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A COMPUTER-CONTROLLED SPRAY CHILL UNIT FOR RED MEAT CARCASSES

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ABSTRACT. A computer controlled and operated spray chill unit which can be used in future research studies for both spray chilling and decontamination of red meat carcasses is described. The unit consists of two parts: (1) an electromechanical system, and (2) a data acquisition/control system. Design concepts for the spray chill system are (1) versatility, (2) rapid change of spray parameters, and (3) computer control of the electromechanical system. An added feature is the computer data collection system for recording information related to each carcass (pH of muscle, surface and internal tissue temperatures, and weights of each half carcass during the cooling cycle; velocity, temperature, and humidity of the chill cooler air) and environmental data related to spraying conditions (time and duration of spray period and temperature of sprayed solution). **Keywords.** Decontamination, Dehydration, Meat, Quality control, Sanitation.

Normally, red meat carcasses are exposed to dehydration from the environment and deterioration from bacterial growth during the chilling process. Recently, spray chilling of carcasses in the cooler to reduce shrinkage has become an accepted practice in the red meat industry. Application of a chlorine solution sprayed intermittently on carcasses was an attempt to address both the dehydration and deterioration problems (Heitter, 1975). This process reduced carcass shrinkage but did not significantly reduce bacterial populations on carcasses (Heitter, 1975; Stevenson et al., 1978).

When conventional cooling systems are used, shrouded beef carcasses typically shrink from 0.75 to 2.0% during 24 h post-slaughter (Kastner, 1981), whereas unshrouded beef carcasses shrink by about 1.5% during the same time period (Allen, 1987). Smith and Carpenter (1973) reported an average shrinkage of 2.3% for lambs. Weight loss of unsprayed hog carcasses averaged 2.6% in 24 h. Carcass shrinkage is generally absorbed by the packing plants; therefore, it is considered an economic loss.

Several reports have described attributes of spray chilling and its effects on red meat carcasses (Dickson, 1991; Dickson and Anderson, 1991; Greer and Dilts, 1988; Hamby et al., 1987; Jeremiah and Jones, 1989; Jones and Robertson, 1988a, 1988b; Weakley et al., 1986). Lee et al. (1990) reported average shrinkages of only 0.53% for shrouded and 0.44% for unshrouded beef carcasses that

were spray chilled. Jones et al. (1988) observed shrinkage of only 0.6% when sprayed hog carcasses were held for 24 h.

Designs of carcass spray chillers were not included in the above scientific reports. Definitive studies related to spray chilling and decontamination of red meat carcasses in the chill cooler require a well-defined and versatile spraying system which accurately controls the several variables including spray time, concentrations and types of sanitizing solutions, volume and temperature of sprayed solutions, and nozzle size and type.

Spray chill systems for commercial slaughter plants must be well-designed and properly operated to reduce shrinkage and eliminate or reduce numbers of pathogenic microorganisms on surfaces of carcasses. Under controlled conditions, spray chilling and decontamination of red meat carcasses are accomplished simultaneously.

The purpose of this article is to describe a versatile carcass spraying system that combines chilling and decontamination in one operation. This unit was designed, fabricated, and installed in the abattoir at Roman L. Hruska U.S. Meat Animal Research Center, Clay Center, Nebraska.

CONCEPTS OF SYSTEM DESIGN

Design requirements for this spray chill and decontamination system were: (1) versatility, (2) rapid change of spray parameters, (3) computer control of the electromechanical system, and (4) computer collection of data related to carcasses (pH and temperature of surface and internal tissue; weights of each half carcass during the cooling cycle; velocity, temperature, and humidity of the chill cooler air) and environmental data related to spraying conditions (duration of spray period, water temperature, and time of spraying).

The system, designed to provide maximum flexibility for research studies, consists of two parts: (1) electromechanical system (fig. 1), and (2) data

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Figure 1—A schematic diagram of the electromechanical system for the spray chill unit.

acquisition/control system (fig. 2). The electromechanical system encompasses four plastic 1140-L (300-gal) solution supply tanks, a chilled water supply unit, a tap water line along with an air blowdown device, two valving manifolds (input manifold for routing the flow of solutions from the six sources of supply to the solution pump, and an output valve distribution manifold for directing the flow of solutions to any one of six spray zones within the chill cooler), spray nozzles (nozzle tips can be changed) in each of six zones, a centrifugal solution pump with pressure control regulator, 24 V DC solenoid-operated valves, portable air compressor, and miscellaneous components. The data acquisition/control system consists of two computers (IBM AT compatible with color monitor; IBM XT compatible with monochrome monitor, used for data display only; no printer used, data stored on disk); a control panel with three computer input/output modules (Digital Transmitters, Omega Engineering Inc., Stamford, Connecticut); 24 24-V relays; 12 data loggers (DSM-3260, Odessa Engineering, Austin, TX) with support equipment; 84 pH probes, accurate to 0.1 units (No. PHE-2381, Omega Engineering, Stamford, CT); 84 temperature probes,

accurate to 0.1° C (thermistor type, No. THX-700-NP, Omega Engineering, Stamford, CT); 10 air velocity probes, 0 to 100 FPM, accuracy $\pm 3\%$ (Series 435DC linear air velocity transducer, Kurtz Instrumentation Inc., Monterey, CA); four humidity probes, measuring range 0-100%, accuracy $\pm 2\%$ (HT46 series, Rotronic Instrument Corp., Huntington, NY); 12 matched load cells, 0 to 200 kg, sensitivity 0.1 kg (0.2 lb) (Series 616, Tedea, Canoga Park, CA) (to be installed); and a line solution pressure transducer (Model 206/207, Setra Systems, Inc., Acton, MA) for monitoring line pressure and verification of each spray cycle.

