liquid. As a gas, liquid nitrogen exhibited a Prandtl number of 0.72 which closely resembled that of air (Barron, 1966). The extremely cold temperatures of liquid gases enable them to freeze biological products rapidly.

The Prandtl number of an oil may vary from one to several thousand due to temperature change. In the selection of an efficient cooling medium, oil could provide a greater Prandtl number than any other fluid mentioned if the correct oil selection is made. The proper selection is important in that one oil may have a Prandtl number several times larger than another when both are evaluated at the same temperature. The difference is due to the relationship of the oil viscosity ($\mu$), specific heat ($C_p$), and thermal conductivity (K), where Prandtl number = $\mu C_p/K$

## Immersion Chilling

Immersion chilling has been in existence since about the turn of the 20th cen-

tury (Brant, 1963) with most chilling of this type being done on poultry carcasses. Considerations of importance when implementing immersion chilling are: color development of the chilled or frozen product, moisture absorption, bacterial contamination, tenderness, flavor, cooking loss, and drip loss. Brant, further reported that immersion time and agitation of carcasses had an effect on water uptake during the chilling process. More water was absorbed when the carcasses rather than the liquid were agitated. The initial wash water added as much as 3 percent to the carcass weight. Brant also stated that it was not unusual for the carcass to pick up six percent moisture during chilling, but most of this was lost if wet chilled birds were frozen and then thawed. The loss was due to thaw weep. Klose et al. (1960) reported that as the immersion liquid agitation increased so did water absorption. This chilling procedure was done on unpackaged birds. Thompson et al. (1961) found that fryers chilled in slush ice absorbed less water than those chilled in air for one hour at 21.1°C and then finished chilling in ice.

The color of the chilled or frozen product is very important for marketing purposes. Stadelman, (1957) reported that immersion freezing of poultry was quicker than other methods of freezing, and improved the color of the carcass, particularly turkey. The quality of the bird was not affected when frozen in calcium chloride brine at -6.67°C to -15.0°C. Freezing at lower temperatures decreased the amount of pink color on the poultry carcass. Skintight packages were necessary to obtain a uniform color.

Immersion chilling of poultry carcasses as related to flavor was deleterious to the maintenance of optimum flavor upon prolonged holding, and should be avoided in the unpackaged product according to Pippen et al. (1955). Results indicated

that ice-slush chilling of whole, ready-to-cook chicken carcasses, as normally practiced in industry, did not result in detectable loss in flavor of the fried or roasted chicken product.

The Meat Inspection Division of the United States Department of Agriculture is vitally concerned with bacterial contamination received during immersion chilling. Immersion chilling has been approved for poultry but not for the red meat products because of potential bacterial contamination. Birds immersed in water-ice solution (0.56°C) had less total bacterial contamination than those carcasses chilled in circulating air at 4.44°C (Casale et al. 1965). They also found that continuous chillers provided reduced chilling time, increased uniformity and effectiveness of chilling, and improved broiler quality.

Prolonged use of an immersion liquid contaminated the medium; therefore, a given number of reuse times needed to be determined. Fromm, (1958) reported that chilled water and slush ice could be used five times and still not significantly influence the bacterial numbers on the chilled carcass nor affect shelf life of the carcass or flavor of the cooked product.

Alcohol and propylene glycol can be used as immersion coolants. They have Prandtl numbers that are larger than air, water, or the liquid gases (Scott, 1959). Poultry carcasses can be immersed in refrigerated propylene glycol, followed by blast-freezing at -23°C (Pinchin, 1957). An advantage of using alcohol or propylene glycol is that these liquids have low freezing points; which allow lower cooling or freezing environments to be employed than when water or brine is used. Pinchin, (1957) found that poultry carcasses frozen in propylene glycol had a uniform color regardless of the type or age of the bird. This method was more satisfac-

tory than blast-freezing alone for use with hot-scalded poultry. This was true partly because of the efficient heat removal interface provided by a liquid as contrasted to air or an individual gas. Any poultry carcass contaminated with propylene glycol, due to leaks in the bag, could be washed and re-packaged (Pinchin, 1957).

Alcohol used as a coolant has its limitations due to its toxicity and undesirable odors and flavors that may be imparted to the product being chilled or frozen. Wells, (1946) immersed sealed food filled tin cans in alcohol, and found a considerable reduction in freezing time, as compared with air blast freezing. Since containers immersed in alcohol must be pressure tight, the process is limited to the use of tin, glass, fiber, or other containers which can be made pressure tight (Wells, 1946).

The unpleasant taste of pure isopropanol is preceptible in dilutions of 1:1000 and technical isopropanol in dilutions of 1:10,000. Cabbage, turnips, beans, and plums frozen in the isopropanol immersion process and stored nine months contained over one percent isopropanol when raw and somewhat less after cooking (Keil, 1953).

Cryogenic compounds such as nitrogen, carbon dioxide, and freon have been used to provide fluid immersion systems and gaseous atmospheres for chilling and freezing of meat products. These liquid gases reduce cooling and freezing time greatly as compared to other fluid systems. Nitrogen, carbon dioxide, and freon are inert; therefore, these do not contaminate the products with which they come in contact. While working with liquid nitrogen, Costello, (1963) found that drip loss, cooking loss, shear tenderness, and taste panel evaluations for tenderness and juiciness were not influenced significantly by variation in freezing temperature

within a range of -17.8°C to -196°C. Color may be affected by freezing temperature as he found that beef frozen by immersion in liquid nitrogen varied in color from light pink to dark red when frozen at -196°C and -17.8°C respectively. He further suggested that loss of eye appeal caused by cracks in steaks frozen at low temperatures (-129°C and -196°C) might influence consumer acceptance of the product. Moline, (1964) reported that when steaks were frozen by immersion in liquid nitrogen physical damage often occurred. Pressures were built up by expansion of the water in the tissue which were relieved by cracking, usually along the plane of the perimysial connective tissue surrounding the muscles or within the sarcolemma itself. When the cut of meat was thin and immersion was not prolonged, cracking did not occur.

Meat surface color of liquid nitrogen frozen meat is due to the size of the ice crystals formed. Rapid freezing resulted in a much lighter color due to the increased reflection and refraction of light at the interfaces of the minute ice crystals formed (Moline, 1964).

Immersion freezing times of gelatin models, with thermal properties similar to those of poultry carcasses, varied with the rate of agitation (Van Den Berg and Lentz 1957). Freezing times were approximately inversely proportional to the difference between the temperature of the liquid and the freezing point of the material.

## Packaging of Meat to be Immersion Chilled

Packaging of meat to be chilled or frozen can provide protection from contamination by bacteria and/or chemicals that might be present in the cooling medi-

um. During immersion chilling, with continued use of the same medium, some contamination will occur. Cellulose acetate and polyethylene films were permeable to the microorganisms while cellophane, Pliofilm, and Cry-O-Vac were not significantly permeable (Hartman et al. 1963).

The time required for freezing of beef samples by air blast (-16.7°C) was increased by 53 percent when the product was placed in Cry-O-Rap (Dunker et al. 1953). If a film is used on the product, it should fit skintight so that no air pockets will be formed which retard cooling over and above the effect of the package.

Color development and retention in conjunction with packaging films is another consideration. The most important cause of fresh meat discoloration is the lack of sufficient oxygen to keep the bright red "bloom" of oxymyoglobin. Celophanes such as MSAT-80 are especially designed to permit the passage of large amounts of oxygen through the film while in actual use with fresh red meat (Landrock et al. 1955).

## Thermocouple Placement

Thermocouples placed in meat used to record changes in temperature over time, can vary in their location, arrangement, and interpretation depending on the desired information. If a record of temperature change within the most difficult portion of the piece of meat is desired, the thermocouples must be placed in the geometric center of that product. This is assuming that the geometric center area is the most difficult point to cool even though in reality this assumption may not be true. The reason for this is that fat and lean vary in both concentration and location in the muscle. If a temperature gradient across the specimen is desired, the

thermocouple profile will have to be arranged so as to represent specified areas in the meat sample.

When several thermocouples are used to measure the mass center temperature the thermocouple point that required the longest cooling time was considered to give the most accurate cooling time. This thermocouple point was judged to give the most representative record of the mass center temperature (May et al. 1961).

Thermocouple placement in biological material can be done by threading the wire (copper, constantan) into the meat with a needle. Lentz et al. (1957) reported, while recording temperature changes in immersion chilled poultry, that a special jig with suitably spaced parallel needles was used to thread the thermocouples (30 gauge copper constantan) through the flesh. Leads were taken out through the end of the bag which was sealed by twisting and tying.

Rizika et al. (1952) and Cowell et al. (1959) reported that thermocouples can measure only the temperature at its measuring junction and often errors caused by conduction of heat down the thermocouple wire and subsequent loss to the environment may cause the junction temperature to differ greatly from the temperature of the substance being measured. It was suggested that fine wires of much lower thermal conductivity than copper should be used when accurate assessment of the cooling phase is required (Cowell et al. 1959).

Associated with thermocouple placement is the geometric configuration of the product being cooled. As the geometry or shape of a biological material changed so did the cooling time (Smith et al. 1967). They also indicated that in order for cooling times to be comparable between objects of the same material they must be of the same characteristic shape (ellipsoid, cylinder, sphere etc.) and of the same

dimensions. The most important dimension was the characteristic length or diameter.

## Odor of Packaged Meat

Meat, packaged hot immediately after slaughter, has been described as emmitting an off odor once the package is opened. This is especially true if the bag is vacuum sealed. Once the seal is broken the undesirable odor begins to dissipate. Clauss et al. (1957) vacuum sealed fresh, raw beef samples in Cry-O-Vac packages and found upon opening that a faint odor was present. At times, raw odor was almost imperceptible. Odor data collected in this study were erratic and considered practically valueless by the authors.

