EFFECT OF BEEF CARCASS CHARACTERISTICS AND COOLER CONDITIONS ON MEAT SHRINKAGE

by

JEROME D. LEISING

B. S., University of Nebraska, 1969

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1973

Approved by:

Major Professor

THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH THE ORIGINAL
PRINTING BEING
SKEWED
DIFFERENTLY FROM
THE TOP OF THE
PAGE TO THE
BOTTOM.

THIS IS AS RECEIVED
FROM THE
CUSTOMER.

ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to Dr. H. J. Tuma, Major Professor, for his guidance and inspiration during the author's masters program. The author also expresses appreciation to Dr. D. H. Kropf and Dr. P. L. Miller for their unselfish service on the author's graduate committee.

Special thanks is extended to Dr. A. D. Dayton for his help with the statistical analysis and interest in the research.

I wish to thank my wife, Vestey, for her encouragement and help in preparation of this thesis and to my parents, Mr. and Mrs. Gilbert Leising for their encouragement and support of my academic career.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF APPENDIX TABLES AND FIGURES

CHAPTER I

INTRODUCTION

Meat marketing is dependent upon chilling, freezing, drying or some other form of preservation to maintain quality and freshness. Lurie (1966) stated that with the advent of mechanical refrigeration in 1834, meat preservation techniques were "established" and meat distribution systems were expanded. Adequate refrigeration all along the system is important in maintaining product quality, reducing shrinkage, and controlling equipment and maintenance costs. Carcass chilling immediately after slaughter is one of the most important steps in the marketing sequence. The design of the chill room and control of environmental conditions within the chill cooler effect the product shrink and bloom. Design factors indirectly affect initial and maintenance cost of the refrigeration system.

Justification for the refrigeration investment is measured in terms of profit. For example, high air velocities increase power requirements for fans and unless additional costs can be off-set by savings in lower product weight losses or considerable improvements in bloom and general appearance, the utilization of high air velocities cannot be justified.

Meat shrinkage may be due to water loss, microbial spoilage, contamination or other product deterioration. Today, the major portion of beef carcass shrinkage occurs the first twenty-four hours after slaughter. If rigor mortis effects could be controlled, hot boning of beef after slaughter and immediate packaging would eliminate most weight loss during cooling. Such production of boneless packaged beef should require a shorter chilling time and result in greater marketing efficiencies.

Beef cooler conditions and carcass shrinkage are highly variable. A 275 kg beef carcass chilled 16 to 20 hours, will shrink one to two percent (2.7-5.4 kg) varying with processing conditions. At this rate of shrinkage, a loss of $3.50 to $6.75 per carcass will result with beef priced at $56/cwt. A 0.5% shrinkage reduction can occur by adjusting the chill cooler conditions (Fleming and Earle, 1968; Ewell, 1935). A reduction of shrinkage the first 24 hours can mean thousands of dollars in savings to the beef processor. In most cases, the savings will justify installation of proper refrigeration.

Limited information is available concerning effects of carcass and cooler factors on shrinkage during the first 24 to 48 hours post mortem. Optimum conditions for given carcasses must be known to minimize shrinkage.

The objectives of this study were:

1. To determine the effect of carcass weight on carcass shrinkage.
2. To determine the effect of adipose covering on carcass shrinkage.
3. Identify some of the optimum cooler conditions that will minimize shrinkage.
4. To develop cooling curves for beef carcasses of different weight and fat thicknesses.

CHAPTER II

REVIEW OF LITERATURE

Successful chilling of carcass beef results in low shrink, rapid chilling, attractive color and a firm non-exudative carcass. The factors to be considered for efficient chilling are cooler air temperature, relative humidity and air velocity.

The two areas to be discussed are the mechanical and the biological systems. The refrigeration system is the mechanical system while the beef carcass is the biological system. In the process of converting muscle to meat, minimal shrinkage should result when both systems are most effectively combined. A review of meat shrinkage mechanisms and the process of heat transfer will supply principles for further discussion of carcass characteristic and optimum cooler conditions.

Mechanisms of Meat Shrinkage

Carcass beef muscle at the time of slaughter, on a total weight basis, is approximately 75% water. The major portion of weight loss is attributed to water. An investigation by Golovkin, Chizhor, and Alamovsi (1955), states that meat is devoid of moisture proof membrane. "Free water" on the surface of the fat and lean is the major contributor to moisture loss according to studies by Fleming (1970), Hodgson (1970), Fleming and Earle (1968), Retrum (1958), Heller (1949), Scott and Vickery (1939) and Ewell (1935). That portion of water lost from the fat surface and lean tissue has not been clearly defined, thus presenting an area for further investigation.

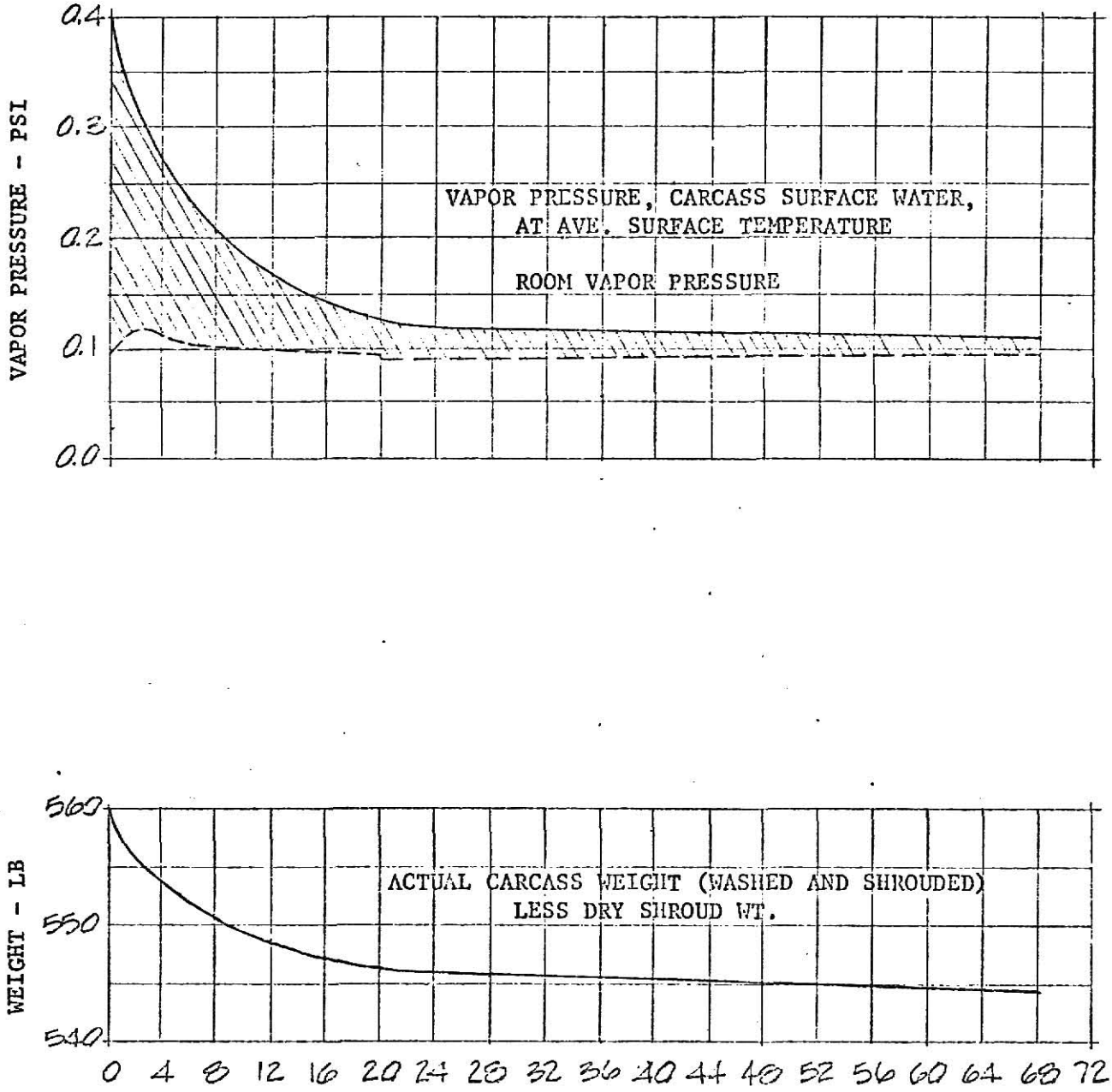
Drip loss and evaporation are the main sources of moisture loss during the first 24 to 48 hours post mortem, ASHRAE (1971). Hagen (1954) investigated the "drip time" of carcasses before entering the cooler and found that a half-hour drip time prior to chilling added 0.4% to the normal total shrinkage.

In order to eliminate all shrinkage, the water vapor in the air should equal the saturated vapor pressure of the water solution at the meat surface. Rate of evaporation or rate of shrinkage was found to be a linear function of temperature and time, (Heller, 1942). Work by Scott et al. (1939), found that evaporation of water from sides of beef during chilling under constant conditions of air flow was not the same as evaporation from a free water surface. Evaporation of moisture from the carcass surface varies due to decreasing water activity in muscle, fat and connective tissue as cooling proceeds. An important driving force on evaporation of moisture is vapor pressure differences for the carcass surface and chillroom air as shown in Fig. 1. Slight contrasting results were produced by Heller (1942), who reported that meat surfaces of veal and beef and pure water surfaces of equal area to differ very little in evaporation rate until the meat sample had shrunk more than 35% of the initial weight. Heller (1942), studied the effect of surface area on shrinkage. By coating veal with varying amounts of paraffin, it was determined that loss of weight was proportional to the uncoated initial surface area. After further study it was concluded that beef and pork samples of 35.0 to 70.0 gms. shrink faster the smaller the initial weight. These results were in agreement with work done by Golovkin et al. (1955) and Fleming (1970).

Evaporation of moisture from the surface is rapid during the beginning of the chill period because of larger temperature differences between various

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.



(ASHRAE, Guide and Data Book, 1971)

Fig. 1. Typical beef carcass chilling-holding shrinkage curves.

points on the surface and the surrounding air; however, as the surface temperature and cooler air temperature converge the rate of evaporation will decrease. Scott et al. (1939), concluded that rapid cooling at the beginning of the chill period will significantly reduce shrinkage.

Heat Transfer

Rapid cooling by heat transfer occurs when energy is transmitted from a biological system to a mechanical system. When a temperature difference exists between two systems, heat is transferred by conduction, radiation and convection according to Kreith (1967) and Sellers (1955). Basic laws of heat transfer depend on surface areas as well as differences between surface temperatures and cooler air temperatures. Rate of heat transfer can be measured in BTU per hour from the following equation:

$$\text{BTU/hr} = \underset{\text{conductive}}{\text{BTU/hr}} \quad \underset{\text{coefficient}}{\text{ft}^2\ ^\circ\text{F}} \times \underset{\text{area}}{\text{sq. ft.}} \times \underset{\text{temperature difference}}{\Delta T}$$

Hodgson (1966) has indicated that a carcass will lose 25% of its initial heat content in the first 10% of chilling time, which is often the case in quick chilling installations.

From the preceding information we can conclude that energy exchanges between the carcass surface and surrounding air results in heat transfer. ASHRAE (1970), Fleming (1970), Hodgson (1970), Fleming and Earle (1968), Hodgson (1966), Golovkin et al. (1955) and Hagen (1954) agree that heat loss occurs by latent and sensible heat exchanges between the surface of the carcass and the surrounding air. ASHRAE (1971) reported that chilling of the shrouded beef carcass occurs during transfer of heat from the warm

carcass to the cool air, thus raising the temperature of the air immediately surrounding the carcass. The rate of transfer is increased by more rapid circulation of air and by lower air temperature, but this is limited by the necessity of avoiding surface freezing. Latent heat exchange involves continuously vaporizing moisture from the surface, thereby cooling the surface. Hodgson's (1966) investigations showed that latent heat losses account for 25-50% of the total heat load. He has suggested that many factors affect mass transfer of heat from the surface of a carcass.

A principle factor effecting convective and mass transfer coefficients is air velocity. The thickness of the air film at the carcass surface determine the rate of diffusion of heat and vapor from the carcass (Hodgson, 1966). An average coefficient of convective and mass heat transfer is 7.6 and 5.5 BTU/hr ft^2 °F respectively, at an air velocity of 3.5 m/sec. Hodgson (1966) has shown that heat transfer coefficients vary as to the square root of the air velocity, where velocity is expressed in m/sec.

Large quantities of refrigerated air uniformly distributed are required to absorb heat from the carcass and transfer heat from the product as shown by Lawrie (1966) and Hodgson (1970). In a study by Hodgson (1970), air velocity of at least .75 m/sec. was required to reduce internal round temperature of a 100 kg. beef carcass side to 10°C within 16 hours in a room controlled at 0°C during chilling.

Fleming (1970) showed that weight loss results could be calculated for lamb carcasses by using a heat balance equation. Once the total heat exchange is known along with carcass weight, surface area, average surface temperatures and the thermoconductivity properties of the carcass, moisture loss can be calculated. High humidity enabled more accurate predications while low humidity resulted in incorrect estimates.

Thermal Conductivity of Carcass Beef

Thermal conductivity of meat must be known in order to study the heat removal processes. Heat removal from the deep of the round is a slow process because of the low conductivity of bone, lean and fat tissues. Specific heat within a carcass varies from 0.50 BTU/lb. F° for beef fat up to 0.80 BTU/lb. F° for muscle with average values of 0.75 BTU/lb. F° as shown by Hodgson (1966) and Retrum (1958). Price et al. (1971) suggested that the specific heat of meat depends to a large extent on the ratio of fat to muscle in the carcass showing values of 0.51 to 0.57 BTU/lb. F° for pork and .70 to .77 BTU/lb. F° for veal.

Thermal conductivity of beef as studied by Hill, Leitman, and Sunderland (1964), Mill and Sunderland (1963) and Lentz (1961) depends on temperature, moisture content and direction of heat transfer with respect to the muscle fiber. Lentz (1961) found that 15-30 percent greater heat conduction occurred along the muscle fibers rather than across the fiber. Thermoconductivity of unfrozen beef increases as temperature is lowered. When temperatures are above freezing the conductivity of meat is approximately equal to the conductivity value of water. Fat with added moisture showed increased thermoconductivity. Beef fat and lean both containing 74% moisture at 0°C, had a conductivity value of .277 BTU/hr. ft.^{2} °F. The conductivity of fat increases slightly with lower temperatures. Hodgson (1966) reported thermal conductivity of .288 BTU/hr. ft.^{2} °F for carcass beef.

Bone, an essential component that stretches muscle during rigor mortis, also holds heat during chilling. Ramsbottom and Strandine (1949) have confirmed that chilling of beef in the form of boneless cuts rather than sides of beef will increase rate of chill. Boneless loins were 10 to 15 degrees

cooler at two to eight hours after slaughter than control bone-in loins. However, beef chilled as carcass sides was more tender than beef boned prior to chilling. In a cooking test by Thille, Williamson, and Morgan (1939), used beef rib roasts and demonstrated that temperatures rose slower near the bone than through surface fat. They concluded that "bone was a poor conductor of heat". Funk, Aldrich, and Irmiter (1968), concluded that bone pieces of predetermined size and shape, within a ground meat cylinder, had no significant effect on the rate of temperature rise during cooking.

Affects of Carcass Characteristics on Cooling Rates and Shrinkage

Carcass characteristics such as weight, fat cover, and quality were found to affect cooling rate and shrinkage according to Bouton, Howard, and Lawrie (1958) and Hagen (1954). Bouton et al. (1958) reported that grade 1 beef (fatter according to British Standards) cooled more slowly than canner quality when adjusted for carcass weight differences. Carcasses of grade 1 as compared to canner beef carried higher mean temperatures for a period of two days after slaughter. Carcasses with higher temperatures were heavier muscled and had thicker fat coverings. Hagen (1954) after randomly selecting carcasses from a production line, consisting of all grades of beef, concluded that shrinkage for cutter and canner beef was more than that of high grade steer beef and suggested that a layer of fat resulted in lower shrinkage. An additional experiment was conducted comparing carcasses with low and high shrinkage during chilling. The results of this experiment indicated that shrinkage during shipment was similar for all carcasses no matter what the shrinkage the first 24 hours post mortem.

Carcass round temperatures varied from 38.5°-40.5° C with an average of 39°C upon entrance to the chill cooler (Stringer, Bilskie and Naumann,

1969; and Retrum, 1958). Stringer et al. (1969) found that rounds with deep temperatures of 40.5°C were 23.9°C on the surface when entering the cooler, while chucks with an internal temperature of 39.5°C were 15.6°C on the surface. A study of internal carcass temperatures after 18 hours of chilling with cooler air fluctuation between 0°-10°C, showed internal round temperatures of 15.6°-17.2°C.

Chill Cooler

Considerable differences of opinion exist on the optimum environmental conditions required within a carcass chilling room to minimize product shrinkage while preserving the bloom and general appearance of meat. The functions of the chill cooler are to cool freshly slaughtered carcasses to storage temperature in a minimum of time, with controlled drying of the carcass surface. Optimum conditions of air temperature, humidity and air velocity are necessary to efficiently chill and store meat.

Before reviewing the findings concerning optimum environmental conditions within a chill room, a few of the general aspects related to components of a cooling system will be considered. Refrigeration systems for carcass chilling are commonly comprised of four components; compressor, condensor, receiver and evaporator (including expansion valve or valves). The refrigerant, an essential component, must absorb large amounts of heat when it evaporates from a liquid to a gas and must do so under reasonable and easily (mechanically) handled pressures and temperatures. Ammonia is the primary refrigerant used in most carcass chilling installations with sodium chloride brine acting as a secondary refrigerant. A normal ammonia system generally operates at 20 to 25 p.s.i.g. according to ASHRAE (1971) and Hodgson (1964b). Figure 2 depicts a typical cooling cycle which occurs by action of the four primary components.

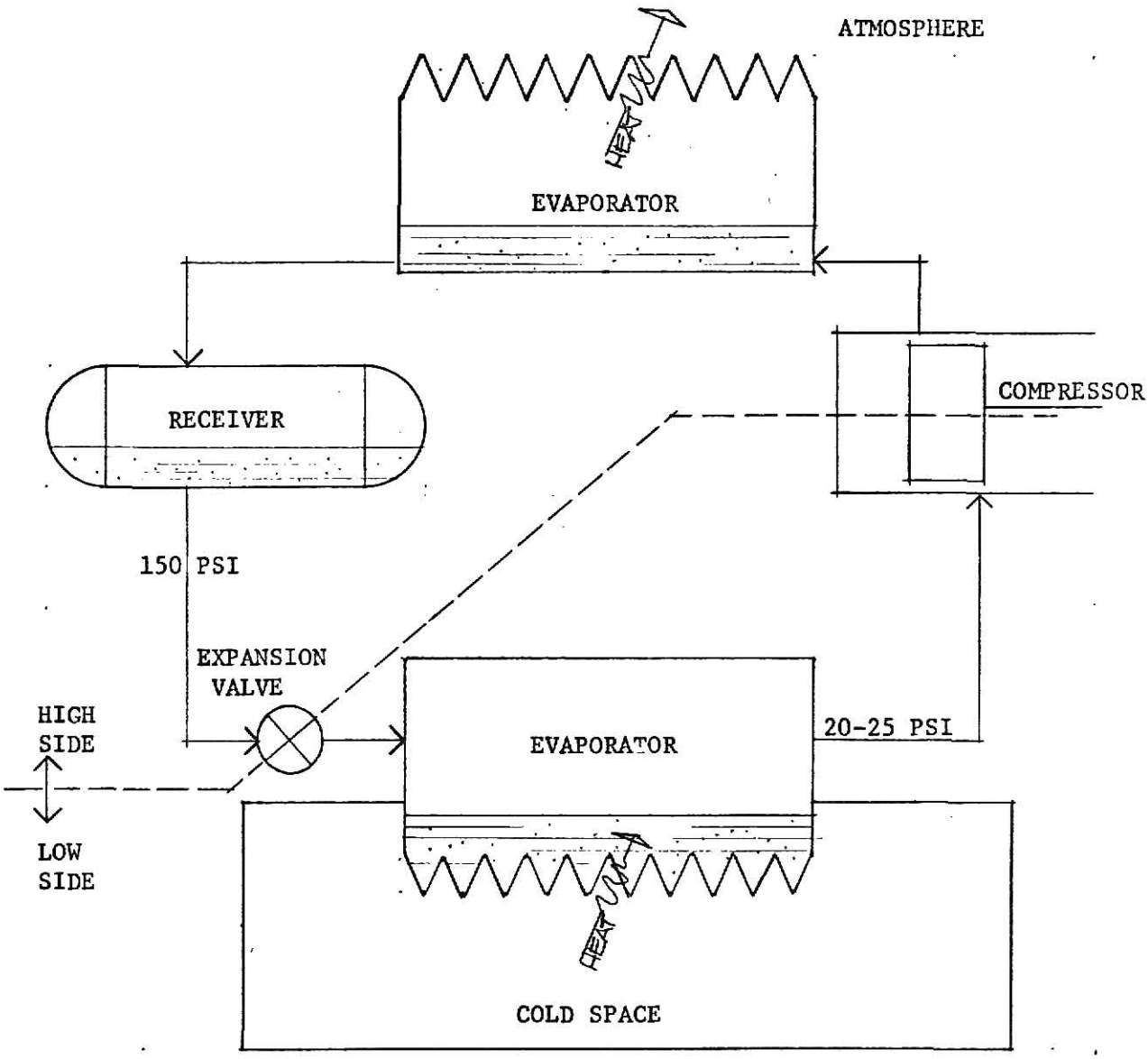


Fig. 2. Schematic diagram of compression refrigeration cycle.

(Lurie, H. A. 1966. Refrigeration for the Meat Processing Plant. Amer. Meat Institute. p. 12)

It is sound practice to base equipment selection on conditions at peak load, when product loss is the greatest. Hodgson (1964a) recommends that selection of compressors and condensors should be based on the overall peak load, taking all chill as well as the freezing and holding room at the plant into consideration. Peak load may depend on rate of loading, chill schedule, etc., usually occuring towards the end of the day when all rooms are fully loaded. Hodgson (1964a) suggests that compressor capacity should not be beyond 110% of the anticipated peak load. An industrial rule of thumb for determining compressor capacity is in the range of 1.5 cattle/ton of refrigeration capacity.

Condensers. Heat exchange equipment such as the condenser and evaporator are important items because of their decisive influences on capacity and running costs of the system. Hodgson (1964a) evaluated size and type of condensers in relationship to given economic conditions. Important factors to be considered are: power cost, cost of cooling water, and capital costs. The two types of condensers commonly used today are the evaporative condenser and the shell-and-tube condenser according to Lurie (1966) and Hodgson (1964a). Hodgson (1964a) recommended the condenser be calculated for 120% to 140% of the normal required cooling capacity. An evaporative condenser capacity is based on temperature differences corresponding to condenser pressure, on the one hand, and wet bulb temperature of the surrounding air on the other.

Evaporator. The main objective of the evaporators or blower-coil units in modern chilling installations is to provide a good circulation of low temperature air around the carcass. Evaporators are of three general types; a) chilled brine spray, b) sprayed coil and c) dry coil, ASHRAE (1966),

Lurie (1966) and Hodgson (1964a). Today the sprayed coil system comprises the majority of chilling and holding room installations in use (ASHRAE, 1971). An industry trend in the last several years has been installation of dry coil units for chilling with high levels of air flow and hot gas defrost. Dry coil units have been used very little in chilling until recently because of the inadequate coil capacity. Hodgson (1964a) suggests that in the case of a dry coil installation, the "flooded coil system" is 15 to 25% more efficient than the "dry expansion systems" because of more sufficient wetting of the coil surface at the outlet end. In selecting an evaporator of the dry type, proper attention should be given to fin spacing as well as defrost arrangements in order to avoid excessively high resistances due to frost build-up. ASHRAE (1971) reports that normally coils are equipped with 3-4 fins per inch and defrost every 4 to 24 hours. When refrigerant temperatures are below freezing, close fin spacings will rapidly accumulate ice and reduce efficiency. Selection of evaporator size can be based on 3 to 4 cattle/ton of evaporator capacity. It is standard practice to provide enough evaporator capacity to maintain cooler temperature at 0°-1°C for sprayed coil systems and as low as -4°C for dry coil installations (ASHRAE, 1971).

Cooler Air Temperature

Low air temperature is desirable and necessary in order to rapidly chill carcass beef. It is generally agreed that air temperatures should be kept as low as possible. Hodgson (1964b) states that low temperatures are preferred in view of the fact that air at higher temperatures can take up larger absolute quantities of moisture and excessive shrinkage occurs because of the forced air circulation. Studies by Hodgson (1964b), Howard and Lawrie

(1956), Heller (1942) and Scott (1939) showed that low air temperatures (-2.0°-0.0°C) with high air velocities increase the rate of chilling and shorten the required chill time, thus decreasing total shrinkage. Hodgson (1964b) studied the effect of air temperature on cooling by assuming a carcass was similar to a plate 20.3cm in thickness having a heat transfer coefficient of 12 BTU/hr. ft.^{2} °F. Conclusions showed that an air temperature of -1.1°C instead of 1.6°C will give a surface temperature of 7°C instead of 9°C after two hours chilling, a reduction of 2°C. Theoretically, if a 7°C surface temperature was to be produced with an air temperature of 1.6°C, the air velocity would have to be doubled since heat transfer coefficients vary approximately with the square root of the air velocity. Hodgson (1964b) referred to work by Burke (1956), showing that air temperatures and velocity of 2°C and 4.1 m/sec respectively, resulted in longer time for carcass temperature to be reduced to 5°C than with air temperature and velocity of -1.1°C and 1.0 m/sec.

Cooler air temperature fluctuations have been shown to be an indicator of cooler overload. Retrum (1958) found that temperature fluctuation from 0° to 10°C at flank height was due to inadequate evaporator capacity. The limited coil surface and decreased air circulation prevented rapid surface-to-air heat transfer.

According to Heller (1942), air temperatures affect the rate of shrinkage rather than total shrinkage. When exposing pieces of meat to 3°C and 145°C, 94% to 95% of the weight lost at 145°C was also lost at 3°C. In this study, temperature variation caused 5%-6% of the loss with final weight primarily dependent on the moisture content of the air. Since they used pieces of meat rather than total carcasses, it may not be possible to draw any conclusions regarding temperature effect on carcass shrinkage.

Cooler air temperatures affect biochemical reactions within beef carcass as well as the weight loss and microbial growth. Howard and Lawrie (1956) studied ATP breakdown in muscle in relation to fluid release from muscle protein. By increasing the rate of heat removal in beef quarters before the onset of rigor mortis, there was a reduction in the rate of ATP breakdown and a decrease in the fluid released. Shrinkage results for hot beef quarters chilled by blast freezing at -35°C versus those cooled at 2°C were 0.60% and 2.83%, respectively. Tenderness differences were found to be highly significantly ($P<.01$) in favor of beef that was chilled. Frozen quarters were significantly darker in color and less tender.

Marsh (1954) found that pH drop after death was reduced by lower cooler temperatures. Exposing pre-rigor beef to 43°C or 7°C for one hour or 9.5 hours, respectively, resulted in a pH of 6.5. Allowing for a more efficient cooling rate, it would take nearly 36 hours for all glycolytic changes to occur. Presently with the use of rapid chilling systems, problems associated with "thaw-rigor" due to freezing before the completion of the on set of rigor can present possible tenderness problems.

