To the Graduate Council:

I am submitting herewith a thesis written by John Thomas Melton entitled "Psychrometric Parameters for Accelerated Yellowing of Burley Tobacco." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Mechanization.

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PSYCHROMETRIC PARAMETERS FOR ACCELERATED YELLOWING OF BURLEY TOBACCO

A Thesis
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Master of Science
Degree
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ABSTRACT

The green-to-yellow phase of an accelerated cure of burley tobacco was examined on a laboratory scale. Nine curing cabinets for small samples (100 leaves) were especially designed for this experiment along with controls which maintained temperature within ± 0.5°F and relative humidity within ± 3 percent.

Nine combinations of temperature and relative humidity which covered the range of expected optimum combinations were examined in a 3 x 3 factorial experiment. Evaluation of each treatment was made after a 60-hour period by matching leaf color with preselected standard Munsell colors, including an optimum yellow. A regression equation was formulated that established a relationship among temperature, relative humidity and color. A curve of the temperature-relative humidity combination for the optimum color was presented. Four additional selected temperature-relative humidity combinations were used in a 60-hour cure to check the regression equation. The equation was found to closely predict the resultant color.

The results indicated that burley tobacco can be satisfactorily yellowed in an accelerated bulk cure with color comparable to that found in conventionally cured tobacco. However, an increase in temperature requires a corresponding increase in relative humidity for optimum yellowing. A maximum relative humidity for this phase of the cure appeared to be approximately 90 percent.

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CHAPTER I

INTRODUCTION

I. BACKGROUND

Type 31 Burley tobacco ranks fourth in monetary value among Tennessee agricultural products behind cattle, soybeans, and dairy products. In 1976, 127.5 million pounds of burley tobacco were harvested in Tennessee with a gross value of 144 million dollars (Tobacco Situation, 1977).

A substantial amount of labor (an average of 210 man hours/acre) is involved in the harvesting and marketing of burley tobacco (Burley Tobacco Production Costs, 1975). The methods used to implement these phases are much the same today as they were 100 years ago. Conventional harvesting consists of cutting the stalk, spearing an average of six stalks onto a stick, transporting the sticks to the barn, and hanging the sticks across spaced poles in the barn. The tobacco hangs in this position for a period of six to eight weeks until it has cured in the natural air environment. It is made ready for marketing by removing the stalks from the sticks, stripping the leaves from the stalks, and tying the leaves into bundles or "hands." The hands are packed on baskets and sold at auction. There is an increased interest toward a more mechanized system of harvesting, curing, and marketing burley tobacco resulting from lower availability and higher cost of farm labor during the past few years.

One possibility for improvement of the present system is to adapt methods now used in harvesting, curing, and marketing flue-cured tobacco to burley tobacco production. The harvesting phase consists of stripping the leaves from the stalk in the field, placing them in bulk packages, and transporting them to a bulk barn (Figure 1). The barn is equipped with heat, humidity, and forced ventilation systems that control the environmental conditions within the barn. The decrease in labor required for this system, as compared to the conventional burley tobacco system, would result from elimination of the stalk and stick and using a bulk package that is more adaptable to mechanical handling.

The cost of the bulk curing barn is a large investment (about $8,000). To make the investment economically feasible for burley tobacco, the barn must have a seasonal capacity that justifies the cost. The capacity of the barn is increased by curing four or more cures per season per barn. The number of days available for harvesting, and consequently curing the tobacco, spans from the time the bottom leaves reach maturity to some time before the tip leaves become overripe. This time is usually 45 days or more, so a curing period of six to ten days per cure would allow four cures per season. Therefore, in order for the bulk curing system to function properly, it must be shown that burley tobacco can be satisfactorily cured without a reduction in quality using a psychrometric schedule that appropriately shortens the burley curing process.

It should be emphasized here that tobacco quality is affected by more than the environmental conditions under which it is cured. Cultivar, weather during the growing season, soil, management practices, maturity

FIGURE 1. A bulk tobacco curing barn being filled.

at harvesting, and position of the leaf on the stalk, all have a major effect on the quality of the cured leaf.

II. OBJECTIVES

The burley tobacco curing process may be divided into phases which include: (1) yellowing, (2) coloring, (3) lamina drying, (4) stem drying, and (5) ordering. The psychrometric parameters that give optimum results during one phase of the cure are not necessarily the ones required to bring about desired results in another phase. To obtain a curing period of short duration, each phase should be subjected to the maximum curing rate possible without damaging the quality of the end product. One of the most dramatic changes of the leaf during curing is the change from green to yellow. This is known as the yellowing phase and is the result of an enzymatically controlled breakdown of chlorophyll which unmasks the yellow pigments in the leaf (Weybrew and Green, 1952).

The purpose of this research was to gain information which could be used to formulate an acceptable accelerated process for the yellowing phase of burley tobacco curing. The specific objectives were to:

1. Determine psychrometric parameters for the yellowing phase of an accelerated bulk cure of burley tobacco.
2. Design and construct environmental cabinets adequate to accomplish the first objective.
3. Develop a color based system for the evaluation of a cure at the end of the yellowing phase.

CHAPTER II

REVIEW OF LITERATURE

I. PSYCHROMETRIC PROPERTIES FOR CURING BURLEY TOBACCO

Jeffrey (1940) conducted experiments with cv. Kentucky 16 burley tobacco that was stalk cut, speared on sticks, and hung in small chambers. Conventional spacing was used, and the chambers were equipped with blowers that produced a 15 fpm airflow. The tobacco was subjected to selected temperatures between 55°F and 95°F and relative humidities (r.h.) from 50 to 83 percent over a four-week curing period. He concluded that good quality tobacco could be cured at temperatures from 60°F to at least 90°F if the relative humidity was at optimum (65 to 70 percent). He expressed the belief that 77 percent r.h. or higher is undesirable when held for periods of more than a week; however, it may be acceptable or desirable for the relative humidity to be higher than the stated optimum for shorter periods during the cure.

A study was made by Henson and Bunn (1971) to compare primed leaf with whole stalk curing. Their evaluations were made by comparing leaf drying rates and physical and chemical characteristics of the leaf over a two-week period of curing. Treatments were: (1) 90°F--60 percent r.h., (2) 90°F--70 percent r.h., (3) 90°F--80 percent r.h., (4) conventional curing, and (5) primed or whole stalk. The order of preference based on standard grade analysis of the cured tobacco was:

1. Whole stalk, cured at 90°F--70 percent r.h.
2. Primed leaf, cured at 90°F--70 percent r.h.
3. Primed leaf, cured at 90°F--80 percent r.h.
4. Primed leaf, cured at ambient conditions.
5. Primed leaf, cured at 90°F--60 percent r.h.
6. Whole stalk, cured at ambient conditions.

Walton and Henson (1971) tested the effect of low r.h. on curing whole stalk tobacco. The tobacco was cured at 70°F and 70 percent r.h. except for selected time periods when it was subjected to the treatment variables. Temperatures of 50°F, 65°F, and 80°F, and relative humidities of 30 percent, 45 percent, and 60 percent were coupled with exposure times of 0, 12, 24, 48, 72, and 96 hours to ascertain their effects when applied during the yellowing phase of the cure. Damage to the leaf was determined by comparing support prices of the cured leaf. They concluded that: (1) danger of damaging by excessive drying is encountered mainly in the first four to six days of the cure before yellowing, (2) green can be set in the leaf much quicker than yellow, and (3) a yellow leaf may result from over-drying in the initial phase of the cure at high temperatures. A similar study was made by Henson et al. (1974). They studied the effects of high humidity curing on burley (whole stalk and primed) with temperatures of 50, 70, and 90°F and relative humidities of 70 and 95 percent. An increase from 50°F to 90°F at 70 percent r.h. resulted in a price increase from 64 to 72 cents per pound and at 95 percent r.h. a decrease from 60 to 43 cents per pound. They concluded that a high r.h. - high temperature combination was more likely to result in price reduction

Bunn et al. (1973) reported an eight-day schedule that produced acceptable bulk-cured tobacco as judged by the appearance of the cured leaf. A temperature of 106°F and 70 percent r.h. was used for the yellowing phase of the cure. Powell Manufacturing Company (1975) recommended 105°F and 87 percent r.h. for yellowing the bottom tier of their three-tier barn.

The literature verified that certain combinations of psychrometric parameters have produced acceptable quality burley tobacco cured at an accelerated rate. It also verified that acceptable quality burley has been cured with varying combinations of psychrometric parameters. This indicates that acceptable burley tobacco may be cured over a range of psychrometric parameters, or that factors other than psychrometric curing schedules effect the curing process. However, combined effects are not known and more research is needed to show complete interrelationships.

