Bulk Curing of Bright Leaf Tobacco[1]

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A problem inherent to the conventional methods of tobacco production is the great amount of hand labor required. Some mechanization has been achieved, particularly in cultural operations, but approximately 420 man-hours per acre are still necessary in tobacco production.[2] This is based on a tobacco allotment of 4-5 acres and a yield of 1800 pounds per acre. Approximately three-fourths of the total labor is required in the harvesting and processing operations.

Present mechanical harvesters have not been successful in the solution of this problem. It is true that a measure of convenience has been introduced, such as conveying the field workers, and that the number of leaf handlings has been slightly reduced. According to Chumney and Toussaint, labor reduction in machine harvesting comes about largely through the elimination of a single harvesting operation—handing. However, all other essential operations (priming and looping) are retained. Progress notwithstanding, high labor requirements still exist. Furthermore, it is recognized that individual leaf handling operations, essential for the conventional curing method, are the bottlenecks to the development of mechanical complements for eliminating hand labor in harvesting and processing. These operations, however, because of their complexity in terms of requirements for selectivity, orientation, and timing, present a real challenge to practical mechanization.

Systems engineering, which is concerned with overall processes, involves application of new operational techniques which maximize efficiency. Since the inherent difficulties to advancing tobacco mechanization reside with the conventional curing method, past research at North Carolina State College has been directed towards the development of a curing operation which would be more com-

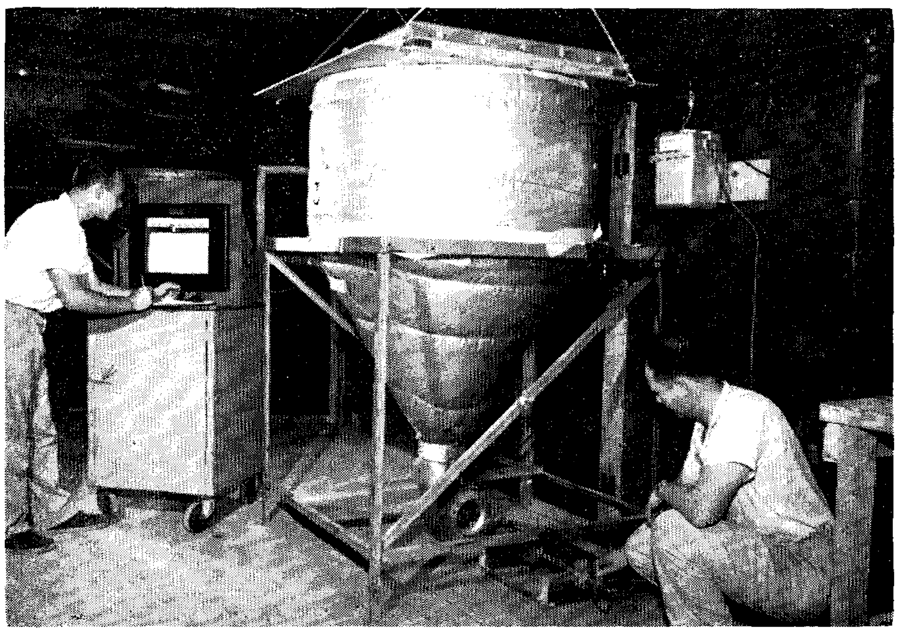

Figure 1. Apparatus for the initial experimentation on bulk curing.

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[2] *Private communication with Dr. W. D. Toussaint, Agricultural Economics Department, North Carolina State College, Raleigh.*

patible with overall mechanization. Results suggested the possibility of curing packed leaves, and by this approach eliminating the requirement for stringing leaves on a stick. Based on this conclusion, research and development have been initiated to test the feasibility of a curing method referred to as Bulk Curing.