Cold Shortening

The consumer generally regards tenderness as the most important quality factor of meat. The significance of the effect of cold shortening on tenderness must be considered in assessing the merits of a cooling process. The cold shortening effect was investigated by Marsh, Woodhams, and Leet (1968), Herring, Cassens and Briskey (1965), Partmann (1963) and Locker and Haryard (1963) who found that when excised pre-rigor muscled was placed in cold environments, greater shortening occurred at 1°C than at 5°C. Marsh and Leet (1966) have shown that intact skeletal attachments of post-mortem muscle

do not necessarily overcome the development of shortening - induced toughness. When pre-rigor muscle was absolutely fixed in over-all length it still was capable of appreciable shortening in one zone, with compensating lengthing elsewhere if the application of cold is uneven along its surface. Locker (1960) suggested that certain muscles are under more tension than others in the suspended carcass and thus shortening is greater for muscles under less tension. Locker and Hagyard (1963) using neck muscle, sternomandibularis and longissimus dorsi (LD) exposed to 2°C found neck muscle to shorten immediately on cooling (1.5 hours), while rapid shortening for LD occurred 3 to 5 hours post-mortem. The LD muscle was almost identical to sternomandibularis muscle in degree of shortening at 2°C and 37°C. Marsh and Leet (1966) point out that *sternomandibularis* muscle is severed during dressing and could shorten appreciably when chilled; this may be partly responsible for the general belief that neck muscle is excessively less tender. Even the LD muscle is able to shorten in spite of, its skelatal attachments when cold application does not reach the entire span of muscle simultaneously. In practice it would require only a slight covering of fat, the proximity of a bone or protective shielding of part of a muscle from the cold, moving air to result in unequal cooling and activate this shortening mechanism.

Buchter (1970) using various cooling temperatures, 10°, 8°, 6°, 4°, 2°, 0°C and a chilling tunnel at 1°C, investigated the effect of chilling conditons on meat quality for young calves and bulls. The right and left side of each carcass was chilled at different temperatures for 24 hours post-mortem. Carcass weights for calves and bulls were 140 kg and 295 kg, respectively. From the results, a decreasing temperature in the chilling room increased the number of animals having less tender meat. The results

suggested that heavier carcasses, which have larger muscle mass than calves, could be chilled at lower temperatures without increasing the number of carcasses with less tender meat, except for surface muscle effects.

Relative Humidity

Shrinkage and product color are related to cooler humidity. Relative humidity, as used here, is the percent to saturation water vapor in the air (Platt and Griffiths, 1966). Humidity is dependent on air temperature as well as vapor pressure. Hodgson's (1970) findings show that humidity in a conventional carcass chilling room is determined to some extent by temperature differences between the refrigerant passing through the evaporator or cooling coil and the air passing over the coil. Results show that the larger the temperature differences the lower the relative humidity.

The relationship of higher shrinkage to low humidity has been long accepted by the industry. Fleming et al. (1968) and Ewell (1935) have reported that 0.50% more shrinkage occurred with 70% humidity than with 95%. Humidity has been found to be most critical during the last 12 hours of chill, since moisture is readily available during the beginning of the chill cycle from the wash water and beef shroud, (Golovkin, et al., 1955). Hodgson (1964b) reported that Burke found that within the limits of air temperature of -8°C to 0°C and velocities of 3.0-4.1 m/sec., humidities down to 85% had no significant effect on weight losses.

Air Velocity

According to Hodgson (1966) the principle effect of air velocity is on the heat transfer coefficient (BTU/hr. ft.^{2} F°) and mass transfer coefficient. By increasing air velocity, heat transfer is increased, thus resulting in a

decrease in carcass temperature. Lurie (1966) reported that uniform refrigerated air distribution with a sufficient amount of air movement is required in order for adequate heat transfer to occur from the product to the air. Hodgson (1966) states that air velocity of at least .75m/sec is required to reduce bone temperatures of a beef carcass side (100 kg) to 10°C within 16 hours in a room controlled to 0°C during chilling. Authorities consider carcasses not chilled to bone temperature (at least 10°C) as being susceptible to spoilage due to bone taint during subsequent storage. Scott (1939) investigated cooling rates in beef carcasses using air speeds of .30, .50 and .77 m/sec., with the air surrounding the sides at -0.8°C after a temperature rise of not more than 7.5°C in 7, 11, and 15 hours, respectively. After 24 hours of cooling, internal round temperatures of 11°, 12° and 13°C were found using sides weighing 147.3 kg. A mean air speed over carcass beef in excess of .80 m/sec produced the most desirable results during the cooling phase. Ideally, end results of the chilling process should be a uniform carcass temperature not over 1.7°C including the deep of the round. U.S.D.A. (1971) guidelines insist that internal round temperatures of 4.4°C be reached before shipping. Literature findings concerning the effect of air velocity on weight loss are not clearly defined. A proper combination of air velocity, air temperature and humidity varies with the plant. In Fig. 3 Hodgson (1970) summarizes the effect of air velocity and humidity on carcass weight loss during chilling. In this study a carcass side weighed 100 kg.

Carcass Bloom

During rapid chilling, the maintaining of carcass bloom or a bright red meat color, may be as important as preventing weight loss. Generally,

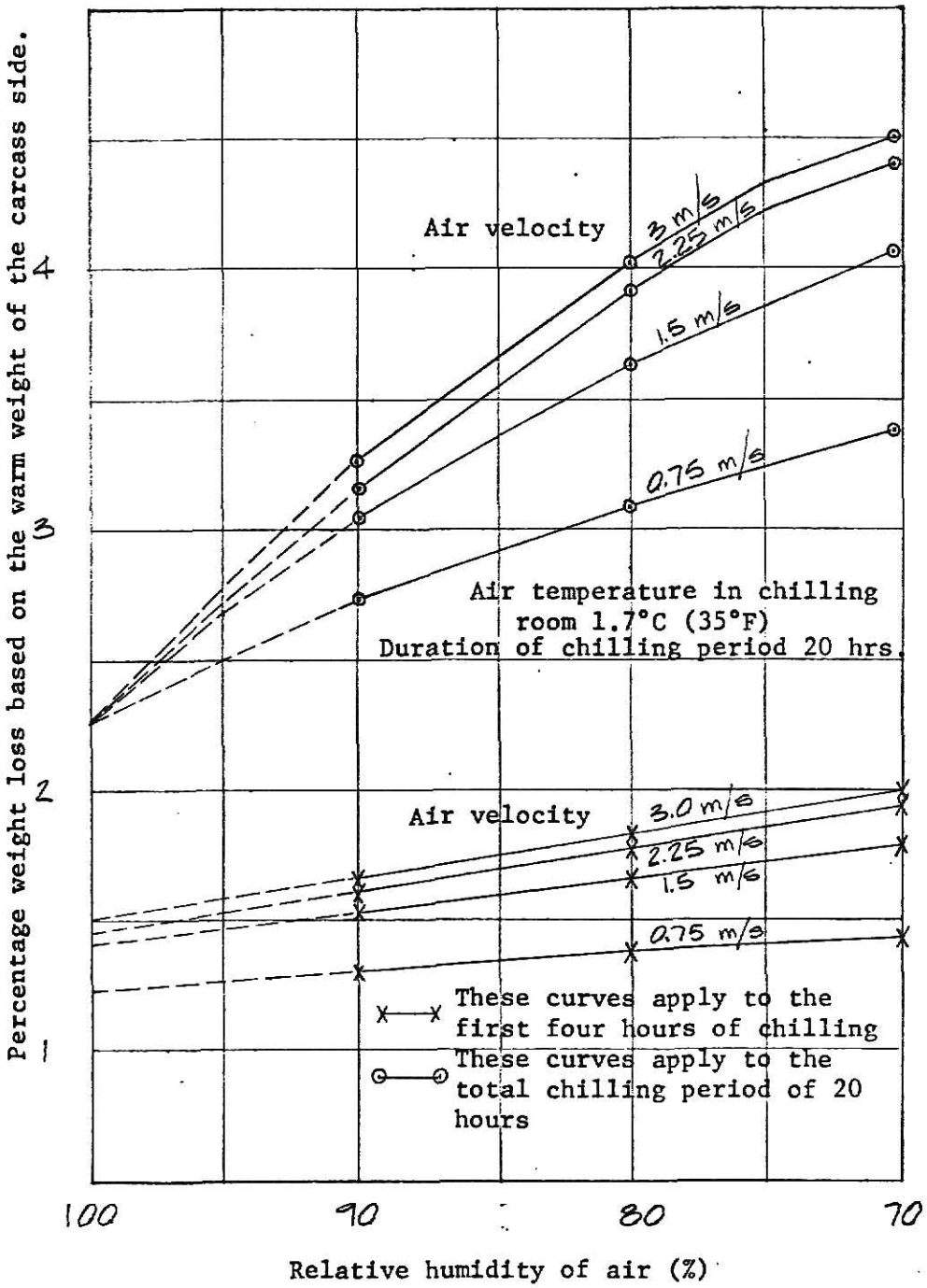


Fig. 3. Effect of air velocity and relative humidity on carcass weight losses during chilling.

(Hodgson, T. 1970. The effect of air velocity and evaporator size on product weight losses in carcass chilling rooms.)

loss of bloom is negligible during chilling 18-20 hours post-mortem. Scott et al. (1939) reported that when higher shrinkage occurred, there was a lowering in the rate of loss of bloom. One factor that controlled loss of bloom was surface drying. Most of the exposed surface of a beef carcass consists of fat and connective tissue. Hodgson (1964b) concluded that during chilling the dry layer, which is found on the surface of the carcass, is so thin that the permeability of the skin is retained. The thin transparent layer of dry skin enables oxygen to permeate through the skin and be taken up by the muscle, thus forming oxymyoglobin, the bright red meat color. Contrasting results reported by Fleming (1968) and Ewell (1935) indicated that by increasing humidity from 70% to 100%, the storage time, as determined by color, was increased by two days while a drying effect decreased storage time. The literature findings report both dry and humid conditions as desirable to maintain carcass bloom.

Ledward (1972) and Baker and Penrod (1954) studied the effect of storage conditions on beef discoloration and concluded that dehydration on the meat surface would lead to discoloration due to pigment concentrations. In their studies, lean beef samples were used rather than a carcass, thus exposing more meat surface than normal. By decreasing the relative humidity from 99% to 97%, the metmyoglobin concentration of semitendinosus muscle increased 2.0%.

The removal of water from the carcass, by drying the surface, is desirable for controlling microbial growth and preventing loss of bloom during storage (Hodgson, 1964b; Scott et al. 1939; and Ewell 1935). Robach and Costilow (1961) concluded that the primary role of bacteria in meat discoloration is in the reduction of oxygen tension in the surface tissue.

Microbiology of Carcass Beef

Meat shrinkage in terms of moisture loss is the primary concern during the first 24 hours after slaughter. Meat spoilage can become a major source of loss unless rapid chilling methods are used to reduce the carcass temperature. Ayres (1955) points out four principle types of spoilage that can occur in refrigerated fresh red meats: 1) off-odor and slime due to Achromobacter and Pseudomonas; 2) bone-stink or taint due to Baccilus growth on joint fluid and bone morrow; 3) black spots or whiskers due to molds and 4) fat rancidity.

Carcass contamination with bacteria occurs throughout the slaughter and storage process. Stringer et al. (1969) studied beef carcass contamination following slaughter and found the neck and lean surface area above the aitch bone to be highly contaminated. Microbial counts on shrouds and shroud water revealed large numbers of bacteria per square inch. It was suggested that shrouds could be an important source of bacterial contamination to the carcass. Stringer et al. (1969), Ayres (1955) and Empey and Scott (1939) agreed that the predominant organisms present after slaughter were Pseudomonas, Micrococcus, Achromobacter, and Bacillus.

Bacterial growth has been shown to be affected by cooler conditions. Empey et al. (1939) conducted research supporting the fact that cooler temperature is a major factor in preventing meat spoilage. Research by Fleming et al. (1968) and Ewell (1935) indicated a decrease in bacterial growth at lower cooler temperatures and lower humidity. Bacterial numbers on meat surfaces decreased when humidity was less than 85%. Humidity of 87% or greater resulted in an increased number of bacteria. Optimum conditions limiting microbial growth tend to result in serious weight loss.

Sleeth, Henrickson and Brady (1956) support the contention that proper sanitary procedures on the slaughter floor and in the chill room assist in minimizing deep spoilage after aging ribs at 20°C and 30°C although finding no difference in the microbial flora present.

The etiology of deep spoilage or bone taint in beef carcasses is not well understood. Bone taint being unusual in that its incidence is less than one in every thousand animals killed, but in some cases over half of the animals in one group may be affected (Callow and Ingram, 1955). The cause of bone taint may vary from improper cooling to contamination during slaughter or to treatment of live animals. Callow et al. (1955) concludes that if internal round and chuck temperatures are cooled rapidly to 20°C or below, the growth of anaerobic bacteria is reduced. Lepovetsky, Weiser and Deatherage (1952) investigated bone taint by studying the microbiol level of lymph nodes, bone marrow and muscle from 23 beef rounds and chucks. A majority of the lymph nodes contained anaerobes with only a few samples of bone marrow and muscle containing bacteria. Due to the large number of organisms in the lymph nodes, it is suggested that they could be the point from which deep spoilage arises.

LITERATURE CITED

ASHRAE Guide and Data Book, 1971. Meat Products, Part I: Carcass chilling and holding. New York, N. Y.

Ayres, J. C. 1955. Microbiological implications in the handling, slaughtering, and dressing of meat animals. Advances in Food Res. 6:398.

Baker, M. and E. B. Penrod. 1954. Influence of storage conditions on drying and discoloring of beef. Food Technol. 8:511.

Bouton, R. E., A. Howard and R. A. Lawrie. 1958. Studies on beef quality, 7. The influences of certain holding conditions on weight losses and eating quality of fresh and frozen beef carcasses. C.S.I.R.O. Melbourne, Australia. Technical paper 8.

Broumand, H., C. O. Ball and E. F. Stier. 1958. Factors affecting the quality of prepackaged meat. II Determining the proportions of home derivatives in fresh meat. Food Technol. 12:65.

Buchter, L. 1970. Development of a standardized procedure for the slaughter of experimental beef animals from the Danish Progeny Testing Station. Danish Meat Research Institute. Roskilde.

Callow, E. H. 1939. The structure of muscle tissue. Anm. Rept. Food Invest. Board, 55. Great Britain, Dept. Sci. and Ind. Res. Anm. Rept. Food Invest. Bd.

Callow, E. H., Ingram. 1955. Bone-Taint. Food. p. 52.

Empey, W. A. and J. W. Scott. 1939. Investigations of chilled beef. I. Microbial contamination acquired in the meat works. Australian Coun. Sci. and Ind. Res. Bull. 126.

Ewell, A. W. 1935. The cooler storage of beef. Refrigerating Engineering. Jan. Vol. 29:16.

Field, R. A. and M. L. Riley. 1968. Effect of weight and fat on lamb carcass shrink. J. Animal Sci. Abstract Vol. 19:247.

Fleming, A. K. 1968. Cooling and freezing of lamb and mutton carcasses. II. Weight loss during cooling. Food Technol. 22:102.

Fleming, A. K. 1970. Physical aspects of meat cooling. IIF Commissions II, IV, V, VII, Leningrad. Annexe Bull. p. 151.

Funk, K., R. J. Aldrick, and T. F. Irmiter. 1968. Rate of temperature rise, physical and chemical properties of ground beef cylinders fabricated from selected muscles of the round. II. Effect of bone. Food Technol. 22:1183.

Golovkin, N., G. Chizhov, and Alamovsl. 1955. A trial thermophysical timation of the process of cooling foods in air. Proc. 9th Intern. Congress of Refrig. 2, 4:161.

Hagen, H. F. 1954. Turbo-chill in the meat industry. Proc. 6th Res. Conf. Amer. Meat Inst. Found. p. 59.

Heller, W. 1942. Research reveals how meat shrinks. Food Ind. p. 50.

Herring, H. K., R. G. Cassens, and E. J. Briskey. 1965. Sarcomere length of free and restrained bovine muscles at low temperature as related to tenderness. J. Sci. Food Agr. 16:379.

Hicks, E. W. 1935. The evaporation of water from meat. Report Investigation Board, Dept. Scientific and Industrial Research. Great Britian, London. p. 19.

Hill, J. E., J. D. Leitman, and J. E. Sunderland. 1967. Thermal conductivity of various meats. Food Technol. 21:91.

Hodgson, T. 1970. The effect of air velocity and evaporator size on product weight losses in carcass chilling rooms. Intern. Institit. Refrig. Commission II, IV, V, VII, Leningrad. Annexe Bull. 3:161.

Hodgson, T. 1966. The effect of environmental conditions on the chilling rate of meat. Intern. Instit. of Refrig. Commission IV, V, Bologne. Annexe Bull. 1:635.

Hodgson, T. 1964a. The rapid chilling of meat. I. Theoretical and practical considerations. Food Industries of South Africa. Feb. p. 41.

Hodgson, T. 1964b. The rapid chilling of meat. II. Chilling of carcasses. Food Industries of South Africa. March p. 36.

Hodgson, T. 1964c. The rapid chilling of meat. III. The effect of air temperature and velocity on chilling rates. Food Industries of South Africa. April p. 36.

Howard, A. and R. A. Lawrie. 1956. Studies on beef quality. I. The effect of blast freezing hot beef quarters. Australia C.S.I.R.O. Division of Food Preservation. Tech. Paper 2:1.

Kaess, G. and J. F. Weidermann. 1968. Ozone treatment of chilled beef. I. Effect of low concentrations of ozone in microbial spoilage and surfaces colour of beef. J. Food Technol. 3:325.

Kleiber, M. 1961. The Fire of Life. John Wiley and Sons, Inc., N. Y., pp. 81-85.

Kreith, F. 1967. Principles of Heat Transfer. International Textbook Co., Penn.

Ledward, D. A. 1972. Metmyoglobin formation in beef muscles as influenced by water content and anatomical location. J. of Food Sci. 36:138.

Lentz, C. P. 1961. Thermal conductivity of meats, fats, gelatin, gels, and ice. Food Technol. 15:243.

Lepovetsky, B. C., H. H. Weiser, and F. E. Deatherage. 1952. A microbiological study of lymph nodes, bone marrow, and muscle tissue obtained from slaughtered cattle. App. Microbiol. 1:57.

Locker, R. H., 1960. Degree of muscular contraction as a factor in tenderness of beef. Fd. Res., 25,304.

Locker, R. H. and C. J. Hagyard. 1963. A cold shortening effect in beef muscle. J. Sci. Food Agr. 14:787.

Lurie, H. A. 1966. Refrigeration for the Meat Processing Plant. Amer. Meat Institute.

Marsh, B. B., P. R. Woodhams and H. G. Leet. 1968. Studies in meat tenderness. V. The effects on tenderness of carcass cooling and freezing before the completion of rigor mortis. J. Food Sci. 33:12.

Marsh, B. B. and N. G. Leet. 1966. Studies in meat tenderness III. The effects of cold shortening on tenderness. J. Food Sci. 31:450.

Marsh, B. B. 1954. Rigor mortis in beef. J. Sci. Food Agr. 5:70.

Meat Products. 1971. ASHRAE Guide and Data Book. Amer. Soc. of Heating, Refrig. and Air Conditioning Engineers, Inc. New York, N. Y.

Miller, H. L. and J. E. Sunderland. 1963. Thermal conductivity of beef. Food Technol. 17:490.

Partmann, W. 1963. Post-mortem changes in chilled and frozen muscle. J. Food Sci. 28:15.

Platt, R. B. and J. Griffiths. 1965. Environmental Measurement and Interpretations. Reinhold Publishing Corporation, N. Y.

Price, J. F. and B. S. Schweigert. 1971. The Science of Meat and Meat Products. 2nd Ed. W. H. Freeman and Co.

Ramsbottom, J. M. and E. J. Strandine. 1949. Initial physical and chemical changes in beef as related to tenderness. J. Anim. Sci. 8:398.

Rea, R. H., G. C. Smith and Z. L. Carpenter. 1970. Factors affecting lamb carcass shrinkage. Sheep and Angora Goat, Wool and Mohair. Tex. Agr. Exp. Sta. Res. Rpt. 2742.

Retrum, R. 1958. Beef carcass chilling and holding. Refrig. Engr. p. 63.

Robach, D. L. and R. M. Costilow. 1961. Role of bacteria in the oxidation of myoglobin. Appl. Microbiol. 9:529.

Scott, W. J. and J. R. Vickery. 1939. Investigations on chilled beef. II. Cooling and storage in the meatworks. Council for Scientific and Industrial Research. Bull. 129.

Sellers, E. S. 1955. Heat Transfer Processes - 1. Food. p. 44.

Sleeth, R. B., R. L. Henrickson and D. E. Brady. 1956. Effect of controlling environmental conditions during aging on the quality of beef. 16th Annual Meeting Instit. of Food Technol.

Stringer, W. C., M. E. Bilskie and H. D. Naumann. 1969. Microbial profiles of fresh beef. Food Technol. 23:97.

U.S.D.A., Consumer and Marketing Service. 1971. Guidelines for Chilling, Freezing, Shipping and Packaging Meat Carcasses and Meat Byproducts. Agriculture Handbook, No. 412.

CHAPTER III

EXPERIMENTAL PROCEDURES

Survey questionaires, concerning carcass shrinkage and cooler conditions, were sent to nine major beef packers in Kansas. Evaluation of the questionaires resulted in selection of three companies (designated: A, B, and C) as participants in the study.

Sample Selection. Seventy-three carcasses were selected from production line for specific weight and adipose coverings, prior to washing and shrouding. Carcasses for each trial were selected within a two hour period. Carcass weight groups of 250, 295, and 340 kg. (± 11.3 kg.) were selected with adipose coverings of 0.64, 1.27 and 1.91 cm. (± 0.13 cm.) measured between the 12th and 13th rib. Adipose covering was determined by probing the hot carcass four inches from the midline at the 12th and 13th rib with a needle fat probe commonly used in probing fat on lamb carcasses (Field and Riley (1968)).

Measurement of Carcass Temperature. The right side of each carcass was monitored for rate of cooling during the chill period (24 hours) in the deep of the round (8 inches depth), and in the deep of the chuck (under the scapula) by a Honeywell Electronik - 16 potentiometer. Twenty-four thermocouple probes were constructed of 1/8 inch ceramocouples with a stainless steel sheath. Each probe had a polarized quick-coupling plug and jack with approximately 25 feet of insulated extension wire.

Measurement of Cooler Atmosphere. Cooler air temperatures were measured with the Electronik - 16 potentiometer continously during the chill period. Cooler relative humidity recordings were made of each chill cycle with a

Hygrothermograph calibrated to ± 5%. The humidity recordings and air temperatures were taken approximately four feet from the selected carcasses at flank height.

Air velocity was measured with a Hastings RB-1 air meter, equipped with an omniodirectional probe. Four locations in each cooler were used with readings taken above, below, and in-between carcasses at each location.

Design of the chill coolers are presented in Figures A, B, and C. Variation in refrigeration systems was noted in each plant with air flow and air distribution diagrammed for each cooler.

Carcass Information. The percent shrinkage for each carcass was determined by subtracting chilled carcass weight from hot weight (24 and 48 hours) dividing by hot carcass weight and multiplying by 100. Carcass yield grade and quality scores were collected for each carcass.

Statistical Analysis. A three-way analysis of variance was employed to determine 24 and 48 hour shrinkage differences as affected by fat covering, carcass weight, and coolers. Regression coefficients were computed for the round and chuck by a multiple regression stepwise deletion program. A simple quality and yield grade as related to shrinkage. A regression equation was determined by cooler for each weight by fat combination. An analysis of covariance was used to determine 24 hour shrinkage differences due to fat covering, carcass weight and coolers.

Analysis of Covariance. In order to compare coolers A, B, and C, carcass shrinkage was adjusted to the same cooling rate. It was not possible to select carcasses that would cool at the same rate, thus adjustment of carcass shrinkage data to the same rate of cooling was used, the hypothesis being, that as shrinkage decreased, the rate of cooling increased. Since the covariant

is the rate of cooling, any differences in shrinkage means were due to factors other than cooler temperature, humidity or time.

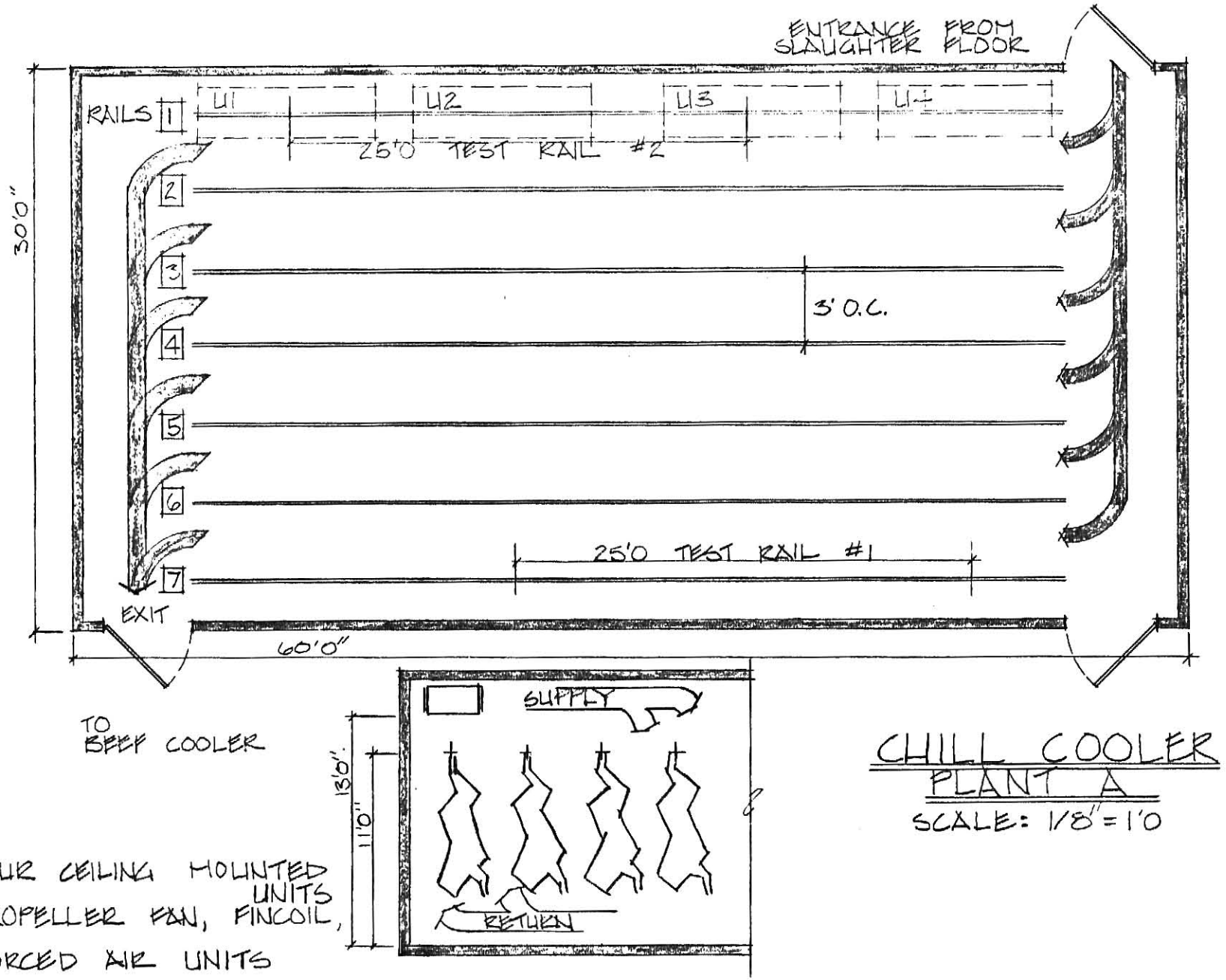


Fig. 4. Plant A, chill cooler design and air flow.

