BRIGHT LEAF TOBACCO CURING

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Introduction

Tobacco was first cured to a bright yellow color on the Slade farm in Caswell County in 1839. A young slave, Stephen, seated in a barn where he was curing tobacco by open fires on the dirt floor, went to sleep. Upon awakening, seeing the fires nearly out, he overdid the rekindling job. The result was - 600 pounds of bright yellow tobacco never before seen in Caswell County or elsewhere. When this tobacco sold for an extravagant price in Danville, the incident of its curing created a sensation.

Nearly fifty years after the incident Stephen was asked to tell again how he discovered the curing technique for bright tobacco. This time his words were recorded in print:

> "...to tell the truth about it, 'twas a accident. I commenced to cure it and it commenced to git yallow. It kep' on yallowin' and kep on yallowin' and kep on yallowin' twell it got clar up...it looked so purty. I kep makin' it yallow and when it was cured it was 'musement for folks to come and see it."

This art of curing tobacco to a bright yellow color by the use of charcoal was improved upon in the 1870's when flues became the standard equipment for curing the bright tobacco. Flue curing provided heat without smoke or gases in the barn, was more easily managed, and it was cheaper. The charcoal method had required 100 bushels of charcoal at 4 cents a bushel to cure 800 pounds of tobacco.

Tobacco curing as an art has been handed down through generations and remains today more an art than a science. 'Twould be a safe bet that more than 50 percent of those operating cures today have little or no profound grasp of why they are doing what they are doing. They do it this way because grandpa or Uncle Zeb or somebody said this would work - and he was good at curing; even used to go to Canada to cure tobacco.

While the art, with its mysticism and romaticism, is not to be disparaged - after all, it has provided livelihood for millions for over a century - its weakness is evidenced by its own contradictions. There are those who swear by a tight barn; others swear by one through the wall of which a cat could be thrown. One believes in ventilation; another in no ventilation a'tall. Some believe in leaf drying at low temperatures around 120° F. because "you can't rush tobacco"; others believe in drying at 150° F. because 120° F. is a "sweating heat".

From such contradictions as these, one may conclude: (1) that what works for one will not work for another, or (2) that tobacco possesses an amazing wide range of tolerance for curing conditions. Conclusion No. (2) is probably more profoundly true than most of us would admit; because two of the most universally accepted statements among tobacco growers are: (1) if tobacco is "right" when you put it in the barn, anybody can cure it; and if it is not "right" going in, nobody can cure it, and (2) nobody really knows how to cure tobacco.

In recent years considerable scientific effort has gone into the curing process. It will be our purpose to examine the results of this scientific effort in the hope of a better understanding of the curing process and possibly the establishment of some scientific guidelines for curing.

A descriptive definition of proper bright leaf tobacco curing would be:

A <u>TIMELY</u> REMOVAL OF LEAF MOISTURE WHEREBY MAXIMUM MARKET POTENTIAL IS DEVELOPED AND PRESERVED.

Thus, this curing process is reduced simply to the "when" and "how" of moisture removal from the leaf. The "when" is of paramount importance in the development of maximum market potential within the leaf and the "how" is of equal importance in not obviating the proper "when".

Leaf Physiology Influences Moisture Loss

The leaf is definitely a living plant tissue during initial stages of curing, and living organisms exert a definite influence on their moisture loss. A discussion of leaf physiology, as it influences moisture loss, is in order.

It has been generalized that organisms, or life, exist so long as the organization of the protoplasmic system of the cell is maintained; and that protoplasm is fundamentally the same in all living organisms.

A descriptive drawing of a typical plant cell, as given in most textbooks dealing with plant physiology, is shown in Figure 1. A tracing of a photomicrograph

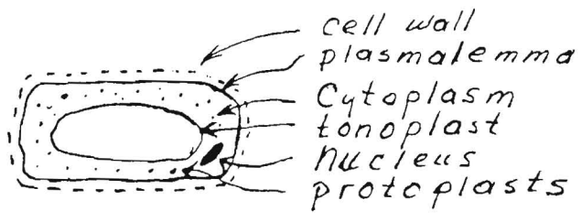


Figure 1. Schematic representation of leaf cell.

of a cross section of mature tobacco leaf lamina is shown in Figure 2.

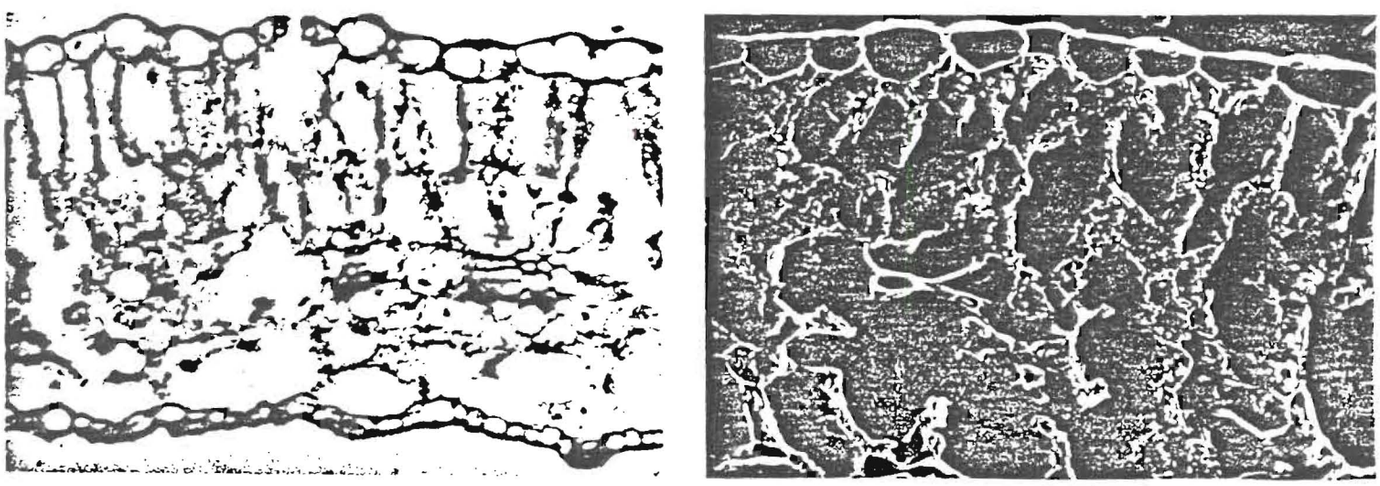


Figure 2. Photomicrograph of cross section of tobacco leaf lamina before curing. Mohapatra (1972)

Cell Structure.