Review of Literature

The development of the bulk curing process, radically different from the conventional as described by Brown and Weldon, was a gradual evolution based upon accumulated observations and measurements of a fundamental nature. Studies by Hassler provided limits for environmental control and information helpful to proper yellowing of leaf tissue. Using a thermocouple inserted between the layers of leaf tissue, he studied the phenomenon of color change as influenced by temperature, drying rate, and leaf moisture content. Concerning browning reaction he stated:

> "The rate of browning (sponging) was found imperceptible below 110° F., but the reaction speeds up with increasing temperature, becoming sufficiently rapid at 135°F. to produce total discoloration within six minutes. Thermal killing of the enzyme system that produces the browning reaction was obtained within one second at 212°F."

These tests showed the necessity of maintaining leaf temperatures consistent with requisite biochemical changes and moisture content in order to produce a satisfactory cure. Drying of the leaf to 75-80 per cent of its initial moisture content was also found desirable for hastening the green to yellow color change.

The impetus for curing in the bulk led to detailed studies on bulk yellowing by Henson *et al* who investigated the conditions existing in ventilated and non-ventilated bulks of tobacco and evaluated the influence of these conditions on certain chemical and physical properties of the cured leaf. In the non-ventilated bulks, temperatures increased almost linearly with time for 35 to 51 hours after the leaves were bulked and reached peaks of 125°F. to 129°F. Almost two-thirds of the tobacco was damaged by these high bulk temperatures which resulted from heat of respiration. Ventilation of bulks with air velocities of 25 ft/min prevented temperature damage and resulted in yellowed tobacco having good color and physical appearance. Chemical analyses showed that bulk yellowing could be accomplished without appreciable reduction of total and reducing-sugar contents, provided forced air was employed to prevent temperature damage.

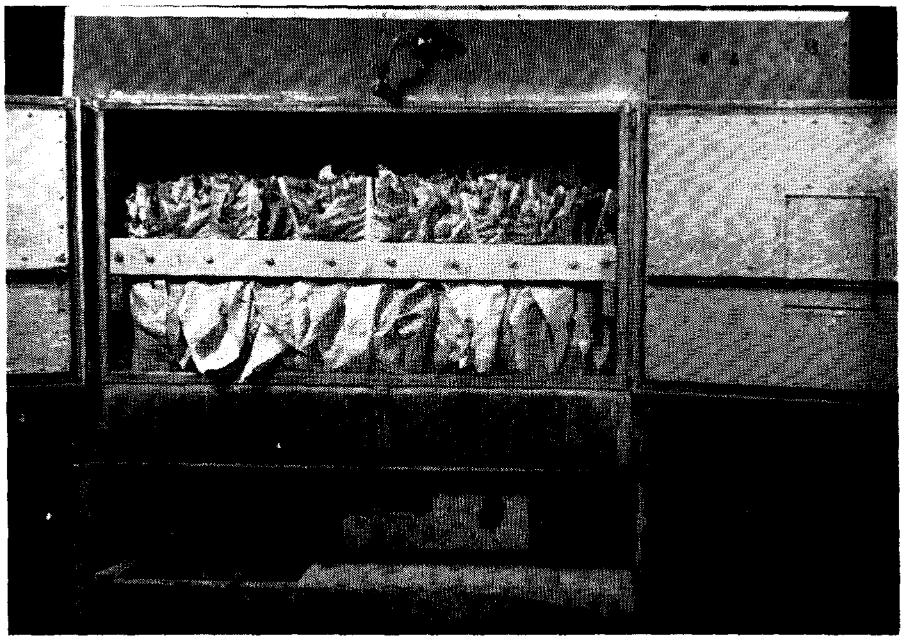

Figure 2. Climatic chamber used in the laboratory testing of bulk curing.

Johnson *et al* studied the edge effects which resulted from shredding tobacco during the green stage. Results illustrated that edge effects from shredding green tissue were negligible when the tobacco was yellowed in a low-drying environment of 96 per cent relative humidity. However, drying conditions of 82 percent relative humidity during yellowing amplified edge effects by producing premature arrestation of certain biochemical reactions along the cut edges. Under properly controlled temperature and humidity conditions, shredded tissue was predicted to yellow to good color in a bulk with negligible edge effects.