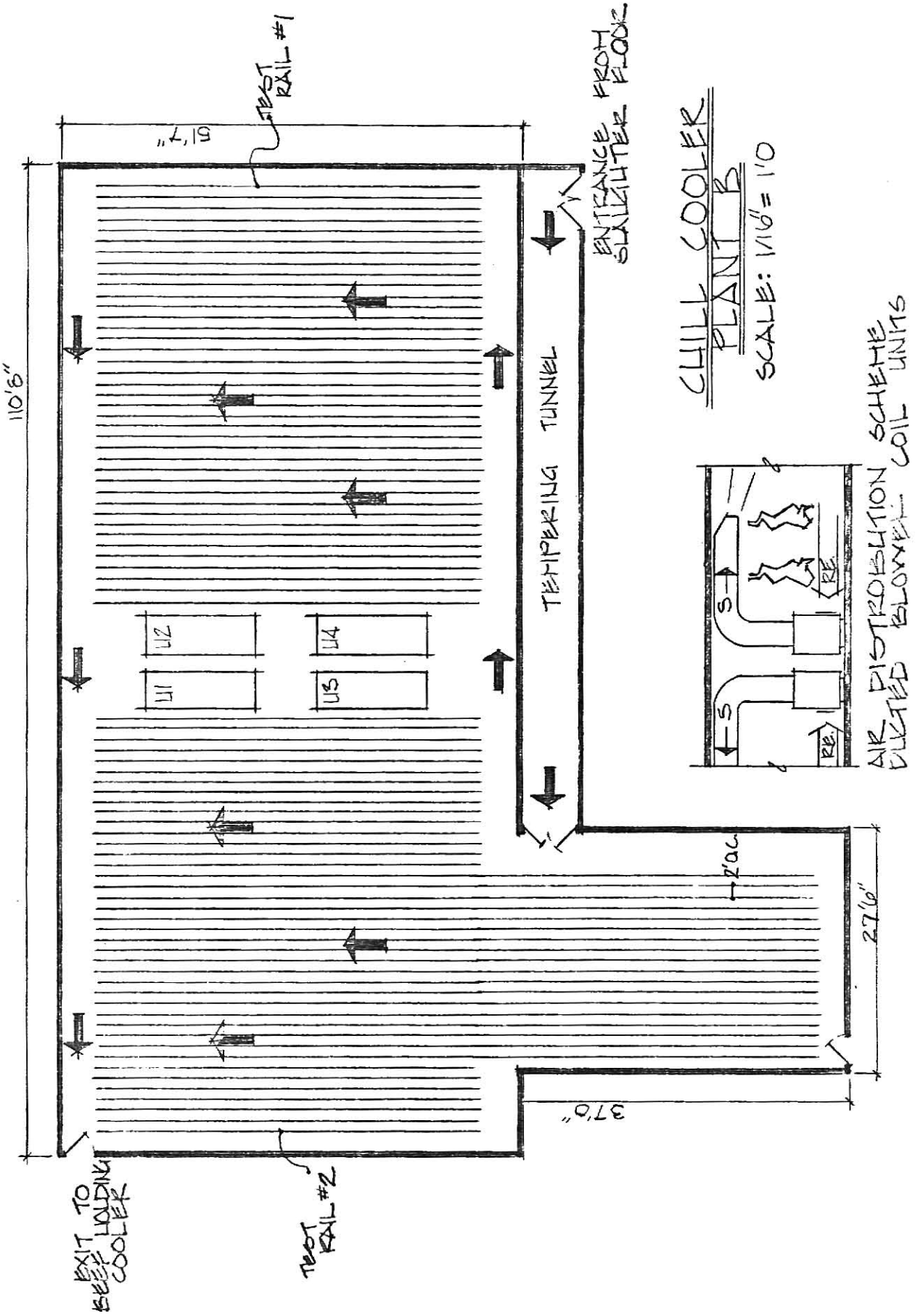


Fig. 5. Plant B, chill cooler design and air flow.

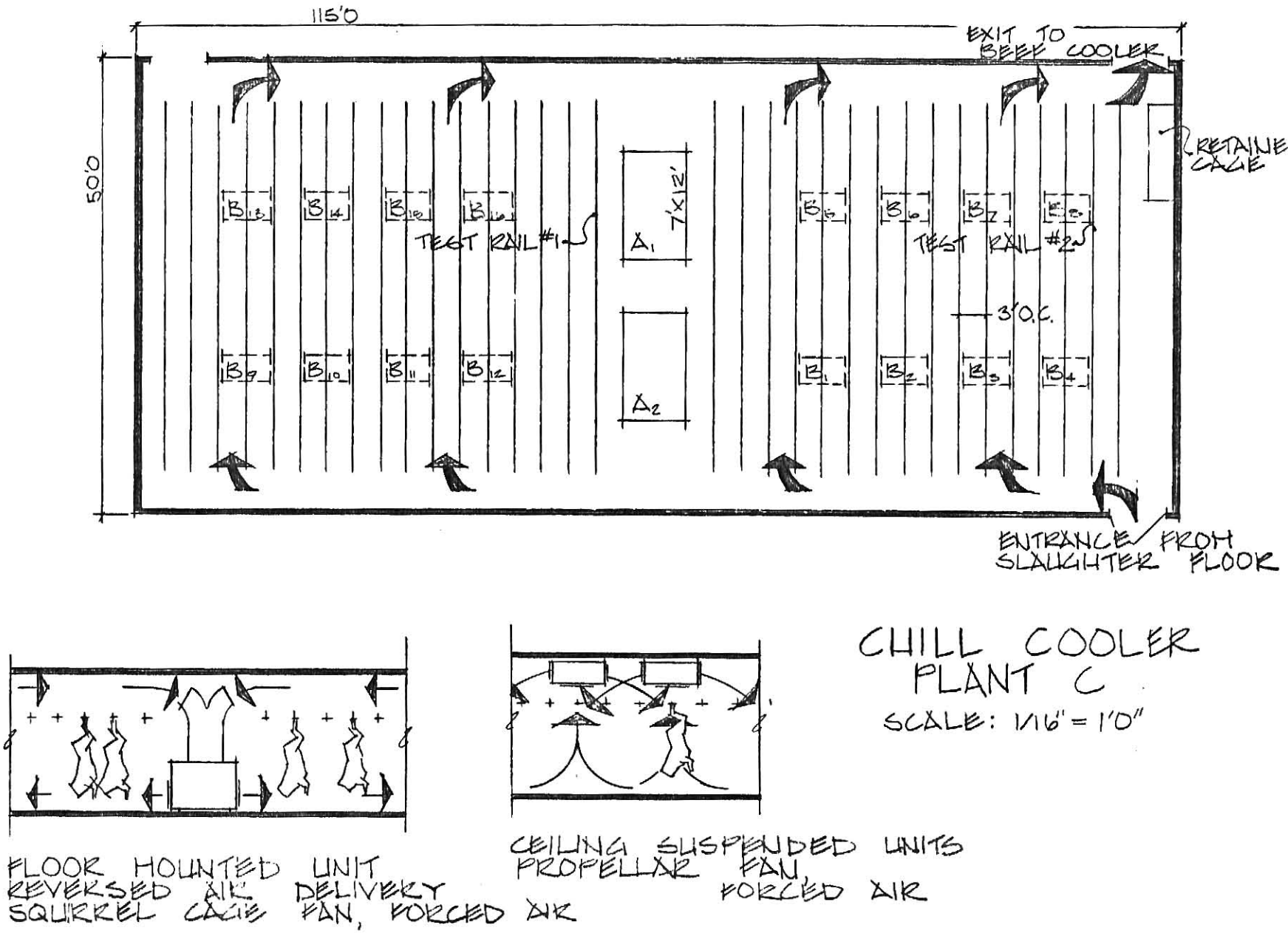


Fig. 6. Plant C, chill cooler design and air flow.

TABLE 1. REFRIGERATION CAPACITY FOR CHILL COOLERS

Cooler	Type of Refrig.Unit	No. of Units	Cooler Design Cap.		Actual Cooler Load		Total Refrig. Cap. (Tons)	Cattle/ Ton of Refrig.	Cooler Floor Area (sq.ft.)
			Cattle/ Day	Carcass Wt.(Kg)	Cattle/ Day	Carcass Wt.(Kg)			
A	Dry coil (overhead)	4	150	295	140	295	48	3.1	1800
B	Chilled brine spray (floor mounted)	4	900	309	925	294	200	4.75	6717
C	Dry coil (overhead)	16	550	295	700	298	72	4.92	5750
	Spray coil (floor mounted)	2					70		

TABLE 2. CHILLROOM AIR VELOCITY, RELATIVE HUMIDITY AND AIR TEMPERATURE

Cooler	Car. Spacing m/side	Rail Spacing (meters)	Total Specified Fan output CFM	Cooler Air Vel. 24 Hr. Test (m/sec) Above Car.	Between Car.	Below Car.	Mean Air Temp. (C°)	Mean Relative Humidity (%)	Air Temp. Fluctuation (C°) High	Low
A	.32	.92	73,200	.75	.50	1.35	1.8	80	9.0	0.0
B	.61	.61	132,000	.60	.40	1.10	1.6	65	4.0	-0.5
C	.38	.92	64,000 96,000	.35	.30	1.00	3.7	85	9.0	-3.0

CHAPTER IV

RESULTS AND DISCUSSION

Surface Moisture

It is generally accepted that the major portion of beef carcass shrinkage occurs due to moisture loss from the surface of the carcass. The proportion of moisture loss from fat and subsurface lean are not clearly defined.

An adjunct study dealing with moisture loss from surface fat and subsurface lean was conducted for a 24 hour chill period with the results presented in Table 3. The average lean tissue in this study had 61% more moisture than the adipose tissue. The initial post-mortem moisture content of the adipose tissue of the round was 17.07% as compared to 14.69% for the chuck. The adipose tissue moisture losses from the round were 2.0% greater than for equivalent tissues over the chuck after a 24 hour shrink. Findings by Stringer, Bilskie, and Naumann (1969) showed that surface temperatures from the round were 23.9°C, while the chuck was 15.6°C just prior to entering the cooler. Higher surface temperatures of the round have been thought to accelerate moisture loss from the carcass. Average moisture losses for subsurface lean were 3.12% for the round versus negligible amounts from the chuck. The effect of thicker adipose tissue over the lean of the chuck as compared to the round may have decreased the moisture loss from the lean. Although not substantiated by research studies, its a commonly accepted industry belief that retail cuts from the round have greater juice loss then retail cuts from the chuck. Muscles of the round might apparently give up water more readily than muscles of the chuck.

The average 24 hour shrink for carcasses used in this pilot study was 1.86%. Rea, Smith and Carpenter (1970), concluded that increased external fat decreased lamb carcass shrinkage since fat has insulating capacity, thereby reducing the effective moisture vapor transmission rate from the exterior of the muscle to the surrounding air currents. Work by Lurie (1966), indicates that during cooling the consistency of the fat surface on a carcass changes so that further loss of water by evaporation is restricted. Exposed muscle surfaces are unlike that of fat due to a continual loss of water from the muscle surface.

TABLE 3. MOISTURE LOSS FROM THE FAT SURFACE AND INTERNAL LEAN OF THE ROUND AND CHUCK DURING A 24 HOUR CHILL PERIOD

	Percent Moisture							
	Immediately Post Mortem				24 Hours Post Mortem			
Carcass No.	Round Lean	Round Fat	Chuck Lean	Chuck Fat	Round Lean	Round Fat	Chuck Lean	Chuck Fat
1	75.70	15.77	74.68	11.84	70.27	10.58	75.83	10.92
2	86.11	14.50	70.89	13.05	70.36	10.87	71.36	9.62
3	86.52	22.51	73.23	14.26	73.57	17.87	75.15	15.83
4	68.34	15.51	74.10	19.61	75.32	12.98	72.95	14.71
$\bar{X}$	79.17	17.07	73.23	14.69	76.05	13.08	73.82	12.77
					Percent Moisture Loss During 24 Hours			
					3.12	3.99	0.00	1.92
					$\bar{X}$ = 3.01 Moisture Loss			

Adipose Covering

The influence of external fat thickness on beef carcass shrinkage was significant at the ($P < 0.13$) level 24 hours post-mortem. The shrinkage values in Table 4 show that carcasses with 0.64 cm.of fat shrunk 0.14 to 0.18% more than carcasses with 1.27 and 1.91 cm. of fat.

TABLE 4. EFFECT OF FAT THICKNESS ON SHRINKAGE 24 AND 48 HOUR POST-MORTEM

Fat Thickness	24 Hr. Post-Mortem[1]			48 Hr. Post-Mortem[2]		Difference
(cm)	n	Mean (%)	S.D.	Mean (%)	S.D.	24 - 48 hrs.(%)
0.64	24	1.73	0.06	2.16	0.07	0.43
1.27	30	1.59	0.06	1.96	0.06	0.37
1.91	19	1.55	0.07	1.88	0.08	0.33

[1]Fat groups had a significant effect on 24 hour shrinkage ($P<0.13$)

[2]Fat groups had a significant effect on 48 hour shrinkage ($P<0.05$)

Carcass shrinkage 48 hours post-mortem was also significantly affected by fat ($P<0.05$). Carcasses with fat thickness of 0.64 cm. lost 0.20 and 0.28% more weight than did carcasses with 1.27 and 1.91 cm. of fat. Shrinkage 24 hours post-mortem accounted for 81% of the total shrinkage while 19% occurred the second 24 hours post-mortem. This data suggests that environmental conditions the first 24 hours post-mortem are the most critical for reducing carcass weight loss. Hagen (1954), showed that choice beef would shrink less than canner and cutter beef due to barrier properties of the increased fat covering. However, increased fat content also decreased available moisture that could be evaporated. The economics of increasing fat

thickness above 1.27 cm. would not compensate for the loss of dollars in carcass value. Rea (1970) and Field and Riley (1968) found that lamb carcass shrinkage was decreased as fat thickness at the twelfth rib increased. Field and Riley (1968) reported 0.174% decrease in shrink for each 1 mm. increase in fat depth when carcass weight is constant.

Carcass Weight

Carcass weight affected carcass shrinkage ($P<0.28$) the first 24 hours after slaughter. The general trend showed lighter weight carcasses shrinking more than heavy carcasses as presented in Table 5.

An interaction between carcass weight and coolers is presented in Table 7. Beef carcass shrinkage was not significantly effected by carcass weight in Coolers A and B. In Cooler C, 234 kg. carcasses shrank 14 and 25.9% more than 278 and 323 kg. carcasses. It should be noted that percent carcass shrinkage was approximately equal in Cooler B for different weight carcasses. Further explanation of shrinkage as related to cooler differences will be discussed in later results.

TABLE 5. EFFECT OF CARCASS WEIGHT ON SHRINKAGE 24 TO 48 HOURS POST-MORTEM

Weight groups	Carcass wt. Actual (kg)	No. of samples	24 Hour[1] Mean %	S.D.	48 Hour[2] Mean %	S.D.	(24-48) Diff.
1	236	27	1.71	0.065	2.11	0.070	.40
2	282	24	1.60	0.060	2.00	0.062	.40
3	324	22	1.56	0.065	1.89	0.070	.33

[1]Shrinkage means 24 hours post-mortem for weight froups differed at the ($P<0.28$).

[2]Shrinkage means 48 hours post-mortem for weight groups differed at the ($P<0.11$).

To explain the independent effect of carcass weight on shrinkage, weight loss is expressed as kilograms loss per unit of surface area (m^2) in Table 6. These data were not analyzed for statical significance. The surface area of the carcass was predicted by the formula; Surface Area (m^2) = Weight $(kg)^{0.625}$, (Kleiber, 1961). Carcass shrinkage expressed as weight loss per unit of surface area in Table 6 revealed that carcasses form weight groups 1 and 2 differed in weight by 46 kg. but lost the same amount of weight when expressed as weight lost per unit of surface area. Carcasses from weight group 3 lost 0.03 kg. more weight per unit of surface area. An increase in carcass weight decreased percent of carcass shrinkage due to less exposed surface area per unit of weight. In Table 6 carcasses of approximately equal surface area showed a trend towards increased shrinkage when fat coverings were less than 1.27 cm. The affect of fat thickness and surface area on shrinkage tend to be interrelated.

The cooler by weight interaction in Table 7 shows variation in shrinkage by cooler, thus suggesting that cooler design can reduce the effect of adipose covering and carcass weight on shrinkage. For example the heavier carcasses in cooler A tended to shrink the most while those in coolers B and C shrank the least. Field and Riley (1968) found that only 8% of the variation in lamb carcass shrinkage between 24 and 72 hours could be explained by carcass weight and fat thickness.

Effect of Fat and Weight On Adjusted Shrinkage

In order to evaluate more closely the effect of fat thickness and carcass weight on carcass shrinkage in Coolers A, B, and C cooling rates of the round were used as a covariant to adjust 24 hour shrinkage. The hypothesis was

TABLE 6. WEIGHT LOSS FOR SELECTED WEIGHT AND FAT GROUPS EXPRESSED AS WEIGHT LOSS PER UNIT OF SURFACE AREA

Weight Group	Average Carcass Wt. (Kg)	Shrinkage (%)	Weight Loss (Kg)	Surface Area (m^2)	Car. Wt. /A (ratio)	Wt. Loss/Surface Area (Kg)
1	236	1.71	4.04	2.95	80.0	1.37
2	282	1.60	4.51	3.30	85.5	1.37
3	324	1.56	5.05	3.60	90.0	1.40
Fat Group (cm)						
0.64	276	1.73	4.77	3.26	84.6	1.46
1.27	282	1.59	4.48	3.30	85.5	1.37
1.91	285	1.55	4.42	3.32	85.8	1.33

that increased cooling rates decreased weight loss. It was not possible to select carcasses that would cool at the same rate, thus adjustment of carcass shrinkage to the same rate of cooling was used. Adjusted shrinkage values are presented in Table 8.

Adjust carcass shrinkage was significantly affected by carcass weight ($P<0.05$). Light weight carcasses shrank 0.18 to 0.23% more as compared to medium and heavy weight carcasses. The affect of fat on adjusted carcass shrinkage was significant as the .16 level with the 1.27 and 1.91 cm. fat levels the same, but less than the 0.64 level.

Carcass shrinkage adjusted for cooling rate of the chuck produced similar results as presented for the round in Table 8. Adjusted carcass

TABLE 7. SHRINKAGE MEANS FOR BEEF CARCASSES 24 HOURS POST-MORTEM FOR COOLER AND WEIGHT[1, 2]

	Weight Group 1				Weight Group 2				Weight Group 3			
Cooler	n	Act.Wt. (Kg)	Wt.Loss (%)	Wt.Loss (Kg)	n	Act.Wt. (Kg)	Wt.Loss (%)	Wt.Loss (Kg)	n	Act.Wt. (Kg)	Wt.Loss (%)	Wt.Loss (Kg)
A	9	239	1.36[a]	3.25	6	282	1.34[a]	3.78	5	323	1.56[a]	5.04
B	6	234	1.32[a]	3.19	8	287	1.38[a]	3.96	7	326	1.31[a]	4.34
C	12	234	2.43[b]	5.69	10	278	2.09[c]	5.81	10	323	1.80[d]	5.81

[1]Means within the same column with different superscript letters differ significantly (P<.05).

[2]Means within the same row with different superscript letters differ significantly (P<.05).

shrinkage appears to be affected more by weight than by fat thickness. However, both variables tend to be inter-related and difficult to separate as shown by Rea (1970) and Field and Riley (1968).

TABLE 8. ACTUAL AND ADJUSTED SHRINKAGE MEANS AND STANDARD DEVIATIONS FOR FAT AND WEIGHT GROUPS 24 HOURS POST-MORTEM

Weight Groups	Actual Carcass Wt. (Kg)	n	Means Actual (%)	Means Adjusted[2] (%)	S.D. Actual	S.D. Adjusted
1	238	27	1.71[a]	1.77[b]	0.07	0.06
2	283	24	1.60[a]	1.59[a]	0.06	0.05
3	325	22	1.56[a]	1.54[a]	0.07	0.06
Fat Thickness (cm.)						
0.64		24	1.73[a]	1.72[a]	0.06	0.06
1.27		30	1.59[a]	1.59[a]	0.06	0.05
1.91		19	1.55[a]	1.59[a]	0.07	0.07

[1]Means within columns having different superscript letters are significantly different (P<.05)/

[2]Carcass shrinkage adjusted for rate of cooling.

Coolers

Twenty-four and forty-eight hour shrinkage means for coolers A and B differed significantly ($P<0.01$) from cooler C as shown in Table 9. Coolers A and B had 0.69 and 0.77% less carcass shrinkage as compared to cooler C the first 24 hours post-mortem. Shrinkage means 24 to 48 hours post-mortem were twice as high for coolers A and B as compared with cooler C. The 48 hour totals for these two coolers were still significantly less than for cooler C. Since the major portion of shrinkage occurs 24 hours post-mortem, total carcass shrinkage for 48 hours was decreased when 24 hour shrinkage was minimized. ASHRAE (1971) has shown that 90% of the total carcass weight loss occurs within 48 hours after slaughted. Hagen (1954) has shown that carcass shrinkage during shipment was similar for all cattle no matter what the shrinkage the first 24 hours post-mortem.

In Table 7 shrinkage means for cooler by weight interaction are presented. In coolers A and B the 24 hour shrinkage means for weight groups 1, 2, and 3 did not differ significantly ($P<.05$).

In Tables 1 and 2, refrigeration capacity and cooler environments are presented. Actual cooler load for plant A and B in Table 1 were within design capacity. Plant C exceeded the design capacity of the cooler by 150 cattle, which may explain part of the increase in carcass shrink.

Cooler air temperature for plant C was 1.7°C warmer than plant B. Overload conditions in plant C caused a 12° variation in air temperature as compared to 3.5° variation under the more optimum conditions in plant B. Retrum (1958) found that temperature fluctuation of 0° to 10°C at flank height was due to inadequate evaporator capacity. The limited coil surface and decreased air circulation in plant C decreased the surface-to-air heat

transfer. Possible reasons are warmer air temperatures and inadequate air flow. Shrinkage was higher in plant C the first 24 hours. Heller (1942) has shown that air temperature affects the initial rate of shrinkage rather than total shrinkage. An industry recommendation of 3 to 4 cattle per ton of refrigeration is commonly used to gauge cooler requirements.

Cooler air velocities in plants A and B were adequate, while air circulation in plant C was inadequate based on recommendations by Hodgson. Hodgson (1970) reported decreased shrinkage and low round temperatures with an air speed of at least .75 m/sec.

Air flow diagrams are presented in Figures 1, 2, and 3. Cooler air flow in plant C was extremely low above and in-between the carcasses. This could be partially attributed to the placement of refrigeration units and the reverse flow of air from the floor mounted units. A common practice is to distribute heavy cold air above the carcass and to allow warmed air to return below the carcass as shown in figures 1 and 2. Cooler humidity apparently did not significantly effect carcass shrinkage 24 and 48 hours after slaughter. Cooler B having a relative humidity of 65%, produced 24 hour weight loss of 1.34% as compared to cooler A humidity of 85% and 1.42% shrink. In plant B, low humidity can be partially due to the chill brine spray and lower air temperatures. Hodgson's 1970 findings show that the larger the temperature difference of the refrigerant passing through the evaporator and air passing over the coil, the lower the relative humidity.

Findings by Golovkin, Chizhov and Alamovsl(1955) have shown that humidity is more critical during the last 12 hours of chill, since moisture is readily available during the beginning of the chill cycle from wash water.

TABLE 9. EFFECT OF COOLER A, B, AND C ON 24 AND 48 HOUR CARCASS SHRINKAGE

Cooler	n	24 Hours		24-48 Hours		Total Shrinkage 48 Hours
		Mean (%)	S.D.	Mean (%)	S.D.	Mean (%)
A	20	1.42[a]	0.07	0.54[a]	0.04	1.96
B	21	1.34[a]	0.06	0.43[a]	0.05	1.77
C	32	2.11[b]	0.06	0.24[b]	0.05	2.35

[1]Means within the same column bearing similar superscript letters are not significantly different ($P<.01$).

Carcass Temperature

Internal round temperatures at 24 hours post-mortem were not significantly different ($P<.05$) for coolers or fat groups. Round temperatures (Table 10) did differ significantly ($P<.05$) between weight groups. Internal temperatures for 250 Kg. carcasses were 3.1°C lower than the heavier weight groups studied. Loin temperatures taken at the twelfth rib, 24 hours post-mortem averaged 4.7°C and ranged from 2.2°C for lighter carcasses to 6.7°C for heavy carcasses. Internal chuck temperatures at 24 hours averaged 6.7°C.

Round and chuck temperatures after 21 hours chill were not highly correlated (0.15 and -0.03) with 24 hour shrinkage. It is important to note that shrinkage was significantly different among coolers even though 24 hour round temperatures were the same for beef in different coolers. Carcass cooling rates for coolers A, B, and C are presented in the Appendix Fig. B-J, L-T and V-DD. In the present study all carcasses selected were high good to high choice in quality which could explain the similarity in 24 hour carcass temperatures. Bouton (1958) reported differences in carcass temperatures between choice and canner grade beef.

It appears that chillrooms have more influence on minimizing shrinkage than does fat or weight. An adequate chillroom can cool carcasses of different weights with similar shrinkages. Carcasses with fat thickness of approximately 1.27 cm. appears to be sufficient to reduce shrinkage.

TABLE 10. CARCASS ROUND TEMPERATURE MEANS AND STANDARD DEVIATIONS FOR COOLERS, WEIGHT GROUPS AND FAT GROUPS

Coolers	n	Temp. Mean (C°)	S. D.
A	25	11.5[a]	0.98
B	26	11.5[a]	1.03
C	21	11.7[a]	1.16
Fat Groups (cm)			
0.64	25	11.6[a]	1.08
1.27	26	11.5[a]	0.88
1.91	21	11.6[a]	1.19
Weight Groups (Kg)			
250	25	9.5[a]	1.11
295	26	12.6[b]	0.97
340	21	12.6[b]	1.10

[1]Means within the same column with different superscript letters differ significantly ($P<.05$).

SUMMARY

The effect of beef carcass weight and fat thickness on shrinkage differences at 24 and 48 hours when chilled by the three different refrigeration systems was studied. Carcass cooling rates were determined for each carcass by recording temperatures in the round interior and in the chuck for 24 hours post-mortem. Chillroom atmospheres were studied to determine relationships to carcass shrinkage.

Moisture losses from the surface fat and subsurface lean were higher for the round than the chuck and less impedement of moisture evaporation due to less fat covering.