# CHAPTER III

## MATERIALS AND METHODS

Twelve market weight swine (8 Hampshire, 4 Yorkshire barrows) of similar management were selected for this study. The animals were obtained from the Station Swine Herd, and all animals were delivered to the Meat Science Laboratory approximately one hour prior to slaughter. The animals ranged in weight from 82.6 to 113.5 kg. Each animal was washed with warm water and cleared for slaughter (ante-mortem) by the Federal Inspector. Each animal was stunned, using a Cervin Model MM electrical tool, shackled by one leg, raised from the floor, and bled in the conventional manner. The bled animal was skinned and eviscerated as rapidly as possible. A post-mortem inspection was made and the carcasses were approved for use as food. The carcasses were split, washed thoroughly, and the leaf fat was removed. Hams were removed from the hot carcasses in the conventional manner, from both the right and left sides. They were trimmed of excess fat and boned. To insure that both hams were of the same weight, they were weighed on a gram balance and the heavier of the two trimmed until their weights were the same. Trimming was done on the face of the ham because it was assumed that differences in weight were due to the point of ham removal from the loin and belly. The hot weights were recorded and the hams were inserted into cellulose casings using a ham stuffing horn. Casings were used to prevent contamination and to insure simi-

lar ham shapes. Care was exercised to form both hams to the same dimensions (length, width, depth), and to exclude all air pockets between the ham and the casing. If both hams were the same weight, but were too large for the package then both were trimmed internally until the proper size limit was reached. The packaged, boneless, "hot" hams were then assigned to one of two treatments, cooling in air (4.44°C) or immersion chilling in light mineral oil (4.44°C). Hams to be chilled were assigned at random to each of the two chilling methods. The bags were then sealed on one end. The packaged hams were forced into brackets, made of metal rod, to insure that the dimensions of each were the same. Through the open end of the bag four thermocouples (20 gauge copper constantan) were inserted into the geometric center of each ham by using a threading needle (Lentz et al. 1957). The thermocouples were attached to a 10 point Honeywell recording potentiometer. It was assumed that the geometric center of the ham was the most difficult part of the ham to cool. Therefore, the thermocouple point or points that required the longest to reach 10°C were the most representative of the mass center temperature (May et al. 1961). The open ends of the packaged hams with thermocouples inserted were then twisted and tied (Lentz et al. 1957). Pre-chill dimensions (length, width, and depth) were taken at this time and recorded.

The metal brackets containing the hams were then placed in their assigned cooling system (air or oil immersion chilling). As little lapse as possible occurred between the time when the hams were removed from the carcass and when they were placed under the respective treatment conditions. Temperature recordings were initiated as soon as the packaged product was placed in the assigned cooling system. The air and oil cooling systems are shown in Figures 1 and 2. Each system's ambi-

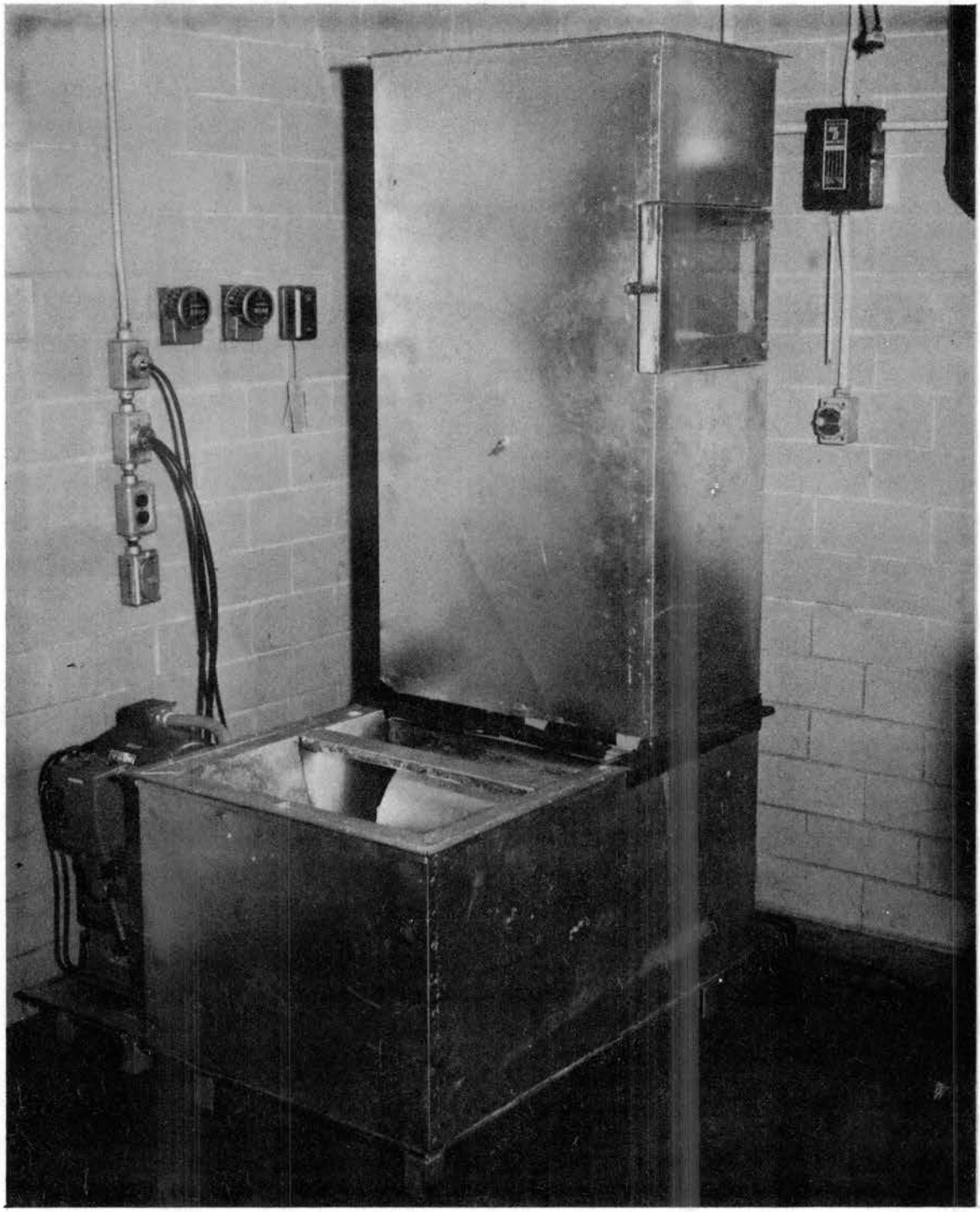

Figure 1. Forced Air Cooling Chamber

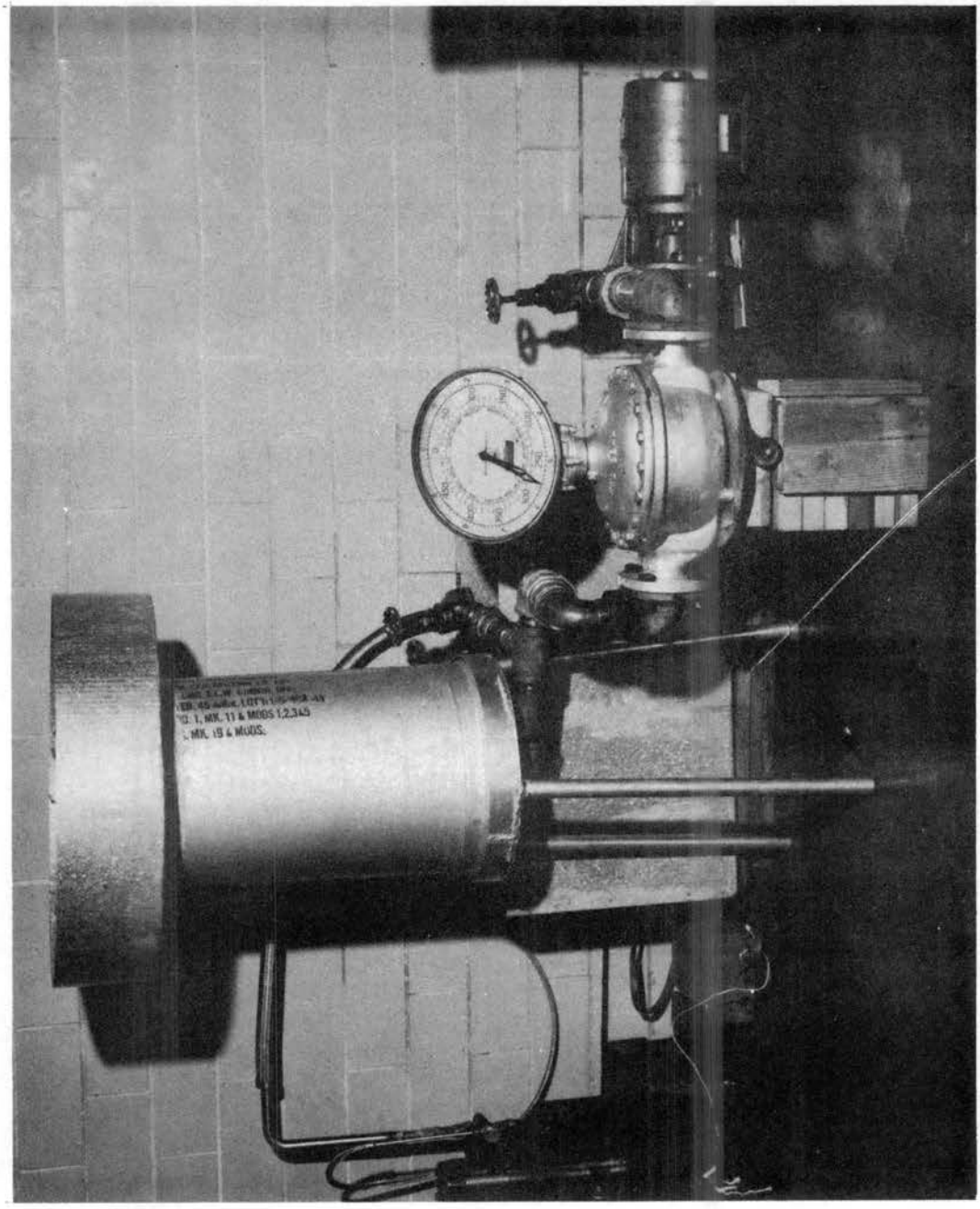

Figure 2. Oil Immersion Circulating Apparatus

ent temperature was to be 4.44°C (± 1°C), and both environments were monitored during chilling using the Honeywell recording potentiometer.