A further study by Johnson *et al* showed that bruising adversely affected both appearance and sugar levels of green tobacco tissue. Bruising of green tobacco tissue prevented normal chlorophyll disappearance and impeded the conversion of starches to sugars which normally occurs during yellowing. These results showed that, in order to maintain a quality product, non-bruising methods of handling must be used in the development of new approaches in mechanizing harvesting and curing operations.

Experimental

Laboratory Investigations — 1956. — During 1956, laboratory studies were conducted to further evaluate the potentialities of bulk curing. Objectives for the experiment were:

1. To make chemical and physical evaluations of both intact and shredded bulk-cured tobacco in comparison with conventionally cured tobacco.
2. To make measurements pertinent to the design and construction of equipment for bulk curing.

Three bulk-curing chambers of the design shown in **Figure 1** were constructed for the initial tests of 1956. Each chamber consisted of a centrifugal fan, a conical section, and a cylindrical section. A metal mesh screen located between the cylindrical and conical sections provided support for approximately 200 pounds of uncured intact tobacco. This particular design was selected because it was considered that a circular chamber would provide uniform air distribution with simplicity of design. Heat was furnished by a jet-type gas burner which was fired directly into the fan. The temperature within the conical section was thermostatically controlled by an on-off valve in the gas line, actuated by a sensing bulb located within the cone. A multiple-point temperature recorder registered the temperatures of thermocouples located in the air inlet and in the bulk. Air volume rates were determined by measurements with pitot tubes positioned beneath the tobacco.

Six tests were conducted throughout the harvesting season in which both intact leaves and leaf material

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Table 1. Results of Chemical Analyses For Laboratory Bulk Curing 1956-57*

	1956	1957
Total Sugar Percentage		
Conventionally Cured	32.24	28.77
Intact Bulk Cured	31.88	28.45
Shredded Bulk Cured	29.04**	24.44**
Reducing Sugar Percentage		
Conventionally Cured	27.30	23.53
Intact Bulk Cured	27.23	23.30
Shredded Bulk Cured	21.85**	18.84**
Nicotine Percentage		
Conventionally Cured	2.04	3.43
Intact Bulk Cured	1.93	3.55
Shredded Bulk Cured	1.70**	2.84**

* *Analyses performed by North Carolina State College Tobacco Laboratory*
1956 analyses—average of 12 samples
1957 analyses—average of 18 samples
** *Significantly lower at the 0.01 level*

shredded in ½-inch strips were cured in cylindrical chambers, while check samples were cured conventionally for comparison. In loading intact tobacco the chambers were tilted and tobacco was placed uniformly by the handful into the chambers, keeping the butts oriented in the same direction. Shredded material was uniformly placed into the chambers by hand to a depth of 15-17 inches above the screen.

Schedules for the initial bulk-curing tests differed markedly from the conventional curing schedules. In conventional curing, yellowing was accomplished in a 90-100° F. environment. After yellowing, the temperatures were increased gradually to 130-140° F. to "set" the color and to dry the leaf, then raised gradually to 170°F. to finish drying the leaf and midrib. With bulk curing, however, no external heat was used during yellowing. Exothermic reactions of respiration caused bulk temperatures to gradually increase; therefore it was necessary to aerate the bulks in order to maintain bulk temperatures below 100° F. Aeration was accomplished by using a liquid-filled sensing bulb which actuated an on-off microswitch in the fan circuit whenever the bulk temperature exceeded 100° F. After yellowing, two temperatures were used for drying the tobacco—130° F. for 8-15 hours and 170° F. until the leaf was completely dry.

Observations during the initial tests showed many aspects of bulk curing that needed improvement. The irregular air flow and temperature schedules during bulk yellowing gave a non-uniform yellowing environment; also the rapid temperature increases appeared to produce discoloration. It was observed that a limited amount of drying during yellowing would be desirable for preventing surface-moisture accumulation within the tightly bulked tobacco and also for promoting more favorable yellowing conditions. More uniform air distribution was obtained when the leaves were supported with the butts upward and with air flow from the tip end to the butt end. Furthermore, this gave the advantage of drying in the same direction as yellowing, i. e., from tips to butts. Non-uniform air distribution, which resulted in uneven drying and lowered quality, was considered to be a major problem to the advancement of bulk curing. Since uniformity of air distribution depends directly on bulk uniformity, the non-uniform loading method employed caused air channeling through less dense sections of the bulk. Tightly packed sections, which dried last, were consequently damaged by high bulk temperatures. Comparisons of energy efficiencies showed that bulk curing using forced convection was only one-third as efficient as conventional curing, since a large amount of sensible heat was discharged from the bulk chambers.