Fat thickness affected 48 hour weight loss more than that at 24 hours. Carcass weight at 24 and 48 hours showed that lighter carcass (251 kg.) shrank 0.10 to 0.20% more than those averaging 295 and 340 kg. A significant ($P<.05$) cooler by weight interaction suggests that cooler design can reduce the effect of carcass weight and fat cover on shrinkage.

Results show that 81% of the 48 hour carcass shrinkage occurred 24 hours post-mortem, while 19% occurred the second 24 hours. A chillroom air temperature of 1.6°C resulted in lower shrinkage. Chillroom air velocity of 0.75 m/sec at the surface of the carcass was sufficient to decrease carcass temperature and minimize shrinkage compared to velocity of 0.35 m/sec. Cooler humidity the first 24 and 48 hours did not significantly affect shrinkage. Mean round and chuck temperatures at 24 hours were 11.7° and 6.7°C.

LITERATURE CITED

ASHRAE Guide and Data Book, 1971. Meat Products, Part I: Carcass chilling and holding. New York, N. Y.

Bouton, R. E., A. Howard and R. A. Lawrie, 1958. Studies on beef quality. 7. The influences of certain holding conditions on weight losses and eating quality of fresh and frozen beef carcasses. C.S.I.R.O. Melbourne, Australia. Technical paper 8.

Field, R. A. and M. L. Riley. 1968. Effect of weight and fat on lamb carcass shrink. Proc. Western Sec. A.S.A.S. Vol. 19; 247.

Golovkin, N., G. Chizhov, and Alamovsl. 1955. A trial thermophysical timation of the process of cooling foods in the air. Proc. 9th Intern. Congress of Refrig. 2, 4:161.

Hagen, H. F. 1954. Turbo-chill in the meat industry. Proc. 6th Res. Conf. Amer. Meat Inst. Found. p. 59.

Heller, W. 1942. Research reveals how meat shrinks. Food Ind. p. 50.

Hodgson, T. 1970. The effect of air velocity and evaporator size on product weight losses in carcass chilling rooms. Intern. Instit. Refrig. Commission II, IV, V, VII, Leningrad. Annexe Bull. 3:161.

Hodgson, T. 1964b. The rapid chilling of meat. II. Chilling of carcasses. Food Industries of South Africa. March p. 36.

Kleiber, M. 1961. The Fire of Life. John Wiley and Sons, Inc., N. Y., pp. 81-85.

Lurie, H. A. 1966. Refrigeration for the Meat Processing Plant. Amer. Meat Institute.

Rea, R. H., G. C. Smith and Z. L. Carpenter. 1970. Factors affecting lamb carcass shrinkage. Sheep and Angora Goat, Wool and Mohair. Tex. Agr. Exp. Sta. Res. Rpt. 2742.

Retrum, R. 1958. Beef carcass chilling and holding. Refrig. Engr. p. 63.

Stringer, W. C., M. E. Bilskie and H. D. Naumann. 1969. Microbial profiles of fresh beef. Food Technol. 23:97.

THIS BOOK CONTAINS NUMEROUS PAGES THAT WERE BOUND WITHOUT PAGE NUMBERS.

THIS IS AS RECEIVED FROM CUSTOMER.

APPENDIX

APPENDIX A

Analysis of Variance

Source	d.f.	Mean Square: Beginning carcass wt.	Mean Square: Shrinkage (24 hr.)
Cooler	2	102.60161	3.96635**
Fat	2	360.57813	0.16892
Weight	2	35904.68750**	0.10509
Cooler x fat	4	140.52708	0.06467
Cooler x weight	4	69.25516	0.31697*
Fat x weight	4	270.17603	0.03647
Cooler x fat x weight	8	96.01414	0.03772
Error	46	212.52079	0.08027

*P<.05.

**P<.01.

APPENDIX B

Analysis of Covariance

Source	d.f.	Mean Squares	
		Shrinkage (round temp.)	Shrinkage (chuck temp.)
Cooler	2	3.81218**	4.00333**
Fat	2	0.12468	0.14097
Weight	2	0.21503*	0.16135
Cooler x fat	4	0.04438	0.07409
Cooler x weight	4	0.38970*	0.36731*
Fat x weight	4	0.04734	0.03881
Cooler x fat x weight	8	0.06567	0.04672
Time	1	0.56160*	0.49162*
Cooler temperature	1	0.12125	0.14834
Humidity	1	0.22048	0.02653
Error	43	0.06448	0.06889

*P<.05.

**P<.01.

APPENDIX C

CARCASS SHRINKAGE FOR 24 AND 48 HOURS BY WEIGHT AND FAT GROUPS FOR COOLER A

Fat Thickness (cm)		Carcass Weight (Kg)		
		249.5	294.8	340.2
0.64 (cm)	[a]Sample No.	5	2	2
	[b]Beg. Wt.	224.89	278.05	314.79
	[c]End Wt.	221.80	273.74	309.34
	[d]Shrink 24 hrs.	1.39	1.55	1.72
	[e]Shrink 48 hrs.	0.73	0.55	0.51
	[f]Rd. Temp. 24 hrs. (C°)	8.8	11.4	14.2
1.27 (cm)		3	2	2
		243.42	279.41	330.66
		240.40	276.01	325.45
		1.24	1.21	1.58
		0.70	0.38	0.44
		10.3	13.7	15.8
1.91 (cm)		2	2	2
		251.39	289.61	325.67
		247.66	285.99	321.14
		1.44	1.25	1.39
		0.54	0.52	0.49
		10.0	12.2	15.8

[a]Sample number per cell
[b]Beg. Wt. or hot carcass weight
[c]Chilled carcass weight at 24 hours
[d]Shrinkage at 24 hrs. = $\frac{\text{Hot carcass weight - Chilled carcass wt. 24 hrs.}}{\text{Hot carcass weight}}$
[e]Shrinkage at 48 hrs. = $\frac{\text{Chilled carcass wt. 24 hrs. - Chilled wt. 48 hrs.}}{\text{Hot carcass weight}}$
[f]Round Temperature 8" depth at the end of 24 hrs. in Centigrade.

APPENDIX D

CARCASS SHRINKAGE FOR 24 AND 48 HOURS BY WEIGHT AND FAT GROUPS FOR COOLER B.

Fat Thickness (cm)		Carcass Weight (Kg)		
		249.5	294.8	340.2
0.64 cm.	[a]Sample No.	[a]2	2	2
	[b]Beg. Wt.	[b]226.34	290.07	335.20
	[c]End Wt.	[c]222.94	285.99	331.34
	[d]Shrink 24 Hr.	[d]1.50	1.40	1.15
	[e]Shrink 48 Hr.	[e]0.50	0.48	0.54
	[f]Rd. Temp. 24 hrs. (C°)	[f]11.1	11.9	12.8
1.27 cm.		2	4	2
		246.30	281.68	318.19
		243.12	277.93	314.11
		1.29	1.33	1.29
		0.46	0.48	0.33
		12.2	13.3	12.2
1.91 cm.		2	2	3
		230.42	292.11	325.37
		227.70	288.03	320.53
		1.18	1.40	1.49
		0.30	0.31	0.51
		10.8	13.3	15.5

[a]Sample number per cell
[b]Beg. Wt. or hot carcass weight
[c]Chilled carcass weight at 24 hours
[d]Shrinkage at 24 hrs. = $\frac{\text{Hot carcass weight - Chilled carcass wt. 24 hrs.}}{\text{Hot carcass weight}}$
[e]Shrinkage at 48 hrs. = $\frac{\text{Chilled carcass wt. 24 hrs. - Chilled wt. 48 hrs.}}{\text{Hot carcass weight}}$
[f]Round temperature (8" depth) at the end of 24 hrs. in Centigrade.

APPENDIX E

CARCASS SHRINKAGE FOR 24 AND 48 HOURS BY WEIGHT AND FAT GROUPS FOR COOLER C

Fat Thickness (cm)		Carcass Weight (Kg)		
		249.5	294.8	340.2
0.64 cm.	[a]Sample No.	[a]4	3	2
	[b]Beg. Wt.	[b]226.68	270.64	321.82
	[c]End Wt.	[c]220.56	264.44	315.92
	[d]Shrink 24 Hr.	[d]2.71	2.29	1.83
	[e]Shrink 48 Hr.	[e]0.27	0.34	0.28
	[f]Rd. Temp. 24 hrs. (C°)	[f]10.7	11.1	11.7
1.27 cm.		7	4	4
		235.93	274.19	326.81
		229.97	268.52	320.91
		2.52	2.07	1.81
		0.25	0.33	0.28
		11.5	11.9	12.8
1.91 cm.		1	3	4
		241.31	290.75	320.80
		236.32	285.15	315.13
		2.07	1.92	1.77
		0.00	0.23	0.14
		8.9	13.9	12.8

[a]Sample number per cell
[b]Beg. wt. or hot carcass weight
[c]Chilled carcass weight at 24 hours
[d]Shrinkage at 24 hrs. = $\frac{\text{Hot carcass weight - Chilled carcass wt. 24 hrs.}}{\text{Hot carcass weight}}$
[e]Shrinkage at 48 hrs. = $\frac{\text{Chilled carcass wt. 24 hrs. - Chilled wt. 48 hrs.}}{\text{Hot carcass weight}}$
[f]Internal round temp. (8" depth) at the end of 24 hrs. in Centigrade.

APPENDIX F

BEEF CARCASS DATA FOR PLANT A

TRIAL I

July 7 No.	Hot car. wt.	Fat th.	Yield grade	% shrink 24 hrs.	lbs. lost in 24 hrs.	% shrink 48 hrs.	lbs. lost in second 24 hrs.	Total shrink	L.E.A.	Kidney %
1	545	.20	1.35	1.10	6	.92	5	2.02	12.1	1.0
1R	380	.10	1.60	1.58	6	.53	2	2.11	8.8	1.5
2	552	.35	1.75	.90	5	.91	5	1.81	11.4	2.0
3	554	.80	3.60	1.44	8	.54	3	1.98	11.3	3.25
4	607	.25	2.80	1.48	9	.66	4	2.14	9.6	2.25
5	612	.40	2.55	.98	6	.65	4	1.63	11.2	1.75
6	643	.75	3.75	1.24	8	.78	5	2.02	10.1	3.5
7	718	.30	1.95	1.95	14	.28	2	2.23	13.4	1.25
8	733	.40	2.45	1.23	9	.82	6	2.05	13.2	2.0
9	718	.85	3.55	1.39	10	.70	5	2.09	11.6	2.0

APPENDIX G

BEEF CARCASS DATA FOR PLANT A

TRIAL II

	Hot car. wt.	Fat th.	Yield grade	% shrink 24 hrs.	lbs. lost in 24 hrs.	% shrink 48 hrs.	lbs. lost in second 24 hrs.	Total shrink	L.E.A.	Kidney %
July 14										
No.										
1	552	.3	1.80	.91	5.0	1.09	6.0	2.00	12.0	1.5
1_2	445	.2	1.40	1.57	7.0	.67	3.0	2.24	11.2	1.5
2	536	.5	3.10	1.49	8.0	.56	3.0	2.05	9.6	2.0
3	522	.5	1.85	1.34	7.0	.96	5.0	2.30	13.4	2.0
4	557	.25	2.00	1.80	10.0	.72	4.0	2.52	11.2	1.75
5	619	.25	1.00	1.53	9.5	.57	3.5	2.10	15.4	1.75
6	620	.50	3.05	1.37	8.5	.56	3.5	1.93	11.1	2.5
6_2	634	.75	3.25	1.26	8.0	.63	4.0	1.89	13.0	3.0
7										
8	725	.5	3.30	1.24	9.0	.41	3.0	1.65	12.1	3.5
9	670	.3	1.55	1.49	10.0	.75	5.0	2.24	14.4	1.75

APPENDIX H

BEEF CARCASS DATA FOR PLANT A

TRIAL III

	Hot car. wt.	Fat th.	Yield grade	% shrink 24 hrs.	lbs lost in 24 hrs.	% shrink 48 hrs.	lbs. lost in second 24 hrs.	Total shrink	L.E.A.	Kidney %
July 15										
No.										
1	579	.70	3.75	1.30	7.5	.26	1.5	1.56	10.7	3.5
2	558	.50	2.80	1.34	7.5	.27	1.5	1.61	10.8	2.0
3	443	.30	2.30	1.13	5.0	.45	2.0	1.58	9.5	2.0
4	640	.55	2.95	1.25	8.0	.31	2.0	1.56	12.6	3.5
4_2	592	.20	2.05	1.18	7.0	.51	3.0	1.69	11.8	3.0
5	623	.50	2.80	1.44	9.0	.32	2.0	1.76	12.2	3.0
6	653	.90	4.45	1.30	8.5	.23	1.5	1.53	10.8	3.5
7	670	.55	2.80	1.42	9.5	.22	1.5	1.64	13.2	3.0
8	728	.60	3.40	1.24	9.0	.41	3.0	1.65	12.0	2.5
8_2	753	.60	3.55	1.20	9.0	.13	1.0	1.33	11.5	2.0
9	696	.85	3.85	1.01	7.0	.29	2.0	1.30	12.5	3.0

APPENDIX I

BEEF CARCASS DATA FOR PLANT B

TRIAL I

July 27 No.	Hot car. wt.	Fat th.	Yield grade	% shrink 24 hrs.	lbs. lost in 24 hrs.	% shrink 48 hrs.	lbs. lost in second 24 hrs.	Total shrink	L.E.A.	Kidney %
1	511	.30	2.85	1.57	8	.59	3	2.16	8.9	2.5
2	553	.55	3.80	1.27	8	.54	3	1.81	8.6	3.0
3	509	.75	4.05	1.57	8	.39	2	1.96	9.0	3.0
4	605	.30	2.45	1.32	8	.66	4	1.98	11.6	3.0
4_2	612	.45	3.15	1.47	9	.49	3	1.96	10.9	3.5
5	619	.50	3.50	1.45	9	.48	3	1.93	9.6	2.5
6	654	.75	3.65	1.22	8	.31	2	1.53	12.3	3.5
7	781	.35	2.70	1.15	9	.51	4	1.66	13.2	3.0
8	692	.50	3.25	1.44	10	.43	3	1.87	11.6	3.0
9	696	1.20	4.85	1.44	10	.57	4	2.01	10.6	3.0
9_2	719	.70	4.07	2.08	15	.42	3	2.50	11.3	3.5

APPENDIX J

BEEF CARCASS DATA FOR PLANT B

TRIAL II

	Hot car. wt.	Fat th.	Yield grade	% shrink 24 hrs.	lbs. lost in 24 hrs.	% shrink 48 hrs.	lbs. lost in second 24 hrs.	Total shrink	L.E.A.	Kidney %
July 28										
No.										
1_2	487	.30	1.30	1.44	7	.41	2	1.86	12.5	1.0
2	533	.50	3.30	1.31	7	.38	2	1.69	9.6	3.0
3	507	.70	2.85	.79	4	.20	1	.99	11.8	2.0
4	616	.50	2.35	1.30	8	.49	3	1.79	13.0	2.0
5	637	.45	3.25	1.10	7	.47	3	1.57	10.9	3.5
soft fat										
6	634	.70	3.80	1.58	10	.32	2	1.90	11.1	3.5
7	674	.20	1.83	1.48	10	.30	2	1.78	12.9	2.0
7_2	697	.30	2.37	1.15	8	.57	4	1.72	12.3	2.0
8	710	.50	2.95	.99	7	.28	2	1.27	12.8	3.0
8_2	711	.60	3.35	1.13	8	.28	2	1.41	11.7	2.0
9	737	.85	4.15	1.09	8	.54	4	1.63	11.3	2.5

APPENDIX K

BEEF CARCASS DATA FOR PLANT C

TRIAL I

Aug. 18	Hot car. wt.	Fat th.	24 hr. wt.	% shrink	second 24 hr. wt.	% shrink	Total shrink	L.E.A.	Quality grade	Yield grade
1	521	.25	507	2.69	506	.19	2.88	10.6	G+	2.20
1_2	488	.40	477	2.25	475	.41	2.66	10.5	C+	2.80
2	462	.25	448	3.03	447	.22	3.25	9.7	G-	2.25
2_2	520	.50	507	2.50	506	.19	2.69	10.3	C°	2.85
3	498	.50	485	2.61	483	.40	3.01	10.5	C-	2.80
3_2	471	.30	457	2.97	455	.42	3.39	10.1	C°	2.40
4	587	.25	573	2.39	572	.17	2.56	12.1	C°	1.95
4_2	580	.15	565	2.59	564	.17	2.76	14.0	Standard	1.00
5	622	.40	608	2.25	607	.16	2.41	11.0	C°	2.75
6	643	.65	629	2.18	629	0.00	2.18	11.8	C-	3.25
7	703	.35	691	1.71	689	.28	1.99	12.9	C°	2.45
8	713	.55	699	1.96	698	.14	2.10	13.1	G+	2.80
9	682	.75	668	2.05	667	.15	2.20	13.0	C+	3.35

APPENDIX L

BEEF CARCASS DATA FOR PLANT C

TRIAL II

Aug. 19	Hot car. wt.	Fat th.	24 hr. wt.	% shrink	second 24 hr. wt.	% shrink	Total shrink	L.E.A.	Quality grade	Yield grade
1	504	.30	492	2.38	491	.20	2.58	11.3	C-	2.15
1_2	477	.50	467	2.10	465	.42	2.52	10.7	C-	2.70
2	549	.50	538	2.00	536	.36	2.36	11.2	C-	2.65
2_2	482	.45	469	2.70	469	.00	2.70	9.8	C-	2.40
3	532	.75	521	2.07	521	.00	2.07	11.0	C-	3.35
4	591	.30	578	2.20	575	.51	2.71	12.8	C-	2.00
5	596	.65	584	2.01	582	.34	2.35	11.2	C°	3.20
5_2	608	.50	599	1.48	596	.49	1.97	12.1	C-	2.80
6	646	.75	635	1.70	632	.46	2.16	9.9	G+	4.15
7	718	.45	705	1.81	704	.14	1.95	12.9	C-	2.85
8	721	.55	708	1.80	705	.42	2.22	10.7	C-	3.80
9	731	.85	719	1.64	718	.14	1.78	11.2	C-	4.40

APPENDIX M

BEEF CARCASS DATA FOR PLANT C

TRIAL III

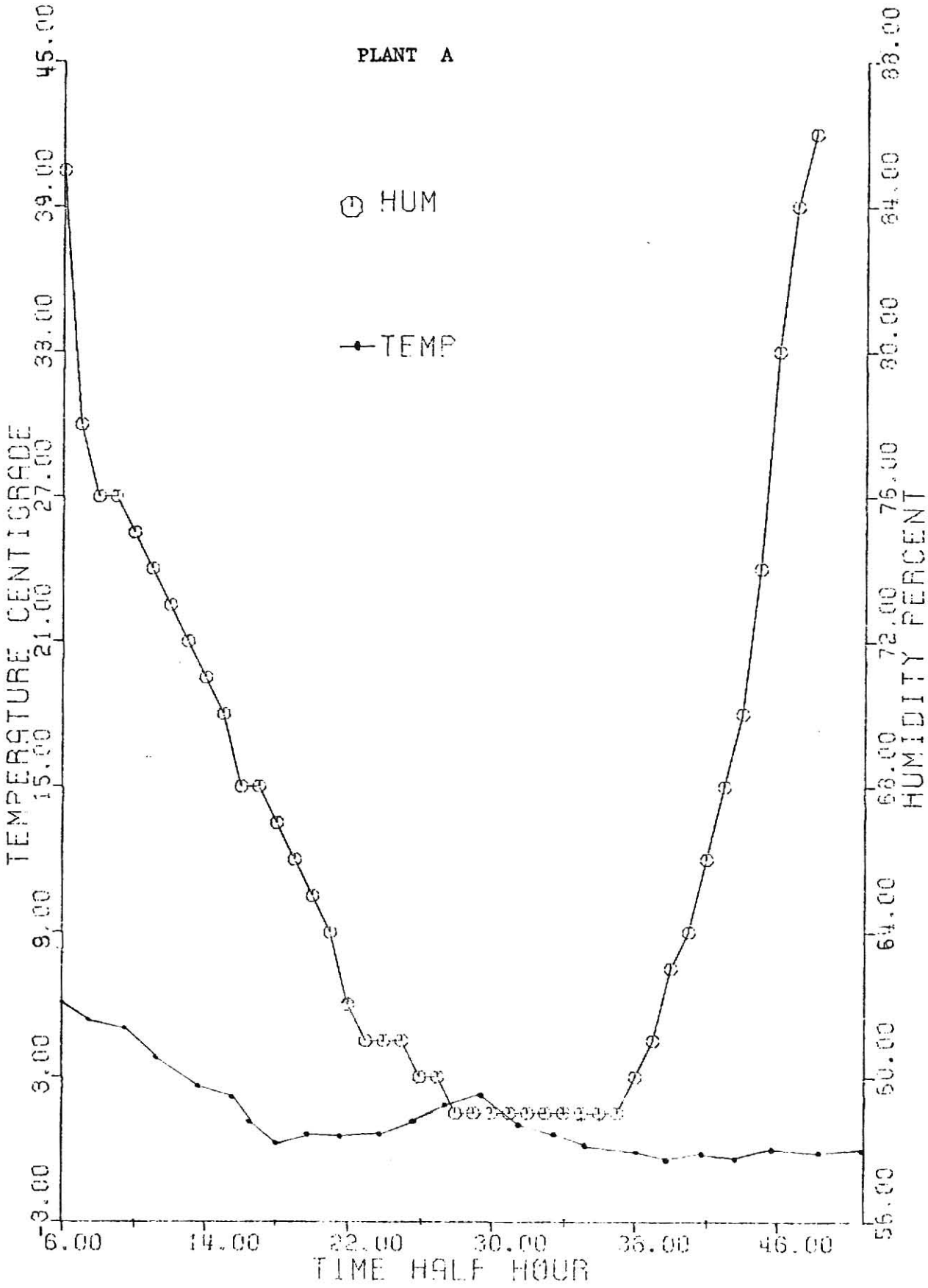
Aug. 20	Hot car. wt.	Fat thickness	24 hr. wt.	% shrink	second 24 hr. shrink	L.E.A.	Quality grade	Yield grade
1	503	.25	489	2.78	2.78	12.0	G-	1.60
2	539	.55	526	2.41	2.41	9.3	G-	3.35
3	545	.50	530	2.75	2.75	10.9	G°	3.05
4	612	.30	598	2.29	2.29	13.2	C+	1.75
5	592	.55	577	2.53	2.53	11.3	C-	3.00
6	634	.65	622	1.89	1.89	10.6	C°	3.65
7	716	.35	702	1.96	1.96	12.4	G+	2.65
8	723	.60	711	1.66	1.66	12.8	C°	3.30
8_2	708	.70	696	1.69	1.69	12.6	C°	3.50
9	730	.50	718	1.64	1.64	13.9	C°	2.80
9_2	708	.90	696	1.69	1.69	12.1	C+	4.15

ILLEGIBLE DOCUMENT

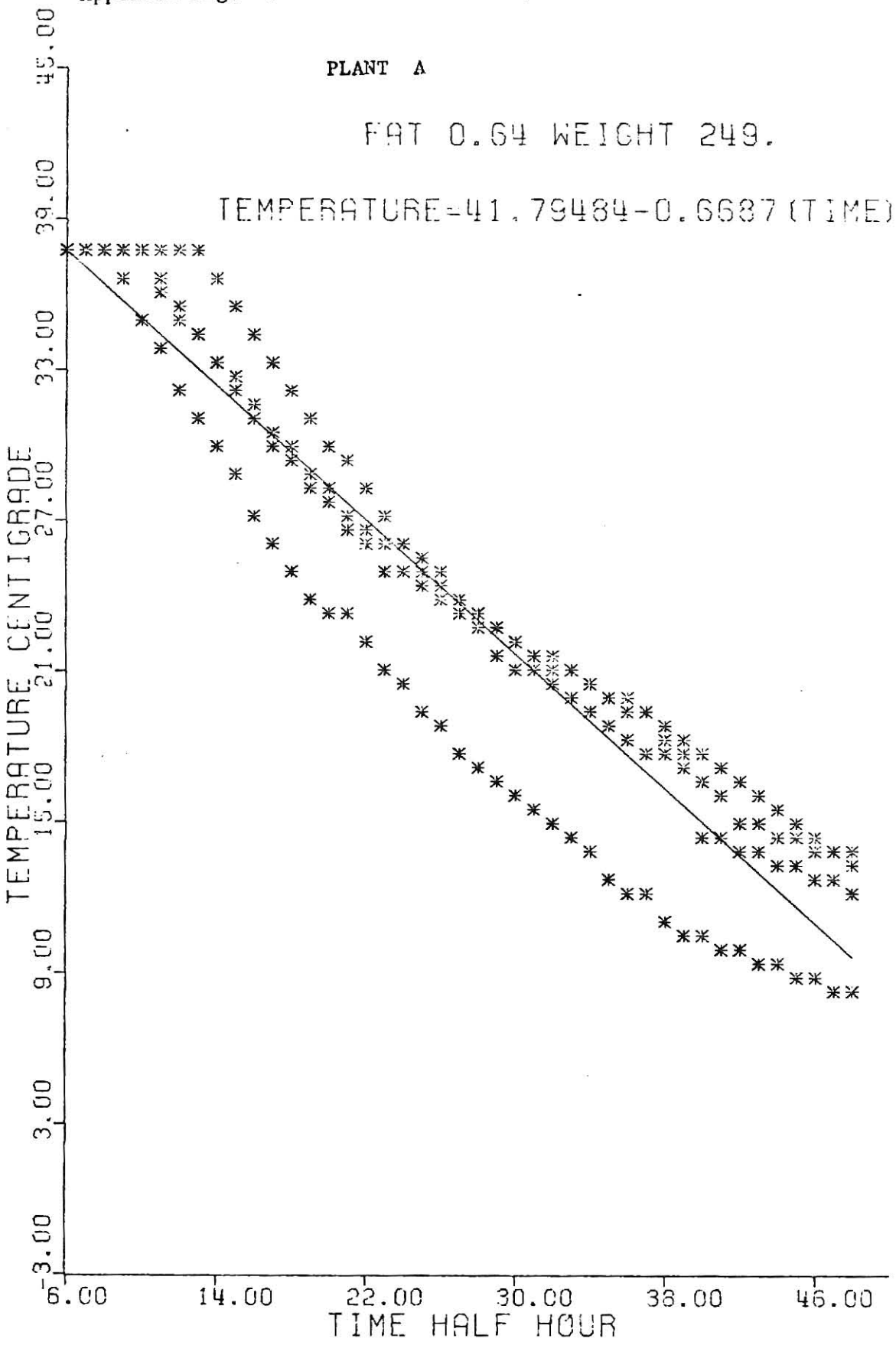
THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

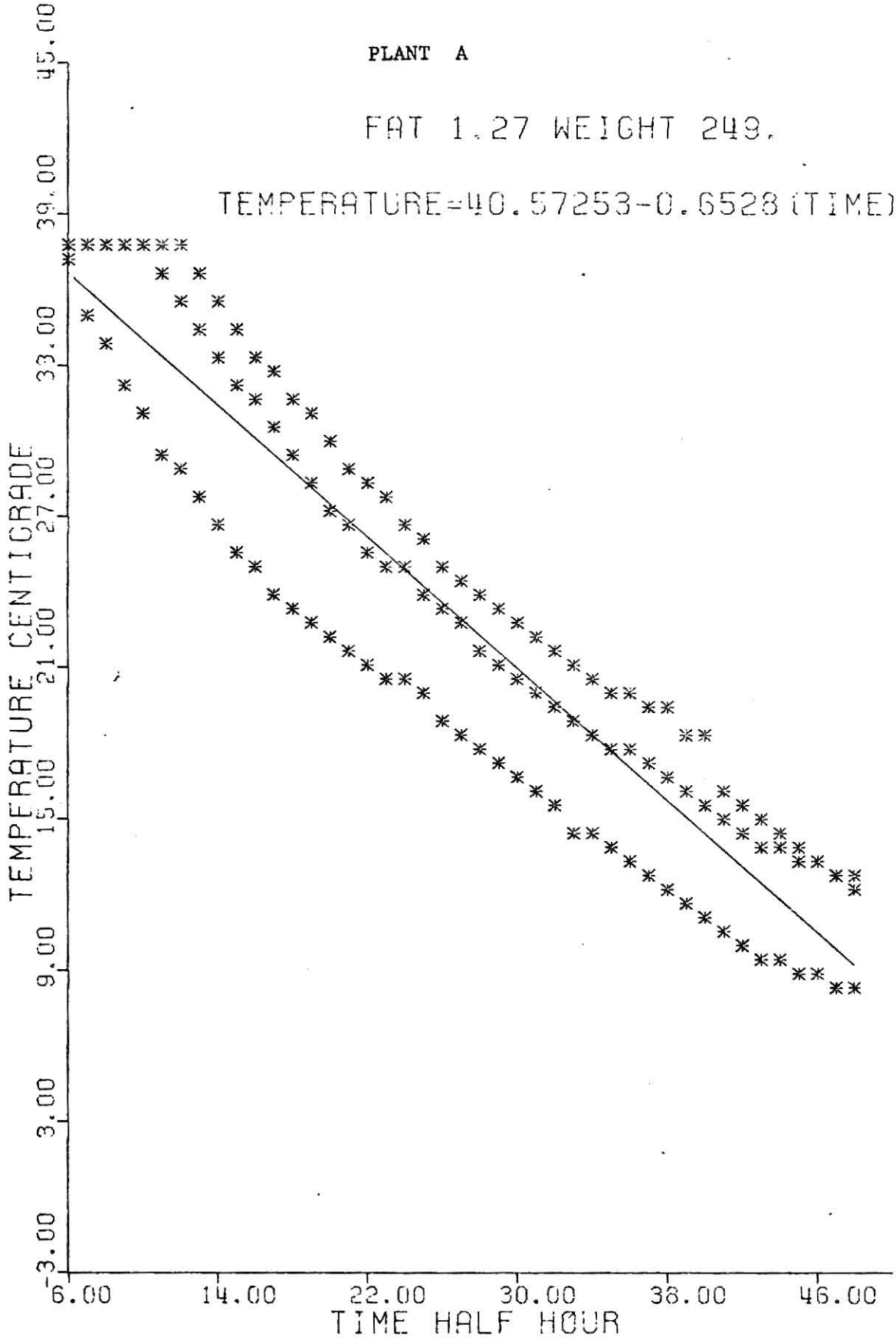
Appendix Fig. A. Chillroom humidity and temperatures (24 hours).



