Philip Morris USA Leaf Department is committed to promoting, understanding and sharing the continued implementation of Good Agriculture Practices. This includes information on curing technology and improved energy efficiency. This publication, Flue Cured PostHarvest and System Efficiency Guidelines was written at North Carolina State University and is an excellent reference for this very important part of flue cured tobacco production.

Our goal in sharing this information with you is to focus on practices that will assist you in being efficient and effective in producing quality tobacco. The land grant universities are a valuable source of information for the US tobacco producer. For many years, we have partnered with researchers and extension workers at these institutions to develop production technology and information. This useful reference is an example of that cooperation.

We believe that you, like us, have a strong passion to succeed and that your standard is Excellence–doing things right by implementing Good Agriculture Practices as you produce high quality tobacco.

Contents

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Funding for this publication was provided by Philip Morris USA.

Proper Control of Curing Conditions

Proper control of the temperature and relative humidity are essential for efficient tobacco curing. Three types of air measurements that are important in curing are the dry-bulb temperature, wet-bulb temperature, and relative humidity. Psychrometrics deals with the physical and thermal properties of air and water vapor mixtures. If any two of the three air measurements are known, the third can be determined from a psychrometric chart or table. Due to the fact that very few relative humidity sensors can function accurately in the harsh curing environment, relative humidity is not measured directly. However, the dry-bulb and wet-bulb temperature are typically measured and monitored.

Dry-Bulb Temperature, Wet-Bulb Temperature, and Relative Humidity

The dry-bulb temperature, which is the actual air temperature, is measured with a conventional thermometer or thermostat. The dry-bulb temperature is controlled by the thermostat, which cycles the heat input. To determine the relative humidity, a wet-bulb thermometer is used. A wet-bulb thermometer is simply a dry-bulb thermometer connected to a water reservoir by a wick that is wrapped around the thermometer bulb. Provided there is sufficient air movement around the wetted wick for evaporation to occur, the wet-bulb thermometer indicates the wet-bulb temperature. As a result of the evaporative cooling process the wet-bulb temperature will be lower than the dry-bulb temperature. The amount of cooling depends on the relative humidity. The relative humidity is the ratio of the actual weight of the water vapor in the air to the maximum weight of water vapor the air can hold for a given dry-bulb temperature. The higher the relative humidity the slower the evaporation rate and vice versa. The difference between the dry-bulb and wet-bulb temperature determines the relative humidity of the air. Thus, the difference between the two temperatures indicates the amount of moisture in the air and is often referred to as the drying potential or wet-bulb depression. As the temperature difference between the dry-bulb and wet-bulb increases, the relative humidity of the air decreases, resulting in an increase in the drying potential. The smaller the difference in temperature indicates an increase in the relative humidity and a decrease in the drying potential. If the air were completely saturated, that is a relative humidity of 100 percent, the dry-bulb and wet-bulb temperatures would be the same. The tobacco-drying rate depends on the dry-bulb temperature, wet-bulb temperature, and airflow rate.

Curing Schedule

Figure 1 shows a typical wet- and dry-bulb curing schedule used for normal ripe tobacco. Also shown is the relative humidity corresponding with the given wet- and dry-bulb temperatures. Typically the curing schedule is divided into three phases defined as yellowing, leaf drying, and stem drying. Although each phase in Figure 1 is divided into 48-hour intervals, the actual time required may vary. The curing schedule is a general guide and the actual schedule followed may deviate due to factors such as the tobacco ripeness and maturity, weather, airflow, and others. The maximum relative humidity occurs during the yellowing phase of the curing schedule and is a minimum during stem drying. Yellowing is a delicate balance of maintaining a high relative humidity, but removing as much moisture as possible without excessive drying. The goal is to allow completion of the biological and physiological processes occurring in the leaf and avoid over drying. Removal of as much water as possible during yellowing while maintaining the proper humidity can reduce fuel consumption, thus improving energy efficiency. An additional benefit of

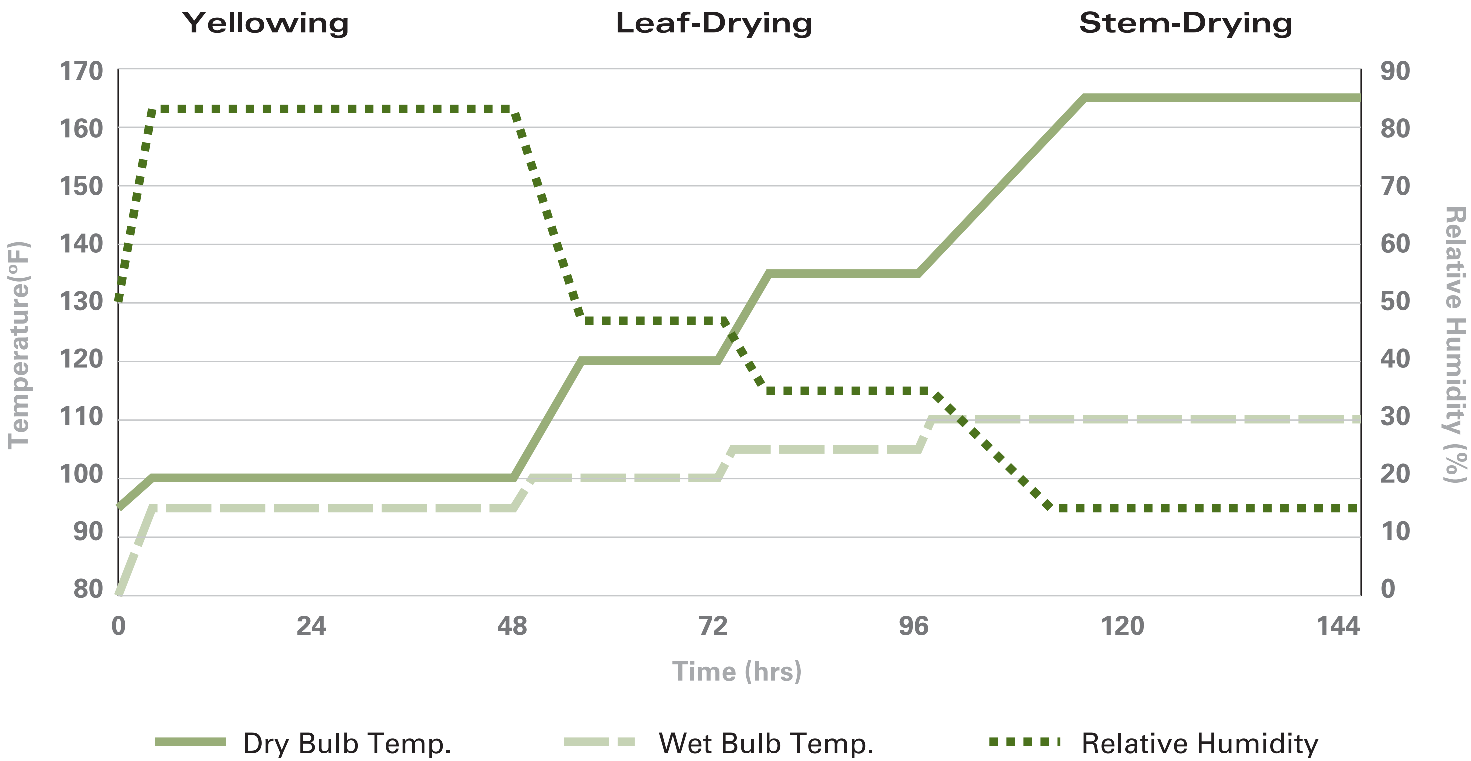


Figure 1.

Typical Curing Schedule for Normal Ripe Tobacco

sufficient moisture removal during yellowing is that the leaf drying and wilting will assist with improving airflow through the containers. The resistance to airflow will decrease as the tobacco shrinks and improves air passages around the leaves.

As the curing schedule is followed, the difference between the dry-bulb and wet-bulb temperatures increases and the relative humidity decreases. When air is heated without changing the moisture content, both the dry-bulb and wet-bulb temperatures will increase. The dry-bulb temperature will increase more than the wet-bulb temperature, thus decreasing the relative humidity and increasing the drying potential of the air. The maximum dry-bulb temperature advance rate recommended is 2°F per hour during leaf drying and no more than 3°F per hour during stem drying. This gradual increase allows sufficient time for the moisture removal to keep up with the temperature increase, therefore minimizing the possibility of scalding the leaf. By the end of the leaf drying phase, the tobacco moisture content has significantly decreased. As a general rule of thumb, for every 20-degree increase in the dry-bulb temperature the moisture carrying capacity of the air approximately doubles. For example, air at 120°F can hold twice the amount of moisture as air at 100°F.