Physical evaluations of the cured tobacco showed no apparent differences in color among samples of tobacco that were conventionally cured, shredded bulk cured, and intact bulk cured (from less dense sections of the bulk). However, the bulk intact tobacco exhibited a flat, unnatural appearance while shredded tobacco had an abnormal and undesirable aroma.

Laboratory Investigations — 1957. —From the above observations, two additional objectives were added to the following 1957 experiment:

1. To make improvements in the loading techniques and equipment which would simplify the process and contribute to curing a more acceptable and higher quality product.
2. To improve the curing schedule and develop techniques of recirculation for improving process efficiency.

Six climatic chambers of the type shown in **Figure 2** were used to provide a controlled environment and to accommodate an improved loading technique. Electronic temperature controls maintained conditions within one degree F., while air-flow and recirculation dampers allowed any desired air movement. A steam supply to the chambers provided a positive method for maintaining high humidities during yellowing as well as for conditioning the tobacco after curing.

An improved loading method contributed to faster, easier bulking, and allowed much greater uniformity in packing of tobacco within racks. The loading rack consisted of two wooden members constructed of 2" x 4" x 48" material. One member had a series of ⅜-inch metal rods spaced at 6-inch intervals along the rack to provide support for the tobacco. In principle, a side member of the loading rack, without the rods, was placed in the bottom of a loading form which was similar to a box with an open top and front. After tobacco had been placed to a given height in the form (by the armful or handful), a second side member of the loading rack was connected to the first side member, thereby clamping the tobacco in a rectangular shape, 16" x 48", and at the same time piercing the tobacco with the rods. A filled rack of tobacco is shown in the chamber of **Figure 2**. Each chamber held two racks of intact tobacco (160 lb.) or one metal basket of shredded tobacco (100 lb.).

Six tests were conducted throughout the harvesting season in which bulk tobacco was cured with three replications in climatic chambers, while check samples were cured conventionally for comparison. Temperature schedules for bulk curing followed closely those for conventional curing. Air-flow and recirculation schedules for bulk curing were designed to improve the efficiency.

As a result of these modifications in equipment and improvements in the controls, noticeable improvements were recognized in the quality of cured intact tobacco. Visual observations showed no apparent color differences between tobacco cured in the bulk and that cured conventionally. The appearance of tobacco cured in the bulk was greatly improved over that cured in 1956, and much of the objectionable flat appearance was overcome by adequately conditioning the tobacco after curing. Shredded tobacco, however, still continued to exhibit an undesirable aroma. As a consequence of the improved loading technique, uniform air distribution and even drying resulted, thus maintaining quality by proper drying. In addition to upgrading quality, fuel efficiencies for bulk curing surpassed conventional curing as a result of proper recirculation of air.

Results of sugar and nicotine assays by the North Carolina State College Tobacco Laboratory on representative samples of tobacco from 1956 and 1957 tests are shown in **Table 1**. In every case, shredded tobacco had lower contents of sugar and nicotine while intact, bulk-cured leaf did not differ significantly from normally cured leaf. Chemical evaluations by several tobacco companies agreed closely with the results of **Table 1**. Moreover, shredded tobacco had significantly smaller contents of total alkaloid and petroleum ether extract but larger ash content and specific volume. Although the importance of each chemical component is uncertain these significant differences were considered undesirable.

Smoking tests were conducted by several tobacco companies on tobacco samples from the 1956 and 1957 curing experiments. Consistently, the results showed that bulk-cured leaf was similar in smoking characteristics to that cured by the conventional method. Shredded tobacco, however, produced an undesirable smoke which lacked flavor and had an acrid aroma.