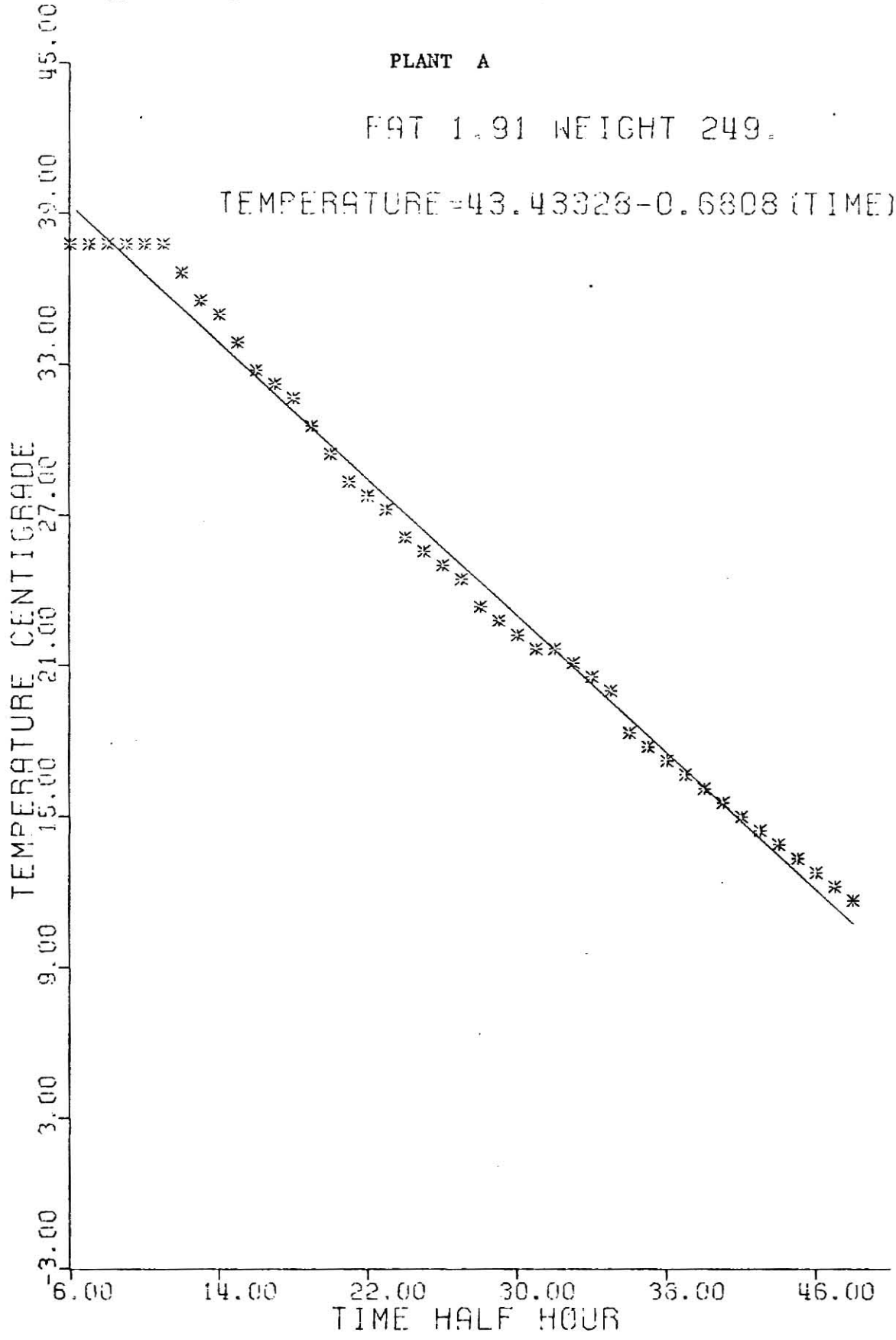
Appendix Fig. B. Internal round temperatures (24 hours).



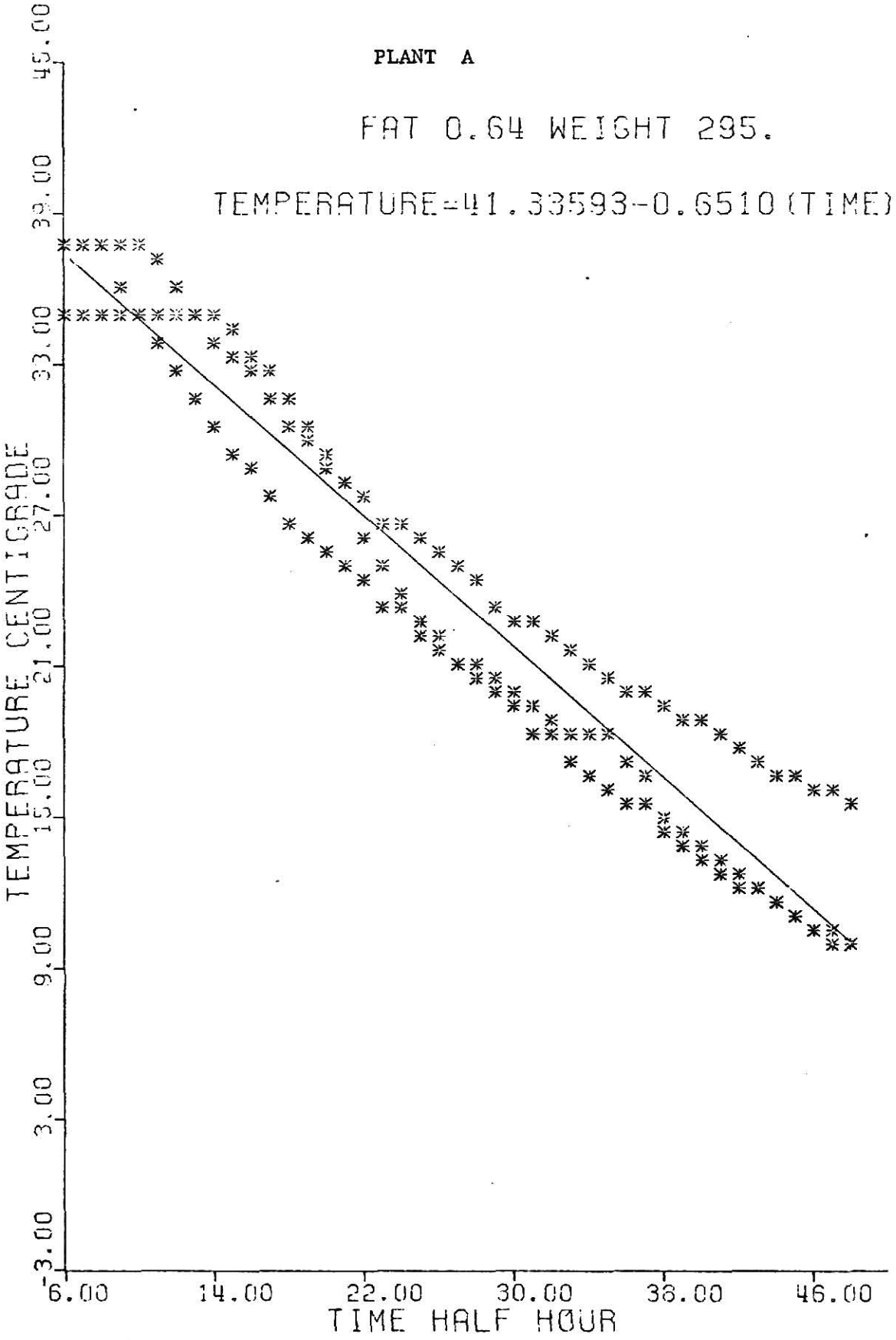
Appendix Fig. C. Internal round temperatures (24 hours).



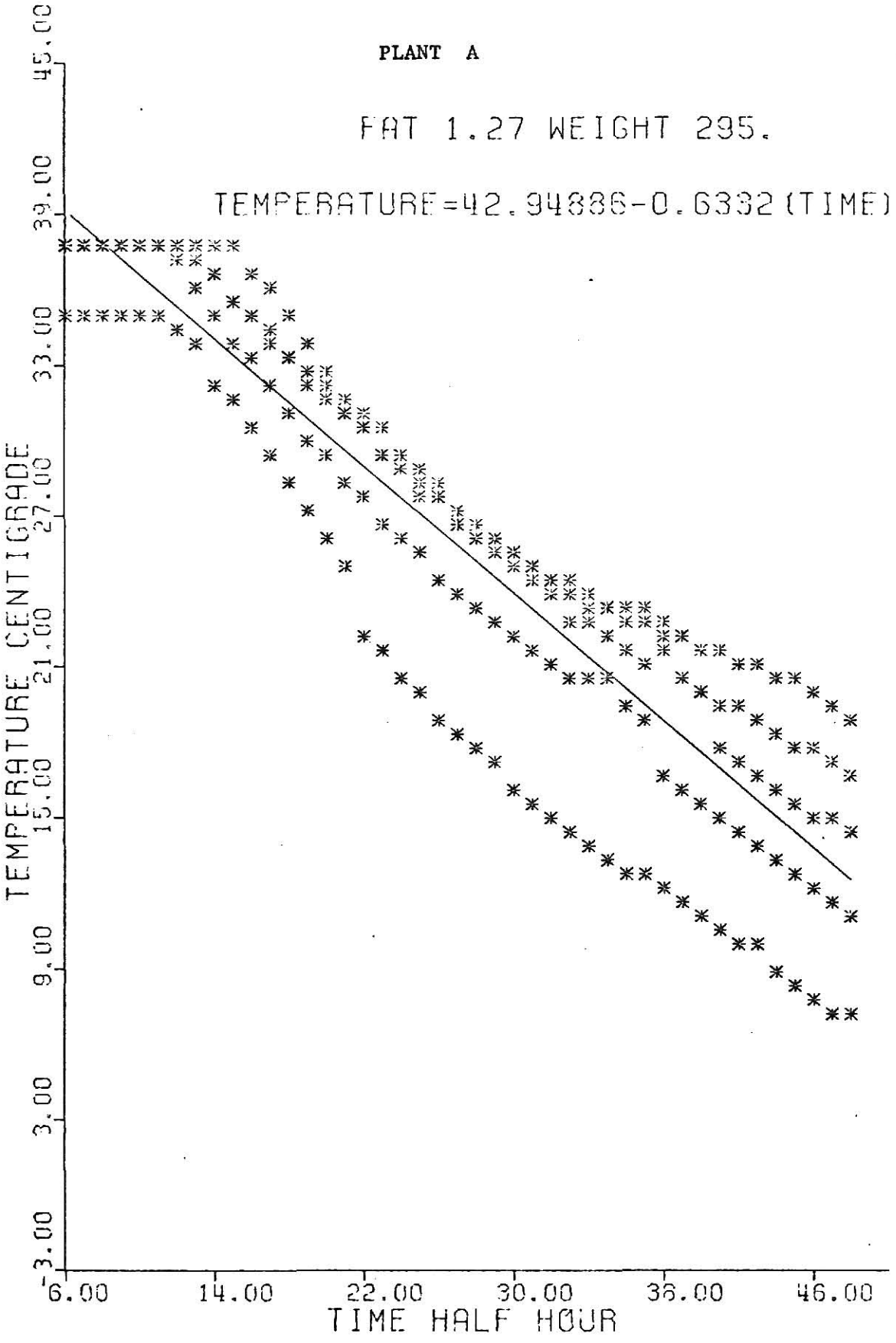
Appendix Fig. D. Internal round temperatures (24 hours).



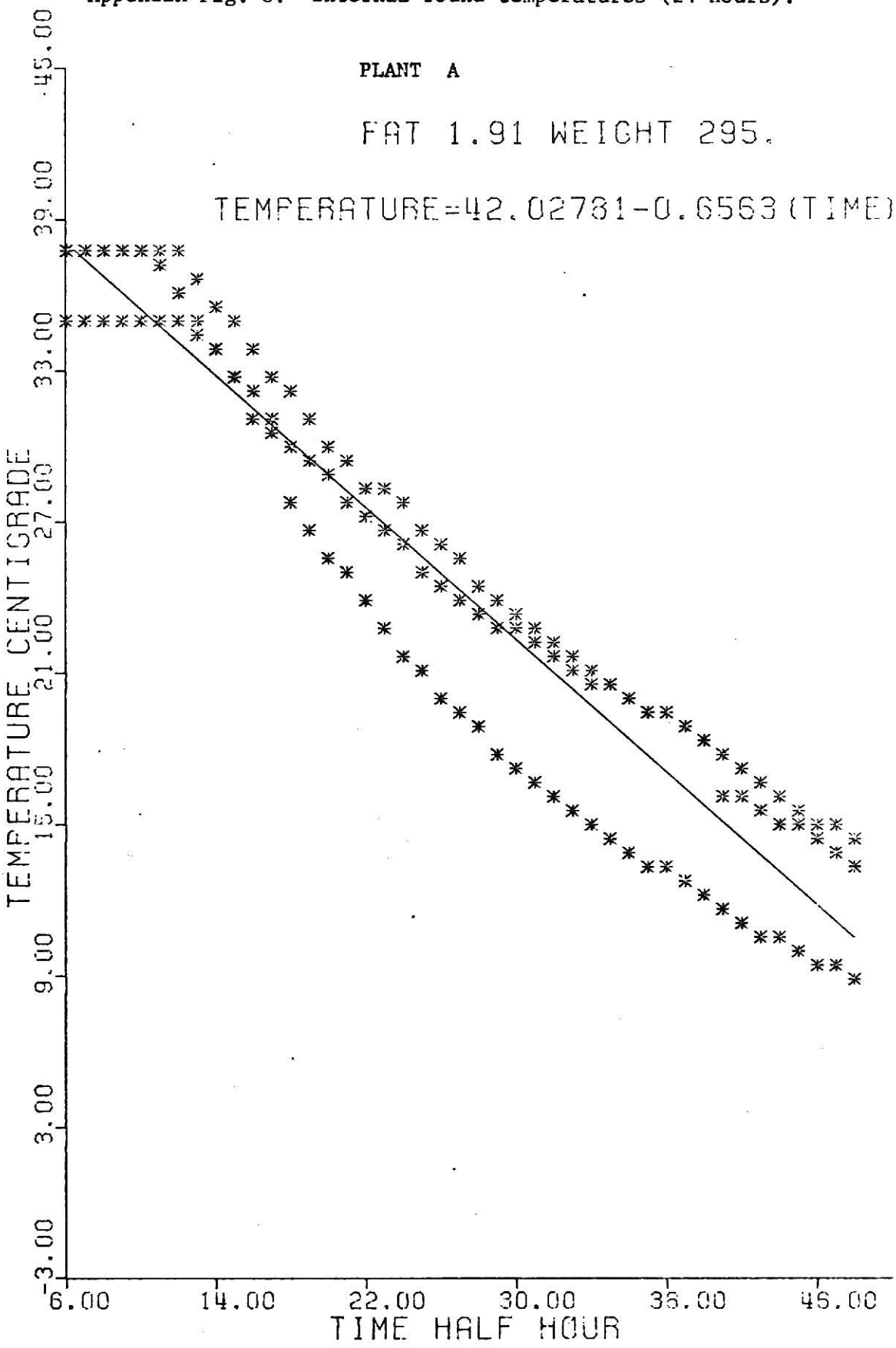
Appendix Fig. E. Interanl round temperatures (24 hours).



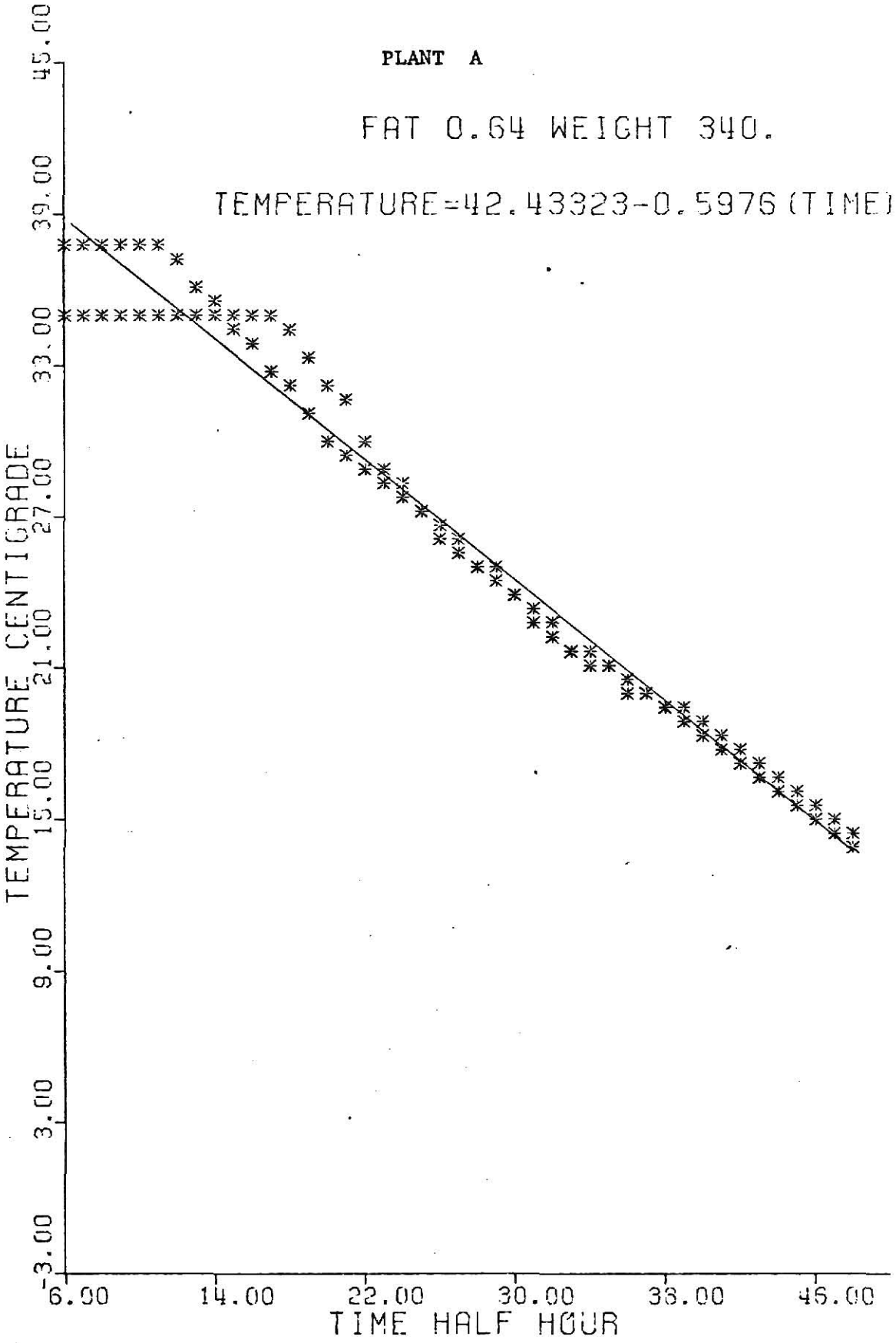
Appendix Fig. F. Internal round temperatures (24 hours).



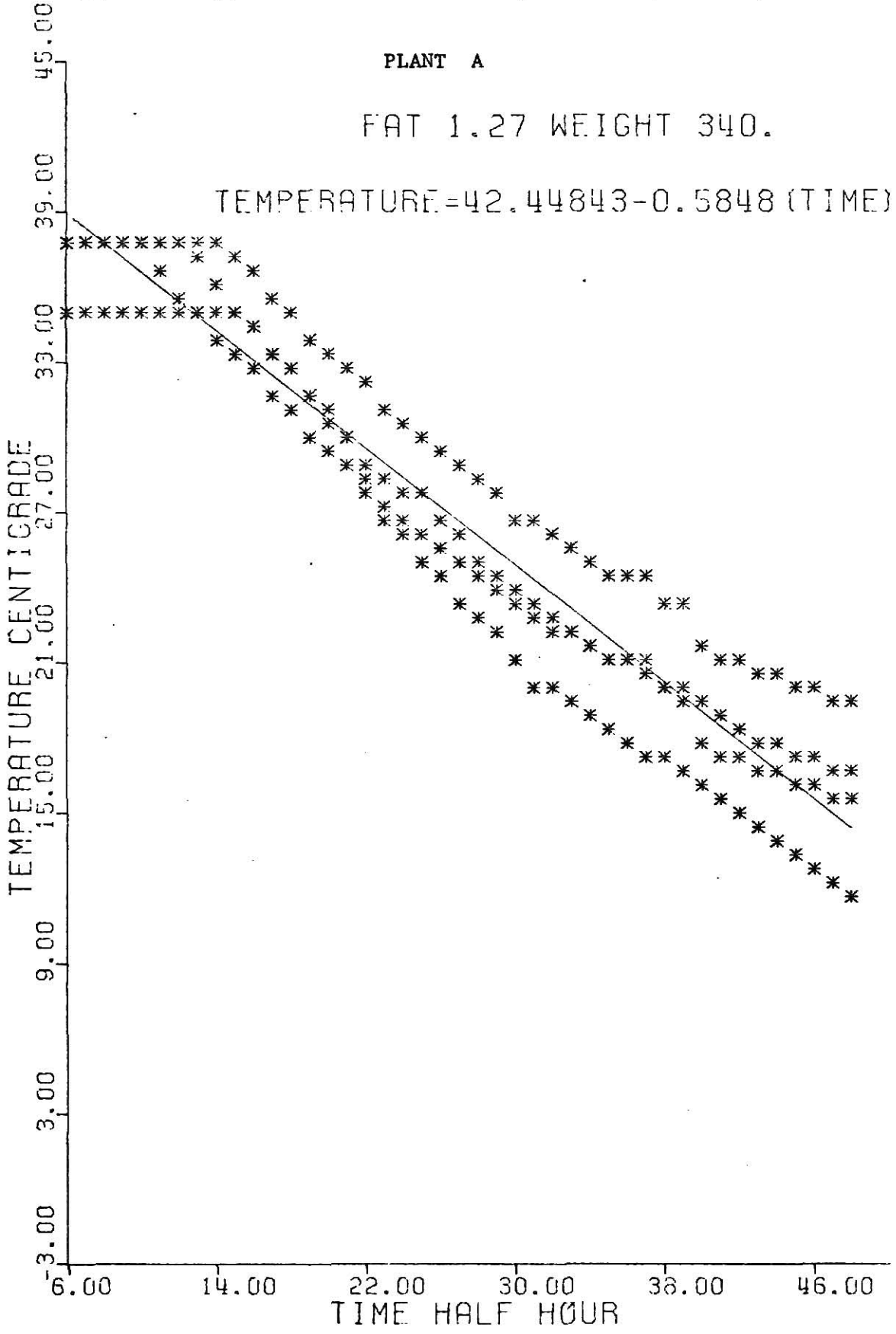
Appendix Fig. G. Internal round temperatures (24 hours).