## Equating Heat Transfer Coefficients

Both the oil and air cooling systems were designed and constructed so as to equate the heat transfer coefficient of both systems. The systems were constructed so that velocity control of the cooling mediums could be easily manipulated. By having the heat transfer coefficient in each system dependent on velocity, the velocity was selected for one method of cooling and the other unit adjusted accordingly. Air velocities of 100, 350, 600, and 750 ft./min. were selected because these velocities could be used in commercial chilling operations. The following general equation was reported by Clary et al. (1968), and is the basis for equating heat transfer coefficients for boneless hams of the same dimensions with a geometry index of 0.45.

$$Nu = 0.367\ (Pr)^{0.333}\ (Re)^{0.564}$$

$$Nu = \frac{hl}{K}$$

therefore:

$$h = \frac{K}{l}\ (0.367)\ (Re)^{0.564}\ (Pr)^{0.333}$$

| Symbol | Quantity | | Units |
|---|---|---|---|
| Nu | Nusselt Number | $\frac{hl}{K}$ | --- |
| Pr | Prandtl Number | $\frac{\mu C_p}{KNe}$ | --- |
| Re | Reynolds Number | $\frac{VdPNe}{\mu}$ | --- |

| Symbol | Quantity | Units |
|---|---|---|
| $C_p$ | Specific heat of the cooling medium at constant pressure | $Btu/lb_m °F$ |
| d | Diameter 2l | ft. |
| h | Average heat transfer coefficient | $Btu/hr.ft.^2°F$ |
| K | Thermal conductivity of the cooling medium | $Btu./hr.ft.°F$ |
| l | Characteristic dimension | ft. |
| V | Velocity of the cooling medium | ft./sec. |
| $\mu$ | Viscosity of the cooling medium | $lb_f$-sec./$ft.^2$ |
| P | Density of the cooling medium | $lb_m/ft.^3$ |
| Ne | Newton's Second Law Coefficient (0.0311) | $lb_f$-$sec.^2/lb_m$-ft. |

The properties of the oil and air at 4.44°C are:

| Air | Oil |
|---|---|
| $K_a$ = 0.015 Btu/hr.ft.°F | $K_o$ = 0.076 Btu/hr.ft.°F |
| $\mu_a = 1.2 \times 10^{-5}$ $lb_f$-sec./$ft.^2$ | $\mu_o$ = 0.0862 $lb_f$-sec./$ft.^2$ |
| $P_a$ = 0.0788 $lb_m/ft.^3$ | $P_o$ = 53.5 $lb_m/ft.^3$ |
| $C_{pa}$ = 0.24 $Btu/lb_m°F$ | $C_{po}$ = 0.46 $Btu/lb_m°F$ |

When the heat transfer coefficient of the oil is set equal to the heat transfer coefficient of the air, and the oil velocity is solved for in terms of the velocity of the air this yields:

Velocity of Oil = (.00568) Velocity of Air

Once this relationship between the velocity of the oil and the velocity of the air has been established on the basis of equating the heat transfer coefficients of

both fluids, for any velocity of air a corresponding velocity of oil can be calculated if the oil has the above mentioned properties. The theory for these calculations was set forth by Clary et al. 1968.

The hams from three animals were assigned to each of the four air velocities (100, 350, 600, and 750 ft./min.) with corresponding oil velocities. In each experiment cooling times were recorded until the mass center temperature of the ham reached 10°C. Theoretically, by equating the heat transfer coefficients for each system, both hams should chill to an internal temperature of 10°C within the same length of time; this is assuming that the hams are identical in thermal properties and characteristic shape. Cooling time differences could also be due to differences in ambient temperatures, internal starting temperatures (ham), error in adjusting velocities in the two cooling systems, error in thermocouple placement, and air pockets trapped beneath the cellulose casing which would retard cooling.

Once the hams were chilled to 10°C, they were removed from the systems and the dimensions remeasured to observe if any change had occurred during chilling. The hams were cut at the location of each thermocouple point and the type of tissue surrounding the thermocouple was evaluated as fat, lean, or air pocket formed inside the ham. A chilled weight was taken in order to calculate percent moisture loss.

## Evaluation of Equating Heat Transfer Coefficients

Evaluating how well the heat transfer coefficient of each system could be equated was done graphically. The F-test in conjunction with the analysis of variance was also used (Steel and Torrie 1960). Time versus cooling temperature

was plotted, where temperature was dimensionless as defined by:

$$T = \frac{Tc - To}{Ti - To}$$

T = Dimensionless temperature

Tc = Temperature increments during cooling (100, 90, 80, 70, 60, 50°F)

Ti = Internal starting temperature of the ham

To = Average environmental temperature during chilling

Graphs were plotted for both oil and air within each repetition at each velocity increment. The reasons for using the dimensionless temperature was due to differences in environmental and internal starting temperatures between the ham chilled in oil immersion and the ham chilled in the forced air system. Dimensionless temperature was plotted on the log scale while time to chill was plotted on the linear axis.

The analysis of variance and F-test were utilized to evaluate statistical differences between cooling times of each treatment at each velocity selection.

## Economies of Cooling Times

Economies of cooling time were determined graphically. Two graphs were constructed so that time saved by one chilling method could be directly compared with time saved by the other. Time in these comparisons was velocity dependent. From the general formula $h = \frac{K}{l} (0.367) (Re)^{0.564} (Pr)^{0.333}$ (Clary et al. 1968), for any given velocity a cooling medium heat transfer coefficient can be calculated. This was done for both the oil immersion and the air cooling systems. Within the velocity range selected, heat transfer coefficients were calculated for corre-

sponding oil and air velocities. These were then plotted on logarithmic paper.

The companion graph to the heat transfer coefficient versus velocity graph was the heat transfer coefficient plotted against cooling time determined by the dimensionless temperature formula:

$$T = \frac{Tc_1 - To}{Ti - To} = 0.2$$

T = Dimensionless Temperature (constant)

$Tc_1$ = Adjusted temperature representative of 50°F

To = Average environmental temperature during chilling

Ti = Internal starting temperature of the ham

This formula was used to adjust for differences in the average environmental temperature during chilling and the internal starting temperature of the hams. Once the adjusted temperature representative of 10°C was determined, the time required to reach the adjusted temperature for each ham was read from the potentiometer recording paper. This time was then plotted against the corresponding heat transfer coefficient using semi-logarithmic graph paper.

For each velocity on the velocity versus heat transfer coefficient graph, a corresponding heat transfer value was read for both oil and air. By entering the heat transfer coefficient versus cooling time graph, differences in cooling time for both oil immersion and air chilling was determined for a given velocity.

## Percent Moisture Loss

Percentage moisture loss in each treatment was calculated by taking ham weight before and after cooling.

$$\frac{\text{Before Chill Weight} - \text{After Chill Weight}}{\text{Before Chill Weight}} \times 100 = \text{Percent Moisture Loss}$$

## Odor Evaluation

As soon as the hams chilled to 10°C, the bag was removed from each ham and an organoleptic evaluation was made of the odor present. If any off or undesirable odor was present this was recorded.

# CHAPTER IV

# RESULTS AND DISCUSSION

## Equating Heat Transfer Coefficients

The oil immersion and the air chilling systems were equated on the basis of their heat transfer coefficients. Theoretically both systems should chill identical hams in the same length of time. In order to evaluate the accuracy of equating the heat transfer coefficients, the F-test in conjunction with the analysis of variance was used to test for differences in the total cooling period between treatments. Graphical illustrations of the cooling curves for each repetition within each velocity increment were also used.

The cooling curves for each repetition when the air velocity was 100 ft./min.; oil velocity 0.568 ft./min. with a heat transfer coefficient of 1.35 are shown in Figure 3. Cooling by oil was 4.8 (Repetition I), 2.5 (Repetition II), and 2.4 percent (Repetition III) faster than air chilling. However, when the data was evaluated by the F-test, total chilling time proved to be non-significant (Table I, Appendix Table VI).

Repetitions I and II in Figure 4 demonstrate that oil immersion chilling is slightly faster than the forced air chilling method (3.7 percent for both Repetitions). However, Repetition III, Figure 4, indicates that air chilling is 2.1 percent faster than oil immersion. Despite cooling time discrepancies, the F-test (Table II, Appendix Table VII) substantiated that differences in cooling times (Figure 4) were non-significant.

TABLE I

ANALYSIS OF VARIANCE OF TOTAL COOLING TIME TO 10°C FOR AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 1.35 BTU/HR.FT.$^2$°F)

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 5 | 2442.71 | 488.54 | |
| Blocks | 2 | 2189.59 | 1094.80 | |
| Treatments | 1 | 234.38 | 234.38 | 25.01 ns |
| Error | 2 | 18.74 | 9.37 | |

ns - non-significant $P < .025$

Velocity of air 100ft./min.

Velocity of oil 0.568ft./min.