II. TOBACCO QUALITY

Tobacco quality is not easily determined or described. Tso (1972) states, "Tobacco quality represents a balance of essential properties in a product that meets the preference of a special group of consumers at a given time and location." Tobacco quality is indicated by a United States Government Standard Grade that is assigned to the leaf at the marketplace. The grade is subjectively assigned by a grader who has a mental picture of what the visible and readily detectable properties of the leaf should be in order for it to receive a particular grade. Those properties which are used to determine the picture of quality that the grader harbors inclue color, texture (grainy or soft), size, damage, thickness, odor, and maturity. In addition to the visible and detectable criteria listed above, Tso (1972) lists other determinants of quality which he groups into two classes: (1) physical criteria such as filling power, strip yield, combustibility, stalk position, shatter resistance; and (2) chemical criteria such as nicotine, sugar, starch, protein nitrogen, and total nitrogen. All of the above criteria are indicative of tobacco quality but the final test is based on taste and odor. Thus, tobacco quality is a term that describes a very complex combination of variables, and a particular leaf could be judged from excellent to poor quality depending only on the use for which it is sought at a particular time.

III. COLOR AS AN INDICATOR OF TOBACCO QUALITY

If the optimum psychrometric parameters to produce an accelerated bulk cure of good quality are to be found, a method of determining the quality of the tobacco as the cure progresses is a necessity. One possible method is the use of color as the determining criteria. Color is one of the important criteria used by graders to determine the grade that a group of leaves will be assigned. While color is an important grade criteria, it should be kept in mind that color is a visual indicator of other non-visible traits and is not a direct measure of quality.

Some research has been done to relate color change to the progression of the cure. Henson et al. (1968) used time-lapse photography to record the progress of tobacco during curing. Transmittance of the color film in the yellow band of the spectrum was used as an indicator of the coloring rate of the leaves. The influence of temperature, r.h., and air velocity on the coloring rate was determined by regression analysis. Bunn et al. (1965) reported initial steps taken to link curing rate and color. The color of the leaf was evaluated according to the International Commission on Illumination system. They were able to distinguish differences in leaf stalk position, maturity, and curing procedures by relating them to color. Weybrew and Green (1952) tested a "Yellowmeter" during the yellowing phase of flue-cured tobacco. A portable reflectometer was designed to measure the absorption of chlorophyll at 680 nm wavelength. To test the instrument, leaves were carefully selected in the field and then screened by an experimental photoelectric selector to assure uniform maturity. Even with the careful screening techniques, the Yellowmeter indicated a variation in yellowing time of up to 28 percent among leaves in the same curing environment. The variation was attributed to the combined affects of physiological differences among the leaves and the micro-curing environment of each individual leaf.

IV. MUNSELL COLOR NOTATION

A less sophisticated method of measuring color is by comparison of the leaf with color chips on color charts. For grading purposes, the leaf may be compared with a standard that exactly matches a color chip, or the color chip may be used to specify a general approximation of the standard color (Nickerson, 1946). One of the widely used color charts is the Munsell system of charts. The Munsell color system is based on the following color perception attributes: (1) hue--the means by which an object is judged to be red, yellow, green, blue, purple, or intermediate between some adjacent pair; (2) value (lightness)--the means by which an object is judged to reflect more or less light than another object; and (3) chroma (saturation)--expression of the degree of departure from the gray of the same lightness (ASTM, 1968). The hue of a color is expressed as a number/letter. Value is assigned a number between 0 for ideal black, and 10 for ideal white, by approximately equal visual steps. Chroma varies between 0 for no departure from gray to about 20 for the strongest colored specimens. Munsell's color notation takes the form--Hue Value/Chroma. For example, a notation of 5Y 9/6 means the color has a hue of 5Y, a value of 9, and a chroma of 6 (Munsell Book of Color, 1970).

V. ENVIRONMENTAL CABINETS

Environmental cabinets have been utilized in a number of research areas including tobacco research. Solvason and Hutcheon (1965) listed and discussed guidelines for designing environmental cabinets. They emphasized the fact that essential requirements of the cabinets must be clearly outlined and understood. They also stated that each component of the cabinet must be considered to determine its interaction with other components. Failure to do so may result in a cabinet that will not meet the needs, or may cause excess cost due to an over-designed cabinet. Watson (1965) recommended the following elements for temperature control: (1) thermocouple, resistance bulb, or thermistor sensing element; (2) electric heating coil; and (3) proportional control of the heating coil. For humidity control he recommended: (1) Dunmore electric hygrometer sensing, (2) a steam valve with a positioner, and (3) a direct steam injection humidifier. Bunn and Henson (1965) designed environmental cabinets for agricultural research that used a resistance thermometer for heat sensing and a "Dewcell" for dewpoint sensing. The temperatures were then recorded by continuous balance Wheatstone bridges. Each bridge was a part of a controller that regulated steam heating and humidifying valves by proportioning and reset action. Ross and Myers (1965) constructed cabinets for testing crop materials. Their system consisted of a spray chamber through which air was delivered for humidification. The air then flowed through a heating chamber where the desired wet- and dry-bulb temperatures were established. Heat was controlled by a variable transformer connected to electric resistance heating elements.

CHAPTER III

INSTRUMENTATION

I. DESIGN SPECIFICATIONS FOR ENVIRONMENTAL CABINETS

Finding the optimum psychrometric parameters for bulk-curing burley tobacco required subjecting the tobacco to selected curing environments to determine resultant effects on the tobacco. Previous experiments at The University of Tennessee (Henry, 1975) indicated that the optimum psychrometric parameter combinations may be of an exact nature. Small experimental curing cabinets were designed to give the necessary positive environmental control.

The design of the cabinets was simplified by the fact that the general range of temperature and humidity for bulk-curing burley tobacco is known. Also temperatures and humidities for bulk-curing tobacco are, for the most part, above ambient which eliminated the need for either refrigeration or dehumidification.

The design specifications for the cabinets were:

1. Temperature control of $\pm$ 0.5°F from set point over a range of from 80°F to 160°F.
2. Relative humidity control of $\pm$ 3 percent from set point over a range of from 60 percent to 95 percent.
3. A chamber capacity of approximately 100 leaves.
4. A recirculating air flow of at least 15 fpm.

5. A means of intake and exhaust of outside air.

6. Component cost of $275.00 or less per cabinet.

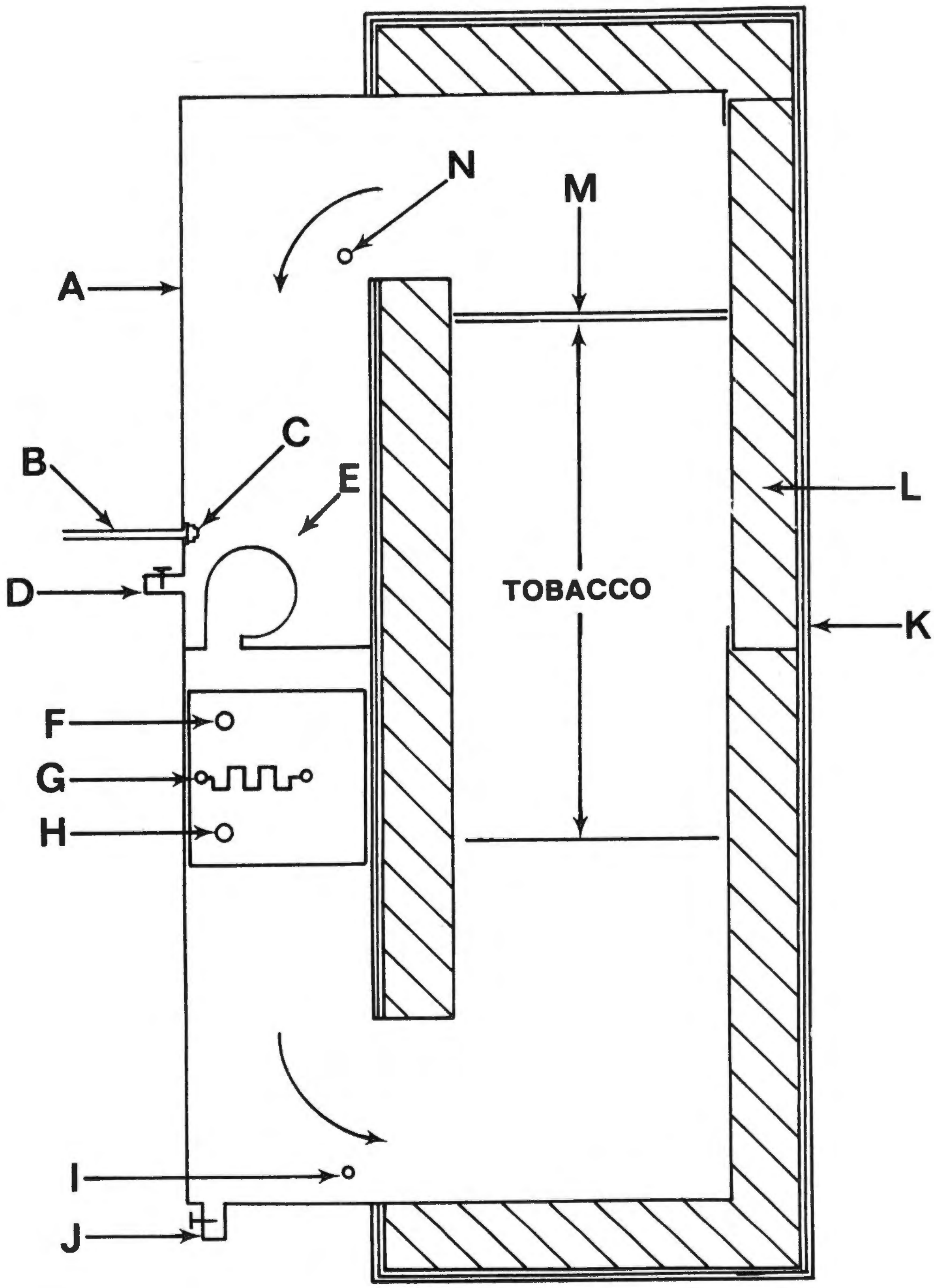
II. DESCRIPTION OF THE ENVIRONMENTAL CABINET