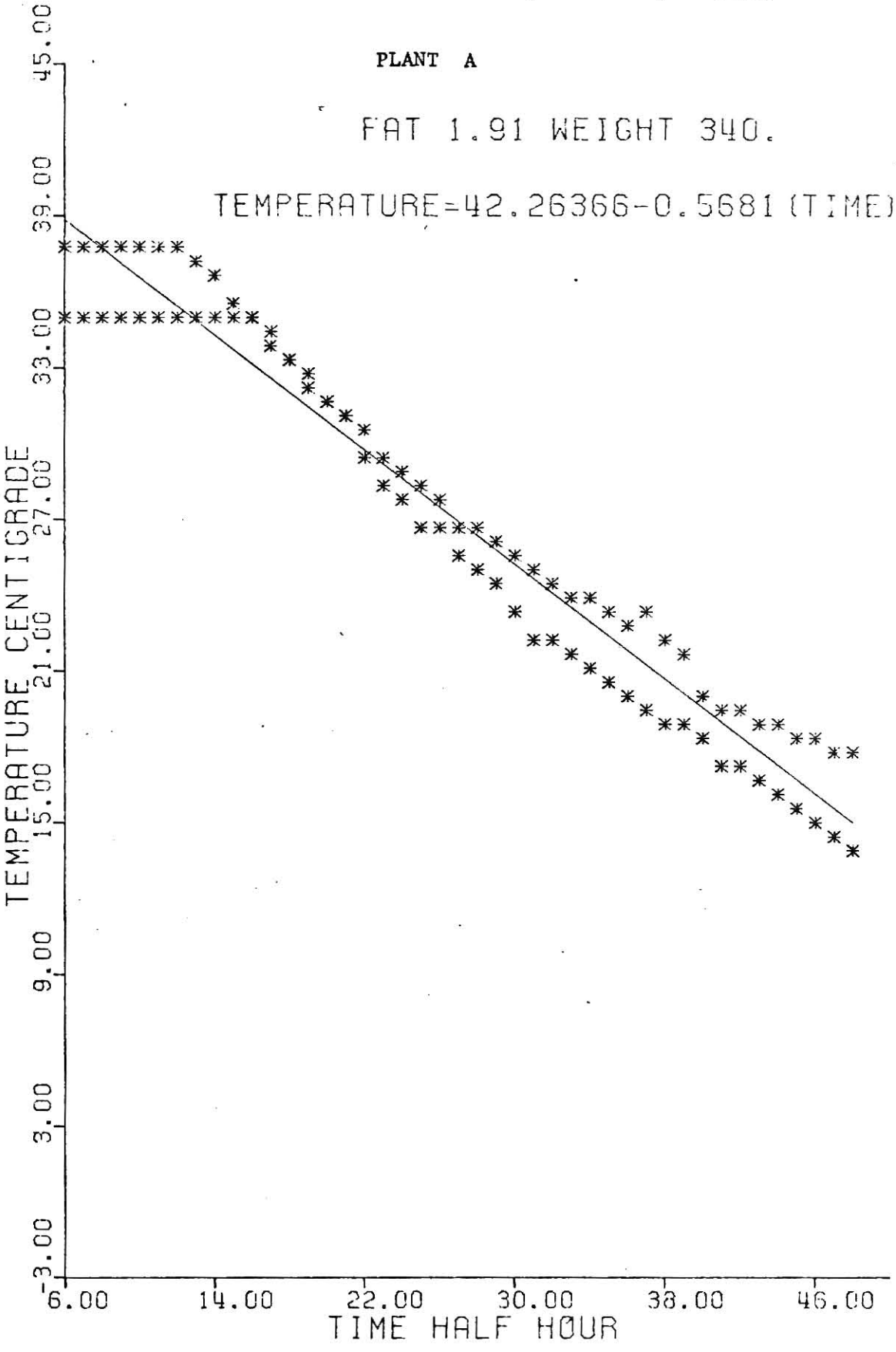
Appendix Fig. H. Internal round temperatures (24 hours).



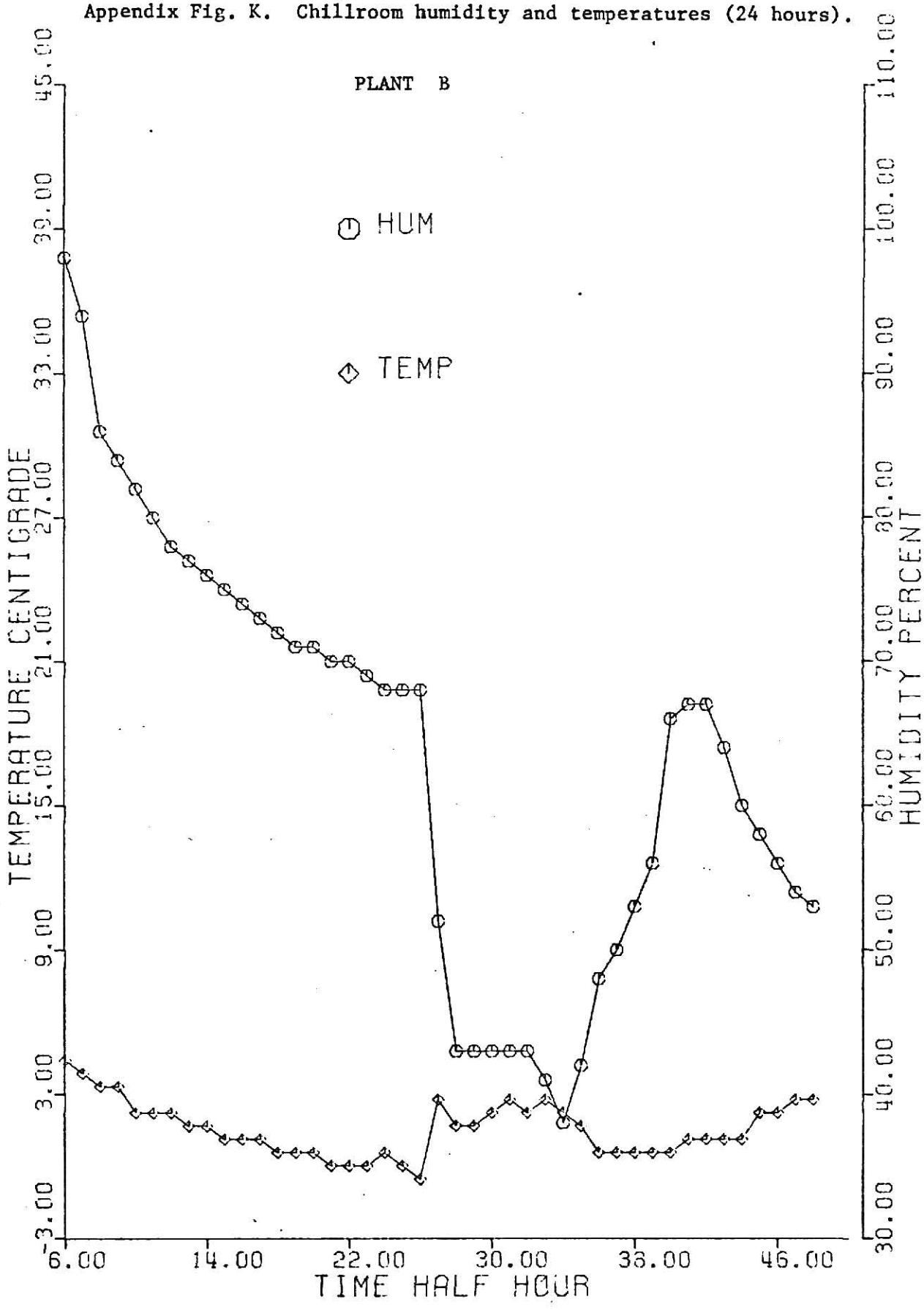
Appendix Fig. I. Internal round temperatures (24 hours).



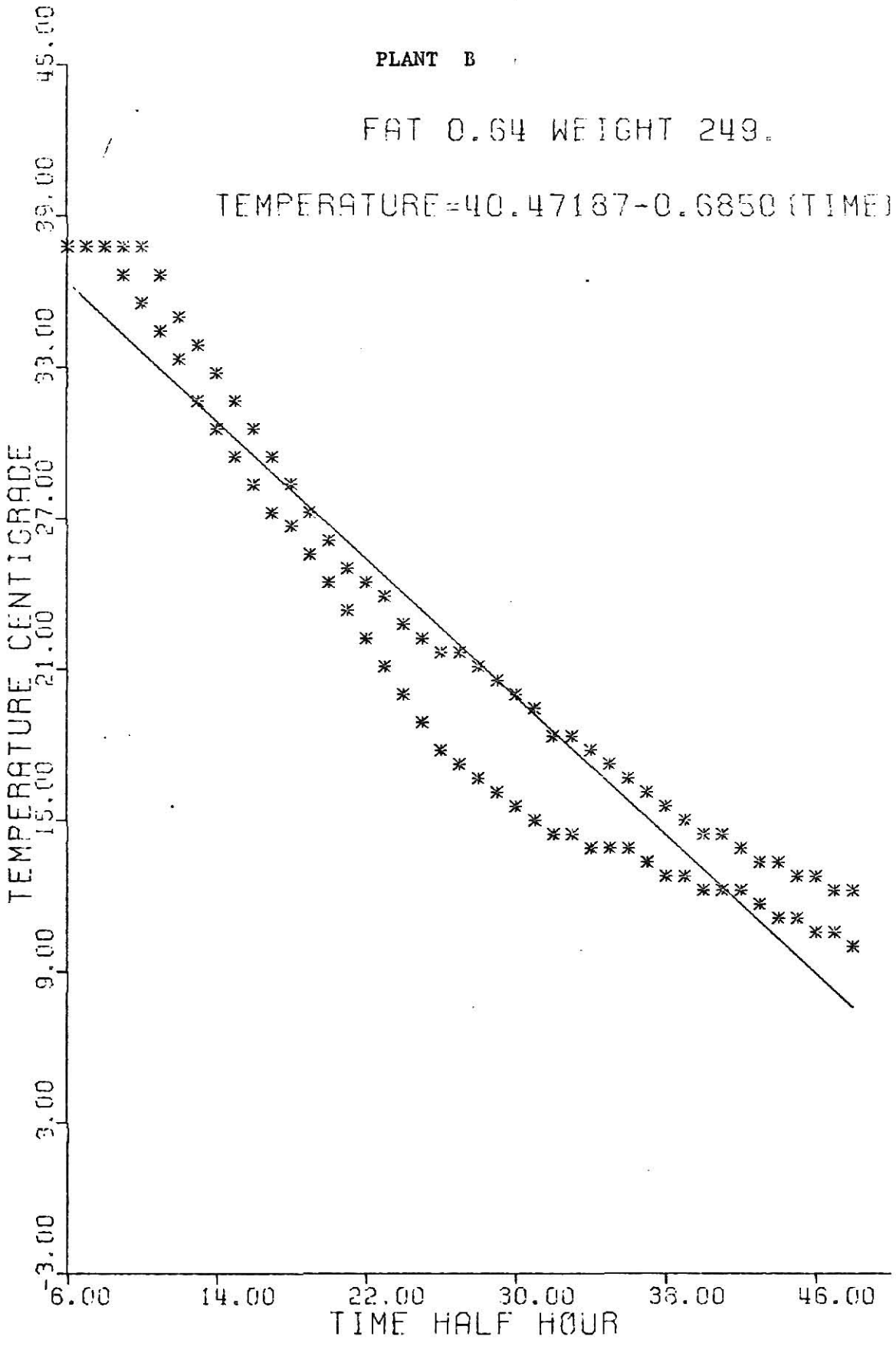
Appendix Fig. J. Internal round temperatures (24 hours)



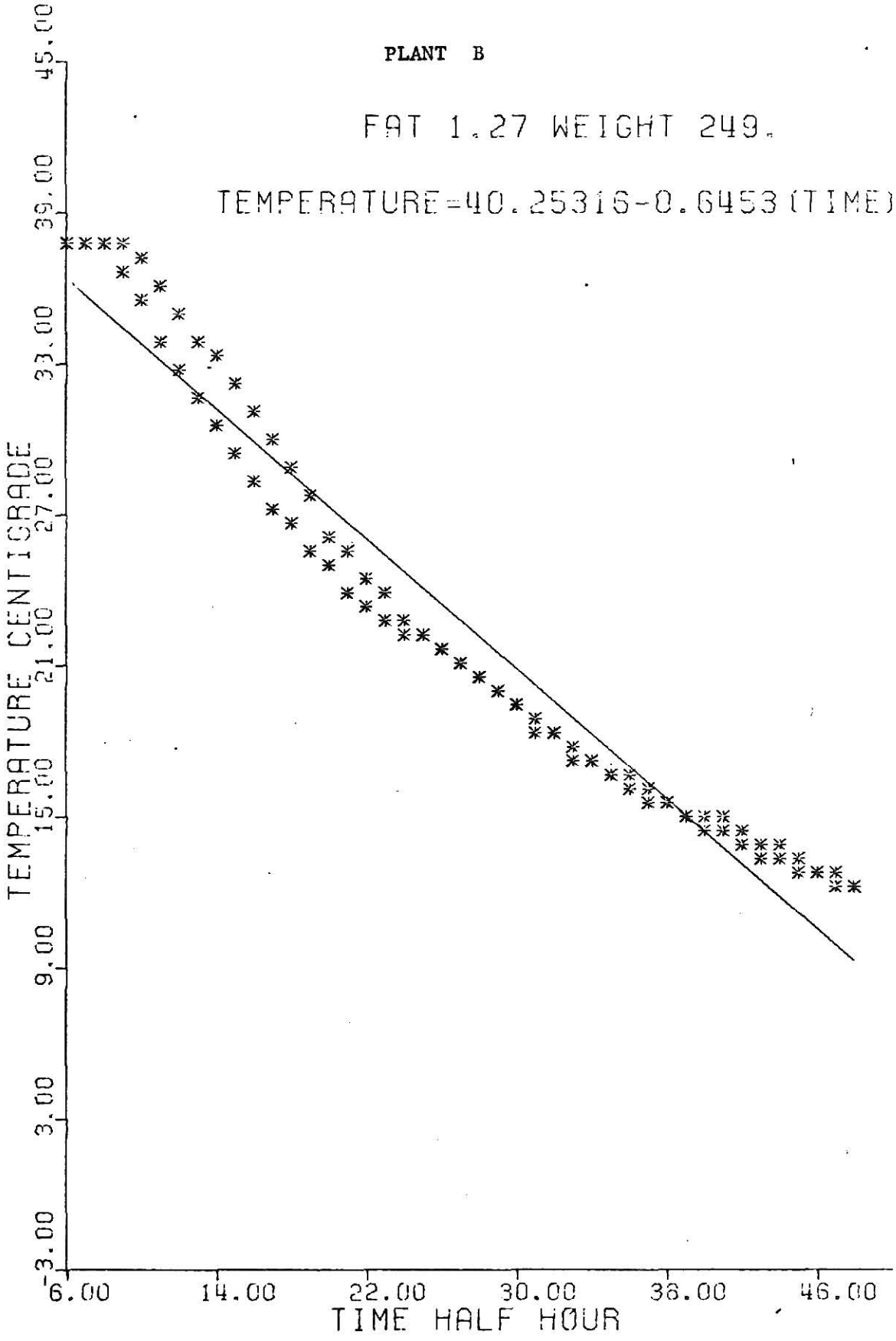
Appendix Fig. K. Chillroom humidity and temperatures (24 hours).



Appendix Fig. L. Internal round temperatures (24 hours).

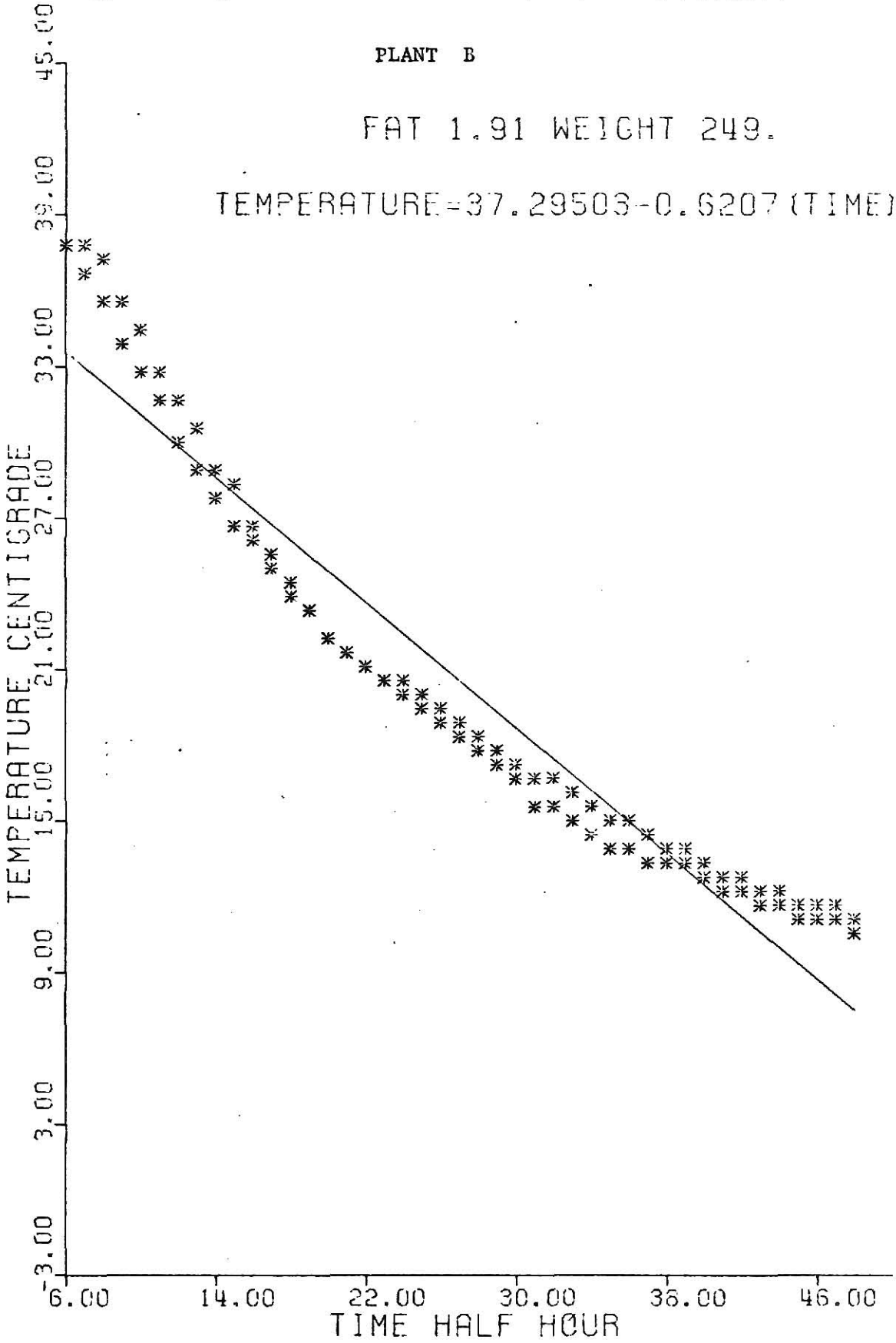


Appendix Fig. M. Internal round temperatures (24 hours).

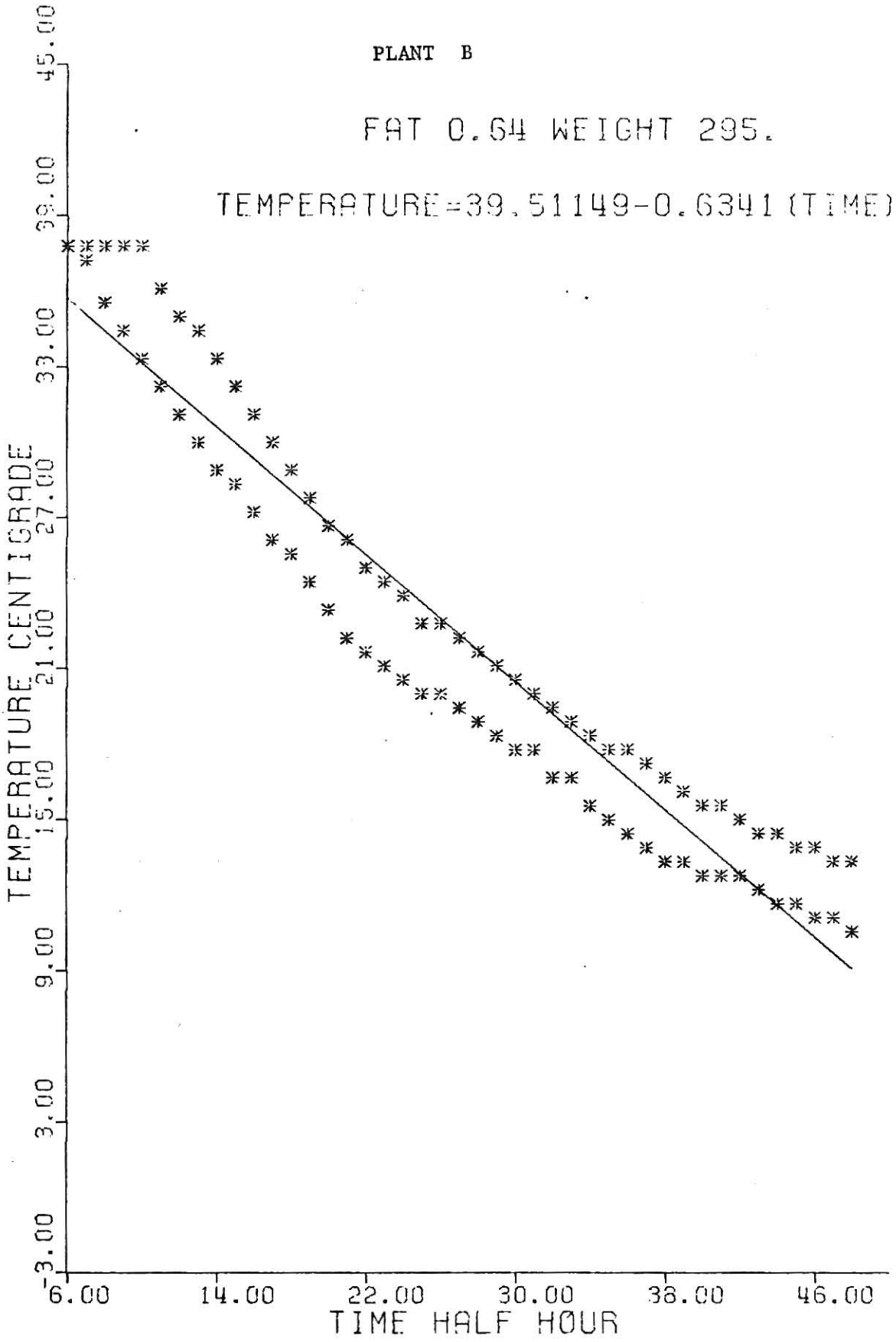


Appendix Fig. N. Internal round temperatures (24 hours).

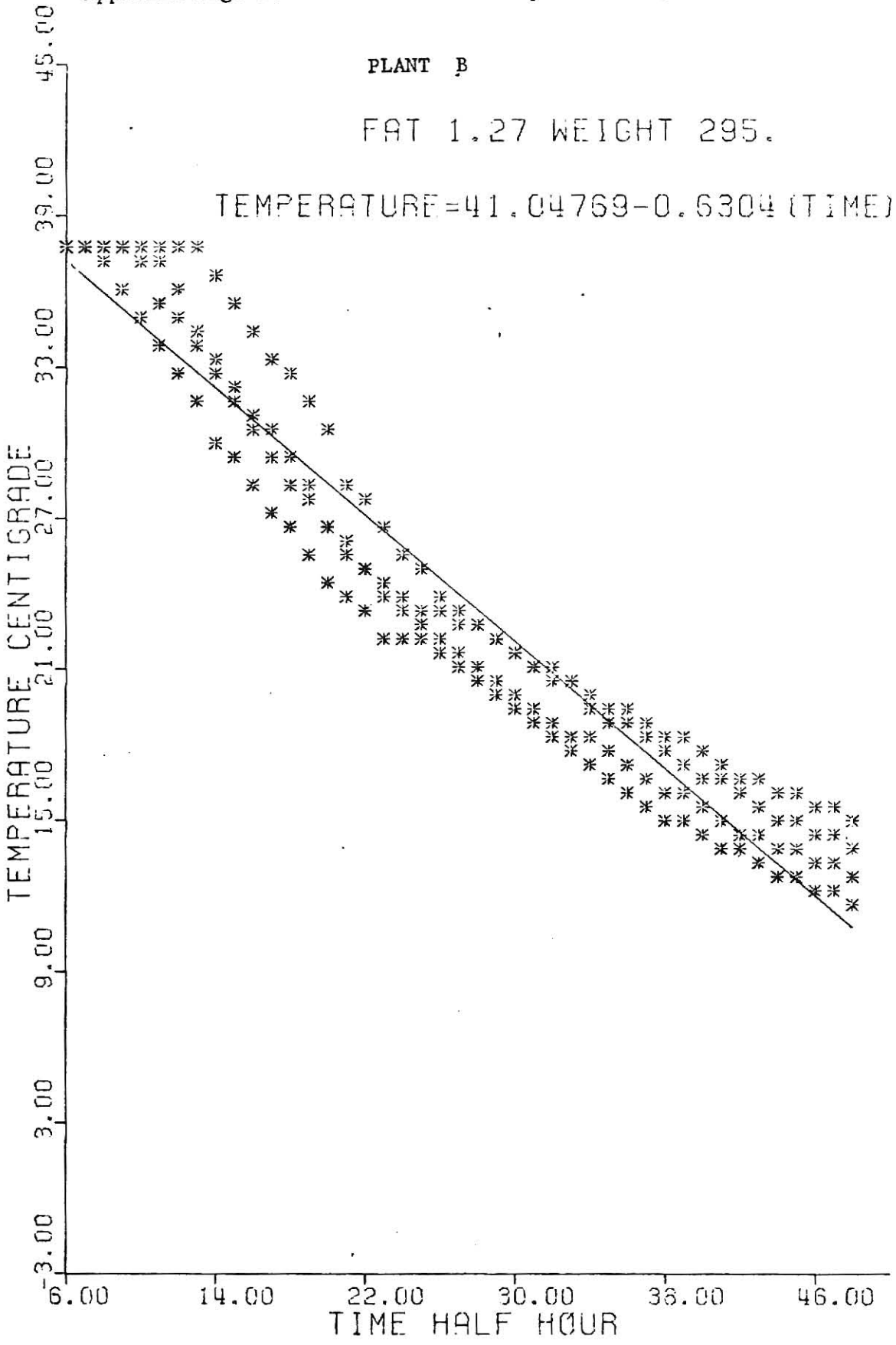
PLANT B



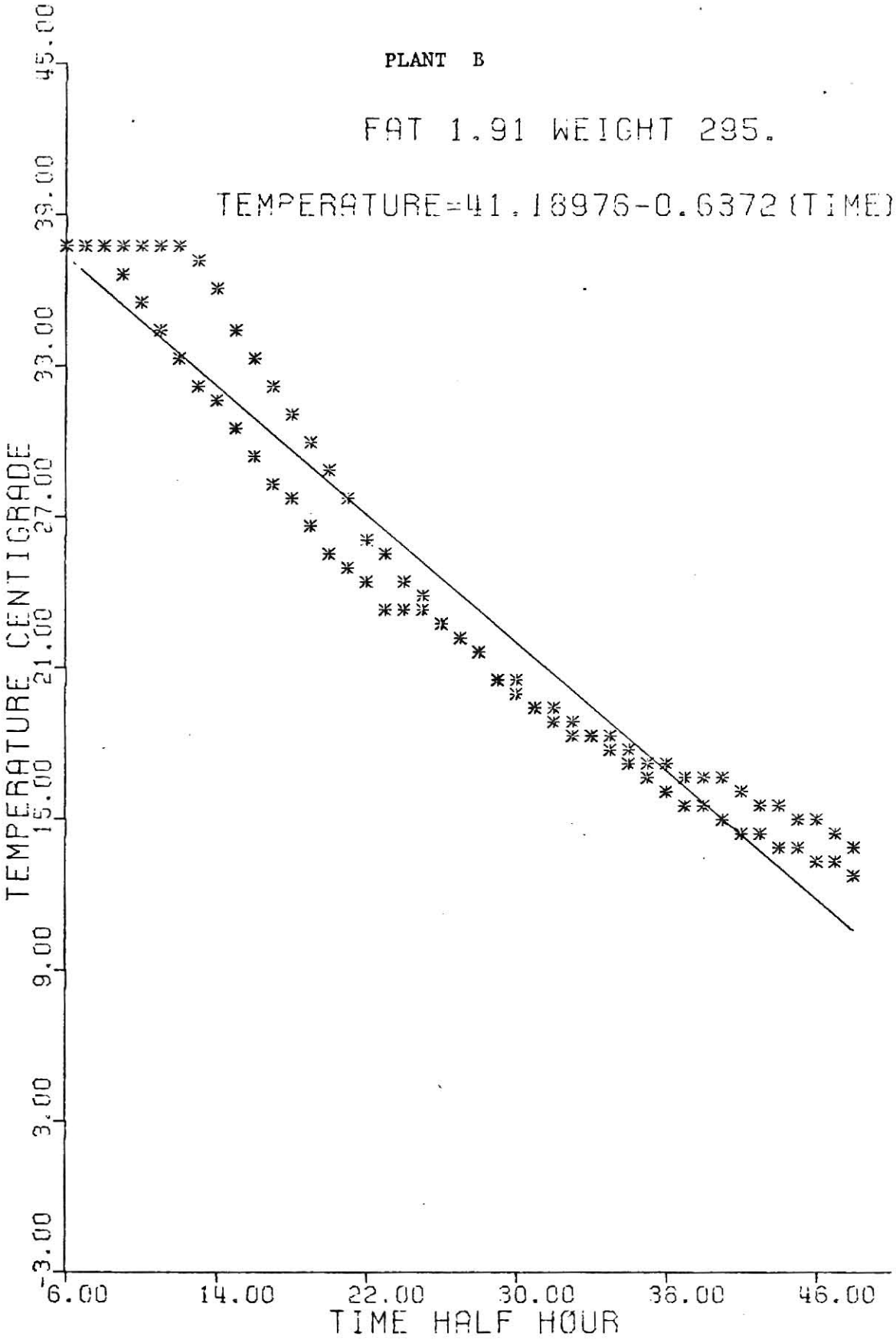
Appendix Fig. 0. Internal round temperatures (24 hours).