TABLE II

ANALYSIS OF VARIANCE OF TOTAL COOLING TIME TO 10°C FOR AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 2.68 BTU/HR.FT.$^2$°F)

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 5 | 792.71 | 158.54 | |
| Blocks | 2 | 608.34 | 304.17 | |
| Treatments | 1 | 51.04 | 51.04 | 0.7656 ns |
| Error | 2 | 133.33 | 66.67 | |

ns - non-significant $P < .1$

Velocity of air 350ft./min.

Velocity of oil 1.99ft./min.

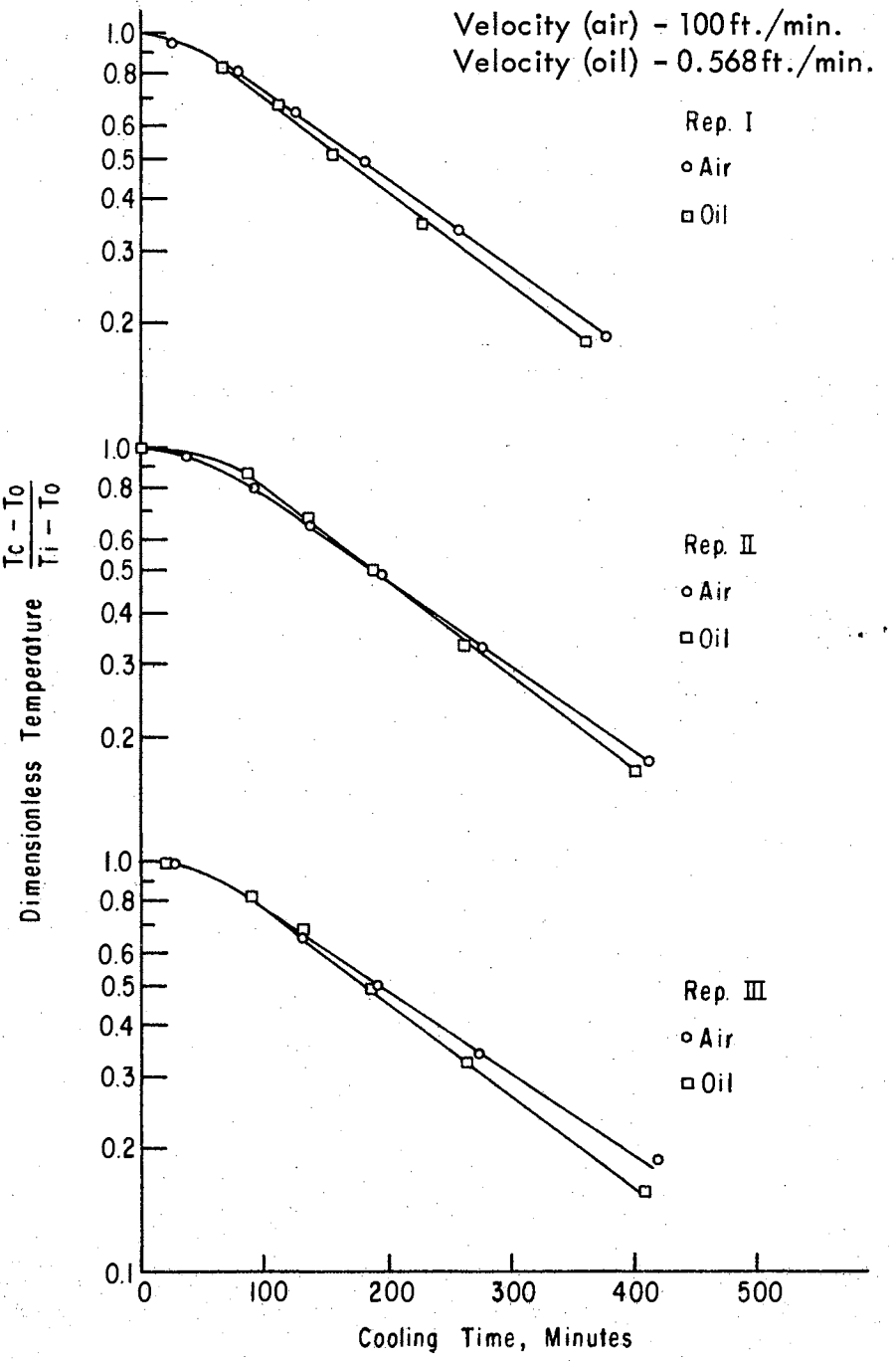


Figure 3. Cooling Curves for Hams Chilled at an Ambient Temperature of 4.44°C (Heat Transfer Coefficient = 1.35 Btu/hr.ft.$^{2}$°F).

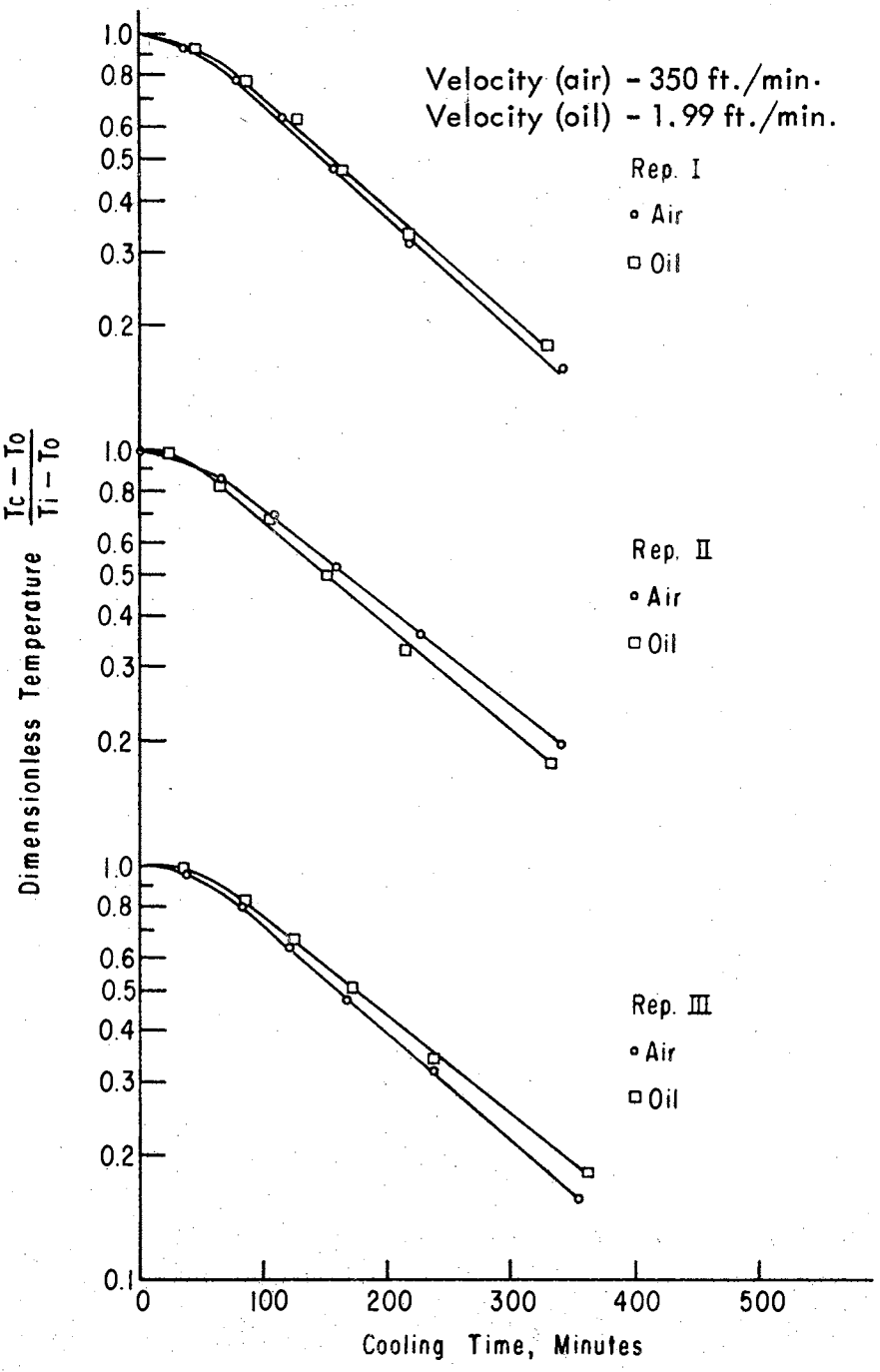


Figure 4. Cooling Curves for Hams Chilled at an Ambient Temperature of 4.44°C (Heat Transfer Coefficient = 2.68 Btu/hr. ft. $^2$°F).

Oil immersion exhibited a cooling advantage over air chilling in Repetition I, Figure 5, of 7.5 percent; however, air chilling was 8.6 percent faster, as shown in Repetition III, Figure 5. No advantage in cooling time can be observed for either air or oil immersion chilling within Repetition II. The F-test (Table III, Appendix Table VIII) provided confidence that the cooling time differences, corresponding to the curves in Figure 5, were non-significant.

TABLE III

ANALYSIS OF VARIANCE OF TOTAL COOLING TIME TO 10°C FOR AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 3.60 BTU/HR.FT.$^2$°F)

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 5 | 2858.33 | 571.67 | |
| Blocks | 2 | 2233.33 | 1116.67 | |
| Treatments | 1 | 0 | 0 | 0.00 ns |
| Error | 2 | 625.00 | 312.50 | |

ns - non-significant $P<.1$
Velocity of air 600 ft./min.
Velocity of oil 3.40 ft./min.