As long as sufficient moisture is still in the leaf, the wet-bulb temperature is approximately the same as the leaf temperature. If the leaf temperature exceeds approximately 113°F, the cells die allowing browning or scalding. This is a result of too high a wet-bulb temperature and a slow drying rate. Therefore, after yellowing the wet-bulb temperature should never exceed 105°F until the leaf lamina is completely dry. Once the leaf is dry enough to advance the dry-bulb temperature above 135°F, maintaining a wet-bulb temperature of 110°F or higher will reduce fuel consumption. Many growers rely on curing experience to control the humidity, but accurate and optimum control of the curing conditions and fuel consumption require the use of a wet-bulb thermometer. For more details concerning the curing schedule contact the local extension office for assistance.

Controlling the Wet-Bulb Temperature - Ventilation

One of the most energy saving recommendations, but least used, is the proper use of a wet-bulb thermometer. Controlling the wet-bulb temperature also allows the grower to control and monitor the actual leaf temperature as long as the leaf contains sufficient moisture. Monitoring the leaf temperature will help avoid curing problems mentioned previously. To control the wet-bulb temperature and therefore relative humidity, the fresh air intake damper is adjusted manually, typically in small increments. Opening the damper increases the fresh air intake or ventilation rate, which decreases the wet-bulb temperature and relative humidity. Closing the damper decreases the ventilation rate and increases the wet-bulb temperature and relative humidity. Growers that do not measure or monitor the wet-bulb temperature are almost certain to overventilate to avoid browning or scalding the tobacco. It only requires a few degrees difference in the wet-bulb temperature to significantly increase or decrease the drying potential of the air, especially during the early stages of the curing schedule when the dry-bulb temperature is only a few degrees higher than the wet-bulb temperature. As the damper opening is increased, the ventilation rate and fuel consumption increase. This increase in fuel consumption is a result of the heat energy required to increase the additional incoming volume of air to the dry-bulb temperature. The amount of energy wasted increases as the dry-bulb temperature increases, which is highest during the stem-drying phase. As the damper opening increases, less air is recirculated inside the barn and more air is exhausted out the vents. The air that exits the top of the boxes and out the barn will seldom be saturated resulting in a quantity of the available heat energy in the air to be lost to the outside. Curing with a lower than recommended wet-bulb temperature will increase this wasted quantity of heat. Additionally, overventilation during yellowing may result in accelerated drying, setting the color green, especially on the bottom of the boxes or racks that are in contact with the air first. A barn with excessive air leaks may result in difficulty maintaining the desired wet-bulb temperature and relative humidity. Excessive leaks increase the infiltration or amount of fresh air pulled in by the fan to compensate for the air exhausted. This wastes fuel and energy because the air is exhausted out the barn prior to passing through the tobacco.

Although most dampers are adjusted manually, they can be adjusted automatically. Automatic damper adjustment uses the wet-bulb temperature measurement as a control signal to a fractional horsepower motor that is connected to the damper. The motor adjusts the damper opening for the desired wet-bulb temperature. Regardless of manual or automatic damper control, if the wick on the wet-bulb dries out, the measured temperature is higher than the actual wet-bulb temperature. As a result the damper is opened in an attempt to lower the wet-bulb temperature, which leads to overventilation. Therefore, eliminating the wick from becoming too dry during curing is critical to proper ventilation control.

An example of a homemade wet-bulb thermometer and a hygrometer are shown in Figure 2. A hygrometer simply uses the continuous dry- and wet-bulb temperature measurements to determine the relative humidity. The relative humidity value can be read directly from a table or chart. Both of these devices are commonly used to monitor the wet-bulb temperature inside curing barns. The homemade wet-bulb thermometer is assembled from 1-inch PVC components and is relatively inexpensive to make. In addition the PVC wet-bulb has a large water reservoir to minimize replenishing during curing. The hygrometer wet-bulb has a smaller water reservoir and requires frequent refilling. Contact the local cooperative extension agent to obtain additional information about construction of a homemade wet-bulb thermometer.

Growers may have noticed that curing with heat exchangers has resulted in less ventilation (a decrease in the damper opening) than compared with direct-fired curing for a desired wet-bulb temperature. This is a result of the drier heat produced from indirect-fired heating. In the direct-fired case, for every gallon of LPG consumed approximately **1.5** gallons of water vapor are produced, which is now vented externally to the barn. Although good cures can result from guessing the wet-bulb temperature, overventilation and increased fuel consumption are almost guaranteed.

Wet-Bulb Thermometer Location

The drying process occurs at a constant wet-bulb temperature and therefore the wet-bulb temperature should be the same below and above the tobacco. However, the dry-bulb temperature below the tobacco will be greater than above. As the air passes through the mass of tobacco, the moisture content increases and the temperature decreases due to the evaporative cooling. To obtain the most accurate wet-bulb temperature a few guidelines are suggested.

1. The wet-bulb thermometer should be placed far enough away from the burner output to ensure adequate mixing of the air, but in a location with sufficient air movement across the wick for evaporation. Typically, the wet-bulb is positioned on the floor below the curing containers near the front of the curing barn. This allows easy access and is in an environment with sufficient airflow.

2. The wet-bulb thermometer reservoir should be monitored and maintained with water to keep the wick wet at all times. The wicks should be changed or washed frequently due to the decrease in water absorption that commonly occurs. Impurities in the water and the unforgiving curing environment contribute to the decrease in moisture absorption. If the wick becomes dry the wet-bulb thermometer will indicate an incorrect wet-bulb temperature, which will result in overventilation and increased fuel consumption.

Figure 2.

Wet-bulb thermometers.

Uniform Loading & Adequate Airflow

Uniformity is the key to adequate airflow, which is necessary for top-quality cures. Uniform loading is essential in both rack and box barns. A barn full of racks or boxes that are not uniformly loaded is almost sure to cure improperly and waste fuel and electrical power. Although there are many rack barns still in use, they typically are replaced with box barns. This is mainly due to the box barn's increased capacity and ease of integration into completely mechanized curing systems. Overloading boxes can result in scalded tobacco, particularly on lower-stalk tobacco. More often, however, scalded or improperly cured tobacco results from uneven loading that allows air to pass through less dense areas while bypassing more dense areas. Typically the middle of the containers are loaded more densely than the sides. Furthermore, proper placement of racks or boxes is a must for adequate airflow. It has been estimated that a 1/2 inch crack between adjacent boxes may allow as much as 50 percent of the air to "short-circuit" past the tobacco. Good box-to-barn and box-to-box sealing should be obtained for maximum leaf ventilation and top-quality cures. The same holds true for racks.

Although most curing containers are effectively loaded by hand, many types of mechanical loading systems have become available. Green leaf box loading systems have become more common as growers have become more dependent on mechanization. Mechanical loading systems are designed to load the boxes in thin uniform layers. The loading systems range in complexity, and therefore cost, but all incorporate some type of weighing system. This one aspect of the system allows the grower to load each container with exactly the same amount of green tobacco. It is suspected that boxes not uniformly loaded results in containers drying at different rates. This differential drying can occur within a given box and between adjacent boxes in the same barn. Uneven drying can result in longer curing times therefore increasing the electrical and fuel consumption per cure. Although the electrical energy consumption is approximately 10 to 15 percent of the total energy required for curing, the electrical energy cost is approximately 20 to 25 percent of the total cost per cure. Therefore, it is very important to make sure the box corners and sides are loaded tightly with any type of loading method used to minimize the curing time. Although good cures can be obtained with slight air leakage between containers provided adequate airflow, poor cures are likely when low airflow occurs with leakage, nonuniform loading, or both.

Estimating Airflow

Early research investigating airflow through bulk containers recommended a minimum airflow of approximately 0.5 cubic feet per minute per pound of green tobacco (cu ft/min/lb) for optimum curing. There is not a maximum other than the economic factors of providing the airflow, such as initial fan cost and electrical energy requirement. With the increasing use of box loading systems and incorporated weighing systems, growers can accurately monitor the amount of green tobacco loaded per box. The amount of green tobacco loaded per volume is referred to as the bulk density and is expressed as pounds per cubic feet (lb/cu ft). To determine the bulk density of the box simply divide the green weight by the box volume. The typical large curing boxes that are approximately 6- feet in height have an empty volume of approximately 200 cubic feet (cu ft). For example, a box loaded with 2000 pounds of green leaf would have a bulk density of approximately 10 lb/cu ft (2,000 divided by 200). To accurately estimate the bulk density, you should measure the empty box volume. The bulk density of the boxes significantly affects the airflow through the tobacco. Typically, less amounts of lower- stalk tobacco are loaded into the boxes as compared to middle- and upper-stalk tobacco. This is primarily due to the high moisture content and the ability to tightly pack lower-stalk tobacco.

Static air pressure developed by the fan is the pressure required to force air through the barn and tobacco. The static pressure is expressed in inches of water and is measured with a relatively inexpensive device called a manometer. The most common manometers are simply rigid, clear plastic U-tubes filled with water (Figure 3). Many of the fuel dealers should have experience using manometers and access to one.

Figure 3.

U-tube Manometer

Figure 4.