A schematic of the completed cabinet may be seen in Figure 2. The cabinet was composed of two major components: (1) an 8 inch by 8 inch by 48 inch duct, and (2) the curing chamber with inside dimensions of 12 inches by 12 inches by 48 inches.

The duct was partitioned horizontally in the center, and a 100 cfm centrifugal blower circulated air from the upper to the lower portion of the duct and through the chamber. A removable 8 inch by 8 inch metal plate was positioned directly below the exhaust of the blower. The plate provided a base for two 0.25 inch to 0.125 inch brass pipe bushings used for thermistor assembly receptacles and ceramic washers used to mount a 600-watt electric resistance heater element (Figure 3).

Five copper-constantan thermocouple leads entered the duct on the left side. One dry-bulb and one wet-bulb thermocouple each were located at the duct entrance and exit of the chamber. The fifth thermocouple was placed inside the bulk of the curing tobacco. Response of the thermocouples was recorded by a digital data acquisition system. A plastic laboratory bottle equipped with a gauze filled stainless steel tube at its base provided wicking for the wet thermocouples (Figure 4).

Steam for humidification was provided by a 21-quart pressure cooker that was heated by a 2200-watt hot plate. The steam traveled from the cooker through a 0.125 inch galvanized water pipe that entered



A. Duct
B. Steam line
C. Nozzle
D. Air intake valve
E. Blower
F. Wet-bulb thermistor
G. Heater
H. Dry-bulb thermistor
I. Wet- and dry-bulb thermocouple
J. Air exhaust valve
K. Plywood
L. Insulation
M. Tobacco rack
N. Wet- and dry-bulb thermocouple

FIGURE 2. A schematic drawing of the environmental cabinet for studying the curing phases of burley tobacco.

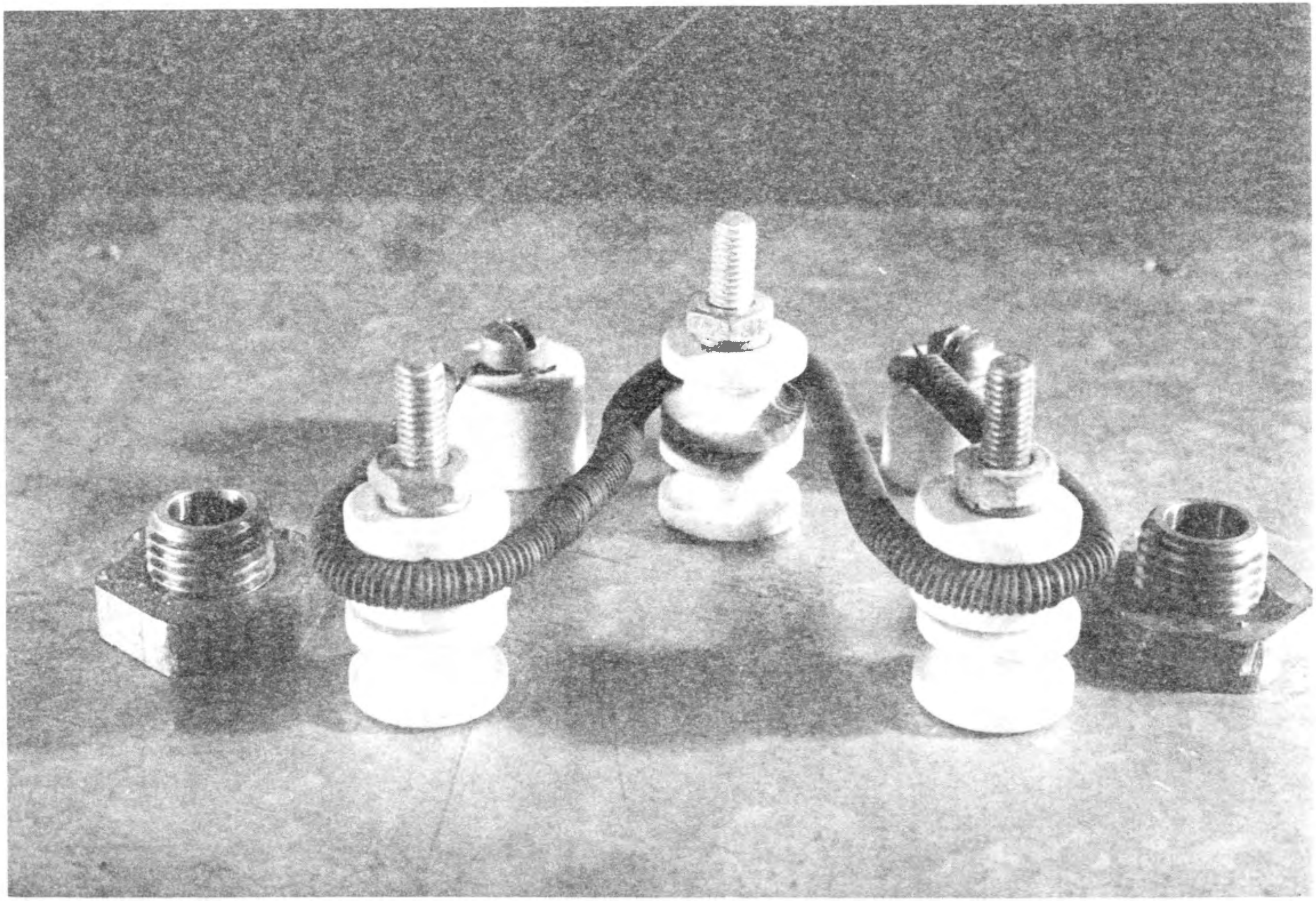


FIGURE 3. The metal plate with the two thermistor assembly receptacles and the heater element of the environmental cabinet.