The cooling curves as shown in Figure 6 agree with the previous curves in that there appears to be little difference between oil immersion and air chilling once the heat transfer coefficients are equated. However, Repetition I, Figure 6, shows oil chilling to be 6.0 percent faster than air, but Repetition II indicates that air chilling has a 4.8 percent advantage. No cooling advantage was observed for Repetition III (Figure 6). Data from the three trials when analyzed by the F-test,

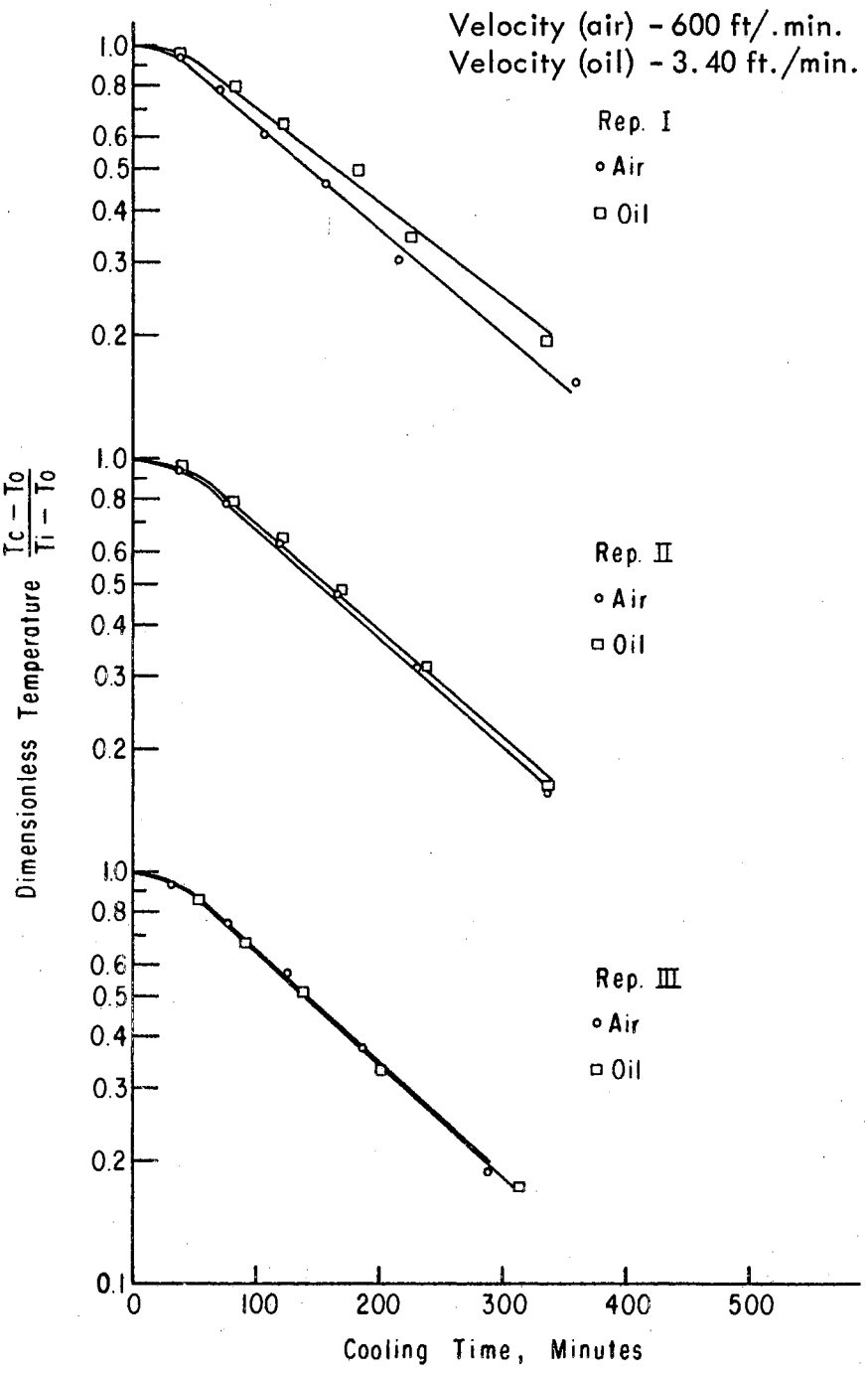


Figure 5. Cooling Curves for Hams Chilled at an Ambient Temperature of 4.44°C (Heat Transfer Coefficient = 3.60 Btu/hr.ft.$^2$°F).

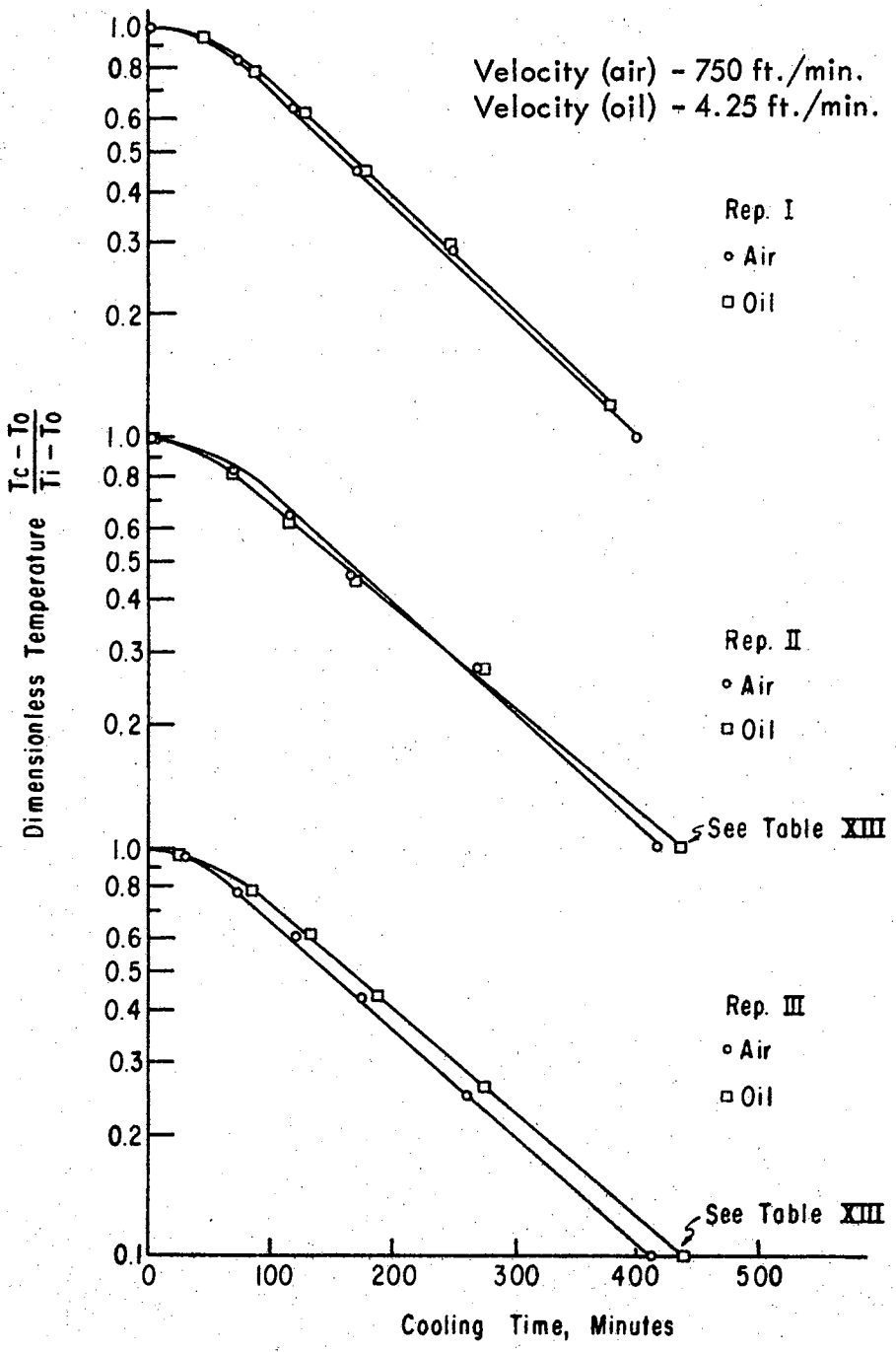


Figure 6. Cooling Curves for Hams Chilled at an Ambient Temperature of 4.44°C (Heat Transfer Coefficient = 4.15 Btu/hr.ft.$^2$°F).

did not reveal any difference in cooling times (Table IV, Appendix Table IX).

TABLE IV

ANALYSIS OF VARIANCE OF TOTAL COOLING TIME TO 10°C FOR AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 4.15 BTU/HR.FT.$^2$°F)

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 5 | 7917.71 | 1583.54 | |
| Blocks | 2 | 7464.59 | 3732.30 | |
| Treatments | 1 | 1.04 | 1.04 | .0046 ns |
| Error | 2 | 452.08 | 226.04 | |

ns - non-significant $P < .1$

Velocity of air 750 ft./min.

Velocity of oil 4.25 ft./min.

By equating the heat transfer coefficients it was expected that no difference in cooling times would result. Any differences in the cooling period could have been due to: (1) errors in adjustment and measurement of velocities, (2) heterogeneous ham shapes, (3) differences in ham composition (lean to fat ratio), (4) ambient temperature differences, (5) differences in initial internal ham temperature, (6) error in thermocouple placement, and (7) air pockets trapped beneath the cellulose casing which would retard cooling.

## Economies of Cooling Times

Large differences in heat transfer coefficients result between the oil immersion and air systems at any given velocity (Figure 7). The heat transfer coefficient was

calculated for both oil and air by using the general formula $h = \frac{K}{l}$ (0.367) $(Re)^{0.564}$ $(Pr)^{0.333}$ (Clary et al. 1968). At a given velocity (ft./sec.) and corresponding heat transfer coefficient, economies of cooling times can be read directly using Figure 8. For example, at a velocity of 10 ft./sec. (Figure 7), the heat transfer coefficients of oil would be 69 and 3.7 for air. The corresponding cooling times (Figure 8) were 195 minutes (oil) and 308 minutes (air); giving a cooling time in oil that is approximately 1.6 times faster than cooling in the forced air chamber. Selected economies of cooling time for oil immersion and air chilling are shown in Table V.