Results obtained in bulk curing of intact leaf, from standpoints of operation and quality of cure, suggested the initiation of the development of a practical bulk curing system. On the other hand, negative results in bulk curing of shredded tobacco suggested more fundamental research to find ways of improving its curability.

Pilot Operation — 1958. — An applied study in bulk curing of intact leaf was conducted in which laboratory findings and techniques were extended to encompass a pilot operation, intermediate between laboratory and field operations. The design and operation of this curing system were concerned with simplifying the loading and unloading of racks of tobacco, adopting air-flow and temperature schedules which enhance the quality of the cured product, and obtaining maximum operational efficiencies.

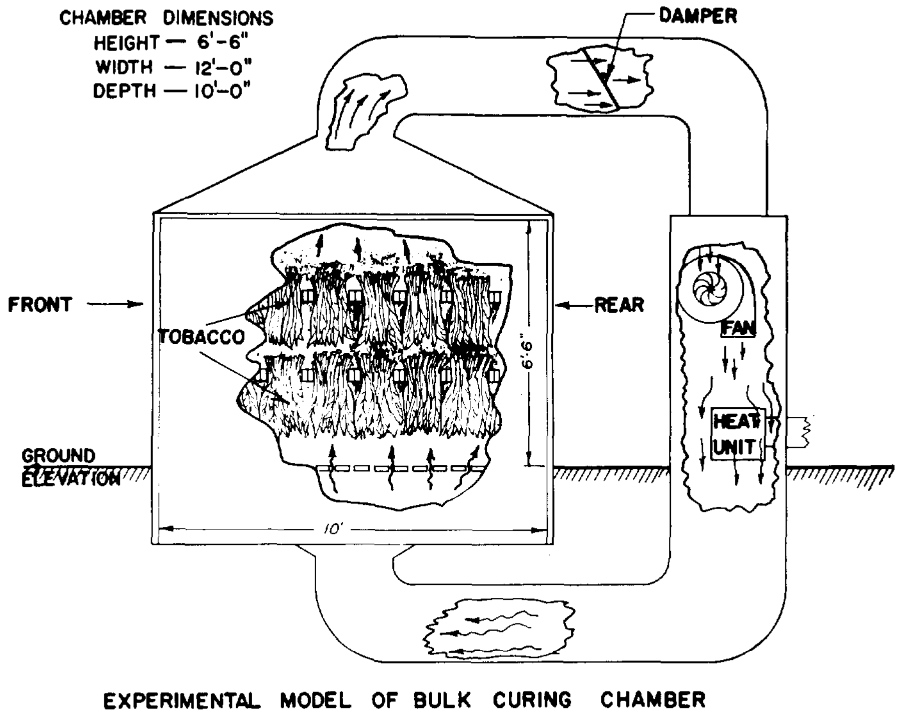

Figure 3. Schematic of pilot stage bulk curing system.

Figure 3 shows a schematic drawing of the curing system. It consisted essentially of a curing compartment for bulked tobacco, a thermostatically controlled heating furnace (indirectly gas-fired), and a dampered duct for regulating the amount of air to be recirculated. To simplify the operation of loading the racks of bulked tobacco into the barn, the structure was designed so that two men standing on the floor of the barn could lift the racks of tobacco onto the tiers. An essential feature of this system is the forced air movement. Hot air, forced up through the compartment floor and through the racks of tobacco at rates from 15 to 30 ft/min, promoted drying and prevented "scalding" of the tightly packed tobacco.

The loading technique used in the preceding laboratory tests was improved to allow more rapid clamping of tobacco into racks. As shown in **Figure 4**, tobacco was placed uniformly into the loading form by the handful. By having the form balanced on two pivot points, it was possible to place an approximately equal amount of tobacco in each rack—the right amount indicated by a slight tilting of the form. Each rack, 6 feet in length and 16 inches wide, held approximately 120 lb. of uncured tobacco. Twenty-eight racks of tobacco, required for filling the 10′ x 12′ x 6½′ compartment **(Figure 5)**, equalled that normally placed on around 330 sticks for conventional curing. The actual space required for bulk tobacco was one-sixth of that required for conventionally strung tobacco.