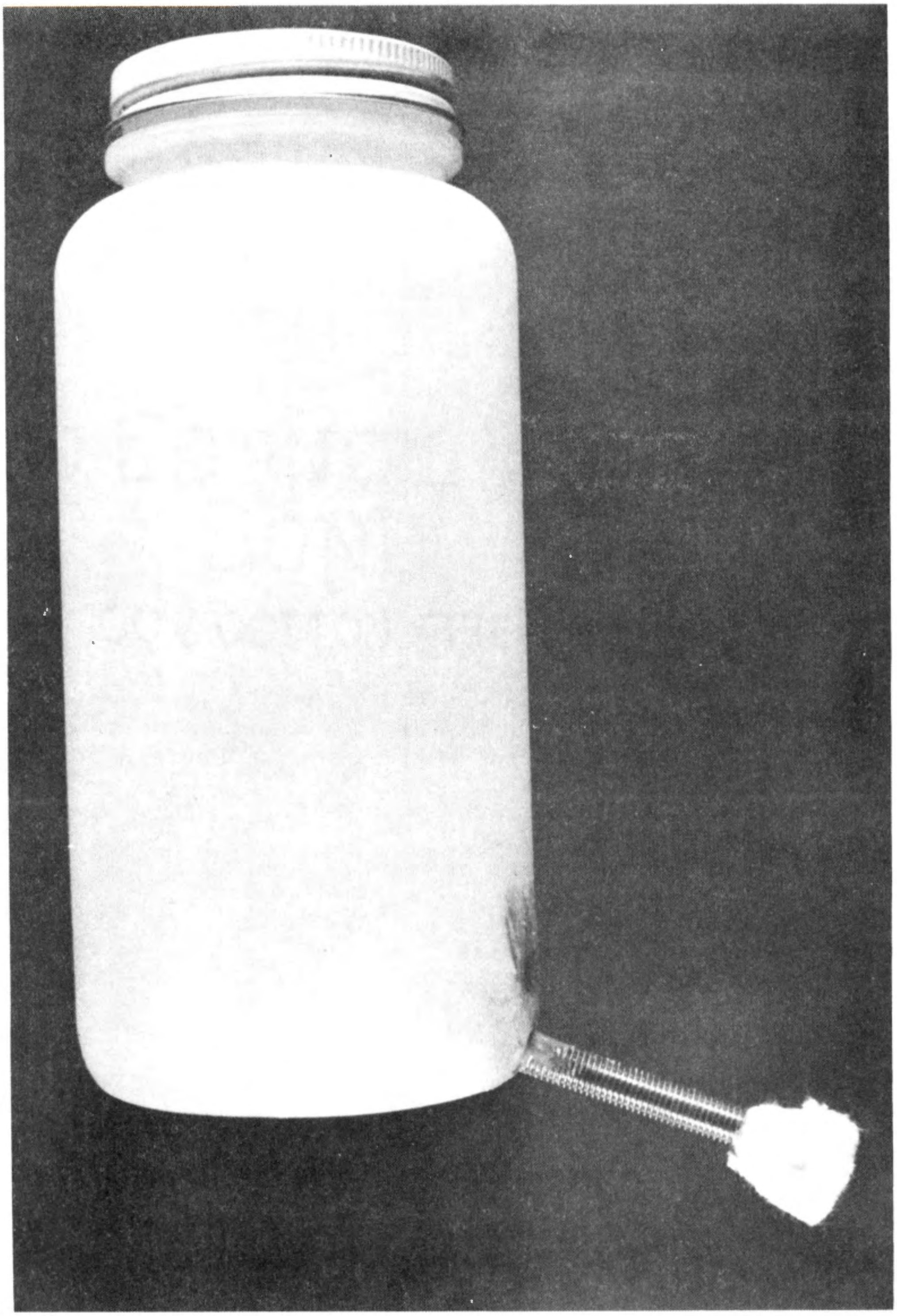


FIGURE 4. Wet-bulb wicking apparatus showing the plastic laboratory bottle and gauze filled stainless steel tube.

the back of the duct through a brass bushing (Figure 2, page 14). The steam was introduced into the duct through a 650017 Tee Jet nozzle (0.017 gal/min rating).

Air exchange was supplied by two 1.5 inch sliding gate valves mounted in the duct system. The intake was located directly in front of the blower intake, and the exhaust was located at the bottom of the duct.

The interior of the curing chamber was made of 22-gauge galvanized steel surrounded by 3-inch glass wool batt insulation and an outer shell of 0.5-inch plywood. A 24-inch by 19-inch door was located at the top front of the cabinets (Figure 5).

III. THERMISTOR MOUNTING ASSEMBLIES

The narrow temperature range and relatively low temperatures for which the cabinets were designed made it possible to use thermistors as the sensing elements for both wet- and dry-bulb control. Thermistors offered the advantages of direct indication of temperature, low-cost, large resistance change per unit temperature change, long-term stability and relatively low cost of associated circuitry (Fenwall, 1974). Thermistor mounting assemblies (Figure 6) were fabricated by soldering one 3-inch length of 22 AWG wire to each lead of a thermistor glass probe. The probe was placed in a 1.25 inch long by 0.25 inch diameter glass tube leaving about one-half of the probe extending from one end of the tubes. The tube was then filled with silicon caulking and the end opposite the probe was inserted and glued one-half way into a 0.125-inch close brass nipple. The assembly was completed by placing the thermistor

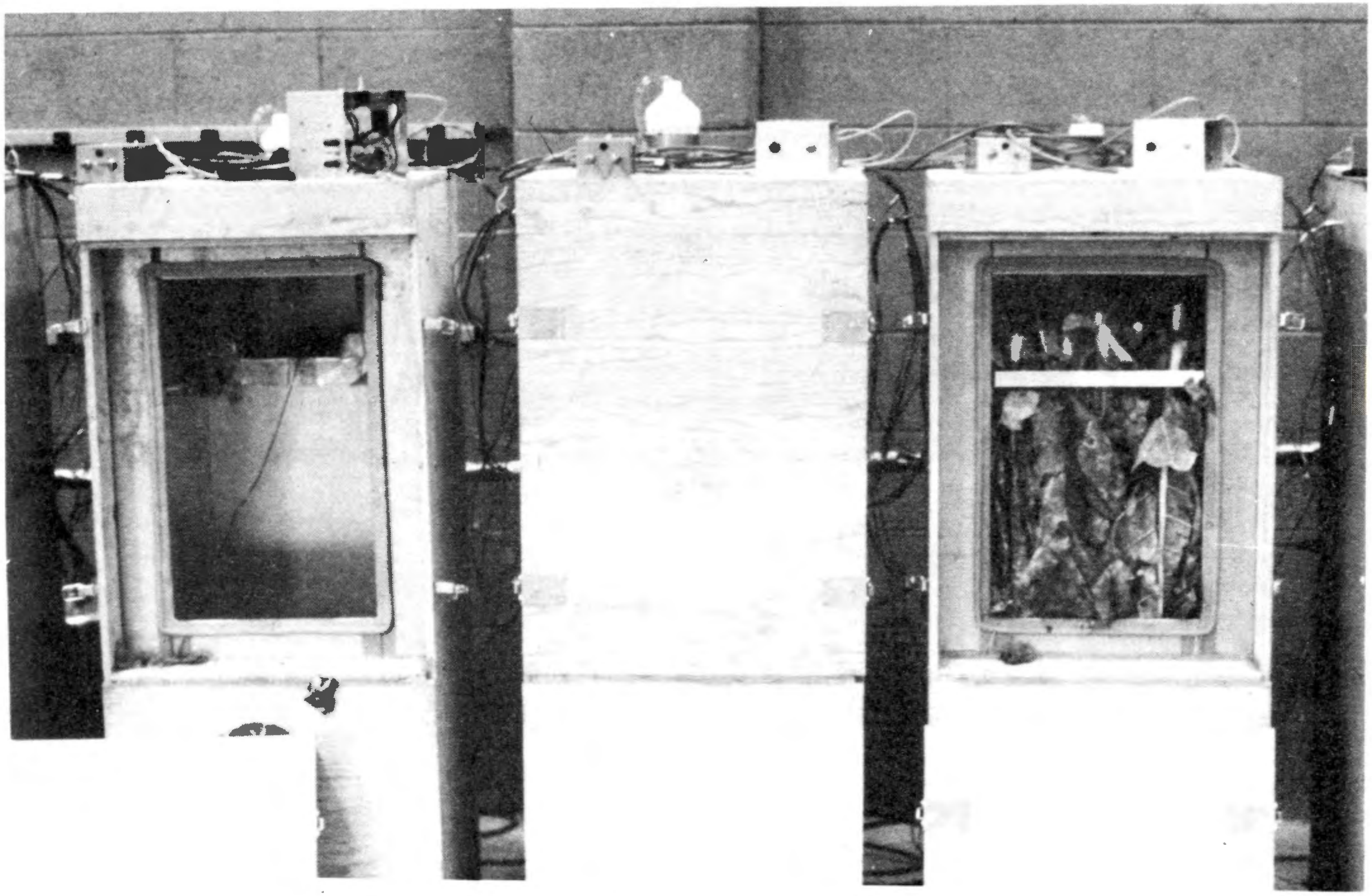


FIGURE 5. Three of the environmental cabinets: left-door open, ready for the sample to be placed on the rack; center-door closed; right-door open with sample in place. The controls may be seen on the top of each cabinet.