TABLE V

SELECTED ECONOMIES OF COOLING TIMES INTERPOLATED AND CALCULATED FROM FIGURES 7 AND 8

| Velocity ft./sec. (Figure 7) | Cooling Time (Min.) (Figure 8) | | Economies of Time $\frac{\text{Cooling time (air)}}{\text{Cooling time (oil)}}$ = |
|---|---|---|---|
| | Air | Oil | |
| 0.06 | 420 | 307 | 1.37 |
| 0.10 | 409 | 295 | 1.39 |
| 1.00 | 359 | 270 | 1.33 |
| 10.00 | 308 | 196 | 1.57 |

It should be noted that as the velocity increases from 1.0 to 10.0 ft./sec. a large difference between cooling rates resulted as compared to similar cooling rates for 0.06, 0.10, and 1.0 ft./sec.

The data presented in Figures 7 and 8 are dependent on the characteristic shapes of the hams and the properties of the air and mineral oil at 4.44°C. Re-

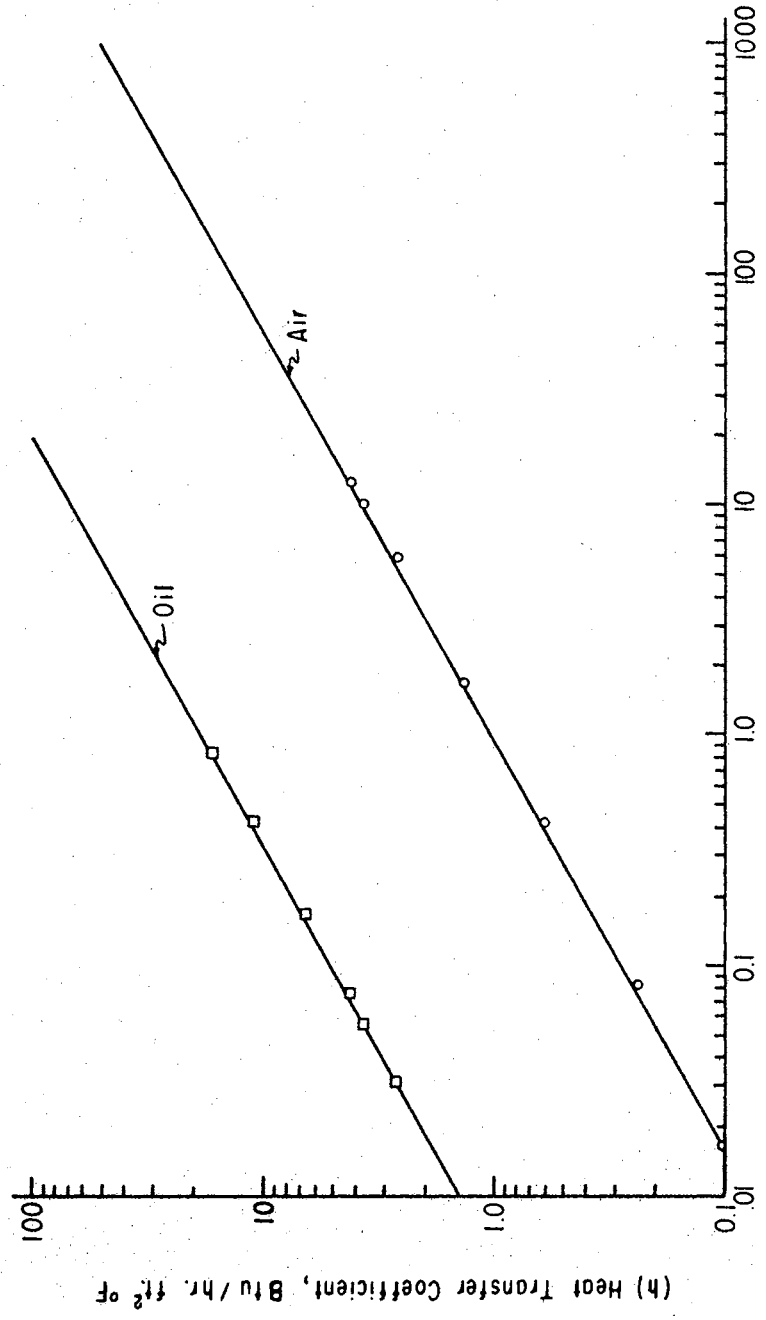


Figure 7. Heat Transfer Coefficients at Selected Velocities for Air and Mineral Oil.

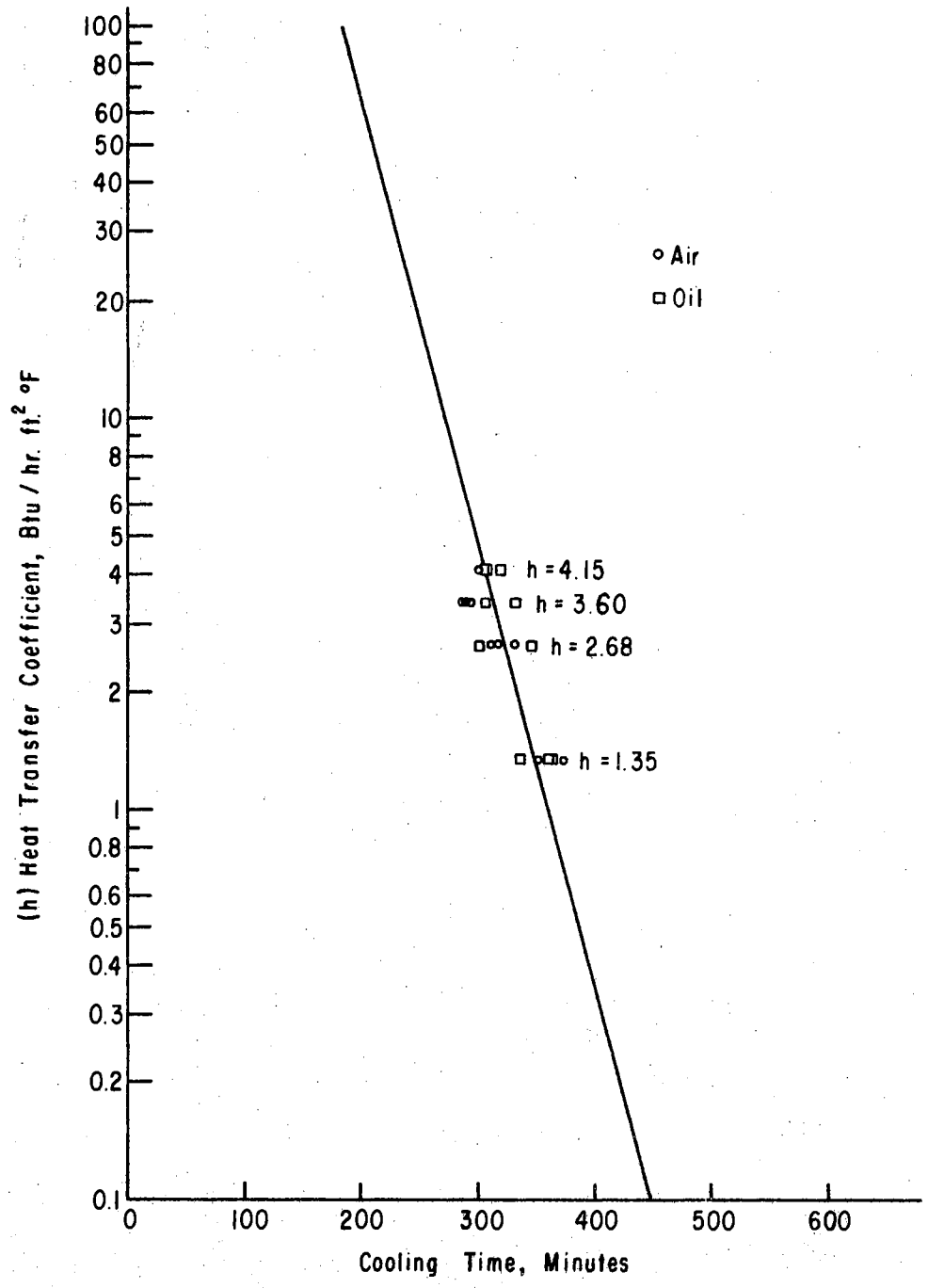


Figure 8. Cooling Times for Corresponding Heat Transfer Coefficients.

sponse lines on Figures 7 and 8 may be extrapolated beyond the points plotted from observed data.

## Percent Moisture Loss

Much larger moisture losses for the forced air cooling method are observed than occur in the oil immersion system (Figure 9). Moisture loss within the air system is from 4.34 to 2.42 times greater than that experienced in the oil immersion system when the corresponding air velocities were approximately 176 times greater than the oil velocities. The difference would possibly have been more pronounced had a casing not been used during the experiment. This might have allowed more moisture to be lost during air chilling than was experienced. The surface of the air chilled ham was dry and crusty as opposed to the moist surface of the oil immersion chilled ham.

## Cooling Mediums

Mineral oil as a coolant is quite efficient but as the oil temperature is lowered the viscosity rapidly increases. This caused problems in circulation of the fluid because of increased friction; therefore, more energy had to be expended by the pumping and cooling systems.

At high velocities (3.40 ft./min.) the normally clear oil became cloudy because of incorporated air. Despite prolonged use, the mineral oil remained clear once the incorporated air had a chance to dissipate. The oil also retained its characteristic bland odor throughout the study.

When the air system was operated at high velocities (600 ft./min.), additional heat was produced by friction requiring more refrigeration to keep the ambient temperature within an acceptable range.