A large central portion called the vacuole contains cell sap and is completely surrounded by the cytoplasm which in turn is enclosed in an elastic cell wall.

The vacuole varies in shape and size depending on the age of the cell and its metabolic activity but is generally considered as globular. It contains various solutes (sugars, mineral salts, organic acids, amino acids, amides, alkaloids, etc.) dissolved or dispersed in water which amounts to as much as 98 percent of the contents. Although the vacuole and its contents are regarded as non-living, it plays an important part in cellular activity.

The cytoplasm is the seat of living processes within the cell. It contains the cell nucleus and the other cytoplasmic bodies which actually control life processes. These bodies are suspended in an everchanging medium which displays both fluid and elastic properties, yet is composed predominantly of water. The cytoplasm is separated from the vacuole and the cell wall by two membranes - the tonoplast and plasmalemma respectively - probably composed of phospholipid materials. The membranes are insoluble in water and as long as they are intact the cytoplasm does not disperse in water. On the other hand, the cytoplasm (boundary membranes included) is relatively permeable to water and differentially permeable to most solutes. Concerning the structure of the medium extending throughout the cytoplasm, Meyer and Anderson (1952) write:

> "The highest magnifications reveal no evidence of any structural background in active cytoplasm, yet its complex activities suggest that it must possess an intricate structural organization. The marked imbibitional capacity of cytoplasm, its stability toward electrolytes, its electrical properties, its coagulability, and its gel-forming capacity all suggest that it is to be classed with the hydrophilic colloids."

In 1960 Meyer wrote, concerning the protoplasm of plants in general:

> "although protoplasm, on cursory examination, appears to be a liquid, no simple liquid could possibly possess the remarkable powers of synthesis, assemilation, reproduction, growth, and sensitivity that characterize the protoplasm of living plant cells. The properties and behavior of protoplasm clearly show that it is not a single substance but that it must be regarded as a complex system of substances. This system is dynamic; it is constantly undergoing changes yet at the same time the changes are so regulated and controlled that the system is not disrupted. A cell is alive only so long as the organization of this dynamic protoplasmic system is maintained."

The cell wall is largely composed of cellulose molecules which provide the wall with both its elastic and non-elastic properties depending on the arrangement of the molecules. In some regions the cellulose molecules display a crystalline structure which is very rigid compared to other regions in which the molecules are arranged in a random manner. The mature cell wall is chemically inert with respect to the constituents found in the cell and its primary function is to provide structural strength and form. The cell wall offers very little resistance to the movement of water across its boundaries as it is readily permeable to water, solutes, and even small particles. The cell wall is insoluble in water and under normal conditions of turgor the spaces or voids between cellulose fibers are filled with liquid water which is, in varying degrees, bound with lignin or pectic compounds that may also be present.

Leaf Structure.

The manner in which individual cells are combined to form leaf tissue is determined by heredity and environment. Perhaps we can best describe the cellular structure of the lamina by considering its development. Avery (1933) made an

extensive study of the structure and development of the tobacco leaf. According to Avery, cell division in the various tissues of the lamina ceases before the leaf attains one-fourth its mature size; the remaining growth resulting from cell enlargement. The duration of cell enlargement in the various tissues has an important bearing on the internal structure of the leaf. Avery observed that cell enlargement in the epidermis continues longer than in the other tissues resulting, literally, in a pulling apart of the internal cells giving rise to rather evenly distributed, large, intercellular air spaces. Wilson (1952), describing the typical structure of leaves in general, writes:

> "Internally the leaf is composed largely of thin-walled cells of the mesophyll surrounded by a honeycomb of intercellular spaces which make up 17 to 40 percent of the volume of the leaf. These cavities in the leaf form a branched system of air passages which connect with larger spaces lying just behind the stomates. ... The internal surface thus exposed is seven to thirty times the total of the epidermal surface."

The epidermis is continuous (with the exception of stomates) over both surfaces of the leaf and is covered by a waxy layer of film called the cuticle which is not readily permeable to water.

Resistance to Moisture Migration.

In the removal of water from the tobacco leaf, as in curing, there are at least two realms of resistance to moisture migration: (1) cytoplasmic resistance and (2) epidermal resistance.

Cytoplasmic resistance: In mature leaf tissue the vacuole contains the bulk of the water held in the leaf. Since the vacuole is surrounded by the cytoplasm, the water must diffuse through the cytoplasm if it is to escape.

Although the cytoplasm is said to be "freely permeable to water", a resistance

to moisture movement must exist; otherwise, the cell would not be able to develop turgor. Studies by Bienhart (1951) have indicated that the leaf exerts physiological control over its moisture relations. He showed that a simple closing of the leaf stomates could not explain such control, with the conclusion that the cytoplasm controls moisture movement by increasing its resistance.

After escaping the cytoplasm, the water must go through the cell wall. The resistance of the cell wall, according to Meyer and Anderson (1952) is small compared to the cytoplasmic resistance and for practical purposes may be neglected, especially at high moisture contents.

Epidermal resistance: At the outer surface of the cell wall water has ready access, via the honeycomb intercellular spaces, to the leaf epidermis. Here it may escape through the stomates or through the compactly arranged epidermal cells and their protective cuticle.

The stomatal openings would appear to be the easy route if they were open. Investigations by Okuyama (1955), however, showed that the stomates are closed during the normal yellowing process. He reported stomatal opening after about four hours at higher temperatures (110-115° F.). Miller (1938) has stated that stomates respond primarily to light and next to moisture supply. Under curing conditions both of these factors are essentially nonexistent. Thus, we can safely assume that stomates are closed during the least part of the curing process, leaving the epidermal cells and cuticle layer as the only escape route.

In view of the above discussion, we may speculate that in the early stages of curing the epidermal resistance is the limiting factor to drying, and in later stages cytoplasmic resistance is the limiting factor.

When the leaf is at or near full turgor, water moves along cell walls as a liquid and from cell vacuole to cell vacuole as a liquid and through intercellular

space as a vapor. Since water is abundant, cell walls are very wet and intercellular space is saturated; i.e., 100 percent relative humidity. Only the epidermal resistance prevents the vapor pressure within the leaf from coming to equilibrium with the vapor pressure outside the leaf. We are here assuming normal curing or drying conditions wherein the relative humidity (and hence the vapor pressure) outside the leaf is lower than the relative humidity (and hence the vapor pressure) inside the leaf. Thus, during this period the leaf is losing water at a rate limited by the epidermal conductivity.