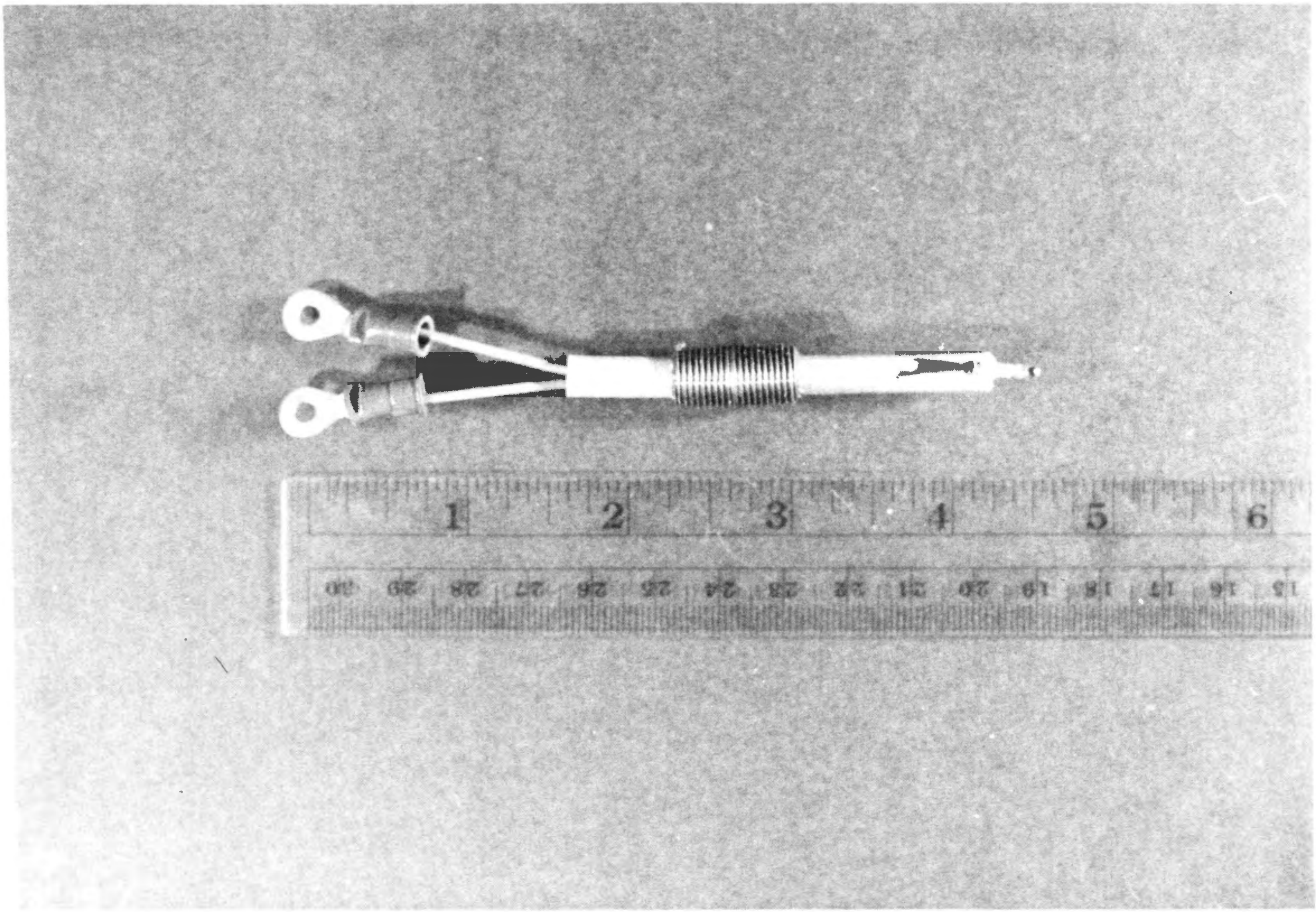


FIGURE 6. The thermistor mounting assembly used as a temperature sensing device for the controls of the environmental cabinets.

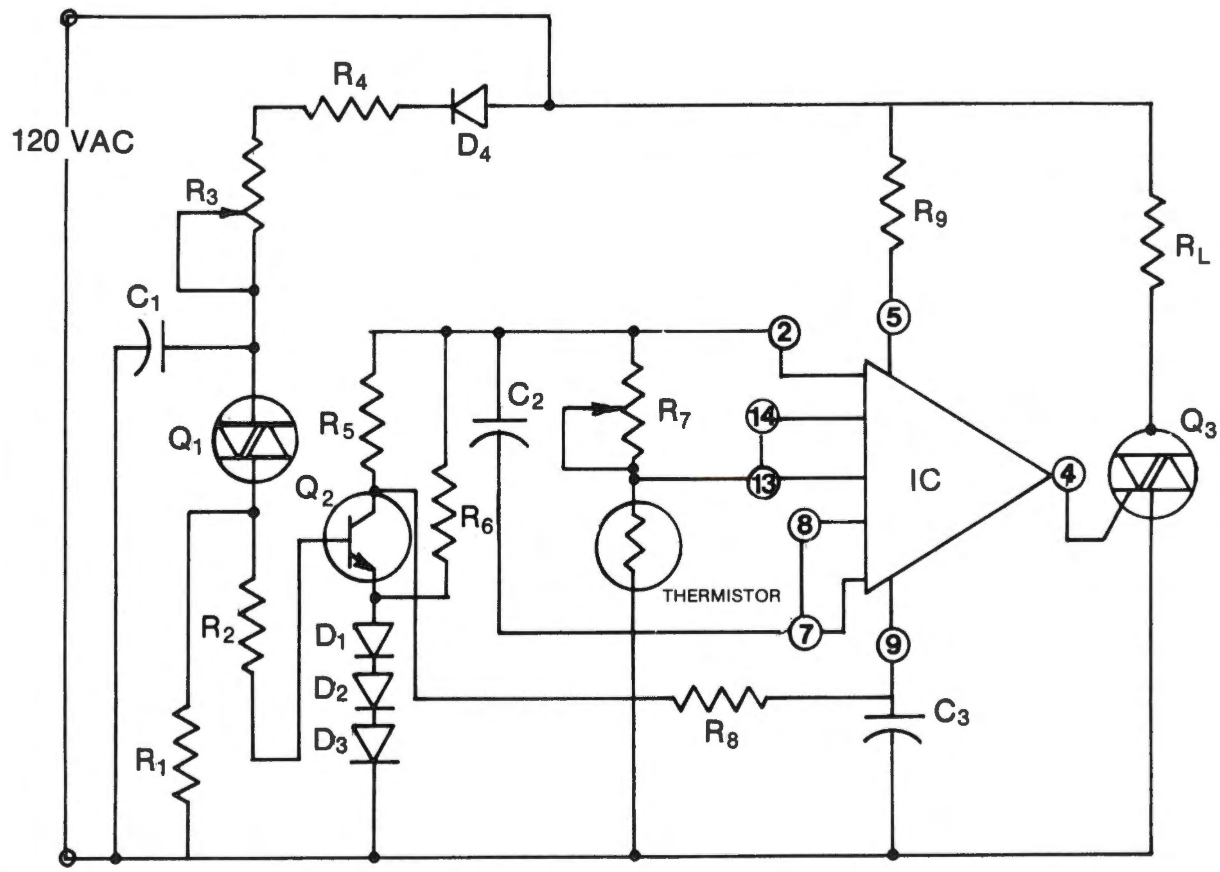
lead wires inside a 0.5 inch long x 0.25-inch diameter plastic tube and inserting the tube into the other half of the 0.125-inch nipple. Solderless terminals were placed on the ends of the thermistor lead wires.

IV. DRY-BULB TEMPERATURE CONTROL

Dry-bulb temperature was regulated by zero voltage switch proportional control of the 600-watt resistance heater. Figure 7 is a schematic of the control (RCA, 1971b). The accuracy of the control is in the order of $\pm$ 0.4°F and is dependent on the input sensitivity of the integrated circuit, the thermistor, and the level of temperature being controlled. If a 10K ohm potentiometer is used for R_7 in Figure 7, the control will function properly over a thermistor range of from about 450 ohms to 1800 ohms. The controlled temperature range can be varied by selecting thermistors that vary within this range at the desired temperature.