Manometer connected to barn.

The airflow through the tobacco can be estimated by measuring the static pressure across the tobacco during the first 24 hours after loading the barn. This assumes uniform airflow through each box and the entire barn. It should be pointed out that the static pressure the fan operates against includes the plenum duct losses plus the resistance developed by the packed bed of tobacco. The static pressure across the tobacco is an indication of the resistance to airflow. As the bulk density is increased, the resistance to airflow increases also. However, once the tobacco wilts and shrinks, the resistance to airflow decreases, resulting in an increase in airflow through the boxes. The static pressure will decrease over time as a result of the leaf shrinkage, which allows more passageways for the air to move around the leaves. Static pressure measurements at the end of the cure are typically less than 10 percent of the initial value.

To estimate the airflow through the tobacco, a static pressure measurement across the tobacco and the bulk density are required. Two lengths of plastic tubing and a manometer are needed to measure the pressure. Position one length of tubing through the barn wall above the tobacco

and the second length of tubing through the barn wall below the tobacco. The tubing needs to extend inside the barn only a few inches. The ideal location for inserting both tubes through the barn wall is about 2/3 the length of the barn from the fan output to avoid the effect of turbulent air. Connect the other end of each tube to either end of the manometer. An example of a manometer connected to a curing barn is illustrated in Figure 4. The fresh air damper should be adjusted to the location used during the early stages of the curing schedule. Many growers open the damper completely to remove excess surface moisture during initial loading and any measurements taken during this time will result in inaccurate readings. Initially the column of water in the manometer will be at the same height or level. Once the tubes from above and below the tobacco are connected to the manometer, the water will move down on one side and up on the other. The difference in height between the water columns is the static pressure across the tobacco. Most manometers have graduations in tenths of an inch. If you start with the initial water column on the zero mark and the water moves down 0.2 inches, it will also move up 0.2 inches. This represents a static pressure of 0.4 inches of water.

Table 1 lists the approximate static pressure across the tobacco required to produce an airflow of 0.5, 0.75, and 1.0 cu ft/min/lb for a given bulk density. It also includes two box heights of

Static Pressure Across Tobacco (inches of water)						
	Airflow per pound green leaf					
	0.5 cfm per lb		0.75 cfm per lb		1.0 cfm per lb	
	Box Height (ft)					
Bulk Density (lb/ft3)	4	6	4	6	4	6
8	0.07	0.17	0.11	0.30	0.17	0.50
9	0.10	0.25	0.17	0.46	0.25	0.72
10	0.14	0.36	0.24	0.67	0.36	1.06
11	0.19	0.51	0.33	0.94	0.50	1.50
12	0.25	0.70	0.44	1.29	0.70	2.10
13	0.33	0.90	0.59	1.72	0.92	2.80
14	0.41	1.20	0.76	2.25	1.20	3.70

Table 1.

Initial Static Pressure Across Tobacco Required for Airflow per Pound of Green Tobacco

4- and 6-feet to demonstrate the increase in static pressure required for a given bulk density and airflow for the different height boxes. If growers are weighing the boxes, then this information can be used to assist with estimating the initial airflow through the boxes. Table 2 lists the approximate pounds of green leaf per box and the static pressure requirements for a given bulk density and airflow.

The static pressure requirements are only for the 6-feet boxes in Table 2. For example, boxes loaded with 2,000 pounds of green leaf (bulk density of 10 lb/cu ft) requires a static pressure of

Bulk Density (lb/ft3)	**Green Tobacco** Per box (lb)	**Initial Static Pressure Across Tobacco** (inches of water)		
		0.5 cfm per lb	**0.75 cfm per lb**	**1.0 cfm per lb**
8	1600	0.17	0.30	0.50
9	1800	0.25	0.46	0.72
10	2000	0.36	0.67	1.06
11	2200	0.51	0.94	1.50
12	2400	0.70	1.29	2.10
13	2600	0.90	1.72	2.80
14	2800	1.20	2.25	3.70

Table 2.

Initial Static Pressure Required for Airflow per Pound of Green Tobacco w/ 6-ft Curing Boxes

approximately 0.36 inches to produce the minimum recommended airflow of 0.5 cu ft/min/lb. In comparison, to generate 1.0 cu ft/min/lb for this box load of 2,000 pounds would require an initial static pressure of approximately 1.06 inches, or almost three times that required for 0.5 cu ft/min/lb. If the actual static pressure measurement for this example was less than 0.36 inches, this would suggest that less than 0.5 cu ft/min/lb is available for each box. Also, if the static pressure measurement was greater than 0.36 inches, an airflow of more than 0.5 cu ft/min/lb would result. Airflow less than 0.5 cu ft/min/lb does not necessarily result in poor cures, but it indicates the existing airflow is not ideal for optimum curing. Remember, the tables only apply to static pressure measurements during the first 24 hours. As mentioned earlier, measure the empty box volume to accurately determine the bulk density before using this information. It should also be mentioned that for a desired airflow, the resistance in rack barns is significantly less than boxes and therefore the static pressure requirements will be less.

Increasing Airflow

There are only two remedies for poor airflow. The easiest remedy is to reduce the air resistance by reducing the amount of tobacco loaded per box. Growers that weigh boxes have the ability to accurately modify the bulk density and improve airflow. For example, from Table 2 the static pressure required to produce 0.5 cu ft/min/lb through boxes loaded with a bulk density of 12 lb/cu ft (2400 pounds per box) is approximately 0.7 inches of water. If the bulk density was decreased to 11 lb/cu ft (2200 pounds per box) then the required pressure is approximately 0.5 inches of water. This demonstrates that small decreases in loading can significantly decrease the static pressure required, or resistance the fan must overcome, to produce a desired airflow through the boxes. In this example, approximately an 8 percent decrease in loading requires approximately 30 percent less static pressure across the tobacco to generate the same airflow. The boxes should be loaded with enough leaf to properly fill the container or under filling can result in air by-passing the leaf also.

The other remedy is to increase the fan output. This may be done by increasing the fan rpm or by increasing the angle on the fan blades. In some cases, an entirely new, more aggressive fan blade may be necessary. Note that increasing the rpm or changing fan blades will increase the horsepower and hence the amp draw to the fan motor. A competent electrician should check your fan with an amp meter. If it is already at or near the nameplate-rated amperage, you must replace the motor with one of a larger horsepower rating before you change the fan blade or fan rpm. Operating an electric motor above its rated amperage for even a short period is dangerous and will result in rapid burnout of the motor.

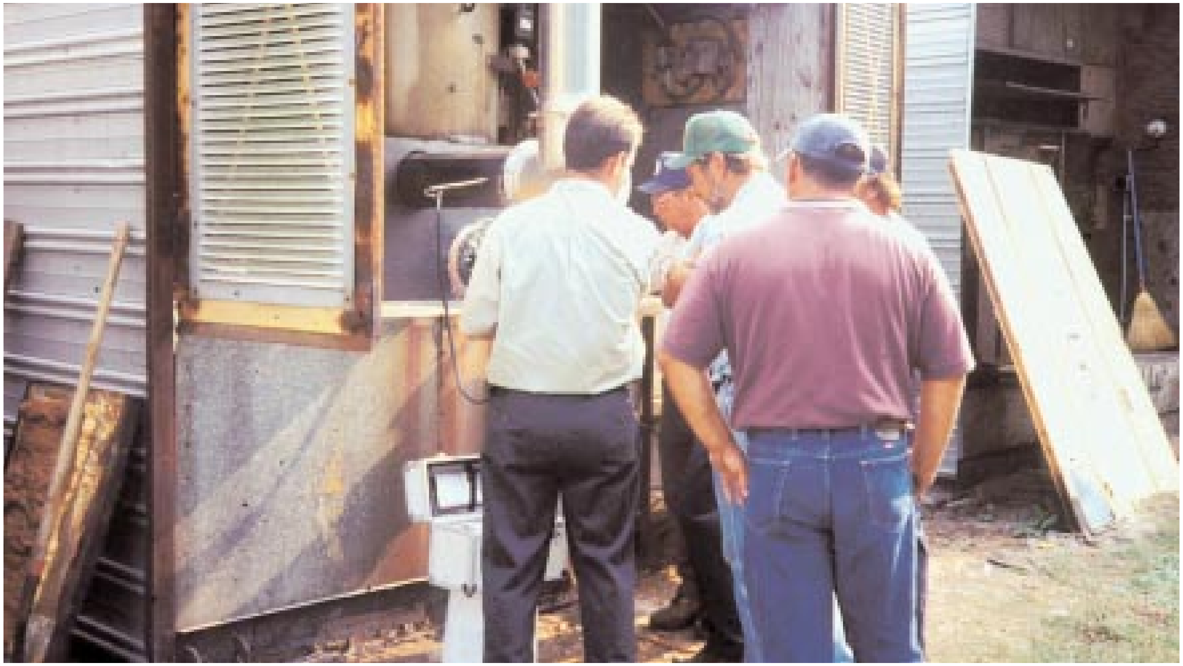
Although the retrofit heat exchangers will produce some resistance and therefore reduce airflow through the barn to some extent, most manufacturers have been careful to avoid designs and installations that restrict airflow. The restriction in some cases may lengthen the curing time or contribute to curing problems such as scald, swelled stems, or barn rot. If you have had such problems with a barn before retrofitting was required, these problems may be more likely after retrofitting.