Six cures were conducted throughout the harvesting season of 1958 for comparing bulk curing with conventional curing. During yellowing, the

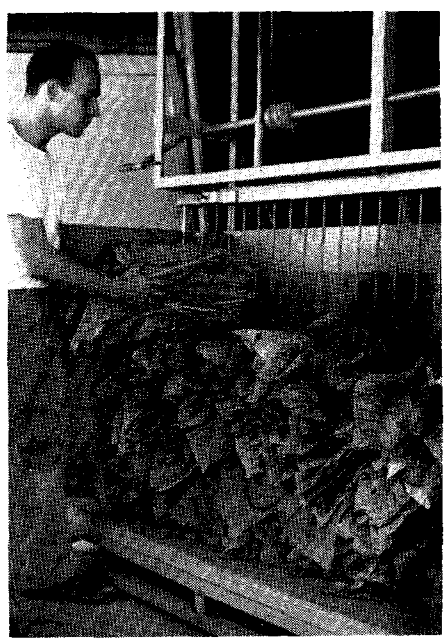

Figure 4. Placement of leaves into the loading form for bulking into racks.

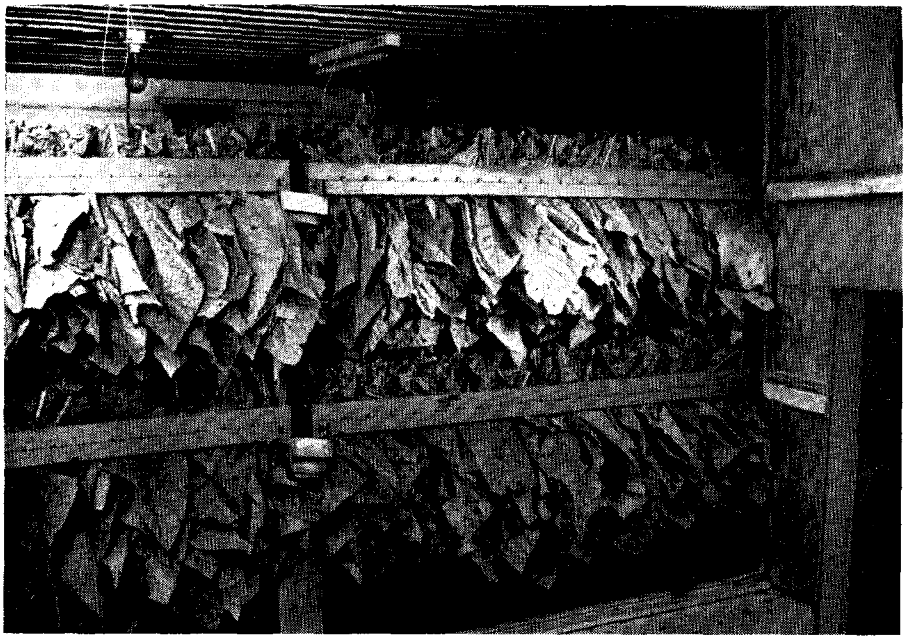

Figure 5. *Front view of bulk curing compartment which held 28 racks of tobacco.*

temperature was held between 90° and 100° F. with complete recirculation of the air. A temperature schedule similar to the conventional schedule was then followed **(Figure 6)**. Color was "set" during a gradual temperature rise to 130-140°F., then the temperature was advanced to 170° F. for stem drying. Relative humidities ranged from 80 to 90 per cent during yellowing and as low as 10 to 20 per cent during leaf and stem drying. The damper setting for air recirculation was varied manually to obtain a drying environment consistent with the stage of curing.