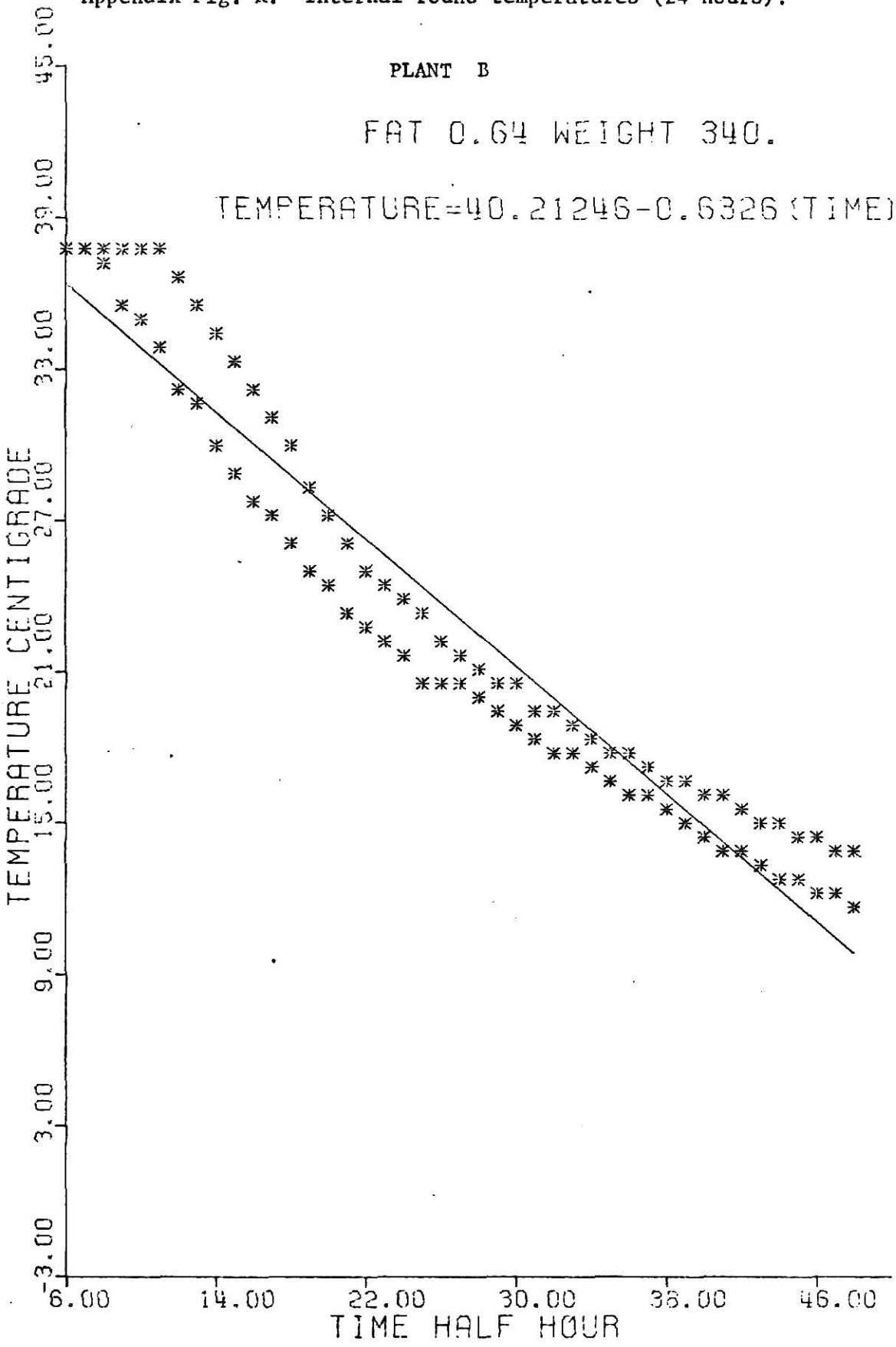
Appendix Fig. P. Internal round temperatures (24 hours)



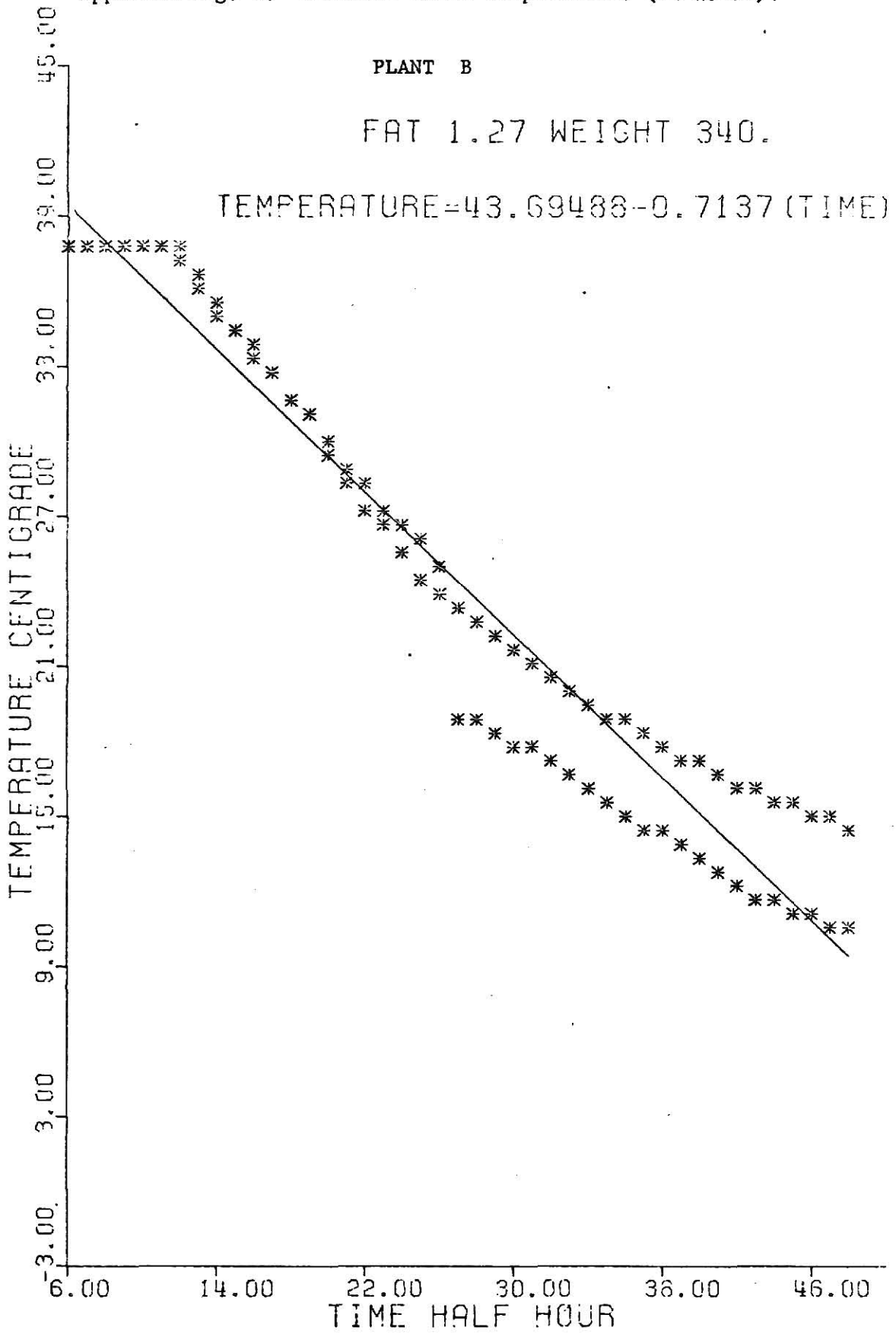
Appendix Fig. Q. Internal round temperatures (24 hours).



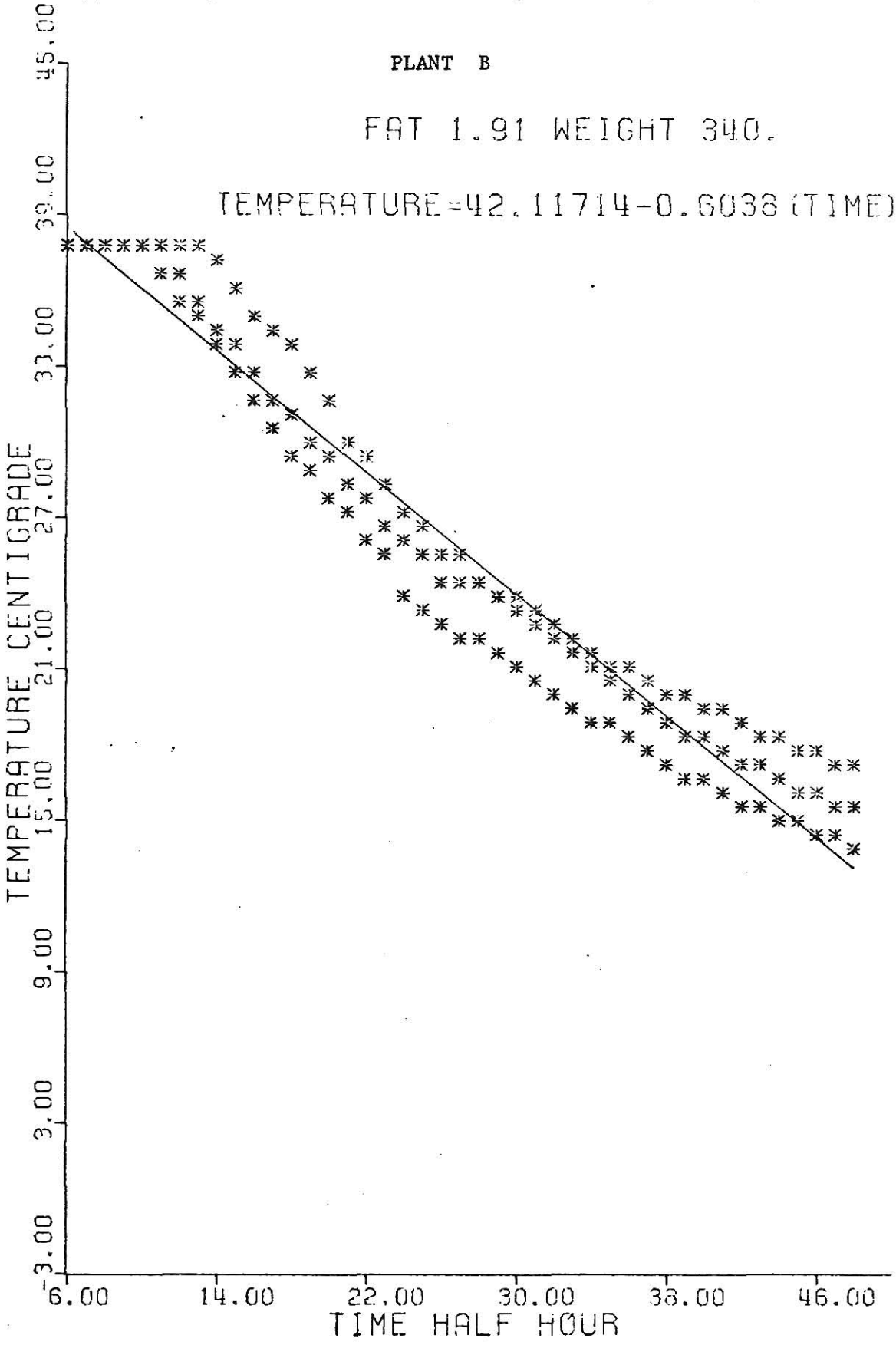
Appendix Fig. R. Internal round temperatures (24 hours).



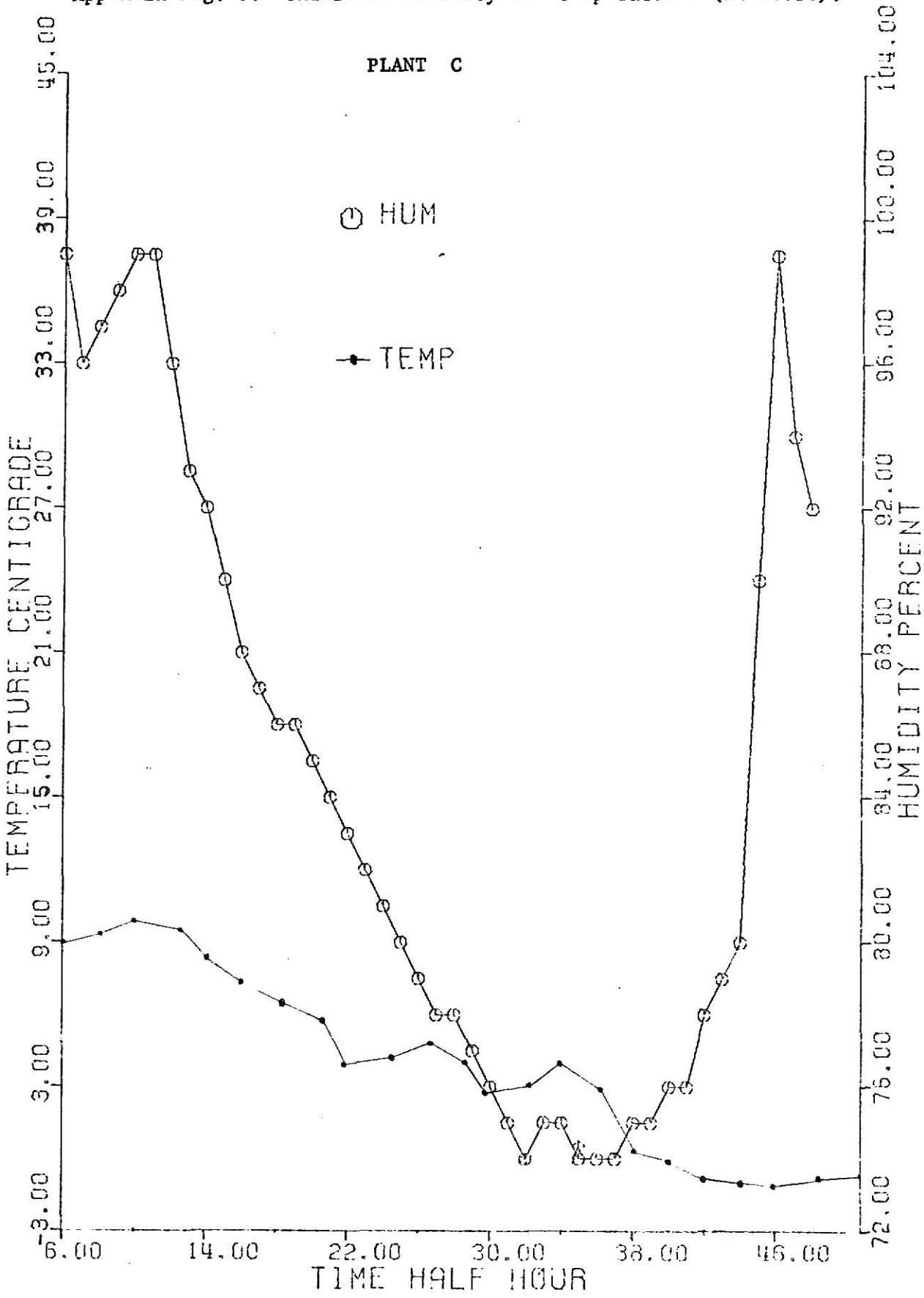
Appendix Fig. S. Internal round temperatures (24 hours).



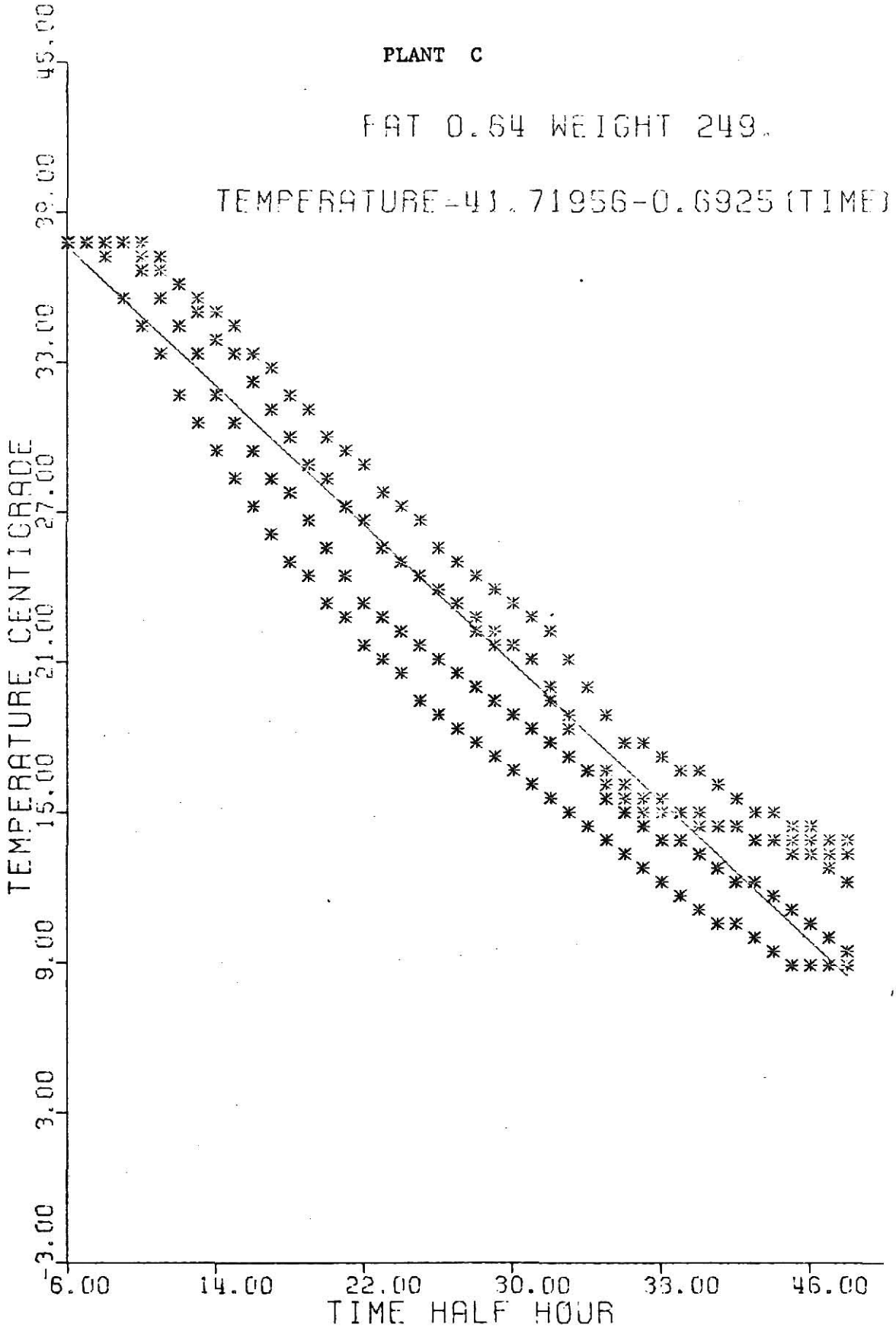
Appendix Fig. T. Internal round temperatures (24 hours).



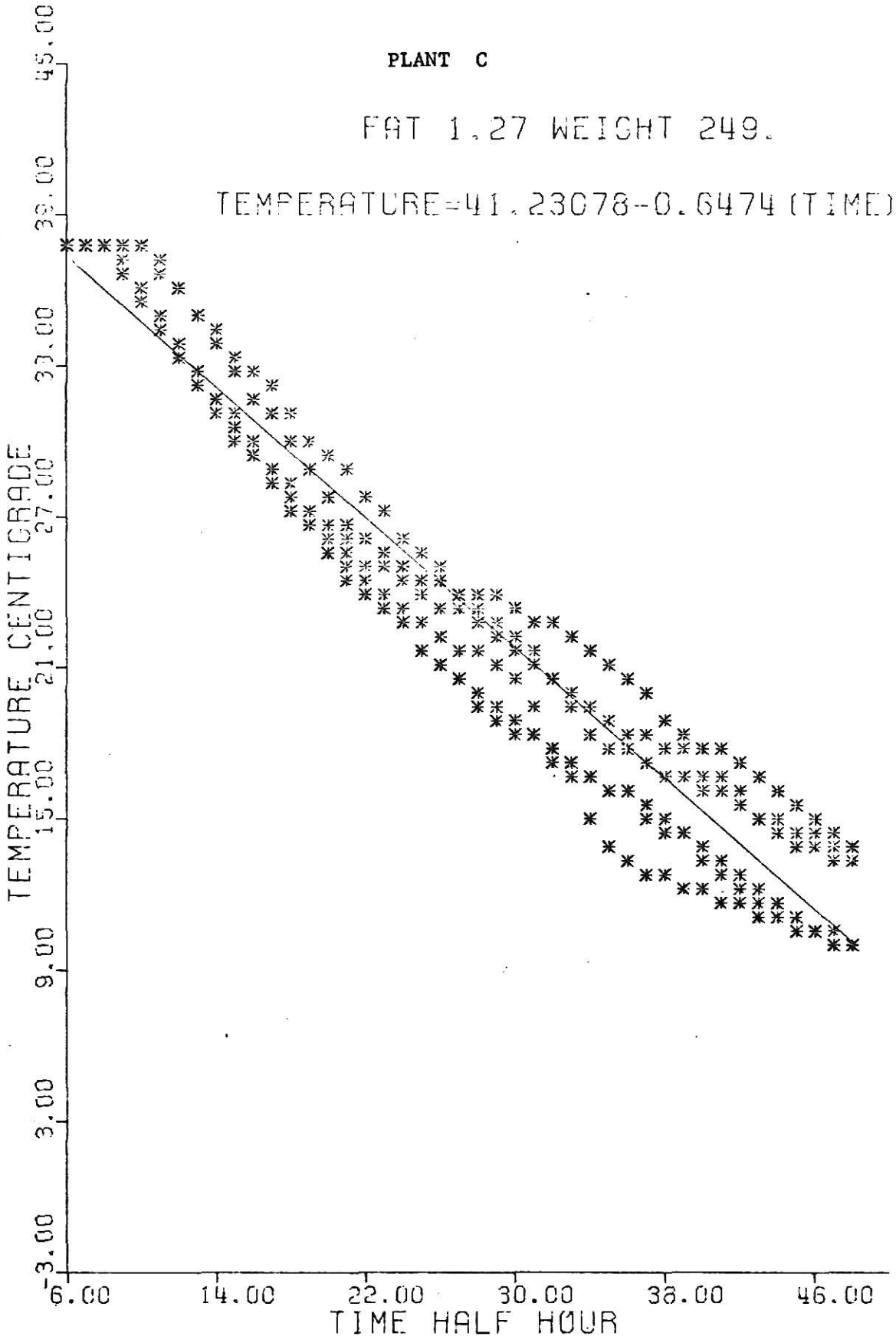
Appendix Fig. U. Chillroom humidity and temperatures (24 hours).



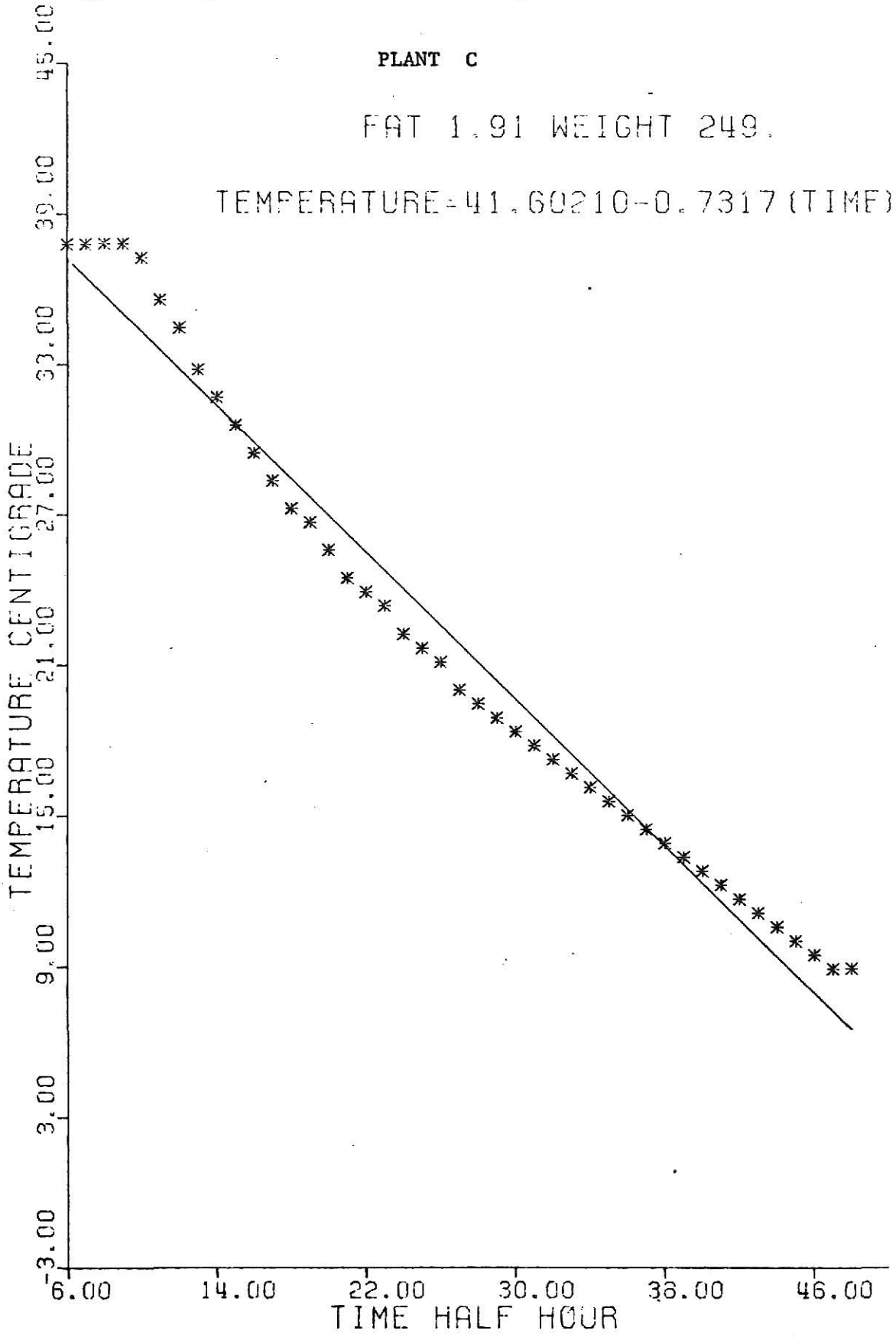
Appendix Fig. V. Internal round temperatures (24 hours).