As drying progresses the assumption is that the cytoplasm becomes the limiting factor in moisture loss from the leaf. Studies by Humphries (1964) have verified this assumption. In his tests a short hollow cylinder capped airtight by tobacco lamina was used to measure intercellular vapor pressure and temperature. He states that "in general the intercellular space vapor pressure does not remain at the saturation level". He concluded that "after drying starts (in some cases after the yellowing stage) intercellular space vapor pressure begins to drop below the saturation pressure." This point, then, can be interpreted as the point at which the supply of water from the cell vacuoles is no longer sufficient to maintain a free water supply on the cell walls. His studies revealed that the upper and lower surfaces of the leaf have different permeabilities and that under different conditions the upper or the lower surface may have the higher permeability. Another surprising observation - leaf permeability was generally higher at 100° F. and 85% relative humidity curing conditions than at 100° F. and 75% relative humidity. Was this due to stomatal activity? Furthermore, the permeability of neither surface remained constant throughout the tests (first 35 hours of yellowing).

From this discussion of cell physiology and moisture movement within the leaf, some insight is gained into the behavior of tobacco leaf during curing, especially in the yellowing phase while the cell is definitely alive.

Temperature Affects Physiology

While we may normally think of temperature as just a driving force for drying, we should not forget the profound influence of temperature on cellular life and activity. 'Tis difficult to find any cellular structural part or biological activity that is not fundamentally related to temperature.

Some of the leaf reactions to drastic temperature change have been investigated by Hassler (1959) and Alphin (1962). Hassler's work, wherein yellowed turgid leaf was subjected to a constant rate of irradiation by infrared energy, showed that the physiological control of the leaf over its moisture movement was lost at higher leaf temperatures. Where radiation intensity was such that the leaf temperature rose from 80° F. to 175° F. in 5 seconds, the physiological "loss of control" occurred at 175° F. Where intensity was such that leaf temperature reached 152° F in 25 seconds, the "loss of control" occurred at 152° F. After this point was reached, the moisture loss of the leaf was more similar to that of an ink blotter or other non-living material. His studies also indicated that at the high rates of temperature elevation, immediately after the "loss of control", the moisture loss from the leaf was in spurts rather than uniformly. Hassler also reported that mature yellow leaf tissue at 135° F. turned brown in 4 minutes.

Alphin (1962) investigating leaf resistance to moisture loss, leaf browning, and leaf electrical conductance reached the following conclusions. Where the tobacco leaf (mature, yellow, turgid) is irradiated with 5 watts of infrared energy per square inch:

(1) The leaf organizational resistance to moisture loss decreased twofold,

(2) the leaf organizational resistance to browning was decreased at least a thousandfold,

(3) the leaf organizational resistance to D.C. charge flow was decreased at least twofold, and

(4) the response time for the above 3 leaf phenomena were indicated to be essentially coincident. This response time was about 5 seconds and the leaf temperature was elevated to about 150° F. during this interval.

In the browning studies the brown color was not visible immediately after the 5 seconds of radiation but was visible in, at most, a matter of minutes at room temperature. Leaf not irradiated would require, at room temperature, several days to reach this degree of browning.

While a leaf temperature of 135° F. is sufficient to trigger the browning reaction, a temperature of 212° F. is sufficient to prevent it. Hassler has shown that by momentarily stamping a yellowed turgid leaf with a hot flat iron the leaf subsequently dries like a blotter and does not turn brown. Alphin demonstrated the same phenomena. When he radiated leaf sections for 60 seconds at 5 watts per square inch, the leaf sections subsequently would not brown. The explanation advanced is: the enzyme which normally causes browning is killed or inactivated by the higher temperatures. Leaf given this thermal treatment, however, does not "age" normally, preventing the practical use of this thermal killing in curing operations.

Thus far the leaf has refused to submit to any practical short cuts to drying. If the cytoplasmic resistance to moisture loss is overcome by a moderate temperature (135° F.) treatment, browning sets in. If an extreme temperature (212° F.) treatment is used to prevent browning, then the leaf will not "age" properly and is not acceptable to the trade. Studies by Watkins (1960) have shown that browning after the temperature treatment can be prevented by withholding oxygen from the leaf; but this requires curing or drying in an atmosphere of controlled composition and is, at this stage, far from practical.

Leaf Chemistry

During the early stages of a normal curing schedule, the tobacco leaf is a veritable living chemical factory. Some of the more important chemical activities from a final quality standpoint are: chlorophyll breakdown, starch conversion to sugar, and protein simplification. As the leaf cell dies of dehydration during the leaf drying stage, chemical activity is decreased drastically leaving the slow activities associated with the "ageing" process.

Leaf Component Changes.

A comprehensive study of the composition of flue-cured leaves before, during, and after curing was made by Bacon, et al. (1951). In this study 16 leaf components were assayed at harvest, after yellowing, and after curing. The results of this study are shown in Table I.

Table I. Changes in composition of tobacco curing the flue-curing process[a]

Constituents	Green %	Yellowed %	Difference green to yellowed %	Cured %	Difference green to cured %
		Average of 6 curings			
Starch	29.3	12.40	-16.90	5.52	-23.78
Free reducing sugars[b]	6.68	15.92	+ 9.24	16.47	+ 9.79
Fructose	2.87	7.06	4.19	7.06	4.19
Sucrose	1.73	5.22	3.49	7.30	5.57
Crude fiber	7.28	7.16	- .12	7.34	+ .06
Total nitrogen	1.08	1.04	- .04	1.05	- .03
Protein nitrogen	.65	.56	- .09	.51	- .14
Nicotine	1.10	1.02	- .08	.97	- .13
Ash	9.23	9.24	+ .01	9.25	+ .02
Calcium[c]	1.37	1.37	± 0	1.37	± 0
Oxalic acid	.96	.92	- .04	.85	- .11
Citric acid	.40	.37	- .03	.38	- .02
Malic acid	8.62	9.85	+ 1.23	8.73	+ .11

(Table continued)

(Continued)

Resins	7.05	6.53	- .52	6.61	- .44
Pectinic acid	10.99	10.22	- .77	8.48	- 2.51
pH value	5.55	5.64	--	5.55	--

[a]Data after Bacon, et al. (1951). Data on water and sand-free basis. Yellowed and cured samples calculated to original dry-weight basis.

[b]Calculated as dextrose.

[c]Average of 4 curings.

As is evident in the table, the starch and sugar components changed drastically.

These results have been verified by other scientists working with air cured as well as flue cured varieties. In one such study the authors concluded that "starch underwent a marked conversion into simple sugars and that these were converted into acids, carbon dioxide, and water; and that although total nitrogen remained almost constant, proteins were converted to amino acids, amides, and ammonia. Another study of Australian flue cured tobacco noted "increases in sugar concentrations from 5 to 25 percent as starch underwent hydrolysis." Other studies have shown that the hydrolysis of protein begins soon after harvest and varies in rate depending on the ratio of protein nitrogen to soluble nitrogen at the beginning of curing.