Any external leaks on the high-pressure side of the boxes, which is the bottom for updraft barns, will become more serious as the static pressure increases. Minimizing external leaks will assist with ensuring the air that is available passes through the tobacco. Weighing the boxes and measuring the static pressure across the tobacco allows the grower to accurately estimate the air-flow through the tobacco and assist with minimizing curing problems associated with low airflow. As harvesting progresses up the stalk, marginal airflow tends to become less of an issue as long as the boxes are at a uniform density. However, many growers comment that weighing boxes

accurately has significantly reduced curing problems, especially those associated with lower-stalk tobacco. Remember that no matter how good the barn, retrofit, or tobacco, if you cannot get air to the tobacco, you cannot cure it. Barn rot, in particular, results in extremely high levels of tobacco specific nitrosamines (TSNAs) in the cured tobacco and completely negates the effects of retrofitting.

Energy Efficient Heat Exchanger & Burner

It is important to follow any annual maintenance requirements recommended by both the heat exchanger and burner manufacturers to ensure both units are functioning at an optimum level. The burners should be annually inspected and adjusted to establish the correct amount of excess air, which will ensure complete burning of the fuel and minimize fuel consumption. The heating systems are not unlike other mechanical systems that require annual inspection and service to maintain a high level of performance and prolonged life.



Energy Efficiency of the Burner

Combustion is essentially a chemical process. A burner facilitates the conversion of the chemical energy contained in the fuel to heat. All fuels contain a certain and fixed heat content per unit measure. As an example, if an LP gas burner were 100 percent efficient, it would produce 90,500 Btu for each gallon of LP gas burned. In practice, some of the fuel passes through the burner unburned and is therefore wasted. A well-designed and -maintained burner limits this waste to no more than 1 or 2 percent.

The single greatest reason for burner inefficiency is too little or too much air. In theory, a precise quantity of air is required to completely burn a precise quantity of fuel. Because of incomplete mixing, a limited but very important amount of excess air is required to get complete burning and the highest efficiency. When too little air is present, the burner will produce partially unburned fuel or smoke. Smoke not only wastes fuel but can deposit soot inside the heat exchanger, where it acts as insulation. Even a thin coating of soot can reduce the heat exchanger efficiency considerably. It has been estimated that 1/8-inch thick soot accumulation on the heat exchanger surfaces can result in increasing fuel consumption by approximately 8 percent. When too much air is present, the excess air cools the combustion gases and carries heat out before it can be captured by the heat exchanger. Adjusting the correct air-fuel ratio on a burner is essentially the same as adjusting the air-fuel ratio on an engine carburetor. Although an approximately correct burner air-fuel ratio may be set by eye (a blue instead of orange flame), the proper air-fuel ratio can best be achieved with a combustion analyzer.

Most fuel dealers have some type of combustion analyzer and the experience to assist with adjusting the heat exchanger burner. The combustion analyzer probe is inserted into a small hole drilled in the heat exchanger exhaust stack. The most accurate location in the stack to perform this test is where the pipe first exits the barn. At this location, any additional heat in the pipe is not transferred to the curing air inside the barn. Combustion analyzers are quick and easy to use, and can assist with significantly reducing fuel cost each year. In addition your local cooperative extension agent can assist with questions about this procedure.

Adjusting the Burner

Most combustion analyzers have sensors that measure the carbon dioxide (CO_2) and oxygen (O_2) concentrations in the exhaust stack, which are expressed as percentages. These measurements are used to adjust the excess air level on the burner. Typically a fresh air inlet vent or shutter on the burner fan is adjusted until the desired excess air level is obtained. Table 3 lists the approximate CO_2 and O_2 percentages for different excess air values and the common fuels used. As the excess air is increased, the percentage of CO_2 decreases and O_2 increases, which results in wasted fuel and cooler flame temperatures. Figure 5 illustrates the effect excess air has on the flame temperature, CO_2, and O_2. The flame temperature corresponds with the left vertical axis and the CO_2 and O_2 percentages with the right vertical axis. Although the temperatures will vary with the different fuel types, the response is the same for any fuel used. As the excess air increases the flame temperature decreases significantly. Notice the peak flame temperature occurs when the exact amount of air is supplied for complete combustion or the percent of excess air is equal to zero. The excess air acts as a heat sink and absorbs significant amounts of the heat energy released during the combustion process. Table 3 also lists the approximate CO_2 levels for the theoretical combustion case (zero excess air). This value would be the percentage of CO_2 in the stack gas for a given quantity of fuel and the exact amount of air needed for combustion. The only combustion products in the exhaust stack for this case would be CO_2 and water vapor. However, the theoretical combustion case is not practical and excess air is required for complete combustion. The general practice is to supply 5 to 50 percent excess air depending on the fuel type, combustion equipment, and other factors. Since LPG and natural gas are already in the vapor form when mixed with air, they typically require less excess air than fuel oil. Table 3 can be used to assist with adjusting the excess air level. For example, to obtain an excess air value of 20 percent burning LPG, requires adjusting the fan inlet shutter until a CO_2 value of approximately 11.4 percent or an O_2 value of approximately 4.0 percent are measured in the exhaust stack gas. Also refer to the burner manual for any additional information or recommended excess air values. The manual

Percentage of CO_2 and O_2 at Given Excess Air Values										
	Theoretical CO_2%	10%		20%		40%		60%	
Fuel Type	**(Zero Excess Air)**	**CO_2**	**O_2**	**CO_2**	**O_2**	**CO_2**	**O_2**	**CO_2**	**O_2**
LPG	13.9	12.5	2.0	11.4	4.0	9.6	6.5	8.4	8.5
Natural Gas	12.1	10.8	2.0	9.9	4.0	8.4	6.5	7.3	8.5
No. 2 Fuel Oil	15.5	14.0	2.2	12.5	4.0	10.5	6.0	9.1	7.9

Table 3.

Approximate $C0_2$ and 0_2 Values with Different Excess Air Percentages.

may list the fan shutter setting for a given Btu per hour firing rate, but a combustion test should always be performed to verify the excess air percentage. The goal is to minimize the excess air quantity, but provide enough to ensure complete combustion. The correct quantity of excess air will result in higher flame temperatures, increased contact time between the hot combustion gases and heat exchanger surfaces, and minimize soot accumulation. As a result a properly tuned burner will increase heat transfer.

Some combustion analyzers calculate and display the excess air percentage based on the CO_2 and O_2 measurements. Additionally, the exhaust gas temperature combined with the excess air parameters can be used to calculate and display the combustion efficiency, expressed as a percentage. Combustion efficiency is a measurement of how well the heating system is converting the fuel into useable heat energy at a specific period of time in the operation of the heating system. The combustion efficiency is complicated by the performance of the burner and heat exchanger acting as a single unit. Due to the fact that some of the heat will always be lost up the exhaust stack, a combustion efficiency equal to and exceeding 80 percent should be targeted. An ideal stack temperature is in the range of 350- to 450°F. The heat exchanger and burner work together and consequently a properly tuned burner can assist with significantly improving the heat exchanger performance.

Energy Efficiency of the Heat Exchanger

The energy efficiency of the heat exchanger is the percentage of the total heat entering from the burner that is extracted (exchanged) for practical use inside the barn. For the heat to be exchanged from the burning flue gases, it must pass through the walls of the heat exchanger. Many factors influence the exchange capacity and hence the efficiency of the heat exchanger. These include the shape and size of the heat exchanger, its material type and thickness, the rate of hot gases flowing inside the heat exchanger, and the rate of air flowing over the outside surfaces of the heat exchanger.

Additionally, the rate of heat generation by the burner (Btu/hr) greatly influences the efficiency of a particular heat exchanger. The correct burner-firing rate (Btu per hour) should be checked annually. Typically the burner-firing rate is 350,000 to 500,000 Btu per hour, depending on the amount of green tobacco loaded, fan output, and other factors. A burner that is firing at too high a rate can overwhelm a particular heat exchanger design, resulting in higher thermal stresses and the increased risk of developing cracks in the heat exchanger. Most modern fuel oil and LP gas burners are adjustable in capacity (Btu/hr) over a considerable range. For the most efficient operation, balance the burner and heat exchanger. The burner/heat exchanger system will operate most efficiently when the burner is operating at the lowest capacity that will allow the barn to maintain the desired temperature. The most heat is required during the early part of leaf drying when the barn temperature should be between 125°F and 135°F. Adjust the heat output of the burner so that the burner is operating nearly continually during this time. For example, a burner that is on for a minute and off for several is probably operating at too great an output and inefficiently overwhelming the heat exchanger. Further, in the short time the burner is operating, the heat exchanger may be getting red hot, inducing severe thermal stresses in the metal and ultimately shortening its life.