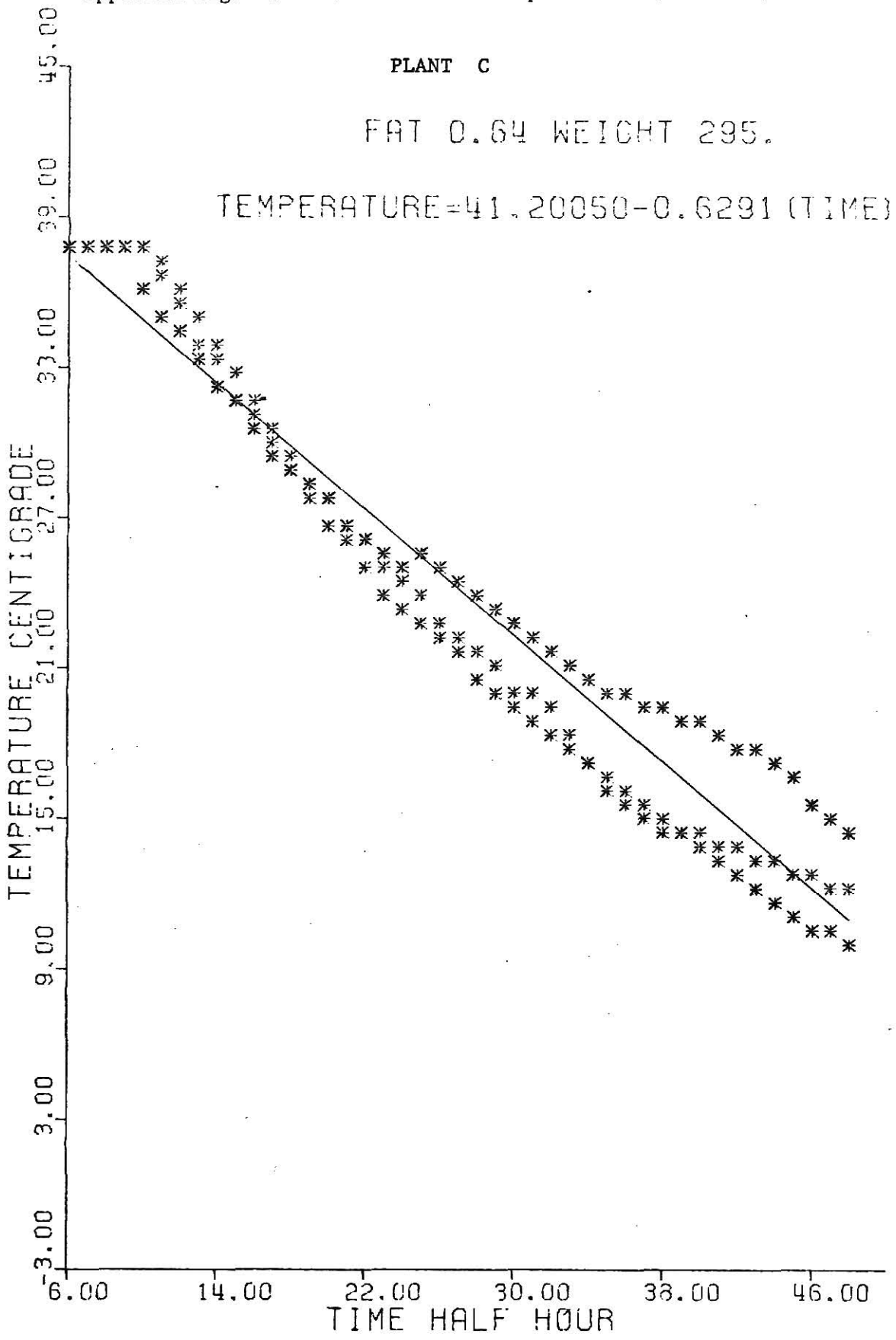
Appendix Fig. W. Internal round temperatures (24 hours).



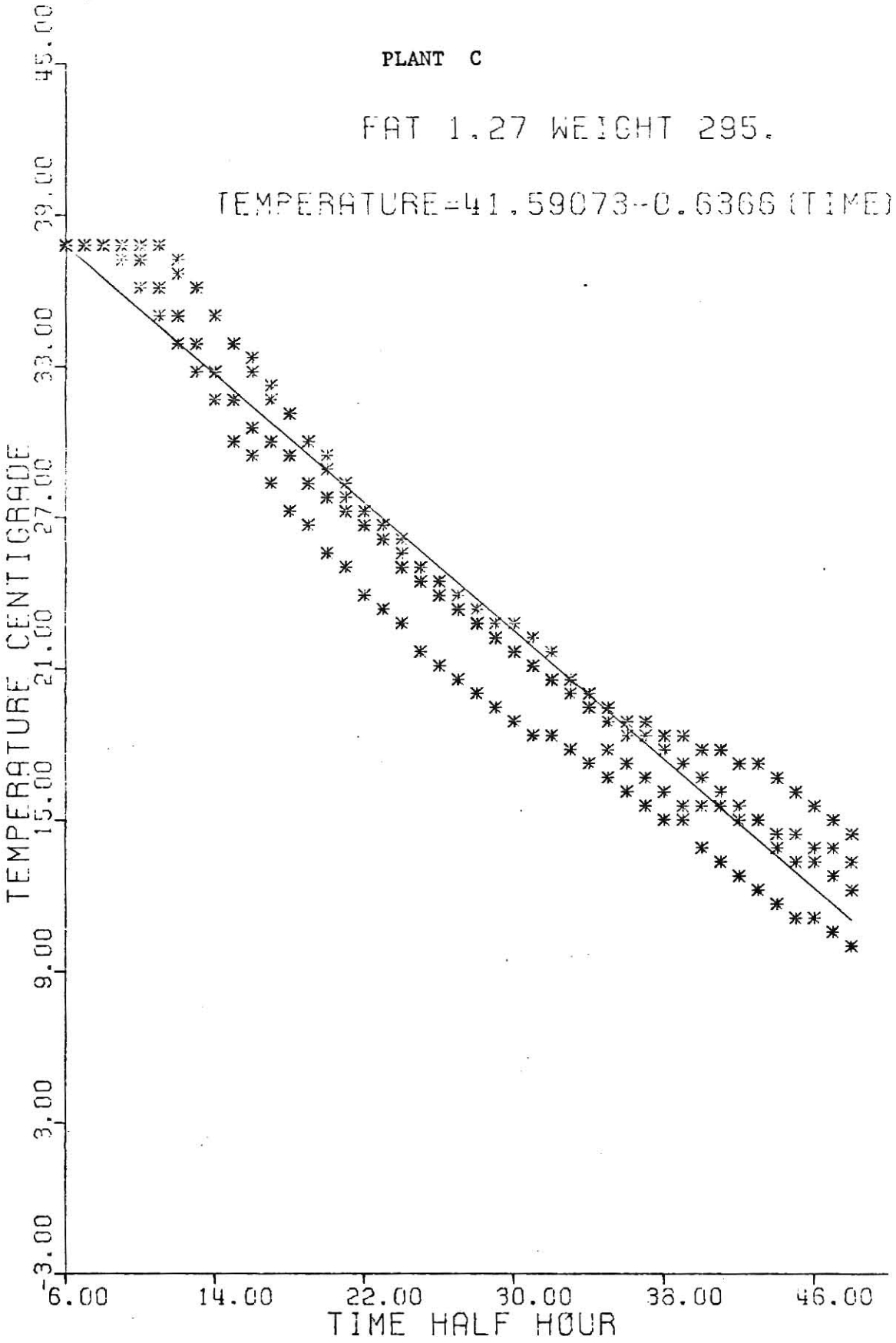
Appendix Fig. X. Internal round temperatures (24 hours).



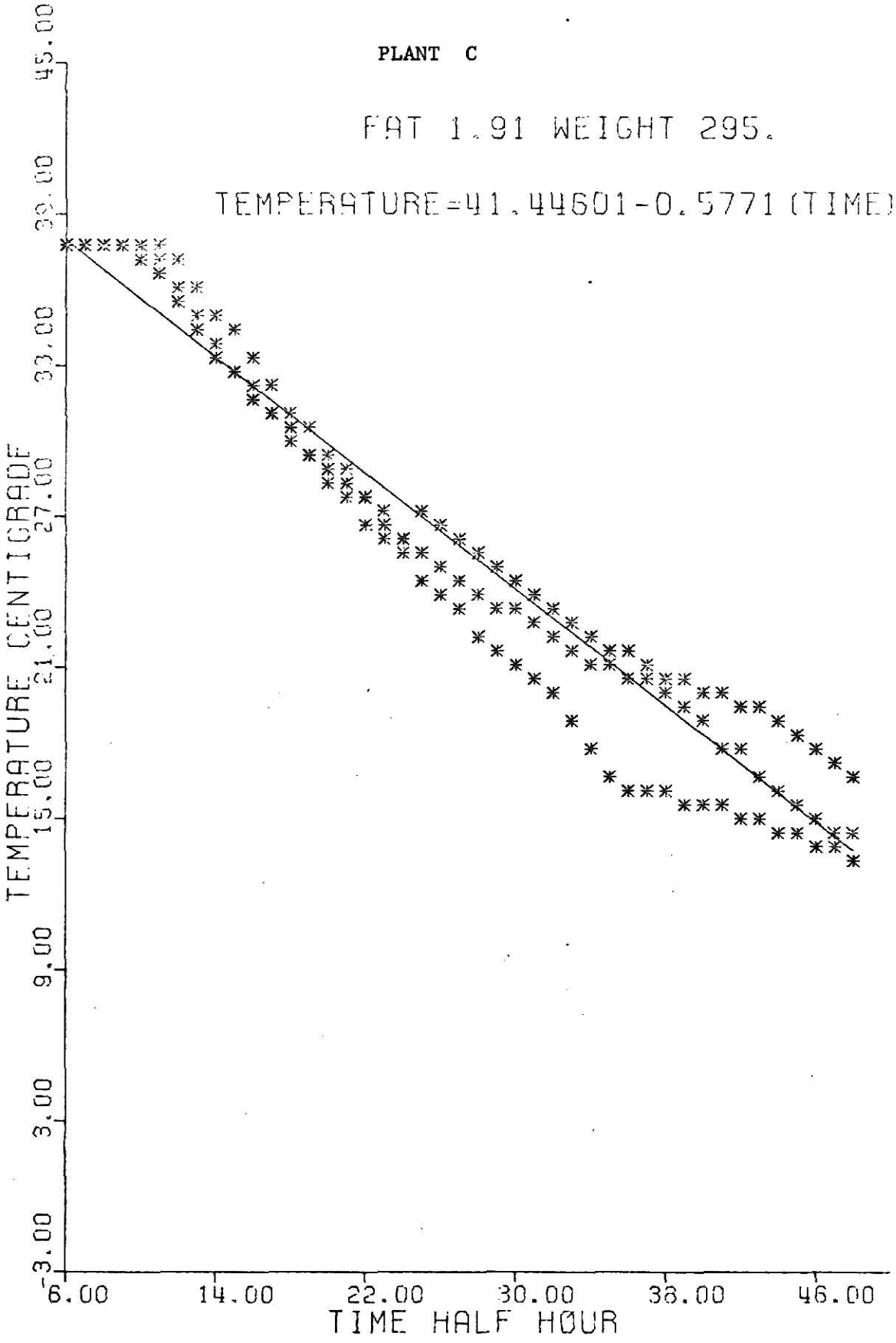
Appendix Fig. Y. Internal round temperatures (24 hours).



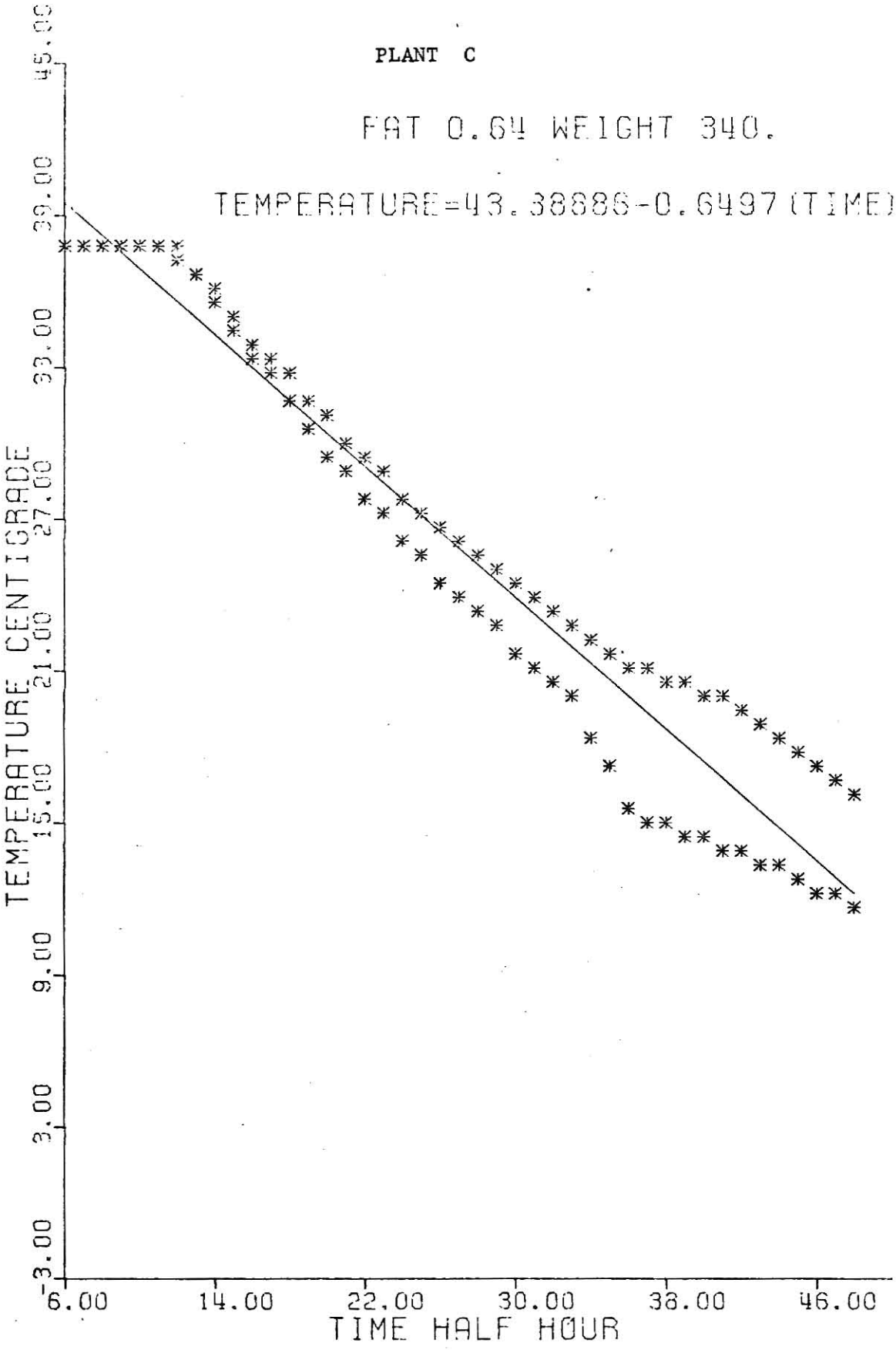
Appendix Fig. Z. Internal round temperatures (24 hours).



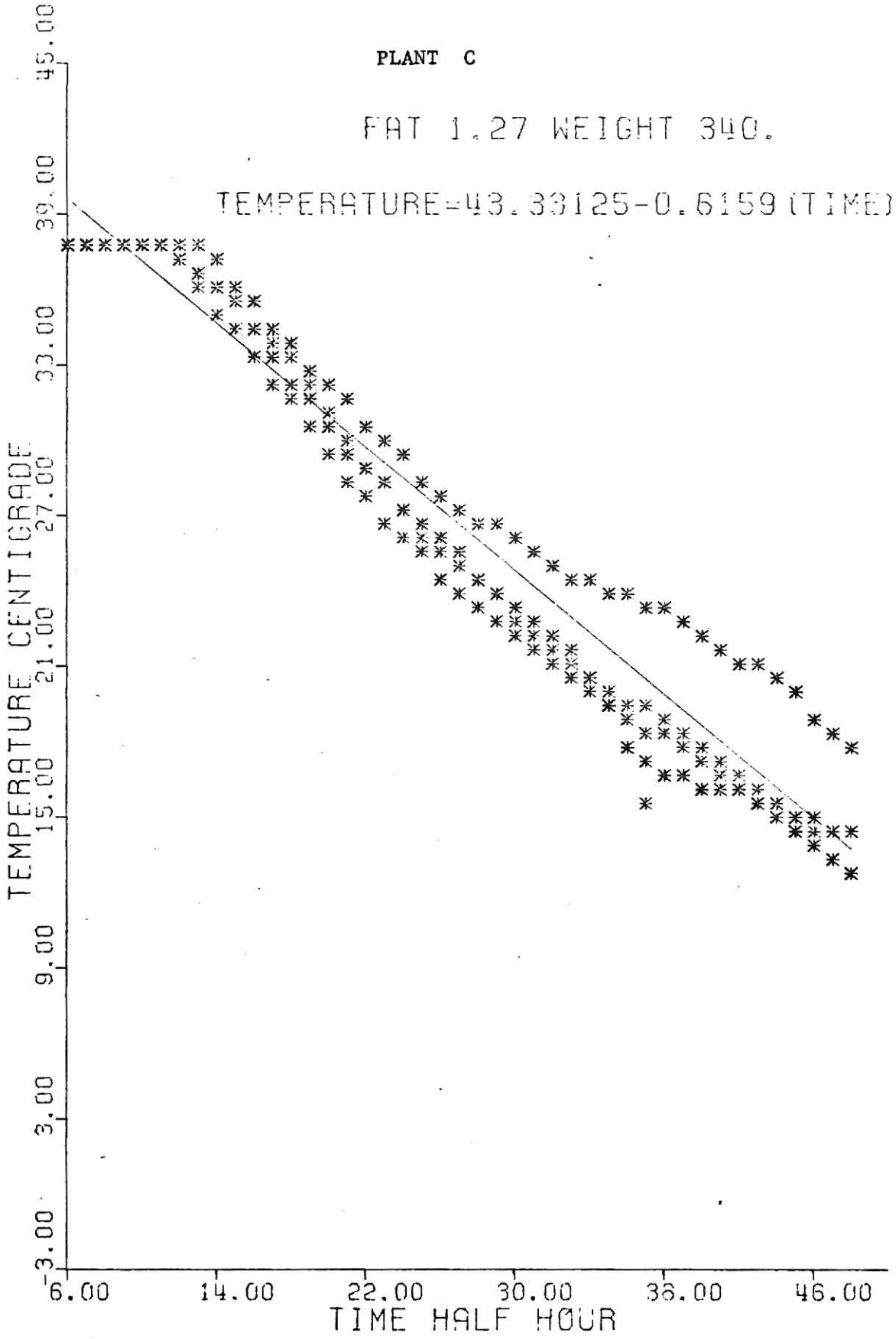
Appendix Fig. AA. Internal round temperatures (24 hours).



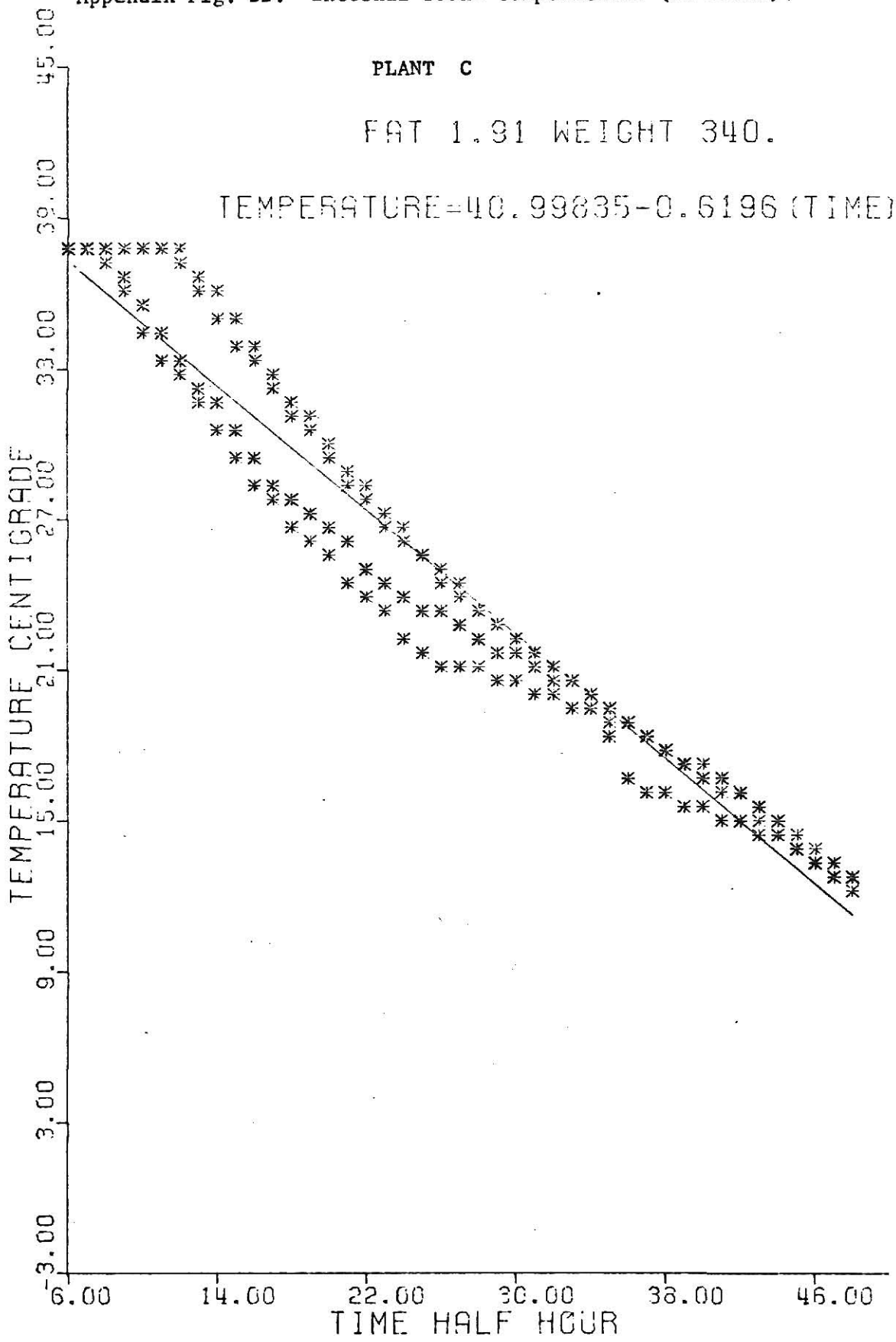
Appendix Fig. BB. Internal round temperatures (24 hours).



Appendix Fig. CC. Internal round temperatures (24 hours).



Appendix Fig. DD. Internal round temperatures (24 hours).



EFFECT OF BEEF CARCASS CHARACTERISTICS AND COOLER CONDITIONS ON MEAT SHRINKAGE

by

JEROME D. LEISING

B. S., University of Nebraska, 1969

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

FOOD SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1973

The effect of fat thickness, carcass weight and cooler conditions on carcass shrinkage after 24 and 48 hours chill was studied by selecting 73 carcasses of three fat thickness groups (0.64, 1.27, 1.91 cm) within three weight groups (250, 295, 340 Kg) and at each of three different processing plants. Carcass cooling rates were determined for each carcass by recording temperatures in the deep of the round and in the chuck for 24 hours post-mortem. Chillroom air temperature, relative humidity, and air velocity were studied for each plant to determine their relationship to carcass shrinkage.

Moisture losses from the surface fat and subsurface lean were 2.07 and 3.12% greater for the round than for the chuck, likely due to less fat covering, thus decreasing the moisture loss from the carcass.

Weight losses for beef carcasses as affected by external fat thickness at the 12th rib were more significant at 48 hours ($P<.05$) than at 24 hours ($P<0.13$) post-mortem. Carcasses with fat thickness of 0.64 cm. lost 0.20% more weight than did carcasses with 1.27 and 1.91 cm. of fat.

Carcass weight effects at 24 and 48 hours showed 251 kg. carcasses shrinking 0.10 to 0.20% more than 295 and 340 kg. carcasses. A significant ($P<.05$) cooler by weight interaction suggests that cooler design can reduce the effect of carcass weight and fat cover on shrinkage.

Cooler B chilled carcasses of different weights to approximately the same percent shrinkage. Decreased shrinkage likely resulted from less temperature fluctuation during cooler loading and more uniform refrigerated air distribution. Mean air temperature for cooler B was 1.6°C with temperature fluctuation of 3.5°C. Cooler air velocity of 0.75 and 0.60m/sec. for coolers A and B may be related to in lower shrinkage. The effect of relative

humidity on 24 and 48 hour shrinkage may not affect carcass shrinkage. Cooler B with 65% humidity had lower shrinkage than coolers with 80 to 85% humidity.

Results show that 81% of the 48 hour carcass shrinkage occurred 24 hours post-mortem, while 19% occurred the second 24 hours. Mean shrinkage for coolers at 24 and 48 hours were: A=1.42%, 0.54%; B=1.34%, 0.43% and C=2.11%, 0.24%.

Carcass temperatures of the round and chuck at 24 hours post-mortem were not significantly different ($P<.05$) for coolers or fat groups, with overall means of 11.7° and 6.7°C. Internal round temperatures were 3.1°C lower for 250 kg. carcasses than for the other weight groups studied.