A recent study of the changes in chlorophyll content during the curing of flue cured tobacco have shown that chlorophyll decomposition began, at a fast rate, with the beginning of the curing process and did not diminish until 80 to 85% of the pigment had been lost. This required, on the average, 40 to 45 hours of curing. After this, the chlorophyll content decreased slowly during the remainder of the cure with the cured leaves retaining about 5% of the original chlorophyll.

Weight Loss in Curing.

Studies by Johnson (1961) may be used to calculate the weight loss of tobacco in curing. Johnson measured the rate of carbon dioxide liberation from flue-cured tobacco during the yellowing phase of curing. Table II is a brief summary of his results.

Table II. Carbon dioxide liberation from tobacco yellowing at various temperatures. Average* values for 48 hour period.

Temperature (^{o} F.)	80	90	100	110
Liberation rate[a]	26.4	36.9	55.3	61.9

*Variation in rate with time was not significant

[a]Expressed in mg per minute - kg dry weight lamina

The equation for the oxidation of sugar, as in plant respiration is:

$$C_6H_{12}O + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 672{,}000 \text{ Calories}$$

Applying the atomic weights of the elements involved reveals that the respiration of 180 grams of sugar gives 264 grams of carbon dioxide:

$$6(12) + 12(1) + 6(16) \rightarrow 6(12 + 32)$$

$$180 \rightarrow 264$$

Using the value from Table II for a yellowing temperature of 100^{o} F. we calculate a weight loss (dry matter) of 2.26 grams of sugar per kg of lamina for each hour of yellowing time.

$$\left(\frac{55.3 \text{ mg } CO_2}{\text{min - kg lamina}}\right)\left(\frac{180 \text{ gm Sugar}}{264 \text{ gm } CO_2}\right)\left(\frac{60 \text{ min.}}{\text{hr.}}\right)\left(\frac{1 \text{ gm}}{1000 \text{ mg}}\right) = \frac{2.26 \text{ gm Sugar}}{\text{hr - kg lamina}}$$

Actually, this rate of weight loss continues past what is normally thought of as the yellowing phase. Respiration ceases or diminishes drastically when the leaf cell dies of desiccation or when the leaf temperature exceeds the upper limit of the biokinetic zone. The biokinetic zone for most plants if 10^{o} C. to 45^{o} C (Giese, 1957).

In a normal cure the leaf would be sufficiently dried to stop respiration after about 75 hours. At the above calculated rate of weight loss, 17 percent of the lamina weight would be lost in 75 hours.

$$\left(\frac{2.26 \text{ gm sugar}}{\text{kg lamina - hr}}\right)\left(75 \text{ hr}\right) = \frac{170 \text{ gm}}{\text{kg}} = 17\%$$

At a yellowing temperature of 90° F., the lower respiration rate (Table II) would consume about 11.3 percent of the lamina in 75 hours.

$$\left(\frac{36.9}{55.3}\right)\left(17\right) = 11.35$$

In Johnson's tests the lamina comprised about 72 percent of the total leaf. Applying this factor to the weight losses at the two temperatures reveals weight losses of 12.2% at 100° F. yellowing temperature and 8.2% at the 90° F. temperature.

(.72)(17%) = 12.2% loss of total leaf @ 100° F.

(.72)(11.35%) = 8.2% loss of total leaf @ 90° F.

This calculation assumes zero weight loss from the stem portion which has much less sugar content than the lamina portion.

Johnson also investigated the effect of concentration of respirable substrate on the rate of carbon dioxide liberation. He measured total sugar and reducing sugar concentrations at 12 hour intervals throughout the carbon dioxide liberation tests. Both total and reducing sugars were found to be increasing throughout all the tests. Since no correlation was found between sugar concentrations and carbon dioxide liberation rates, an enzyme concentration may have been the limiting factor.

Curing Mechanics

As previously mentioned, the objective in curing tobacco is to maximize market potential by a timely removal of leaf moisture. The "when" of moisture removal is important as well as the "how".

The "How" of Moisture Removal.

In tobacco curing as we know it, air is used as a vehicle for moisture removal. Curing structures are designed and equipped such that heated air is passed through (circulated about) tobacco leaves delivering heat to the leaves and carrying moisture away from the leaves.

The water carrying capacity of air depends upon the temperature of the air. The water absorbing capacity of air depends upon its temperature and relative humidity. The relative humidity of air may be determined if the dry bulb temperature and wet bulb temperature of the air is known.

In principle a wet "sock" on the sensing element of a thermometer cools the sensing element by evaporative cooling for the wet bulb reading. The drier the air, the more the cooling effect on the sensing element. At 100% relative humidity the air can do no drying; thence no cooling effect on the sensing element, and the wet bulb temperature is the same as the dry bulb temperature. If the relative humidity

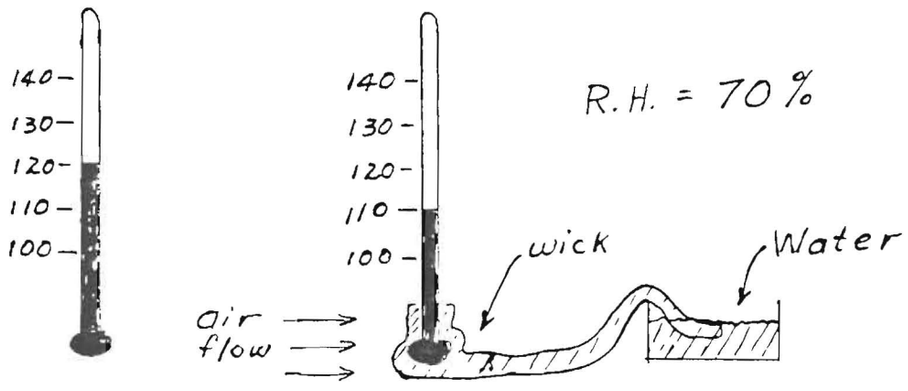


Figure 3. Wet bulb temperature

of the air is 70 percent and the dry bulb temperature is 120° F., then the air has enough drying potential to cool the wet bulb 10° F. as shown in Figure 3.

The psychrometric chart shown in Figure 4 gives the properties of air at various temperatures and moisture contents.

As may be seen in the chart, large volumes of air are required for delivering heat to the leaf and carrying water vapor away from the leaf. About 1000 BTU's are required for evaporating one pound of leaf moisture. Thus, a curing unit with a heat capacity of half a million BTU's per hour can remove only about 500 pounds of water per hour from the tobacco.