The spray chill control and data collection software designed specifically for this unit is moderately complex. The program, written in QUICKBASIC version 4.5 (MicroSoft, Redmond, WA), was designed to control a variety of input and output devices, e.g., solenoid-operated valves and solution pump, and to download data from the data loggers for data collection. Initially, the control software requires entry of five parameter values: (1) name or title of spray program (name will consist of any string of characters 1 to 12 characters long), (2) tank no. 1-6 (a number that corresponds to the source of the solution), (3) spray duration (length of time in seconds that the spray is to last: minimum (about 30 s) is dependent upon the zone and size and type of nozzle, and maximum is dependent upon the size and amount of solution in the supply tank, usually less than 120 s), and (4) duration of air blowdown (length of time in sec required to blow the solution from the solution supply line: default minimum time is 25 s, meaning that it will always blow at least that long; there is no upper limit, but a long blowdown time wastes time and energy), (5) total time of cycle (minutes to allow for completion of the spray schedule; this is an integer value; if in doubt, a minute should be added to the spray time as a safety factor).

A computer controlled safety warning system with visual (blinking red lights) and audio (Personal Speech System, Vortrax, Inc., Farmington Hills, MI) was designed and installed in the chiller unit. The safety warning system alerts employees that the spray chill unit is going to spray a solution in one of the spray zones. An audio warning is given one minute before a spraying schedule is implemented to alert employees in the area. The blinking red lights remain on during the spraying period to warn employees that the spray unit is operating.

The procedure for implementing a study using the spray chill unit is as follows:

1. Enter main menu.
2. Develop individual spray schedules — creates control parameters for electromechanical system that will perform specific spray operations.
3. Develop individual master schedules — setting frequency of data logging and a timetable for individual spray schedules.
4. Develop configuration file: (a) designate temperature probes to be used by zone and location within zone, (b) designate pH probes to be used by zone and location within zone, (c) designate air velocity and relative humidity probes to be used by zone and location within zone, and (d) designate load cells to be used by zone and location within the zone.

Figure 2—A schematic diagram of the data acquisition/control system for the spray chill unit.

5. Calibrate different types of probes being used by zone.
6. Develop a condition file that causes changes in the spray schedule based on environmental conditions in the spray chill cooler or physical parameters of the carcass such as temperature or pH [an example would be to tell the computer to use one master schedule when the temperature of the carcass is above 15° C (59° F) and another master schedule when the temperature drops below 14° C (57.2° F)].
7. Initiate program: (a) identify spray schedule to be used; (b) identify configuration schedule to be used, (c) identify initial master schedule to be used, (d) select a specific list of schedules to run or a condition file to control schedule selection. Program starts automatically after this selection.
8. After study is completed, data are transferred to ASCII file and can then be moved to a Lotus 1-2-3 (Lotus Development Corp., Cambridge, Massachusetts) file for further data analysis.

TEST PROCEDURE

a. Determination of temperature profile for three temperatures of water [1°, 13°, and 24° C (33.8°, 55.4°, and 75.2° F)] sprayed at four distances from the nozzle [0, 20, 40, and 60 cm (0, 7.9, 15.8, and 23.7 in.)] using three sizes of nozzles (3.8, 1.9, 0.4 L/min). One temperature probe was positioned at the tip of a nozzle. Three other probes were positioned within the spray pattern of a second nozzle to measure the water temperature directly in front of the tip at distances of 20, 40, and 60 cm (7.9, 15.8, and 23.7 in.) from the tip. Four probes were used to obtain a temperature profile of the water sprayed from three different sizes of nozzles as noted above. Three replications were run.

b. Operation of temperature probes to measure the internal temperature of meat tissue at selected locations. A temperature cooling profile for ham muscle tissue was determined by placing three temperature probes at depths of 1, 2, and 3 cm (0.4, 0.8, and 1.2 in.) into the biceps femoris muscle of the ham. Plots of the measured temperatures against time show the cooling profile of the ham tissue.

c. Operation of pH probes. Probes were calibrated at pH 5.0 and 7.0 using buffer standards. Three pH probes were inserted to a depth of 2.54 cm (1 in.) (hole made with a sharp object) into the ham muscle (biceps femoris) of three different hog carcasses.

d. Operation of relative humidity, air velocity, and temperature probes to evaluate environmental conditions. Relative humidity probes were calibrated using a sling psychrometer according to accepted procedures. Two relative humidity probes were placed on one side of the hog carcass at the point where the hock was attached to the hind leg. Two air velocity probes, calibrated against a known standard, were placed on the side of the carcass opposite from the relative humidity probes. Temperature probes were placed adjacent to the air velocity probes.