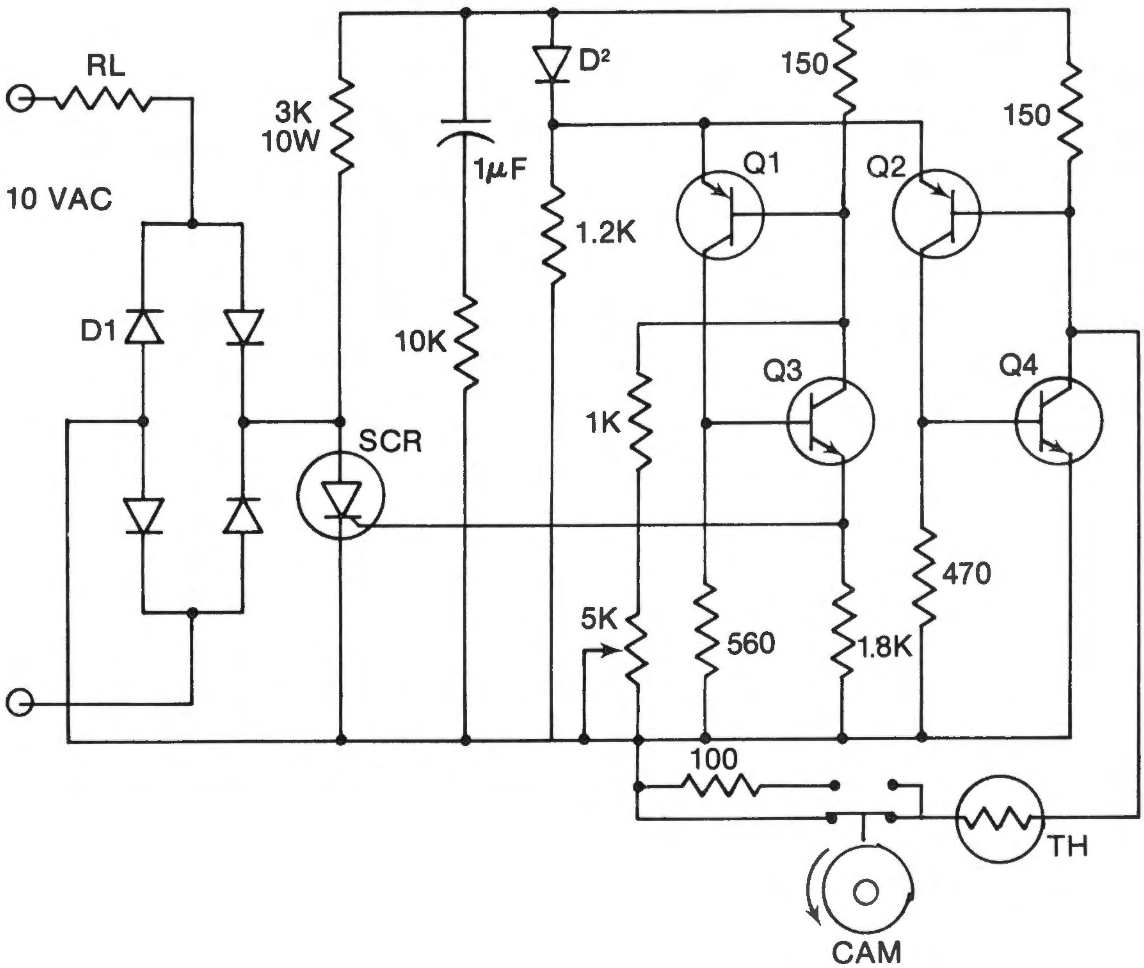
V. WET-BULB TEMPERATURE CONTROL

Wet-bulb temperature was regulated by an on-off control that utilized a wet-bulb thermistor. Figure 8 is a schematic of the control (RCA, 1971a). The control, which provided on-off activation of a solenoid valve in the steam line, will operate satisfactorily within a thermistor range of approximately 1500 to 6000 ohms. The current drawn by the solenoid valve was not sufficient to latch the silicon controlled rectifier of the controller (RCA, 1971b, p. 218), so a 100-watt light bulb was paralleled with the valve coil.



R1 - 1.8K	R7 - 10K	D1-4 - diodes, 1N3193
R2 - 180K	R8 - 10	C1 - 10μF, 50 VDC
R3 - 1 Meg, 2W	R9 - 10K, 2W	C2 - 10μF, 15 VDC
R4 - 150K	Q1 - diac, 1N5411	IC - zero voltage switch, CA3059
R5 - 1 Meg	Q2 - transistor, 2N3241A	RL - 600 watt heater element
R6 - 100K	Q3 - triac, select for load	

FIGURE 7. Schematic diagram of the proportional heater control circuit of the environmental cabinet.



Q1,2 - transistors, 2N2614
Q3,4 - transistors, 2N3241A
D1 - rectifier bridge, IN1614

D2 - diode, IN441B
SCR - 2N3228
RL - solenoid coil in parallel with a 100W light bulb

FIGURE 8. Schematic diagram of the on-off control that switched the steam valve used for wet-bulb regulation in the environmental cabinets.

The wet-bulb thermistor did not respond rapidly enough to prevent considerable overshoot of the set point. In order to understand the action taken to correct this situation, it is necessary to point out an operational characteristic of the control. The control changes state with a change in thermistor resistance of not more than 8 ohms; switching on with an increase and off with a decrease in thermistor resistance. The set point was selected when a 100 ohm resistor was in series with the thermistor. To limit the overshoot, the 100 ohm resistor was switched into series with the thermistor one out of every four seconds by a cam actuated switch. Thus, the steam valve could be on only when the resistor was in the circuit since a 100 ohm decrease in the sensing circuitry was more than adequate to turn off the control.

CHAPTER IV

PROCEDURE

The experiment was conducted in two parts. In the first part, nine combinations of three temperatures and three relative humidities were tested in two replications. Each treatment was evaluated according to color, and analysis of the results gave a regression equation that established a relationship among temperature, relative humidity, and color. In the second part of the experiment, four temperature-relative humidity combinations were selected to test the established regression equation. Each combination was replicated three times and the results were again evaluated by color. Nine environmental cabinets, as previously described, were used simultaneously for all tests. Treatments were assigned to the cabinets by random selection.

I. ESTABLISHMENT OF A LEAF COLOR PREDICTION EQUATION

Nicotiana tobacum L., Cultivar Burley 37, grown on Wolftever soil, using conventional management practices at The University of Tennessee Tobacco Experiment Station, Greenville, Tennessee, was used in the first part of the experiment. The plants had been primed twice before this experiment. The remaining leaves began at about the twelfth leaf position from the bottom. For each replication, the lowest remaining leaf was harvested from 1000 plants. One-hundred leaves were arranged front to back in each of the nine holding racks and were placed in the chambers. Some of the leaves were over-mature and only the best were used in the tests.

Temperature, relative humidity, and curing time as related to the yellowing phase were selected on the basis of results from prior research, and were chosen to cover a range in which the optimum combinations were expected to exist. Temperatures of 100, 107, and 114°F, and relative humidities of 75, 85, and 95 percent were selected, and all possible combinations were used as treatments. Ambient air was circulated through the leaves for 12 hours before a 60-hour curing period was begun. The dry-bulb and wet-bulb temperatures for the air entering and exiting the chambers were recorded every hour. At the end of the 60-hour curing period the leaves were removed from the chambers and evaluated using the system discussed below.

Seven Munsell colors were chosen, one to represent the optimum yellow color and three colors on each side of the optimum to represent expected deviations. The optimum color (5Y 9/6) was selected by comparison of Munsell standard colors with yellowed leaves from an air-cured barn. Numbers were assigned to the seven Munsell colors to form a scoring system. The Munsell colors selected and their respective numbers were: (1) 5Y 7/8, (2) 5Y 8/10, (3) 5Y 8.5/8, (4) 5Y 9/6, (5) 10YR 6/8, (6) 10Y 5/4, and (7) 7.5Y 4/4.

The leaves from each treatment were assigned the color number that best represented their overall color after the 60-hour curing period. SAS 76 GLM Procedure (Barr et al., 1976) was used to obtain the regression equation from the model:

$$y = b_1 + b_2x + b_3x^2 + b_4z + b_5z^2 + b_6xz + b_7x^2z + b_8xz^2 + b_9x^2z^2,$$

where y = color (color number),

x = r.h. (percent), and

z = temperature (°C).

II. TEST OF THE COLOR PREDICTION EQUATION

The four combinations of temperature and relative humidity selected to test the established relationship of the first part of the experiment were 98.6°F--77 percent r.h., 102.2°F--83 percent r.h., 104.0°F--83 percent r.h., and 105.8°F--92 percent r.h. Three replications of each combination were run. The cv. Burley 37 used for the first part of the experiment was too mature for use at the time these last tests were conducted. Therefore, leaves from another plot were selected. They were cv. Burley 37 and cv. Burley 64 that had been grown to test the effect of nitrogen:potassium ratios on seed production. The leaves were taken from the top half of the stalk and were somewhat smaller than those used in the first part of the experiment. To maintain approximately the same bulk density throughout the experiment, 125 leaves per chamber were utilized in the second part. The leaves were removed from the chambers after 60 hours and judged subjectively by color matching.