At a temperature of 120° F. and at atmospheric pressure, one pound of air occupies about 15 cubic feet of space. A fan, then, delivering 15,000 cfm is handling about 1000 pounds of air per minute. In a normal cure, during leaf drying, wherein air with the following conditions

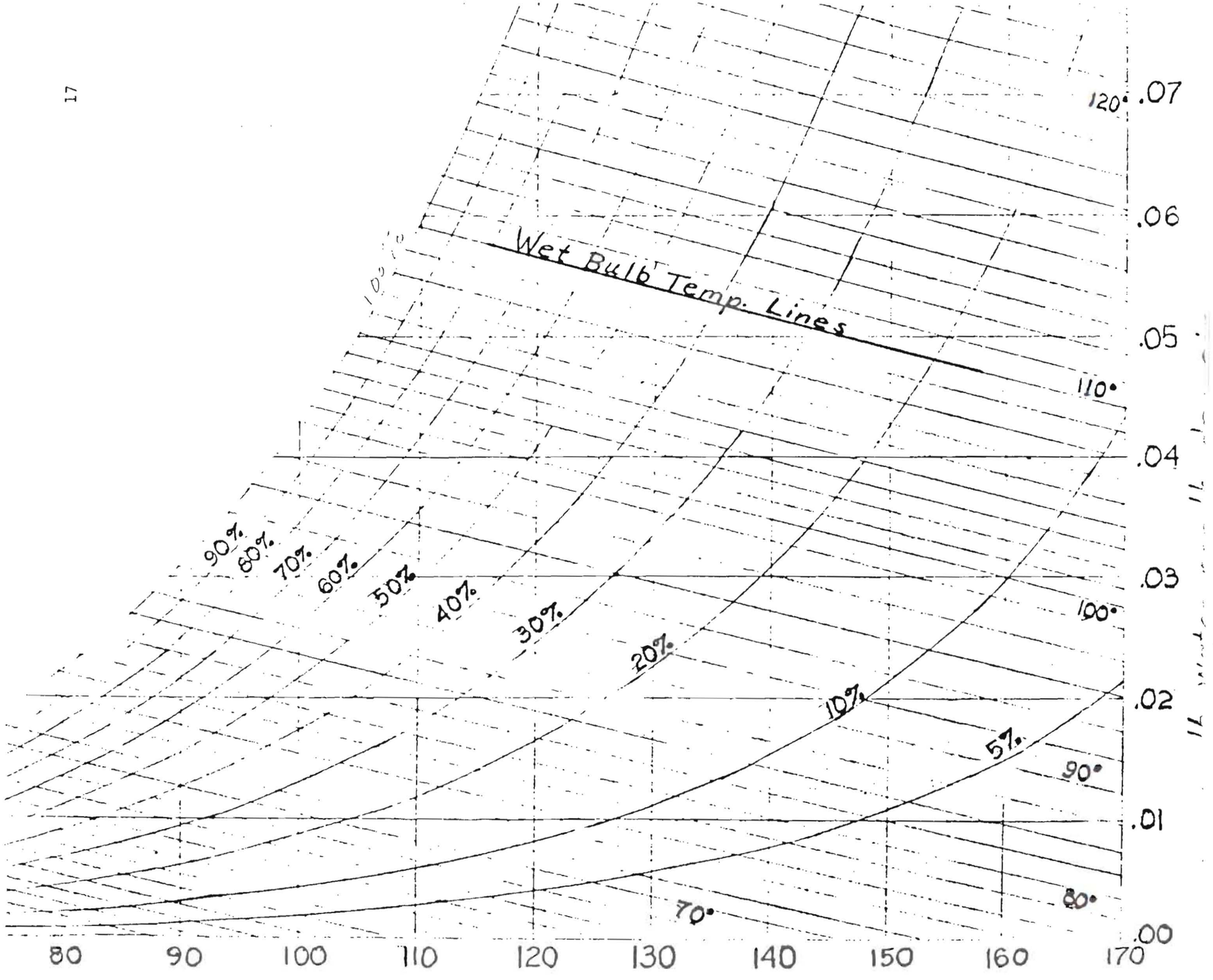
$$120^{\circ}\text{ F DB and } 100^{\circ}\text{ B. WB} = 47\%\text{ RH} = .038\ \frac{\#\ H_2O}{\#\ \text{Dry Air}}$$

is being forced through tobacco and is being exhausted from the curing barn at the following conditions,

$$110^{\circ}\text{ F. DB and } 100^{\circ}\text{ F. WB} = 68\%\text{ RH} = .0405\ \frac{\#\ H_2O}{\#\ \text{Dry Air}}$$

a simple subtraction reveals a moisture removal rate of 0.0025 pounds of water per pound of dry air. Thus, an air flow rate of 1000 pounds per minute removes 2.5 pounds of water per minute.

In a typical bulk tobacco curing barn the temperature and relative humidity of the curing air is controlled by regulating the heat input to the air and by controlling the "ventilation rate" or the amount of outside air admitted into the barn. If no outside air is admitted and if sufficient moisture is present in the tobacco, the air soon becomes saturated and no drying is possible. As drier outside air is admitted and a corresponding amount of humid air is exhausted, drying is accomplished.


Wet Bulb Temp. Lines
120°
110°
100°
90°
80°
70°
90%
80%
70%
60%
50%
40%
30%
20%
10%
5%
.07
.06
.05
.04
.03
.02
.01
.00
80
90
100
110
120
130
140
150
160
170

Air flow patterns and curing controls for a typical bulk curer are shown schematically in Figure 5.

Curing Controls

In an overall view the variety and complexity of controls available for tobacco curers may seem to be surpassed only by the "optional-at-extra-cost" items associated with new automobiles. Automatic temperature controller, automatic advance; automatic humidity controller, manually set; automatic humidity controller, automatic advance; and automatic programmers for temperature and humidity are some of the terms becoming a part of the equipment salesman's vocabulary. We have come a long way from the ridge vents, air holes, and float type carburetors indexed from one to six which were modern only a few years ago.

When viewed separately, functionally, and in light of the pre-existing need for curing controls, these complicated systems seem more gratifying and less confusing.

The automatic advance temperature controller (thermostat with an electric clock mechanism to advance temperature uniformly at a fixed rate (see Figure 6) is in widespread usage on conventional type curing systems and on bulk curers. One can hardly doubt the feasibility of this instrument after considering the wealth of research results recommending slow and gradual temperature elevation for proper leaf drying or "coloring." And what percentage of tobacco farmers can or will find time in the rush of harvesting to manually advance the curing temperature at the recommended rate of one or two degrees per hour? In many instances this automatic advance thermostat would be a good buy even if its current price were multiplied by five.