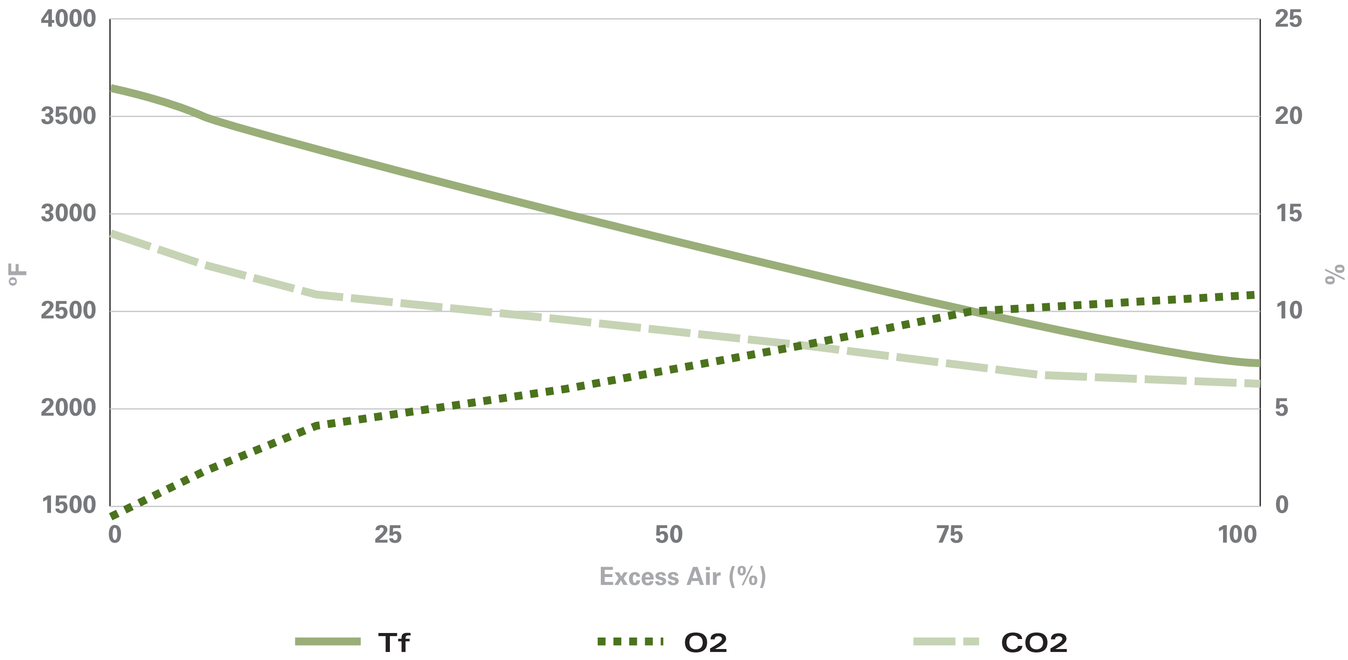


Figure 5.

Typical response of flame temperature, CO_2 and O_2 vs. excess air (LPG Example)

Energy Efficient Barn

Top quality tobacco is not likely to come out of a barn with an improperly adjusted burner, faulty or inaccurate curing controls, or a structure with multiple sources of air leaks. Not only will the quality of the tobacco be lower, but it will significantly cost more to cure in a poorly maintained barn. A statewide bulk barn energy audit program 20 years ago demonstrated conclusively that the quality of cured tobacco as well as the cost of curing depended heavily on the condition of the barn. There were documented fuel savings as high as 50 percent when poorly maintained barns were thoroughly reconditioned. A bulk curing barn is not so much a structure as a piece of equipment. And like any piece of equipment, it requires (and deserves) periodic maintenance to keep it in good shape. A good barn maintenance plan should consider the whole barn.

Curing fuel is a significant cost of tobacco production. Even a brand new, well-insulated bulk barn uses only about 60 percent the heat value of the fuel to cure the tobacco. The remaining 40 percent of the heat is lost through the walls of the barn by conduction and radiation or through air leaks. Leaky and poorly maintained barns without insulation, on the other hand, may waste as much as 60 percent of the fuel. Many growers don't realize how much fuel their older barns are wasting until they put a new barn down beside their old ones. The difference in fuel use sometimes can be startling. Most bulk barns are situated on a 4 inch-thick pad of concrete. Some are insulated, but most are not. This is unfortunate since test after test has shown that even a small amount of insulation will reduce the amount of fuel used and pay for itself several times over during the life of the barn. It may be too late to do much about an uninsulated pad now, but if you are thinking of putting in a new barn or moving an old one, you should consider placing an inch of foam insulation under the concrete.

All of the bulk barns made today are insulated. Some of the older ones are not. There is nothing that can reduce the cost of curing like properly installed insulation. There are several ways to insulate a bulk barn. Growers have used fiberglass batts and foam board with some success. However, experience has shown that the best all-around insulation for a bulk curing barn is sprayed on polyurethane. In addition to its excellent insulation properties, sprayed on polyurethane will seal cracks and openings. One-half to 3/4 inch of sprayed on polyurethane insulation is usually sufficient. Doubling the thickness of insulation will not double the saving. Be careful to keep the insulation off the rails of racktype barns and other places where it may be rubbed off and mixed with the tobacco. Pieces of polyurethane insulation are very difficult to remove from cured tobacco and will result in very serious contamination issues. All barns now must completely cover the insulation with sheet metal to prevent contamination.

After a few years, even the best constructed barn will develop cracks and gaps. The natural daily cycle of heating and cooling will loosen screws, nails, and staples that secure the roofing and siding. A few minutes spent with a screwdriver and hammer will be time well spent. Doors are a particularly good source of maintenance problems. Hinges work loose and gaskets get hard and torn and need periodic replacement. It is also a good idea to reseal the foundation joint with a good grade of butyl caulking compound. A 15-foot-long, 1/4 inch gap between the foundation channel and the pad can increase curing costs 10 percent.

Curing Efficiency

While the combustion efficiency is the combined efficiency of the burner and heat exchanger, curing efficiency takes into consideration the entire process of tobacco curing. In essence, curing efficiency is the bottom line that is often conveniently expressed in terms of pounds of tobacco cured per gallon of oil or gas consumed. Considerable research has established that, on average, a well-maintained and -operated direct-fired barn will cure approximately 9 pounds of cured leaf per gallon of LP gas (or approximately 13 pounds per gallon of fuel oil). For example, if you are taken out 3000 pounds of cured leaf per barn and the fuel consumption was 300 gallons of LPG that would indicate a curing efficiency of 10 pounds cured leaf per gallon LPG (3000 divided by 300). These numbers may vary considerably even in the same barn over a curing season because they are affected by such factors as barn loading rates, stalk position, weather conditions, the condition of the tobacco, and variations in vent settings, among others.

Because some of the heat is lost up the stack with a heat exchanger, a burner/heat exchanger delivering the same amount of heat (in terms of Btu/hr) to the curing barn as was delivered by a direct-fired system will necessarily require more fuel. Surprisingly however, some growers report no increase in fuel use or even that their retrofitted barns use less fuel. There are several possible explanations, with the most likely being that many of the direct-fired burners needed maintenance and adjustments.

Measuring and Controlling Moisture in Cured Tobacco

Uncured tobacco is approximately 80 to 85 percent water. At the end of the curing cycle, the tobacco is essentially zero percent water. At this stage, tobacco is much too brittle to handle without shattering Therefore, good practice dictates that some moisture be put back into the tobacco at the end of the cure to enable good handling. Too much moisture, however, can cause the tobacco to heat, darken, decay and will ultimately ruin its desirable qualities. How to effectively and efficiently control the moisture of cured leaf has always been of great concern to growers and buyers alike.

The old rule of thumb is:

5 parts water to 1 part dry matter when green and

5 parts dry matter to 1 part water when cured (and in good order)

Cured tobacco, like many organic materials, is hygroscopic. Hygroscopic materials have a physical (as opposed to a chemical) affinity for moisture. In the case with tobacco, this moisture is usually absorbed from the water vapor in the air surrounding the leaf. The absorption of water by cured tobacco leaves is a complex process that depends on many biological and physical factors. Biological factors include the properties of the leaf that vary with variety, cultural practices, stalk position, and weather. The important physical factors include ordering temperature and humidity, air velocity around the surface of the leaf, and quantity and arrangement of the leaves.