CHAPTER V

RESULTS AND DISCUSSION

I. TREATMENTS USED TO ESTABLISH THE COLOR PREDICTION EQUATION

The Munsell color notations that best represented the color of the leaves in each treatment are listed in Table 1. The general effects on the leaves at each temperature as the relative humidity went from 75 percent to 95 percent were as expected. The 100°F - 75 percent r.h. treatment was wilted, partially colored, and a few of the leaves had some very light green set around the edge of the leaves. All of these factors indicated that the leaf was drying at a relatively fast rate, but the rate was not acutely excessive since there were no indications of extensive damage to the leaf. The yellow, as well as the tan portions of the leaf, were acceptable colors. The 100°F - 85 percent r.h. treatment leaves were a darker yellow than that found in the 100°F - 75 percent r. h. treatment leaves. They were also turgid which was evidence of a slower drying rate than the 100°F - 75 percent r. h. treatment leaves. No adverse affects were apparent. The leaves of the 100°F - 95 percent r.h. treatment, which were a darker yellow than the other two 100°F treatments, had considerable green color remaining in the leaves, and were extremely turgid. Their turgidity was greater than when they were taken from the field, indicating some moisture may have entered

TABLE 1. Munsell color notation, evaluated color number, and description of leaves at the end of a 60-hour curing period for all treatments of the first part of the experiment.

Treatment Temp.°F - r.h. Percent	Munsell Color Notation	Evaluated Color Number	Description
100-75	10YR 6/8	5	Light tan and yellow mottled, some leaves with light green* tint around edge of leaf, green** bordering midrib of upper portion of a few leaves, wilted
100-85	5Y 8/10	2	75 percent plus yellow, many leaves with no green, turgid
100-95	5Y 7/8	1	75 percent yellow, green bordering midribs and major arteries, yellowish green at butt end, very turgid
107-75	10YR 6/8	5	75 percent tan with yellow bordering midribs, some leaves with light green around edges, wilted
107-85	10YR 6/8	5	60 percent light tan, 40 percent yellow, tan around outside of leaf going to yellow in the center, butt end light yellowish green, yellow portion of the leaf turgid
107-95	10Y 5/4	3	75 percent yellow, dark brown around edge of leaf, very little green bordering midrib, green in "splotches" on about 30 percent of the leaves, yellow portion of the leaves turgid
114-75	10Y 5/4	6	75 percent light green with some light tan mixed with the green, very dry

TABLE 1. (continued)

Treatment Temp.°F - r.h. Percent	Munsell Color Notation	Evaluated Color Number	Description
114-85	10Y 5/4	6	75 percent light green with yellow bordering the midrib of some of the leaves, wilted but not dry
114-95	7.5Y 4/4	7	90 percent dark olive, a few leaves with yellow bordering the midribs, stems beginning to soften and rot

*Light green refers to green color that has probably been set.

**Green refers to green color found in field.

the leaves. Therefore, in addition to the lower drying potential of the 100°F - 95 percent r.h. environment, curing rate may have been further hampered by the "swollen" leaves restricting airflow through the sample. Increasing relative humidity has much the same effect at 107°F. Progressively slower curing rates were evidenced by increased turgidity and less color change with more green in the leaves. At 114°F any effects on the leaves with increased relative humidity were overshadowed by the effect of the 114°F temperature. All of the leaves at this temperature were green because of the arrestment of the enzymatic process that breaks down the chlorophyll in the leaf. The most striking effect of relative humidity at 114°F was the bacterial rot taking place at 95 percent relative humidity. Further discussion of the affect of high relative humidity on yellowing is presented later in this chapter.

Temperature affects of the 100°F and 107°F treatments can be generalized by comparing them at the same relative humidities. The 107°F - 75 percent r.h. treatment leaves were similar to those of the 100°F - 75 percent r.h. treatment. The major difference was that the tan of the 107°F - 75 percent r.h. treatment leaves was lighter than the tan of those at 100°F - 75 percent r.h. Walton and Henson (1971) stated that a yellow leaf may result from over-drying in the initial phase of the cure at high temperatures. Close examination of the 107°F - 75 percent r.h. treatment leaves revealed yellow around the minor veins of the leaf. It seemed evident that a small amount of yellow was set in the leaves giving them a lighter than normal appearance. The 107°F - 85 percent r.h. treatment leaves had progressed further in the 60-hour period than the 100°F - 85 percent r.h. treatment leaves. A large percentage of the leaf of the 107°F - 85 percent r.h. treatment was tan, whereas none of the 100°F - 85 percent r.h. treatment leaves had progressed beyond the yellowing phase. The leaves of the 100°F - 95 percent r.h. treatment were slightly more turgid than those of the 107°F - 95 percent r.h. treatment. Leaves from both treatments were primarily yellow, but were a different yellow as can be seen by comparing the evaluated color numbers. The 107°F temperature was evidently responsible for the difference in color.

By comparing the descriptions of the treatment leaves that were assigned the same Munsell color notation, it can be seen that they were not identical. Of the three treatments evaluated at 10YR 6/8, each has advanced beyond the yellowing stage with a large percentage of the leaf being tan. The tan color was too light, but, assuming the later phases of the cure might be at optimum, the final product of the three treatments would probably have been acceptable (not optimum). The yellow portion of the leaves subjected to the 107°F - 75 percent r.h. and the 107°F - 85 percent r.h. treatments had not reached the optimum yellow color before the leaves began coloring (changing from yellow to final color). In the 107°F - 75 percent r.h. treatment a small amount of light green had been set bordering the leaves' veins giving the leaves a mottled appearance. In contrast, the leaves from the 100°F - 75 percent r.h. treatment were nearer to optimum results. The primary reason for evaluating it at 10YR 6/8 was because the leaf had progressed further than was desired in the 60-hour curing period.

II. COLOR PREDICTION EQUATION

The regression formula derived using the data given in Table 1, page 28, was:

$$Y = 14323.84880130 - 341.52877247X + 2.01735523X^2 - 682.96981326Z + 8.10703690Z^2 + 16.31598675XZ - 0.09659422X^2Z - 0.19394438XZ^2 + 0.00115052X^2Z^2,$$

where Y = color (color number),

X = r.h. (percent), and

Z = temperature (°C).

It was necessary to use all significant figures to obtain correct y values. Figure 9 is a plot of the temperature-relative humidity combinations necessary for the optimum yellow color as predicted by the regression equation.

III. TREATMENT RESULTS FROM THE COLOR PREDICTION EQUATION TEST

The four circles on Figure 9 represent the temperature-relative humidity combinations selected to test the equation. The points are not located on the optimum line because they were selected from a preliminary curve formulated before final analysis. The four temperature-relative humidity combinations used to test the equation are listed in Table 2 along with a description of the results.

Results from this second phase of the experiment reflect the difference in maturity of the leaves which ranges from overripe to dark