The automatic programmer allows one to set up a temperature schedule for as much as seven days. Basically the programmer is a seven-day time switch (dial makes one revolution in seven days) which makes or breaks the circuit supplying power to the clock motor of the thermostat referred to in the above paragraph. This mechanism

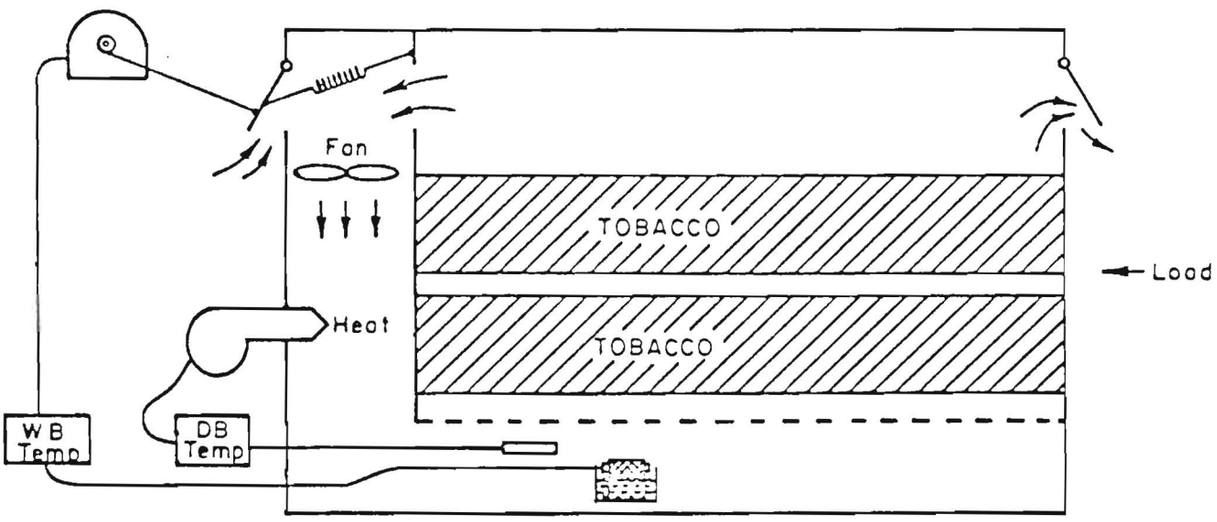


Figure 5. Schematic of air flow and controls on a typical bulk barn.

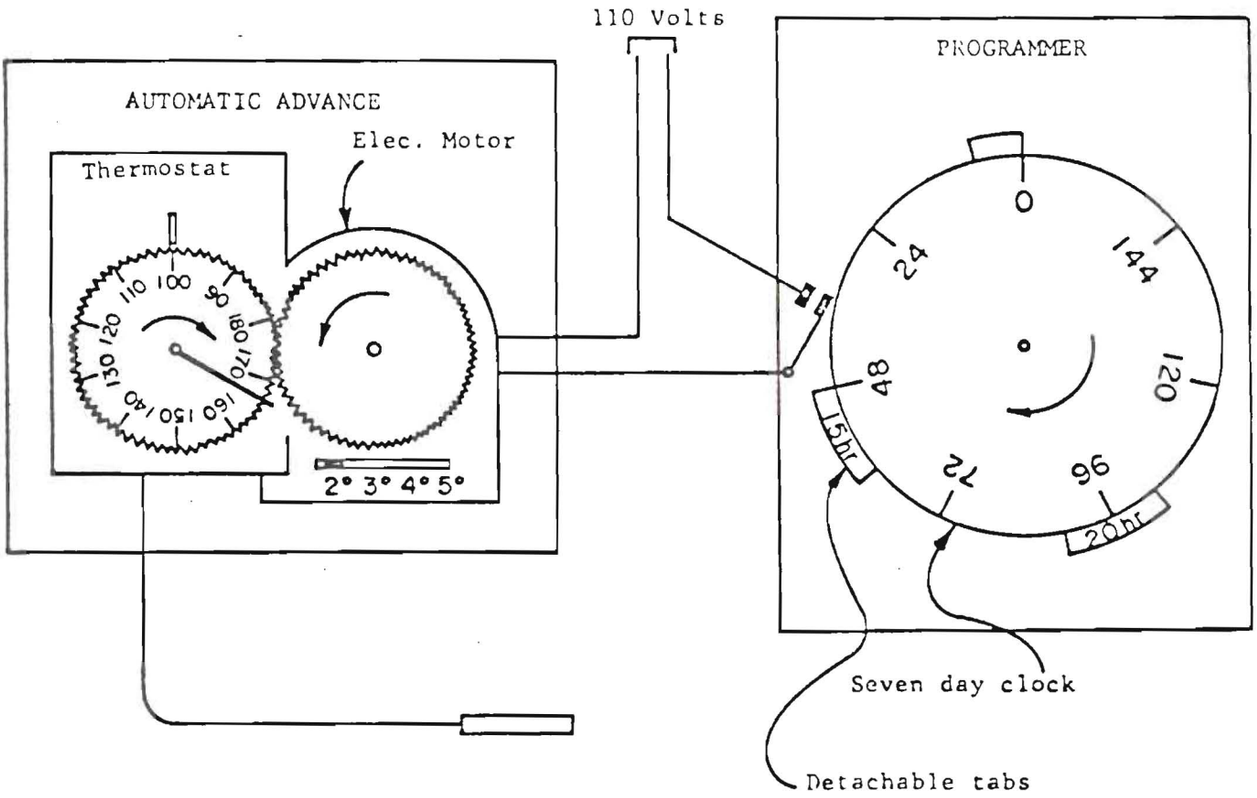


Figure 6. Schematic of seven day temperature programmer.

is shown schematically in Figure 6. The periphery of the seven day dial accommodates detachable "tabs" or trippers which activate or inactivate the clock circuit. These on-off tabs can be placed at the points on the seven-day dial where one wants the clock mechanism to work or not to work. Thus by the combination of an automatic advance (clock) thermostat and a seven-day timer to activate or deactivate the clock, one can set up a seven day temperature schedule or program wherein the temperature is either rising at a given rate or holding steady.

Advantages of the programmer have been cited in many instances, especially on large farms where the operator cannot visit the barns daily. On smaller farms or where the operator inspects each cure daily, economic feasibility may be questionable.

Although programmers are observed generally on bulk barns only, there is no technical reason preventing their application to those conventional systems which employ electric thermostats (such as jet-fired oil curers).