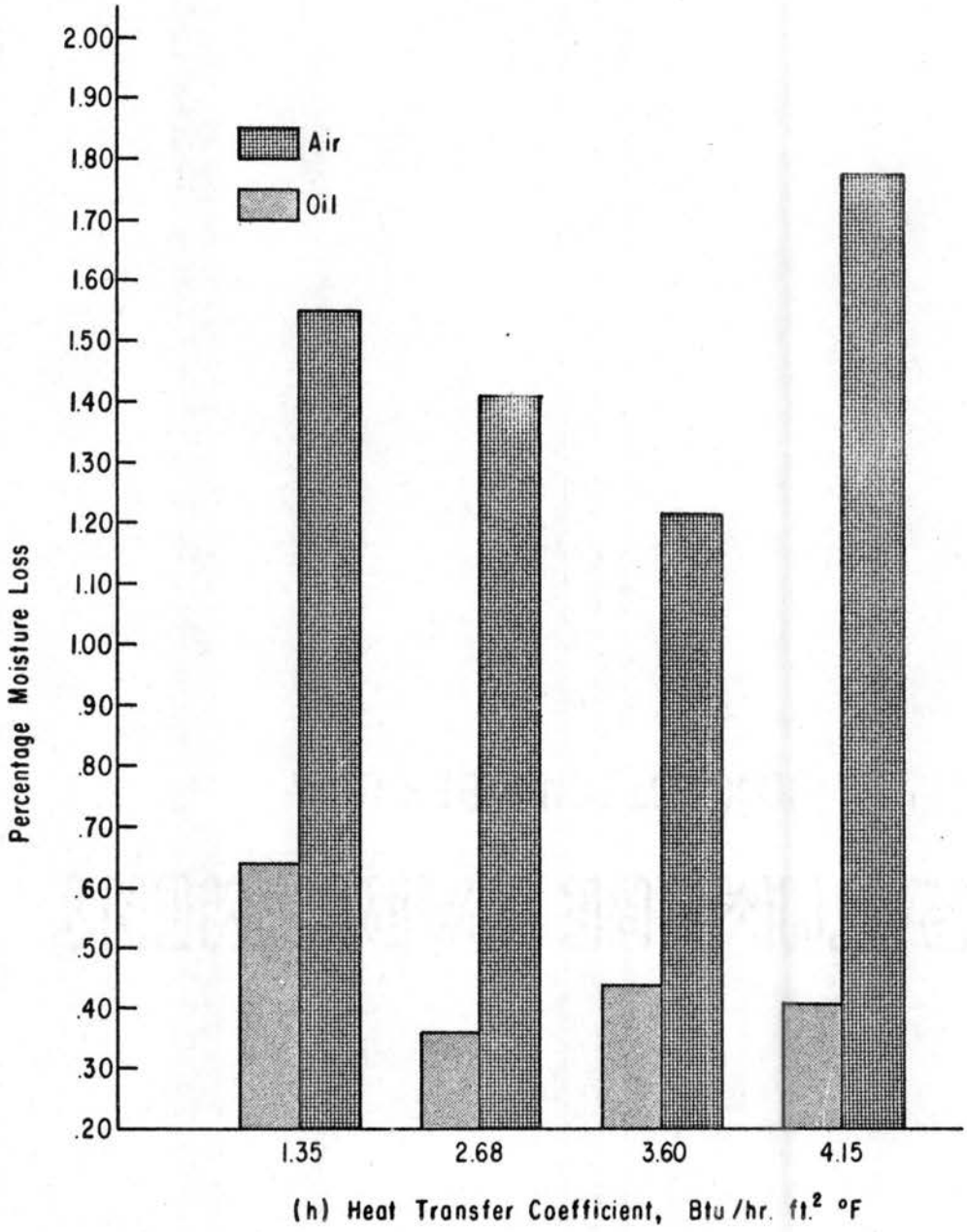


Figure 9. Moisture Loss from Hams During Air and Oil Immersion Cooling.

## Packaged Product Odor

Upon termination of each chilling trial, all hams exhibited a desirable fresh ham odor regardless whether the ham was chilled by the forced air system or oil immersion. No objective odor values were recorded, but the subjective organoleptic tests revealed only characteristic odors that would probably be acceptable to the consumer.

# CHAPTER V

## SUMMARY AND CONCLUSIONS

Twelve swine (8 Hampshire and 4 Yorkshire Barrows) ranging in weight from 82.6 to 113.5kg. were used for the study. All animals were sacrificed at the Meat Science Laboratory, skinned and eviscerated as rapidly as possible. From each "hot" carcass both hams were removed in the conventional manner, boned, and trimmed of excess fat. The hams were trimmed until both were the same weight and then packaged in individual cellulose ham casings. All hams were assigned at random to one of two treatments, air cooling or immersion cooling in refrigerated light mineral oil. Mineral oil was chosen as an immersion medium because of its bland odor, clear color, and large Prandtl number. The Prandtl number is a measure of a fluid's heat removing ability.

Temperature changes within the hams over time were recorded by inserting thermocouples through the open end of the bag into the geometric center of the ham. A Honeywell recording potentiometer was used to chart temperature changes.

With the thermocouples inserted in the hams and the casings sealed on both ends, the hams were placed in the assigned cooling systems (air or oil immersion). Metal brackets were designed for both systems so as to hold the hams and force the diameters to be the same without restricting the fluid movement.

The cooling systems were equated on a heat transfer coefficient basis. By

doing this, identical hams should chill to a given temperature in the same length of time. This gave a basis for comparing oil immersion and air chilling as far as cooling time economies were concerned.

Graphically, cooling times appeared to be quite similar and when total cooling times were tested by the F-test the differences proved non-significant. These data provided confidence that the objective of equating the heat transfer coefficients, was accomplished.

The data also provided evidence that cooling by oil immersion was 1.37-1.57 times faster than chilling by the forced air system. Fluid velocity was found to be important in cooling. As the velocity increased from 1.0 to 10.0ft./sec., large differences in cooling times within each system resulted despite small differences at 0.06, 0.10, and 1.0ft./sec.

Moisture loss from the ham within the forced air system was much greater than in the oil immersion system. This difference would possibly have been larger had protective cellulose casings not been used on the hams.

Light mineral oil as a cooling medium proved more efficient than the air system, but oil immersion must yet be compared with other cooling methods (brine immersion, cryogenic cooling or freezing, etc.) in order to determine its relative efficiency. Future studies should evaluate not only economies of time but search deeper into the economics to encompass materials, equipment, etc.

With pertinent economic data collected on the several cooling systems, immersion chilling in light mineral oil should then be evaluated with respect to the other cooling methods.

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# APPENDIX

TABLE VI

COOLING TIME TO REACH 10°C (HEAT TRANSFER COEFFICIENT = 1.35 BTU/HR.FT.$^2$°F)

| Animal | Oil Immersion (minutes) | Air (minutes) |
|---|---|---|
| $XI_A$ | 360.0 | 377.5 |
| $XII_B$ | 400.0 | 410.0 |
| $XIII_C$ | 407.5 | 417.5 |
| Mean | 389.2 | 401.7 |

$A,B,C_{\text{Repetitions I, II, and III}}$

Velocity of air - 100ft./min.

Velocity of oil - 0.568ft./min.

TABLE VII

COOLING TIME TO REACH 10°C (HEAT TRANSFER COEFFICIENT = 2.68 BTU/HR.FT.$^2$°F)

| Animal | Oil Immersion (minutes) | Air (minutes) |
|---|---|---|
| $VIII_A$ | 327.5 | 340.0 |
| $IX_B$ | 330.0 | 342.5 |
| $X_C$ | 360.0 | 352.5 |
| Mean | 339.2 | 345.0 |

$A,B,C_{\text{Repetitions I, II, and III}}$

Velocity of air - 350ft./min.

Velocity of oil - 1.99ft./min.

TABLE VIII

COOLING TIME TO REACH 10°C (HEAT TRANSFER COEFFICIENT = 3.60 BTU/HR.FT.$^2$°F)

| Animal | Oil Immersion (minutes) | Air (minutes) |
|---|---|---|
| $V_A$ | 332.5 | 357.5 |
| $VI_B$ | 335.0 | 335.0 |
| $VII_C$ | 312.5 | 287.5 |
| Mean | 326.7 | 326.7 |

$A,B,C_{\text{Repetitions I, II, and III}}$

Velocity of air - 600 ft./min.

Velocity of oil - 3.40 ft./min.

TABLE IX

COOLING TIME TO REACH 10°C (HEAT TRANSFER COEFFICIENT = 4.15 BTU/HR.FT.$^2$°F)

| Animal | Oil Immersion (minutes) | Air (minutes) |
|---|---|---|
| $XIV_A$ | 375.0 | 397.5 |
| $XV_B$ | 435.0 | 415.0 |
| $XVI_C$ | 472.5 | 472.5 |
| Mean | 427.5 | 428.3 |

$A,B,C_{\text{Repetitions I, II, and III}}$

Velocity of air - 750 ft./min.

Velocity of oil - 4.25 ft./min.