It is well known that the rate of moisture absorption (usually expressed as percent moisture increase per hour) increases with increasing relative humidity. It is simply that at higher relative humidities, more water is in the air and available for absorption by the tobacco. It is probably less well known that the moisture absorption rates also increase dramatically with increasing temperature. For example, at 80 percent relative humidity, the rate of absorption at 86ºF is more than double the rate at 68ºF. At 140ºF and 80 percent relative humidity, the rate may be as high as several percentage points per minute. In addition, stalk position and leaf quality affect the rate of water absorption. Lower-stalk or thin, poor-quality tobacco has a faster absorption rate than thicker, upper-stalk, or better-quality tobacco. Further, the rate at which tobacco absorbs moisture is also related to the current moisture content of the leaf. The more moisture already in the leaf, the slower the rate of increase. Figure 6 shows a typical ordering curve for initially dry tobacco held for an indefinite period at 80ºF and 80 percent relative humidity.

If a sample of tobacco is allowed to remain for some time in a stable environment of relative humidity and temperature, it will eventually absorb moisture up to a certain percentage.

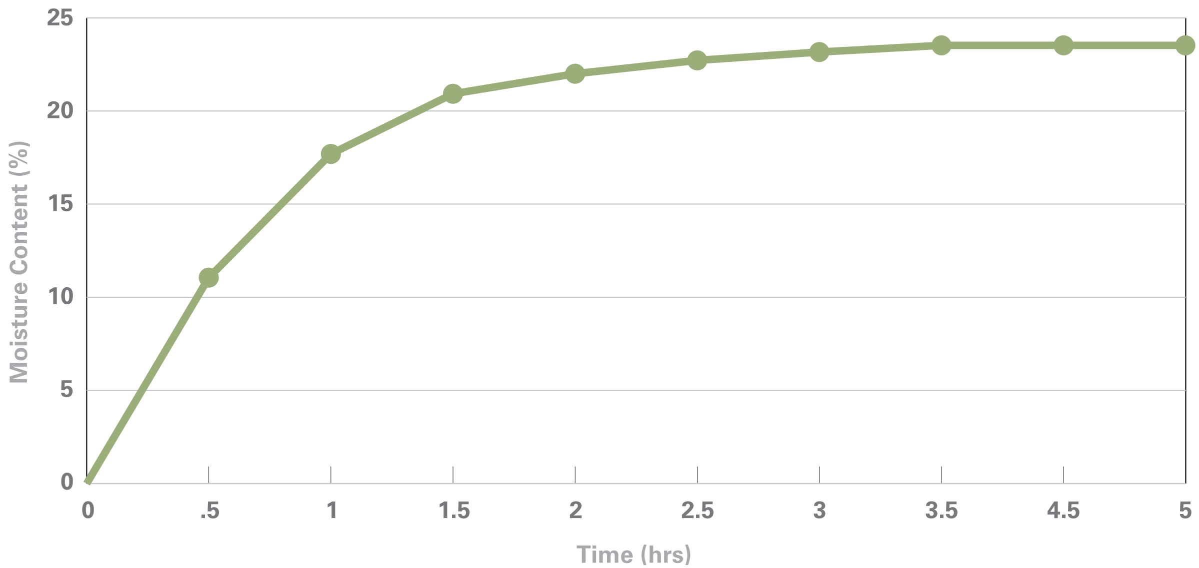


Figure 6.

Ordering curve at 80ºF and 80 percent relative humidity.

This level is known as its *equilibrium moisture content* (EMC). An example of two EMC curves can be seen in figure 7. At the EMC, the adsorption of moisture ceases. With a particular sample of cured tobacco, any combination of humidity and temperature will yield an equilibrium moisture content within a small but predictable range. For example, from figure 7 the equilibrium moisture content of this sample at 80ºF and a relative humidity of 50 percent is approximately 8 percent. At 80ºF and 70 percent relative humidity, the EMC is approximately 16 percent. As mentioned above, tobacco with too much moisture is subject to heating and decay by various microorganisms. The four factors necessary for decay are food, sufficient water, proper environment, and inoculation. If any one of these is missing, decay cannot occur.

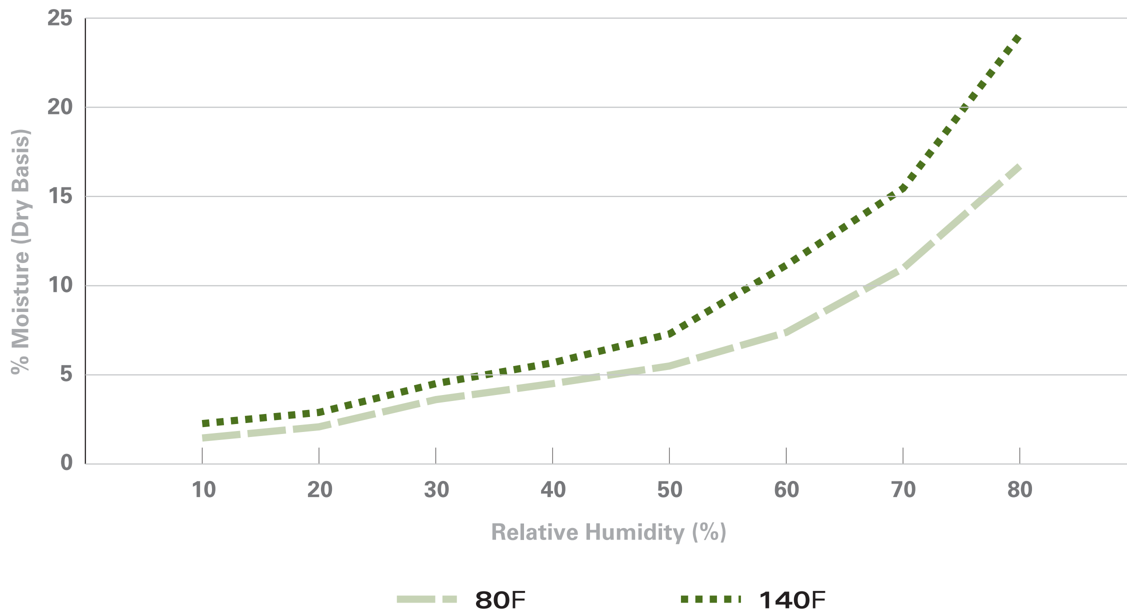


Figure 7.

Equilibrium Moisture Content (EMC) vs relative humidity at 80 and 140ºF.

Food: The food used by the decay organisms are primarily the starches and sugars present in all tobacco leaves. In fact, the better the quality of the tobacco, the more food in the leaves.

Water: The percentage of moisture necessary for decay varies with types of tobacco, stalk position, and other factors, but for flue-cured it is generally in the range of 20 to 22 percent and above. The higher the moisture content, the more rapid the action of the decay organisms. For example, flue-cured tobacco at 20 percent moisture content may take weeks to display significant decay whereas tobacco at 24 percent may begin to decay in a matter of hours.

Environment: Decay organisms thrive in a warm, moist, and dark environment and do not rely on the presence of oxygen. This is precisely the environment found inside a pile or bale of high moisture tobacco. Further, decay produces heat that further enhances the process. Because tobacco is not a good conductor, the heat produced has little opportunity to escape. Therefore, probing piles and bales with long stem thermometers has become a standard way to detect problem high-moisture tobacco. Temperatures above 110°F in the center of piles or bales should be viewed with concern. You should immediately open the bales for examination, cooling, and drying. If discovered early, little damage may occur to the quality of the tobacco.

Inoculation: Decay cannot occur without decay-producing organisms. Unfortunately, the spores of these organisms are everywhere in the air in great numbers. Very little, if anything, may be done to prevent inoculation of the tobacco.

Measuring Moisture in Tobacco

For 350 years, growers and buyers have had to rely on their own subjective judgments of moisture from primarily the "feel" of the tobacco. Actually, this approach also relies on sight, sound, and smell. Those experienced in this method often demonstrate remarkable speed and accuracy. The table below gives some general guidelines for subjective moisture determination in flue-cured tobacco.

<u>Flue-Cured Tobacco Subjective Moisture Content Test</u>

• 0 - 6 % Moisture Content	Readily shatters into small pieces.
• 8 - 12% Moisture Content	Leaf lamella may be bent, but mid-ribs and veins still snap easily. (Grower often refer to this condition as "boney.")
• 14 - 18% Moisture Content	Stems may be easily bent, but leaves still make a "rustling" sound. (Refer to as "good order.")

• 20 - 22% Moisture Content	Leaves have sticky feel and may be folded into small wad that is slow to unfold. (Often referred to as “high order.”)
• > 30% Moisture Content	Leaves feel damp or even wet to the touch.