RESULTS AND DISCUSSION

All probes, with the exception of the spray profile and relative humidity and air velocity probes, were interrogated

Figure 3—Temperature profiles of water sprayed at distances of 0, 20, 40, and 60 cm (0, 7.9, 15.8, and 23.7 in.) using three water temperatures [1°, 13°, and 24° C (33.8°, 55.4°, and 75.2° F)] and three nozzle sizes (3.8, 1.9, and 0.4 L/min); line pressure was 275 kPa (40 psi).

at 15-min intervals over an extended period of time. pH and temperature readings (computer) were made on hog carcasses.

a. Determination of temperature profile of water sprayed. For all three nozzles, the temperature of the water sprayed at 13 or 24° C (55.4° or 75.2° F) decreased as distance from the nozzles increased (fig. 3). Temperature of water sprayed at 1° C (33.8° F) remained constant with distance from the nozzles since the air (ambient) temperature in the cooler was 1° C (33.8° F). Thus, the temperature profile indicates that temperatures of both the water and the air must be considered when temperature of

the impacting spray is an important factor. In a dynamic spray chill system study, sources of variance must be considered. For example, the water from the previous cycle may dilute the water from the present cycle or the sensible heat of the pipe may cause the temperature of the water to change. Part of this problem can be overcome by directing a small portion of the initial water to the drain and by thoroughly blowing out the lines after each spray cycle.

b. Determination of temperature profile within ham tissue during cooling period. Three cooling temperature profiles recorded over 13.25 h at depths of 1, 2, and 3 cm (0.4, 0.8, and 1.2 in.) in ham tissue are shown in figure 4. Chill cooler air temperature was 1° C (33.8° F). The initial temperature of the carcass was slightly less than 40° C (104° F). These probe readings provided the temperature profile existing within the tissue of this hog carcass during cooling. The temperature of the ham was reduced from about 40° to 10° C (104° to 50° F) in the first 10 h of cooling.

c. Determination of pH profile during cooling of hog carcass. The pH readings of three probes inserted to a depth of 2.54 cm in the same ham muscle (biceps femoris) on three different hog carcasses and taken over a 20-h period are shown in figure 5. Initial readings at two hours ranged from 6.5 to 6.2. The pH decreased during the next 8 h and then stabilized. The small deviations at 18 and 22 h are most likely due to computer rounding of the millivolt readings. These pH readings are within the normal range of ham muscle tissue (Davis, 1974). Erratic pH readings may be attributed to fat and/or protein interfering with the movement of electrons at the probe tip. Future research needs to address the effect of leaving a pH probe in meat tissue for periods up to 24 h.

d. Determination of operation of relative humidity, air velocity, and temperature probes to evaluate environmental conditions. Two air velocity probes were mounted on one side of the hog carcass where the hock attaches to the carcass. The two relative humidity probes were located on the opposite side of the carcass. The two temperature probes were located 30 cm (11.8 in.) from the carcass at the same height as the other probes. A decrease in measured values of the outputs from each of the probes was noted between 70 and 210 min. This reduction was

Figure 4—Cooling temperature profiles as determined using three temperature probes inserted at depths of 1, 2, and 3 cm (0.4, 0.8, and 1.2 in.) into the ham of a hog carcass.

Figure 5—Profiles of pH taken over 20 h with three pH probes inserted into the hams of three different hog carcasses.

most likely due to the cooler doors being kept closed and the stabilization of ambient conditions within the chill unit. Air velocity readings taken over the 1,190-min test period were fairly constant except for a dip at 630 min (fig. 6). The relative humidity probe readings were fairly constant with very little difference detected between the two probes. The mean temperature in the chill cooler during this study was 1.4° C (34.5° F). Other studies using the air velocity, humidity, and temperature probes indicated little change within a 24-h period. In future studies consideration should be given to locations of the velocity probes relative to airflow and/or to interference effects of the carcass. In a dynamic environment such as a chill cooler, air velocities may vary at different locations within the unit. Number and placement of the carcasses within the cooler creates changes in airflow patterns and velocities. The relative humidity of air in a chill cooler should remain fairly constant because it is thoroughly mixed by air movement and the conditioning effect of the refrigeration system.

The data from actual trial runs indicate that the spray chill unit has the capacity to perform the different prescribed functions for which it was designed. When planning and designing a study with the chill unit, using the different monitoring components, special attention is required to control all the variables. Possible future research studies include:

Figure 6—Mean of two air velocity, two air temperature, and two humidity profiles over 1,400 min in the chill cooler.

- Mathematical treatment of the unique heat and mass transfers involved in the spray chilling process.
- Description of the water spray temperature as a function of droplet size and velocity, air and water temperature, air velocity, etc.
- Description of temperature and pH decline patterns and bacterial growth and survival as a function of the spray chilling process.
- Comparison of pH measurements on a continuous and intermittent basis.
- Development of optimal design and control of the spray chilling process for specific carcass and carcass-chilling requirements.

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