Although a curing system may be operationally successful, it is recognized that acceptability of the cured product must precede the introduction of the system for practical application. Results from the pilot operation of bulk curing showed only slight differences in quality between bulk and conventionally cured leaf. Chemical and smoking evaluations performed by a cooperating tobacco company are shown in **Table 2**. Percentages of nicotine, nornicotine, reducing sugar, and total nitrogen agreed closely for bulk and conventional curing. Smoking evaluations rated bulk-cured tobacco as having low flavor (mild) and conventionally cured tobacco as having low to medium flavor; both passed the flavor test as suitable for cigarettes. Samples of bulk-cured and conventionally cured leaves from the entire season were also graded according to USDA Marketing Standards. Average prices based on government grades were $58.70 per cwt for bulk-cured tobacco and $56.15 per cwt for conventionally cured tobacco. **Table 3** gives the results of a sale of bulk-cured tobacco on the open market. Representative samples averaged $62 per cwt, with a high of $70 per cwt.

Indications are that the bulking method saved both time and labor in the barning operations. It is estimated, because of the rapidity and ease of filling the racks and placing them into the curing compartment, that barning labor (after cropping) was reduced by three fourths, as compared with conventional methods. This figure was arrived at by comparing the total labor for stringing, handing, and loading a conventional barn with that required for bulking and loading an equivalent amount of tobacco for bulk curing.

Discussion

Objectionable differences between the physical and chemical properties of shredded bulk cured and conventionally cured tobacco are evidently related to the biochemical transformations occurring during the yellowing phase of curing. Reduction of various chemical components suggests an accelerated metabolic rate. Possible losses of aromatic oils or constituents through the cut edges could possibly account for the "different" aroma of the shredded tobacco. Then there is also the possibility that the curing environment adversely affected the chemical conversions of the leaf. Further research is necessary to determine whether tobacco can be cured in the shredded form to an acceptable state of quality.

The first experiments in bulk curing of intact tobacco produced leaves which were decidedly flat or pressed-out in comparison with conventionally cured leaves. In later tests the appearance was greatly improved by adequately conditioning (ordering) the tobacco after curing; however, a detectable difference still remained. Bulk curing produces a somewhat flattened-out appearance because the leaves are held extended in the tight, compact bulks during curing. Con-

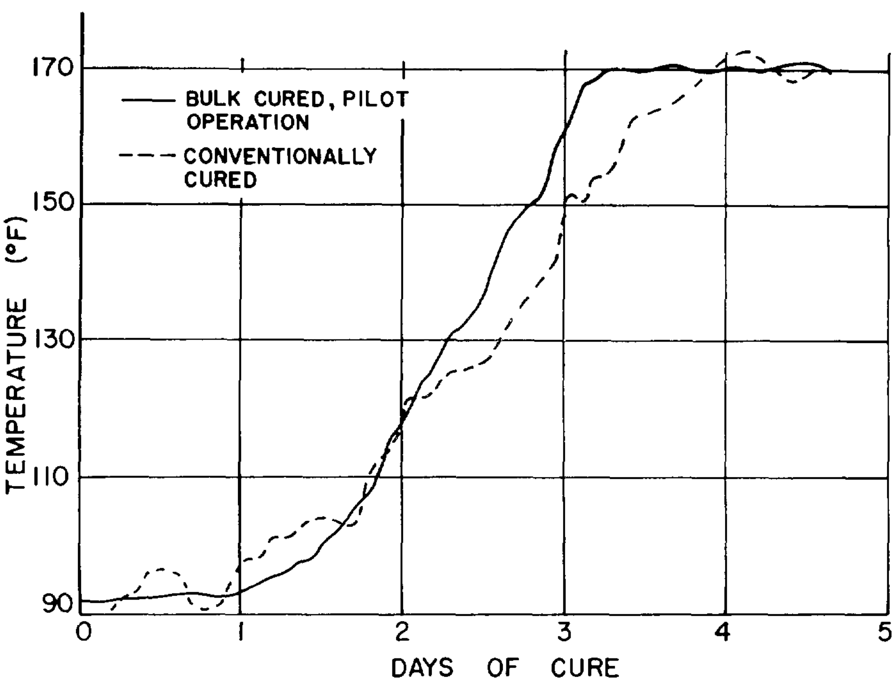

Figure 6. Comparison of temperature-time schedules for bulk and conventionally cured tobacco (1958).

ventionally cured leaves, which are strung loosely on sticks, are free to wrinkle and curl during the curing operation. Because of the similar results obtained in the chemical and smoking tests for bulk and conventionally cured tobacco, the somewhat flattened-out appearance is considered to be incidental to its utility for cigarettes.