Humidity controls round out the picture for what is now considered the ultimate in curing control. With precise control of temperature and humidity, tobacco curing can migrate from the mystic realm of the arts to the exacting realm of science. Now that the "masters touch" on the ventilator can be expressed in hard cold numbers, curing directions may be communicated - even by telephone.

Presently available humidity controllers are, in principle, merely wet-bulb temperature controllers applied to reversible motors which open or close ventilators to maintain the wet-bulb temperature. More simply stated, a wet-bulb thermostat controls a motorized damper which controls humidity. This mechanism is shown schematically in Figure 5.

It seems most fortunate that practical application of humidity regulation in tobacco curing has evolved as merely wet-bulb temperature regulation. Leaf temperature, a prime factor in curing, follows wet-bulb temperature very closely provided sufficient water is present in the leaf. Thus, during the stages of

yellowing and initial leaf drying when leaf temperature is of critical importance, wet-bulb temperature is a valid indicator of leaf temperature.

Curing Conditions.

Now that cookbook type curing is possible, who has the best recipe? Tobacco variety and cultural factors, no doubt, will affect the time period needed for proper yellowing, and possibly even the temperature and humidity needed for proper yellowing. Proper temperature elevation rate and wet-bulb temperature for leaf drying should be less variable, however, and it seems possible that a standard could be established for these two variables - at least as a benchmark.

Should temperature elevation rate be restricted to one or two degrees per hour? Or, are higher rates equally as good if leaf temperature is held constant? And what leaf temperature is best?

In tests conducted by Johnson comparing temperature elevation rates of 2°, 3°, and 4° F. per hour, smoking evaluations showed preference for samples dried at rates of 2° and 3° per hour.

A comprehensive study of temperature elevation rates and drying potentials by Walker shows merit in limiting the temperature rate to 2° F. per hour or less. Table III shows the value of tobacco exposed to the different temperature elevation rates in his tests.

Table III. Grade indices (cents per pound) of tobacco exposed to different rates of temperature increase in the color-fixing phase, 1960

Increase/hr.		Priming					
Temp., °F.	Sat. def. grains	1	2	3	4	5	Av.
1.0	16	53.7	59.0	58.3	52.1	45.6	53.8
1.5	16	49.7	58.8	56.6	53.3	36.5	51.0
2.0	16	50.4	58.3	52.0	39.3	35.4	47.1
2.5	16	30.8	52.3	47.3	38.6	35.3	40.1
3.0	16	35.3	55.3	49.3	36.0	35.0	42.1
L.S.D. .05		8.5	3.2	6.4	6.8	7.5	6.4

Mr. Walker stated that tobacco for these tests was yellowed at 95° F. and a saturation deficit of 25 grains, such conditions being considered optimum for yellowing. After yellowing, the dry-bulb "Temperature was advanced from 95 to 130° F. at rates of 1 to 3° F. per hour in different treatments, maintained at 130° F. until the treatment with the slowest rate of increase was at that level, then increased to 160° F. for all treatments at the rate of 1.5° F. per hour." "The saturation deficit for all treatments was increased at the rate of 16 grains per hour to 600 grains at 130° F.; thereafter, the saturation deficit was increased uniformly among the treatments to a maximum value of 1800 grains at 160° F."

The grade indices given in Table III clearly indicate the benefit of low temperature elevation rates at these drying potentials. Since Middleburg has cited advantages for constant wet-bulb temperatures of 90° F. to 100° F., a question arises as to what wet-bulb temperatures coincide with the saturation deficits of Table III.

Also, from an operational viewpoint, the same question arises since present humidity controllers are merely wet-bulb temperature regulators. In Tables IV, V, and VI, wet-bulb temperatures are tabulated along with dry-bulb temperatures and saturation deficits for three of the temperature increase rates of Table III. Wet-bulb temperature values were taken from a psychrometric chart. In these tables, zero hour is taken as the end of yellowing or beginning of leaf drying.

Table IV. Environmental conditions in a curing test with a temperature increase rate of 1° F. per hour

Hr. of coloring	Dry-bulb temperature °F.	Saturation deficit grains	Wet-bulb temperature °F.
0	95	25	92
5	100	105	90
10	105	185	87
15	110	265	87
20	115	345	87
25	120	425	87
30	125	505	89
35	130	585	94
40	137.5	885	85
45	145	1185	83

Table IV shows that the wet-bulb temperatures of the test using the temperature rate of 1° F. per hour remained well below 90° F. for the major portion of the coloring period. This is considerably lower than the wet-bulb temperatures currently being recommended as safe for proper leaf drying. Wet bulb temperatures of 100° F. to 105° F. are presently recommended. Should recommendations then be reduced to 95° or 90° F.?

Table V. Environmental conditions in a curing test with a temperature increase rate of 2° F. per hour

Hr. of coloring	Dry-bulb temperature °F.	Saturation deficit grains	Wet-bulb temperature °F.
0	95	25	92
5	105	105	96
10	115	185	102
15	125	265	110
20	130	345	112.5
25	130	425	108
30	130	505	101
35	130	585	94
40	137.5	885	85
45	145	1185	83

Table V shows that wet-bulb temperatures of the 2° F. temperature rate test were above 110° F. for approximately 8 hours. Was this period of high wet-bulb temperature primarily responsible for the decrease in value of the upper primings? Curings at the farm level using similar temperature elevation rates with wet-bulb temperature held below 105° F. have been observed with no apparent quality decrease.

Wet-bulb temperatures tabulated in Table VI shows levels in excess of 110° F. for a period of approximately 15 hours. Grade indices of each priming were reduced significantly with this temperature and humidity schedule. It is interesting to note that the decrease in average grade index for the 2° F. rate and the 3° F. rate is roughly proportional to the time period during which wet-bulb temperature exceeded 110° F.

Table VI. Environmental conditions in a curing test with a temperature increase of 3° F. per hour.

Hr. of coloring	Dry-bulb temperature °F.	Saturation deficit grains	Wet-bulb temperature °F.
0	95	25	92
5	110	105	102
10	125	185	115
12	130	217	120
15	130	265	118
20	130	345	113
25	130	425	108
30	130	505	101
35	130	585	94
40	137.5	885	85
45	145	1185	80

From Table III:

average price decrease at 2° rate = 53.8 - 47.1 = 6.7

average price decrease at 3° rate = 53.8 - 42.1 = 11.7

Ratio of price decreases: $\frac{6.7}{11.7} = .57$

Ratio of curing time with wet bulb temperatures in excess of 110°: $\frac{8}{15} = .53$

From this the conclusion could be drawn that quality deterioration begins when wet bulb temperature exceeds 110°; and continues at a constant rate until the wet bulb temperature is reduced to a lower level. While reasoning such as this could be properly labeled "jumping to conclusions," we may safely infer that wet bulb temperatures should be kept below 110° in the interest of maximizing quality.