Note: The term “order” is mostly used with flue-cured tobacco; the term “case” is used for burley. In the technical literature, the process of the controlled reintroduction of moisture into tobacco is known as “conditioning”. Subjective judgment of moisture served the industry well as long as buyers could open piles and examine the tobacco firsthand. With the recent intense emphasis on quality assurance and the introduction of bales, this time-honored method is no longer possible or practical. Intense research is now underway to develop rapid and practical methods for determining moisture in tobacco. Four objective methods that are already in use or under development are outlined below:

Oven Drying: Correctly performed, oven drying is considered the most accurate moisture determination method. Representative samples of the tobacco are first accurately weighed and then dried for 24 hours at 215ºF. After drying, the sample is re-weighed, and the difference in the two weights is used to calculate the original moisture content. This method has been successfully used for many years but requires expensive lab equipment, is slow, and is not practical for growers or most buying situations. In recent years, small automated computerized oven drying kits have become available, but they may cost more than $5000.

***Electrical Capacitance or Resistance Pro*bes**: The amount of moisture in a material influences its electrical properties. Various probes that measure the electrical properties of resistance or capacitance can be used to indirectly measure moisture. As the moisture increases, the capacitance increases and the resistance decreases. Unfortunately, other properties such as density and leaf chemistry also influence electrical properties. Because of the wide variations in density, these probes are not suitable in sheeted tobacco. Properly calibrated, they are more accurate with baled tobacco if the probe is consistently placed in the center of the bale and the density (weight) of the bale is taken into consideration. If used carefully, capacitance probes may yield results within plus or minus two percentage points of the true moisture. Probes are quick, simple to use, and relatively inexpensive compared to other methods.

Microwave Analyzers. A new class of scanner showing promise has recently become available that measures moisture electronically using microwaves. This device uses a transmitter, a receiver, and a computerized signal processing unit, and it can take hundreds of readings per second through a bale of tobacco. The results are instantly given as a bale moisture average as well as the standard deviation. The standard deviation is very useful in detecting isolated over-moist spots or possibly even swell stems. Like the capacitance and resistance methods discussed above, microwave analyzers also are sensitive to density and must be calibrated for different bale weights. Although far too expensive for on-farm use, they are increasingly applied in warehouses, processing plants, etc.

Near Infrared Spectrography: Near infrared spectrography (NIR) has been used for many years to determine various properties (chemical and moisture) of agricultural products. Cotton, wool, feed grains, foods, and dairy products are some of the products commonly analyzed using NIR. This method of moisture determination uses scanners that respond to various wavelengths of reflected light. Unfortunately, NIR cannot "see" inside a bale but would be very useful in continually measuring moisture as the tobacco is prepared for market. Comparatively inexpensive NIR scanners (less than $600) are being developed that, when properly calibrated, may be accurate to within plus or minus 1 or 2 percent.

Accurate Conditioning of Tobacco at the End of the Cure

The rapid and satisfactory ordering of flue-cured tobacco after curing is essential to both the efficient use of barn space and leaf quality. The ability to remove the tobacco in a matter of hours instead of a day or more after the end of curing may add an additional cure to a particular barn during the season. The recent adoption of baling has added emphasis and opportunities for on-farm quality control of flue-cured tobacco. In particular, tobacco growers have become very interested in any method that will allow them to order their tobacco rapidly and precisely at the end of the cure. The several methods or combinations of methods that are now used to put moisture back into tobacco before removal from the barn often result in wide variations in moisture content from barn to barn and even within the same barn.

Before bulk curing, the doors of the conventional "stick barns" were left open at night to allow the humid night air to circulate into the barn and order the tobacco naturally. Depending on the weather, this process could take one to three days or more and often resulted in tobacco either too high or too low in order. To help the process, water was often poured on the dirt floor of the conventional barns to help speed up the process. Although this helped speed ordering, it occasionally resulted in some of the tobacco being too high in moisture in the lower part of the barn but much drier higher up.

Lb Of Leaf Taken From Barn	Moisture Content of Tobacco (%Wet Basis) 12	13	14	15	16	17	18
1,500	21.6	23.4	25.2	27	28.8	30.6	32.4
1,600	23.0	24.9	26.8	28.8	30.7	32.6	34.5
1,700	24.4	26.5	28.5	30.6	32.6	34.6	36.7
1,800	25.9	28.0	30.2	32.4	34.5	36.7	38.8
1,900	27.3	29.6	31.9	34.1	36.4	38.7	41.0
2,000	28.8	31.2	33.5	35.9	38.3	40.7	43.1
2,100	30.2	32.7	35.2	37.7	40.3	42.8	45.3
2,200	31.6	34.3	36.9	39.5	42.2	44.8	47.4
2,300	33.1	35.8	38.6	41.3	44.1	46.8	49.6
2,400	34.5	37.4	40.3	43.1	46.0	48.9	51.8
2,500	35.9	38.9	41.9	44.9	47.9	50.9	53.9
2,600	37.4	40.5	43.6	46.7	49.8	53.0	56.1
2,700	38.8	42.1	45.3	48.5	51.8	55.0	58.2

Table 4. Gallons of Water Required To Bring Flue-Cured Tobacco to a desired Moisture Content.
NC State University, Biological & Agricultural Engineering, 1999

With bulk curing barns, “natural” ordering can literally take weeks or months without the fans operating. Running the fans at the end of the cure brings moist, outside air past all the tobacco in the barn at once for more rapid and consistent ordering. Depending on the weather, this process can vary significantly with time. Particularly late in the harvest season, the nights are cool and

Lb Of Leaf Taken From Barn	Moisture Content of Tobacco (%Wet Basis)						
	12	13	14	15	16	17	18
2,800	40.3	43.6	47.0	50.3	53.7	57.0	60.4
2,900	41.7	45.2	48.6	52.1	55.6	59.1	62.5
3,000	43.1	46.7	50.3	53.9	57.5	61.1	64.7
3,100	44.6	48.3	52.0	55.7	59.4	63.1	66.9
3,200	46.0	49.8	53.7	57.5	61.3	65.2	69.0
3,300	47.4	51.4	55.4	59.3	63.3	67.2	71.2
3,400	48.9	53.0	57.0	61.1	65.2	69.3	73.3
3,500	50.3	54.5	58.7	62.9	67.1	71.3	75.5
3,600	51.8	56.1	60.4	64.7	69.0	73.3	77.6
3,700	53.2	57.6	62.1	66.5	70.9	75.4	79.8
3,800	54.6	59.2	63.7	68.3	72.8	77.4	82.0
3,900	56.1	60.7	65.4	70.1	74.8	79.4	84.1
4,000	57.5	62.3	67.1	71.9	76.7	81.5	86.3

dry, and the night air often does not contain enough moisture to sufficiently order the tobacco in a reasonable amount of time. Faced with the urgent need of the barn for another curing cycle, growers and barn manufacturers have added water sprays and humidifiers to barns. To properly order tobacco, the addition of water at the end of the cure must follow certain guidelines.

- Start while the tobacco is still warm. Research in the 1950s and again in 1999 demonstrated that the best time to start ordering is immediately after the end of curing while the barn and tobacco are still warm. Some growers may refrain from this practice because they mistakenly fear that moisture will darken the tobacco. Moisture will indeed darken warm tobacco, but only if it is *liquid water.* Also, allow the heat exchanger time to cool down before the addition of water.

- Decrease the water droplet size to increase the leaf efficiency or rate of water absorption into the leaf. Water introduced into the air in droplets too large to evaporate will stick to the first surface it encounters (usually the floor or bottom leaves in the barn) and go no further. Some growers suppose that the moisture will migrate and even out when these tobaccos are mixed when sheeting or baling. Previous research has shown this not to be the case. Pockets of high-moisture tobacco inside a generally lower-moisture bale will heat and decay long before the moisture has had a chance to migrate. For sprays or humidifiers to be successful, the droplet size must be small enough to allow the water to evaporate before it encounters leaves of tobacco. This usually requires special nozzles and water pressure in the range of 500 pounds per square inch (psi) or above.

- At the end of ordering, shut off the water, close the vents, and operate the fans for at least another hour to allow the moisture in the tobacco to even out and enter the midribs.

Most experienced growers have a good idea how much cured tobacco they can expect from their barns and can usually guess correctly within 200 pounds or so. In addition, the box loading systems used can result in a better estimate of the cured weight. If a grower knows the cured weight target moisture content, it is simple to determine how much water to add. For example, if a grower expects to remove 2,500 pounds of tobacco from his barn at 15 percent moisture content, then: 2,500 multiplied by 0.15 equals 375. Thus, 375 pounds of water must be added to the tobacco at the end of the cure. Because one gallon of water weighs 8.35 pounds, 375 pounds of water equals approximately 45 gallons. This may seem like a ridiculously small amount of water, but if all the water enters the tobacco and none is wasted running from underneath the barn, 45 gallons is all that is required! If the pump can atomize 30 gallons of water per hour so that essentially all the water enters the tobacco, then it should take approximately 1.5 hours (45 divided by 30) to bring the barn of tobacco into order. However, actual ordering systems are less than 100 percent efficient and require additional time to order the tobacco.