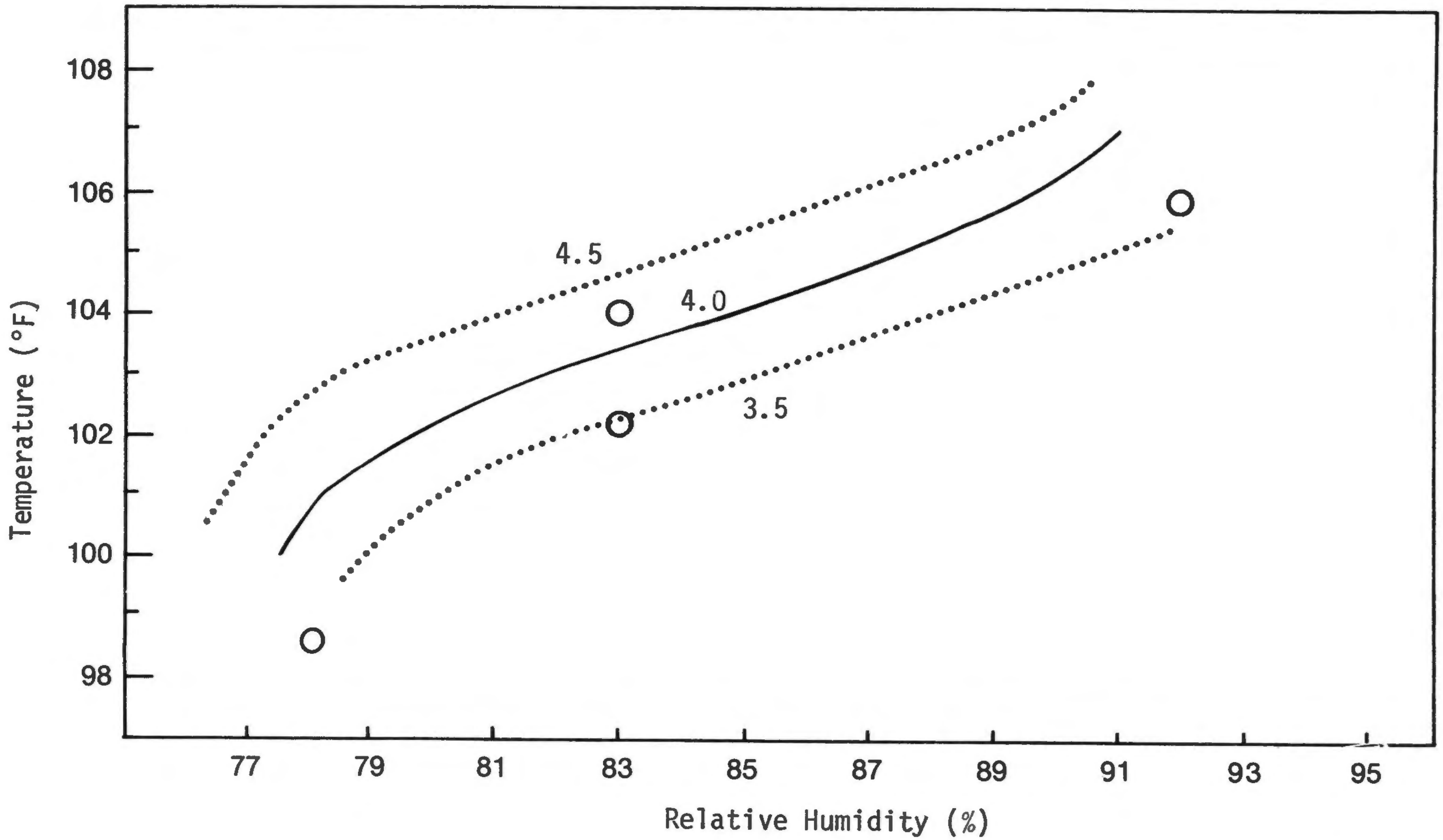


FIGURE 9. A plot of the temperature-relative humidity combinations required to produce the optimum yellow color (4.0) at the end of a 60-hour yellowing period and 0.5 color number deviation on each side of the optimum. The four circles represent the four temperature-relative humidity combinations used to test the color prediction equation.

TABLE 2. Munsell color notation, evaluated and predicted color number, and description of leaves at the end of a 60-hour curing period for all treatments of the second part of the experiment.

Temp. (°F) r.h. (percent)	Munsell Color Notation	Color Number		Description
		Evaluated	Predicted	
98.6 - 78	5Y 9/6	4.0	3.6	Some leaves colored, some light yellow, no green on any of the leaves, wilted
102.2 - 83	5Y 9/6	4.0	3.5	Same as above except a few leaves had green bordering the midrib, not quite as wilted as above
104.0 - 83	10YR 6/8	5.0	4.2	90 percent buff tan, good color but 10 percent light green set in leaves making them undesirable, dry
105 - 92	5Y 8.5/8	3.0	3.4	Almost all of the leaves that were colored had a "barn-burned" appearance, yellowed leaves with green splotches, turgid with some visible water on outside of leaf

green sucker leaves. When taken from the chambers, the sucker leaves were primarily yellow and leaves taken from the lower stalk positions were completely colored. The tobacco subjected to the 98.6°F - 78 percent r.h. and 102.2°F - 83 percent r.h. treatments was judged to be close to optimum as nearly as could be ascertained in the yellowing phase of the cure. In addition to the yellow portion of the leaves being the appropriate color, those leaves that had progressed past the yellowing phase were also of good color. Even though both of these treatments were acceptable, there were detectable differences. The 102.2°F - 83 percent r.h. treatment produced tobacco that was slightly more turgid, and a few of the leaves had green (not set) or an undesirable yellow bordering the midrib. In contrast, the leaves from the 98.6°F - 78 percent r.h. treatment were not turgid but supple, and no green was found. The leaves of the 104°F - 83 percent r.h. were yellowish tan, and green. The green was set and covered about 10 percent of the leaf, indicating that the tobacco was cured too fast.

IV. EFFECT OF HIGH RELATIVE HUMIDITY

The leaves of the 105.8°F - 92 percent r.h. treatment (Table 2, page 34) were of poor quality. Many of them were browning and had the appearance of "barn-burned" tobacco. Those that were not browning were a dark yellow with splotches of green on the lamina. The green splotches were 1.5 to 4 inches across and usually were located near the widest part of the leaf blade. They were dark green in the center and gradually faded into yellow. This treatment coupled with the 100°F - 95 percent r.h. and the 107°F - 95 percent r.h. treatments from the first part of the experiment (Table 1, page 28) helped explain a problem that was encountered during earlier bulk-curing experiments at The University of Tennessee. Leaves that were cured at high relative humidities in a commercial bulk barn had required long periods for yellowing. Some leaves would not completely yellow even though they were subjected to high temperatures (105°F to 110°F) for time periods of up to 96 hours (Henry, 1975). The leaves did not appear to be damaged at that time so it was assumed they were only yellowing at a slow rate. However, the cured tobacco produced from these leaves was dark brown and green mottled. Some of the leaves had a green tint covering the entire leaf. It now seems apparent that too much chlorophyll was remaining in the lamina due to some unexplained effect of the high humidity. The leaf condition that produced this poor quality could be recognized at the end of a 60-hour yellowing period by an experienced observer. Henson et al. (1974) also cured poor quality tobacco at high humidity (95 percent), but at a lower temperature (90°F) than any used in this experiment. Therefore, it is probably safe to assume that 95 percent r.h. is unacceptable for curing quality burley tobacco regardless of the temperature. There is some evidence that the maximum relative humidity for optimum yellowing is much lower than 95 percent r.h. Previous research (Henry, 1975) indicates that the maximum temperature for yellowing is about 108°F. Therefore, according to the prediction equation (Figure 9, page 33), the maximum relative humidity for optimum yellowing is around 91 percent r.h.

V. PREDICTED RESULTS COMPARED WITH ACTUAL RESULTS

Evaluated and predicted color numbers are listed in Table 2, page 34. The leaves were evaluated by matching the predominant color of the leaves with Munsell color chips as previously described. The predicted values were obtained by substituting the treatment variables (temperature and r.h.) into the equation on page 25 and solving for Y (color number).

By comparing the predicted values with actual assigned values, it can be seen that the equation does predict accurately the direction of color deviation from the optimum of 4.0. However, the color numbers from the equation do not coincide exactly with the evaluated color number. This points out the fact that the evaluation system would be more accurate if treatments that did not match a color chip exactly were assigned color numbers intermediate between the whole numbers. This was not apparent in the first part of the experiment because all of the treatment leaves reasonably matched their assigned color number. The 105.8°F - 92 percent r.h. treatment and the 104.0°F - 83 percent r.h. treatment produced leaves that were unacceptable even though their predicted color numbers were close to the optimum of 4.0. This indicates that even small deviation from certain portions of the optimum curve (Figure 9, page 33) will produce undesirable results. It also could indicate that higher temperatures require close relative humidity control for optimum yellowing, but more research would be required to establish this fact.

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

Mechanization of harvesting, curing, and marketing of burley tobacco is needed because of increasing cost and low availability of labor. The bulk harvesting-curing system is under scrutiny as a possible answer to the labor problems. The workability of the system depends in some part on the establishment of a psychrometric schedule that can be used to reliably cure burley in a bulk package at an accelerated rate.

The yellowing phase of the cure was considered in this research. An experiment was designed to determine the psychrometric parameters necessary for optimum quality of the leaf at the end of the yellowing phase as indicated by color.

Experimental curing cabinets were designed and constructed that utilized zero voltage proportional heater controls, recirculating air flow, and an on-off solenoid valve steam injection system for close control of temperature and relative humidity.

Nine of the environmental cabinets were used to test the effects of all combinations of three temperatures (100, 107, and 114°F) and three relative humidities (75, 85, and 95 percent) on bulked burley leaf at the end of a 60-hour yellowing period. The results were evaluated by comparing the treated leaves with seven pre-selected Munsell colors which included an optimum color. Each treatment was assigned a color number that best represented the most predominant color.

A relationship among color, temperature, and relative humidity was established. The relationship was tested by selecting four temperature-relative humidity combinations and comparing actual results to results predicted by the equation.

II. CONCLUSIONS

The results led to the following conclusions:

1. Burley tobacco leaf can be yellowed in the bulk at an accelerated rate with a resulting yellow color comparable to that found in conventionally cured tobacco.
2. As indicated by the prediction equation, an increase in temperature requires a corresponding increase in relative humidity for optimum yellowing.
3. Constant high relative-humidity (95 percent) during the yellowing phase of bulk-curing burley will result in low quality leaf regardless of temperature. The maximum relative humidity that may be constantly used without visibly effect-effecting color lies between 85 percent and 95 percent and evidence indicates that it is probably 90 percent or less.
4. The combination of 98.6°F - 78 percent r.h. produced excellent leaf color and overall appearance at the end of the 60-hour yellowing period.

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