TABLE X

COOLING TIMES CORRESPONDING TO DIMENSIONLESS TEMPERATURES
(HEAT TRANSFER COEFFICIENT = 1.35 BTU/HR.FT.$^2$°F)

| Experimental Conditions | Temperature Tc(°F) | Air | | Oil Immersion | |
|---|---|---|---|---|---|
| | | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ |
| Rep. I | 100 | 25.0 | .9538 | 0.0 | 1.0000 |
| Animal $XI_A$ | 90 | 77.5 | .8000 | 65.0 | .8361 |
| Ti Air - 103°F | 80 | 122.5 | .6462 | 110.0 | .6721 |
| Ti Oil - 100°F | 70 | 180.0 | .4923 | 162.5 | .5082 |
| To Air - 38°F | 60 | 255.0 | .3385 | 225.0 | .3443 |
| To Oil - 39°F | 50 | 377.5 | .1846 | 360.0 | .1803 |
| Rep. II | 100 | 37.5 | .9531 | 0.0 | 1.0000 |
| Animal $XII_B$ | 90 | 90.0 | .7969 | 87.5 | .8333 |
| Ti Air - 103°F | 80 | 135.0 | .6406 | 132.5 | .6667 |
| Ti Oil - 100°F | 70 | 192.5 | .4844 | 187.5 | .5000 |
| To Air - 39°F | 60 | 272.5 | .3281 | 260.0 | .3333 |
| To Oil - 40°F | 50 | 410.0 | .1719 | 400.0 | .1667 |
| Rep. III | 100 | 25.0 | .9688 | 20.0 | .9835 |
| Animal $XIII_C$ | 90 | 87.5 | .8125 | 87.5 | .8182 |
| Ti Air - 102°F | 80 | 130.0 | .6563 | 130.0 | .6529 |
| Ti Oil - 101°F | 70 | 190.0 | .5000 | 185.0 | .4876 |
| To Air - 38°F | 60 | 272.5 | .3438 | 262.5 | .3223 |
| To Oil - 40.5°F | 50 | 417.5 | .1875 | 407.5 | .1570 |

Velocity of Air - 100 ft./min.

Velocity of Oil - 0.568 ft./min.

TABLE XI

COOLING TIMES CORRESPONDING TO DIMENSIONLESS TEMPERATURES
(HEAT TRANSFER COEFFICIENT = 2.68 BTU/HR.FT.$^2$°F)

| Experimental Conditions | Temperature Tc (°F) | Air | | Oil Immersion | |
|---|---|---|---|---|---|
| | | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ |
| Rep. I | 100 | 35.0 | .9375 | 45.0 | .9254 |
| Animal $VIII_A$ | 90 | 77.5 | .7813 | 82.5 | .7761 |
| Ti Air - 104°F | 80 | 115.0 | .6250 | 120.0 | .6269 |
| Ti Oil - 105°F | 70 | 155.0 | .4688 | 160.0 | .4776 |
| To Air - 40°F | 60 | 217.5 | .3125 | 215.0 | .3284 |
| To Oil - 38°F | 50 | 340.0 | .1563 | 327.5 | .1791 |
| Rep. II | 100 | 0.0 | 1.0000 | 22.5 | .9839 |
| Animal $IX_B$ | 90 | 67.5 | .8525 | 65.0 | .8226 |
| Ti Air - 99°F | 80 | 107.5 | .6885 | 102.5 | .6613 |
| Ti Oil - 101°F | 70 | 157.5 | .5246 | 150.0 | .5000 |
| To Air - 38°F | 60 | 227.5 | .3607 | 212.5 | .3387 |
| To Oil - 39°F | 50 | 342.5 | .1967 | 330.0 | .1774 |
| Rep. III | 100 | 37.5 | .9524 | 35.0 | .9840 |
| Animal $X_C$ | 90 | 82.5 | .7937 | 85.0 | .8240 |
| Ti Air - 103°F | 80 | 120.0 | .6349 | 122.5 | .6640 |
| Ti Oil - 101°F | 70 | 167.5 | .4762 | 170.0 | .5040 |
| To Air - 40°F | 60 | 237.5 | .3175 | 237.5 | .3440 |
| To Oil - 38.5°F | 50 | 352.5 | .1587 | 360.0 | .1840 |

Velocity of Air - 350 ft./min.

Velocity of Oil - 1.99 ft./min.

TABLE XII

COOLING TIMES CORRESPONDING TO DIMENSIONLESS TEMPERATURES
(HEAT TRANSFER COEFFICIENT = 3.60 BTU/HR.FT.$^2$°F)

| Experimental Conditions | Temperature Tc(°F) | Air | | Oil Immersion | |
|---|---|---|---|---|---|
| | | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ |
| Rep. I | 100 | 37.5 | .9231 | 35.0 | .9545 |
| Animal $V_A$ | 90 | 70.0 | .7692 | 80.0 | .8030 |
| Ti Air - 105°F | 80 | 105.0 | .6154 | 120.0 | .6515 |
| Ti Oil - 103°F | 70 | 165.0 | .4615 | 180.0 | .5000 |
| To Air - 40°F | 60 | 212.5 | .3077 | 222.0 | .3485 |
| To Oil - 37°F | 50 | 357.5 | .1538 | 332.5 | .1970 |
| Rep. II | 100 | 37.5 | .9375 | 37.5 | .9449 |
| Animal $VI_B$ | 90 | 77.5 | .7813 | 80.0 | .7874 |
| Ti Air - 104°F | 80 | 117.5 | .6250 | 120.0 | .6299 |
| Ti Oil - 103.5°F | 70 | 165.0 | .4688 | 167.5 | .4724 |
| To Air - 40°F | 60 | 230.0 | .3125 | 235.0 | .3150 |
| To Oil - 40°F | 50 | 335.0 | .1563 | 335.0 | .1575 |
| Rep. III | 100 | | | | |
| Animal $VII_C$ | 90 | 32.5 | .9434 | 52.5 | .8462 |
| Ti Air - 93°F | 80 | 77.5 | .7547 | 90.0 | .6752 |
| Ti Oil - 99°F | 70 | 125.0 | .5660 | 137.5 | .5043 |
| To Air - 40°F | 60 | 187.5 | .3774 | 200.0 | .3333 |
| To Oil - 40.5°F | 50 | 287.5 | .1887 | 312.5 | .1624 |

Velocity of Air - 600 ft./min.

Velocity of Oil - 3.40 ft./min.

TABLE XIII

COOLING TIMES CORRESPONDING TO DIMENSIONLESS TEMPERATURES
(HEAT TRANSFER COEFFICIENT = 4.15 BTU/HR.FT.$^2$°F)

| Experimental Conditions | Temperature Tc (°F) | Air | | Oil Immersion | |
|---|---|---|---|---|---|
| | | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ | Cooling Time min. | $\frac{Tc-To}{Ti-To}$ |
| Rep. I | 100 | 0.0 | 1.0000 | 42.5 | .9504 |
| Animal $XIV_A$ | 90 | 70.0 | .8182 | 85.0 | .7851 |
| Ti Air - 100°F | 80 | 115.0 | .6364 | 125.0 | .6198 |
| Ti Oil - 103°F | 70 | 167.5 | .4545 | 175.0 | .4545 |
| To Air - 45°F | 60 | 247.5 | .2727 | 245.0 | .2893 |
| To Oil - 42.5°F | 50 | 397.5 | .0909 | 375.0 | .1240 |
| Rep. II | 100 | 0.0 | 1.0000 | 0.0 | 1.0 |
| Animal $XV_B$ | 90 | 67.5 | .8333 | 67.5 | .8182 |
| Ti Air - 99°F | 80 | 112.5 | .6481 | 112.5 | .6364 |
| Ti Oil - 100°F | 70 | 165.0 | .4630 | 167.5 | .4545 |
| To Air - 45°F | 60 | 267.5 | .2778 | 272.5 | .2727 |
| To Oil - 45°F | 50 | 415.0 | .0926 | 435.0 | .0909 |
| Rep. III | 100 | 30.0 | .9643 | 27.5 | .9649 |
| Animal $XVI_C$ | 90 | 77.5 | .7857 | 85.0 | .7895 |
| Ti Air - 102°F | 80 | 120.0 | .6071 | 132.5 | .6140 |
| Ti Oil - 102°F | 70 | 175.0 | .4286 | 187.5 | .4386 |
| To Air - 46°F | 60 | 260.0 | .2500 | 275.0 | .2632 |
| To Oil - 45°F | 50 | 472.5 | .0714 | 472.5 | .0877 |

Velocity of Air - 750 ft./min.

Velocity of Oil - 4.25 ft./min.

TABLE XIV

PERCENTAGE MOISTURE LOSS DURING AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 1.35 BTU/HR.FT.$^2$°F)

| Animal | Ham Chilled in Oil | Ham Chilled in Air |
|---|---|---|
| $XI_A$ | .0055* | .0167 |
| $XII_B$ | .0084 | .0152 |
| $XIII_C$ | .0054 | .0147 |
| Mean | .0064 | .0155 |

*Decimal notation X 100 = Percent

TABLE XV

PERCENTAGE MOISTURE LOSS DURING AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 2.68 BTU/HR.FT.$^2$°F)

| Animal | Ham Chilled in Oil | Ham Chilled in Air |
|---|---|---|
| $VIII_A$ | .0036* | .0138 |
| $IX_B$ | .0030 | .0131 |
| $X_C$ | .0044 | .0156 |
| Mean | .0036 | .0141 |

*Decimal notation X 100 = Percent

TABLE XVI

PERCENTAGE MOISTURE LOSS DURING AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 3.60 BTU/HR.FT.$^2$°F)

| Animal | Ham Chilled in Oil | Ham Chilled in Air |
|---|---|---|
| $V_A$ | | |
| $VI_B$ | | |
| $VII_C$ | .0044* | .0122 |
| Mean | .0044 | .0122 |

*Decimal notation X 100 = Percent

TABLE XVII

PERCENTAGE MOISTURE LOSS DURING AIR VERSUS OIL IMMERSION CHILLING (HEAT TRANSFER COEFFICIENT = 4.15 BTU/HR.FT.$^2$°F)

| Animal | Ham Chilled in Oil | Ham Chilled in Air |
|---|---|---|
| $XIV_A$ | .0046* | .0172 |
| $XV_B$ | .0046 | .0189 |
| $XVI_C$ | .0031 | .0174 |
| Mean | .0041 | .0178 |

*Decimal notation X 100 = Percent

# VITA

Curtis Lynn Kastner

Candidate for the Degree of

Master of Science

Thesis: OIL IMMERSION CHILLING OF PORCINE HAM

Major Field: Food Science

Biographical:

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