During later stages of leaf drying and early stages of stem drying, wet bulb temperatures should still be kept below 110° to accommodate "tight" spots which dry slower due to reduced air flow. During later stage of stem drying, wet bulb temperatures will remain low due to the limited moisture in the tobacco.

Ordering Tobacco.

Many users of bulk curers have added some means whereby water can be sprayed into the airstream of the curer to aid in ordering the tobacco after curing. Devices used range from simple garden hoses to arrangements of oil burner type nozzles permanently installed and controlled by humidistat. Benefits reported for each scheme have varied widely, but none of them has been observed to be as fast as would seem desirable.

Time saved in ordering is equally as important as time saved in curing. If total loading, curing, ordering, and unloading time can be reduced from 6 days to 5 days, then 5 barns can do the work of 6.

Tests were conducted by Dr. W. H. Johnson at the tobacco research station in Oxford, N. C., during the 1967 season comparing several practical ordering schemes. Results of these tests indicate that tobacco may be ordered within one or two hours after the cure is completed.

Four ordering treatments were tested at three temperature regions with tobacco from three stalk positions. Tobacco was of the C258 variety.

Each of four insulated, forced-air, motel-type curing compartments was equipped for a different humidifying scheme to provide the treatment variables. Compartments were equipped as follows:

(1) Water surface evaporation principle. A water reservoir (3' by 3' by 6" deep) was located beneath the tobacco level to receive and deflect the air blast from the fan immediately before it passed through the tobacco.

(2) Surface evaporation with high pressure spray added. A water reservoir (as in No. 1) was used in addition to 3 nozzles (Teejet TX1) spraying into the airstream 32 to 36 pounds of water per hour at 100 psi.

(3) Surface evaporation with low pressure spray added. Same as No. 2 except that 4 nozzles (Teejet TX1) were used at 50 psi to deliver the same rate (32 to 36 lb. per hour).

(4) Low pressure spray only. Four nozzles (Teejet TX1) operated at 50 psi sprayed 32 to 36 pounds of water per hour into the airstream.

The three temperature regions or hymidifying procedures used were as follows:

95° - Compartment temperature was cooled to 95° F. before humidifying began.

120° - Humidifying began when compartment temperature had cooled to 120°. Heat was then added to maintain 120° F.

170° - Humidifying began immediately at the end of stem drying at 170° F. Heat was added to maintain 120° F.

Tobacco from 1/3 plant harvest studies was used in these tests. Data should, therefore, be representative for the 3 stalk positions, bottom, middle, and top, with each position comprising about 1/3 of the leaves from the plant.

Table VII shows the moisture absorption rates calculated from test data. The researcher states that some of the data may be suspect due to possible equipment malfunction but that the data definitely may be used in establishing trends.

Table VII. Moisture absorption rates of tobacco exposed to different ordering treatments expressed as change in percent moisture[a] per hour for the active moisture absorption periods of each test.

Beginning temp.(°F.)	Stalk position	Surface evap.	High press. + surf. evap.	Low press. + surf. evap.	Low press. spray	Mean
			(percent/hr.)			
95	Bottom	1.21	14.20	3.99	3.94	5.65
	Middle	1.03	14.30	1.52	2.06	4.74
	Top	1.08	6.61	2.62	2.59	3.22
120	Bottom	0.78	15.29	4.55	6.02	6.64
	Middle	1.32	6.55	2.74	3.85	3.61
	Top	0.64	5.49	2.51	4.93	3.39
170	Bottom	0.89	17.15	5.93	6.66	7.66
	Middle	0.52	11.93	4.95	4.68	5.52
	Top	1.65	8.76	5.10	6.39	5.47
	Mean	1.01	11.14	3.77	4.57	

[a]Dry basis.

From the moisture absorption rates shown, it is apparent that:

(1) The high pressure spray is preferable to the low pressure spray or to the water reservoir.

(2) The low pressure spray is preferable to the water reservoir.

(3) A water reservoir is of very little benefit if used in conjunction with spray nozzles.

(4) The 170° F. beginning temperature is preferable to the lower temperatures.

(5) Tobacco orders faster at progressively lower stalk positions.

(6) Tobacco may be ordered sufficiently for handling in one or two hours.

Bulk Curing Recommendations

Rack Loading:

(1) Uniform density of pack is very important.

(2) Avoid excessive fall out.

(3) Racks packed too loose - trouble.

(4) Remember that lugs lay close.

Barn Loading:

(1) Fit racks snugly together.

(2) Block out space at doors.

(3) Cure only two tiers deep with wet weather lugs.

(4) Run fan while loading hot tobacco.

Conditioning:

(1) Remove surface moisture.

(2) Ventilate sappy tobacco.

Humid hot night - heat to 85° - 90°.

Cool dry night - use no heat.

(3) Dry weather tobacco - no trouble.

Yellowing

(1) 95° to 105°.

(2) Vent according to leaf moisture.

(3) If fear soft rot - 90° with ventilation.

(4) Drying accelerates yellowing.

(5) Remember results of 110° test on green 258.

(6) Remember cell dies at 113°.

(7) Respiration rate is higher at higher temperature.

90° - 8.2% loss in 75 hrs.

100° - 12.2% loss in 75 hrs.

110° - 14.2% loss in 75 hrs.

(8) Toad skin look - almost dry.

Leaf Drying:

(1) Raise temperature gradually 2° per hour or less.

(2) Keep wet bulb temperature down to 100°.

(3) Hold at 135° until leaf is dry.

(4) Remember wet bulb temperature reading is average.

(5) Water removal

120° DB, 100° WB

exhaust 110° DB, 100° WB

at 15,500 cfm = 2.5 lb. water per minute

Stem Drying:

(1) 2° per hour rate.

(2) Tight spots spoil if too hot too quick.

(3) Keep wet bulb below 110° until all leaf is dry.

(4) Stop at 170° to kill out.

(5) Close vents completely after <u>all</u> leaf is dry.

Ordering:

(1) <u>All</u> fresh air. Block off return to furnace if possible.

(2) Spray nozzles - high pressure better.

(3) Water holding capacity of air:

80° DB, 80° WB = .00156 lb. per cu. ft.

= 1.56 lb. water per 1000 cu. ft.

therefore, if fan capacity is 15,000 cfm

(1.56)(15) = 23.4 lbs. water per minute

Need about 400 lbs. for normal barn.