Some growers have constructed homemade ordering systems out of PVC or steel pipe and a group of nozzles. If the grower knows the waterline pressure and the nozzle size, he can estimate the gallons per hour introduced into the barn. For example, a typical water line pressure is 40 psi. Using four hollow- cone TX-2 nozzles at 40 psi will deliver approximately 0.132 gallons per minute or 7.92 gallons per hour (0.132 multiplied by 60). Nozzle capacity can typically be found from the manufacturers catalog and is rated in gallons per minute for a given pressure. That would require 5.7 hours (45 divided by 7.92) to deliver 45 gallons of water into the airstream. Table 4 lists the gallons of water required for the estimated cured weight and desired moisture content. Knowing the gallons required for a specific moisture content and the ordering system output capacity can assist growers with more consistent and accurate moisture addition.

Selecting & Using Standby Electric Power Equipment

The widespread loss of power in the aftermath of hurricanes Bertha and Fran illustrated only too clearly tobacco curing's dependence on an uninterrupted supply of electricity. Electrical power is essential for the operation and control of bulk-curing barns. The losses associated with Bertha were more localized and generally of a shorter duration than those experienced after Fran. After Fran, wide areas of the flue-cured growing region of North Carolina experienced outages of a week or more. The loss of power can have a great effect or almost no effect at all on the quality of the tobacco in the barn, depending on the stage of the cure and the length of the outage. Further, as was the case with Fran, the loss of power halted harvesting, resulting in a potential loss of tobacco still in the field.

The beginning of the cure is the most critical stage for the loss of power. Yellowing is primarily a biological process in which timing is very important. During yellowing, tobacco will tolerate less deviation from recommended wet-bulb and dry-bulb temperatures than later in the cure. Tobacco leaves are alive when harvested and remain alive in the barn until near the end of yellowing. During this time the tobacco, like all living tissue, is respiring: using oxygen; burning sugars and starches; and giving off water vapor, carbon dioxide, and heat. Without the circulation of air to prevent the buildup of heat, the temperature of the tobacco can increase to 140°F or more in an hour or so, resulting in widespread scald. Unlike yellowing, leaf and stem drying are primarily physical processes. During this time, biological activity ceases, little or no heat is produced, and the tobacco can tolerate a much longer interruption of power without apparent damage. The damage that is likely to occur will be from the wicking of moisture back into the leaves from the still-moist stems. This condition, known as “run back” or “vein darkening,” will occur more rapidly at early stem drying than later in the cure. A cure that is within 18 to 24 hours of completion may be able to tolerate several days without power with little apparent damage.

Both the timing and duration of power outages are unpredictable. The unusual circumstances of two hurricanes during the height of the 1996 harvest season forced many growers to hastily consider a standby power source. Many growers were able to obtain this equipment on short notice. Most were successful and saved a large portion of their crop, whereas some others were not. When failures with standby power equipment occurred, it was usually the result of improper selection, installation, or use.

Alternator Selection

Although commonly referred to as “generators,” the devices used for standby electrical power service are actually “alternators.” By definition, generators produce direct current (dc) while alternators produce alternating current (ac). Standby alternators are manufactured in many different capacities and may be either tractor- or engine-driven. Large, engine-driven alternators are often referred to as “gen-sets.”

Alternators are rated by their power output, measured either in watts or kilowatts (kW). Most alternators are rated in kilowatts, (A kilowatt is 1,000 watts.) The standard rating is usually given on the alternator’s nameplate but may not be its maximum output. Some alternators have substantial overload capacity, although this additional capacity is always limited to short periods of operation. When two ratings are given on the nameplate (for example: 10,000/5,000), the larger number is the overload rating and the smaller number is the continuous- run rating.

When selecting an alternator, carefully consider *both* the run capacity and the overload capacity. Some large alternators may be rated in kilovolt-amperes (kva) or volt-amperes (va). Their approximate power output in kilowatts may be determined by multiplying the kva rating by 0.8.

The engine or tractor used to power the alternator should be capable of developing about 2.3 horsepower for each kilowatt of power produced. Only 2 horsepower per kW may be required for alternators larger than 75 kW. It is important that the engine or tractor selected be capable of prolonged operation at high output. The engine should also be capable of maintaining a very constant speed over a wide range of load conditions. For this reason, either a mechanical or electronic speed control (governor) is normally required.

Almost all electrical power used on farms is either 120- or 240-volt, single-phase, 60 hertz (cycles per second). In a very few cases, some bulk barn fans and other equipment may be designed to operate on three-phase power. If properly connected, three-phase alternators may be used to power single-phase equipment, but three-phase equipment CANNOT be operated with single-phase power without expensive phase conversion equipment. The alternator selected MUST be able to produce power at the same voltage and frequency required by the equipment. Most large alternators and many small ones are equipped with frequency, voltage, and current meters. These are necessary to ensure the production of power at the correct specifications. The voltage should register at least 230 volts for a 240-volt service or 115 volts for a 120-volt service. Frequency should never be less than 57 hertz nor greater than 63 hertz. Deviations from these ranges can destroy the alternator and the motors.

Sizing the Alternator

The capacity of alternator required depends primarily on two factors. The first factor is the size and nature of the load. Electrical loads are of two types: inductive and resistive. The prime example of an inductive load is an electric motor. Electric motors customarily require three to four times as much power to start as they need to run under full load. The larger starting loads of electric motors *must* be taken into consideration when calculating the total electrical load. The starting and full-load running power requirements for various single phase motors is listed in table 5 below. Resistive loads, such as lights and electric heaters on the other hand, draw the same power to start as to run.

The second factor to consider is whether all or only part of the equipment will be operated at the same time. Alternators and electric motors are designed to operate at a certain voltage and

Motor hp	Amps @ 240 Volts	kW to Start	kW to Run
1/2	5	2.3	0.6
3/4	7	3.4	0.8
1	8	4.0	1.0
1 1/2	10	6.0	1.5
2	12	8.0	2.0
3	17	12	3.0
5	28	18	4.5
7 1/2	40	28	7.0
10	50	36	9.0

Table 5.

Starting and Full-Load Running Power Requirements for Various Sizes of Single-Phase Electric Motors.

frequency. Even small deviations from these ratings for short periods because of overload will reduce service life. Large deviations (20 percent or more) can quickly cause severe heating of the windings and destroy the equipment. The total required alternator capacity may be substantially reduced if part of the load may be switched off temporarily. Situations where motors start automatically are particularly problematic because, sooner or later, several motors starting at the same time will place a huge overload on a system. Taking steps to prevent simultaneous starting of motors can reduce the required capacity and prevent overload.

Transfer Switch

The National Electrical Code, the power companies, and good sense require that any standby alternator be connected to the load through a transfer switch. This piece of equipment is essentially a double-throw switch that prevents the accidental connection of the alternator and the power company to the load at the same time. The switch is designed so that either the alternator or the power grid is connected to the equipment but never both. Unless a transfer switch is used, power could be fed back onto the power line from the alternator, endangering those working on the lines. In addition, the alternator would be destroyed if the power grid were re-energized while the alternator was connected to the load. The switch must be rated to carry the highest potential current. Common sizes are 100, 200, and 400 amps.

Wiring

The wiring of standby alternators, even when temporary, should always comply with the National Electric Code and be installed by a licensed electrician. Alternators should be well-grounded and positioned as close as practical to the loads to reduce the length of wire runs. Every effort should be made to protect the lines from mechanical damage. Wire should be run over- head if at all possible. Where this is not possible, the lines should be buried. There is no wire designed to withstand being driven over repeatedly by trucks and tractors.

Follow this sequence when starting a standby power unit.

1. Call your power company and report the outage.
2. Turn off or disconnect all electrical equipment.
3. Assuming the alternator was previously wired into place through an approved transfer switch, start and bring the unit up to operating speed. Check the frequency and voltage meters for correct readings.
4. Put the transfer switch into the standby power position.
5. Switch on the electric loads one by one. Start with the largest electric motors first. Add each motor only after the previous one has reached its full operating speed.
6. Check the frequency and voltage meters often to ensure they are still within limits. The minimum operation voltage for 240-volt service is 200 volts and for 120-volt service is 100 volts.
7. When regular power is restored, disconnect or switch off each load in turn. Move the transfer switch back to its normal position. Reconnect or switch on each load.

Calculations and questions

What is the largest alternator that may be powered by a tractor the produces 92 pto horsepower?

92 / 2.3 = 40kW

What size alternator is required to power eight bulk barns, each with a 5 horsepower fan motor?

From the table, a 5 horsepower motor requires 4.5 kW to run but 18 kW to start. If each motor is started in sequence, then the last motor will be started while the first four are already running.

Then: (7 X 4.5) + 18 = 49.5 kW required.

What can be done if your alternator does not have sufficient capacity to operate all your barns?

It is possible to switch the power between barns manually often enough to prevent the tobacco from being ruined. Those barns at the early stages of the cure may require a nearly constant supply of power, whereas those in the later stages may be maintained by as little as one hour every three or four hours.

When is the best time to purchase and install a standby power system?

Before you need it.