Bulk curing of intact leaf has many possibilities for achieving marked advantages over the conventional curing method. The potential for producing a more uniform leaf is offered through automatic control of temperature and drying conditions. In addition to saving labor during barning, ease of unloading tobacco from racks speeds up the preparation for marketing. Bulk tobacco requires only 1/6th the curing space required by conventionally strung sticks. This suggests cost saving for basic curing structures, as well as the possibility of designing curing systems to accommodate the individual farmer's acreage. Fire hazard is virtually eliminated since the heating plant is exterior to the curing compartment. During 1958, fuel efficiencies were equivalent to conventional curing, although the damper for recirculating air was manually controlled. Therefore, a compact system for bulk curing, well insulated and automatically controlled, could surpass the conventional barn in efficiency. The curing system also lends itself to the use of a heat exchanger for recovering the heat normally lost through conventional barn ventilators.

Bulk curing, as described, is presently well adapted for conventional harvesting, but there is also the important possibility of integrating mechanical harvesting with bulk curing. The introduction of these or other methods will serve to advance the engineering and operational practices in tobacco harvesting and curing. However, before appropriate curing systems can be developed for farm application, this principle must be evaluated on a farm-scale operation.

Table 2. Company "A" Evaluation of Bulk and Conventionally Cured Tobacco (1958)

	Intact Bulk Cured (Primings 2-6)	Conventionally Cured (Primings 2-6)
% Nicotine	2.65	2.59
% Nornicotine	.10	.14
% Reducing Sugar	15.15	15.62
% Total Nitrogen	2.26	2.12
Smoking Evaluation	Low Flavor (mild)*	Low to medium Flavor*

** Pass flavor test as suitable for cigarettes.*

Table 3. Sale of Bulk-Cured Tobacco (1958)

Grade	Pounds	Price Received	Amount	Auction Av.**	U. S. Govt. Support Price
X 4 KF	178	$.62	$110.36	$.62	$.50
X 4 KF	72	.62	44.64	.62	.50
X 3 L	160	.69	110.40	.70	.69
B 5 FV	216	.50	108.00	.55	.50
B 5 FV	134	.50	67.00	.55	.50
B 5 F	106	.66	69.96	.60	.55
B 4 F	176	.70	123.20	.64	.61
B 4 F	186	.69	128.34	.64	.61
	1,228		$761.90		

Average price per pound—$.62
** Representative samples from cures 1, 3, 4, 5 and 6*
*** Season average at the time of sale*

Summary

This paper describes the research and development of a curing operation which is more compatible with mechanization of bright-leaf tobacco than conventional curing. The feasibility of bulk curing was well established by laboratory studies during 1955-1957.

During 1958 an applied study in bulk curing of intact leaf was conducted in which laboratory techniques and findings were extended to encompass a pilot operation, intermediate between laboratory and field operations. The curing system was designed for simplicity of loading and unloading racks of bulked tobacco, regulation of air flow and temperature schedules which enhance the quality of the cured product, and maximum operational efficiency.

Results of curing in the pilot operation show a possibility for acceptance of bulk-cured tobacco by the tobacco industry. Chemical results showed no significant differences between bulk (intact) and conventionally cured tobacco. Smoking tests rated bulk-cured tobacco as suitable for cigarettes. Representative samples of the bulk-cured leaf averaged $62 per cwt on the open market, with a high of $70 per cwt. Possibilities for achieving advantages over the conventional curing method are discussed.

The described engineering advancements in bulk curing are presently well adapted for conventional harvesting, but there is also the important possibility of integrating mechanical harvesting with bulk curing. Since many requirements for leaf selectivity and orientation in the barning operations are eliminated by bulk curing, this method offers simplifications in the total mechanization of the harvesting and curing operations.

Acknowledgments

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