Equipment should be serviced and checked to ensure trouble free and efficient operation.

HARVESTERS

All harvester systems and parts should be checked for proper operation. The engine, power train, hydraulic system, tires, etc. should be serviced and checked. Check the condition and tension of drive belts and chains and replace if needed. All adjustment mechanisms should operate freely so that adjustments can be made rapidly and easily in the field.

CURING BARN

The bulk curing barn should have a complete inspection before it is put into heavy use. The fan, thermostat and electrical controls should be cleaned. The capillary tube on thermostats should be checked for kinks and/or breaks. The wicks on wet bulb thermostats should be replaced and reservoirs checked. Belts, bearings and shafts should be checked and replaced if needed. Burner components should be inspected and cleaned and/or replaced if necessary. Check the heat exchangers for cracks and leaks.

Examine these few points to make the coming curing season a fuel efficient one.

LOADING DOORS

Loading doors should be hung such that they will seal the entire opening. Gaskets around the door should be in good condition. Torn or frayed gaskets should be replaced. A good substitute material is thick piled carpet. This material can be easily obtained and installed to seal the loading doors. Water hoses will not withstand the high air temperatures and should not be used.

FOUNDATION

The foundation of bulk curing barns should be sealed with an asphalt sealant. This material will expand and contract as the barn heats up and cools during the curing season. A small crack between foundation and pad area can waste more money in energy loss than the small cost of sealing.

CURING CHAMBER AND FURNACE ROOM AREAS

These areas should be examined closely. Look for small and large cracks. They should be sealed with a butyl caulk or a caulking material that can withstand 180°F air temperatures and remain flexible. One way of detecting air leaks is to go into the barn, close the door and look for daylight. These will be the areas to caulk.

INSULATION

Research has proven that insulating the bulk curing barn will save dollars. Payback for insulating ranges from 1 to 3 curing seasons depending on type of insulation used and area insulated. Utilize an insulating material that will not absorb moisture. This is a key factor since during curing humidity levels reach 100%. If the insulation absorbs moisture, the effectiveness of the insulation will be drastically reduced. Use insulation with an R-Value of 3 or more.
HARVESTING AND CURING

Uniformly ripe tobacco is essential to have top quality leaf for sale. Under normal conditions flue-cured tobacco ripens 2 to 4 leaves per week, therefore a harvest rate of 2 to 4 leaves per plant per week for 5 to 7 weeks is required.

Leaf purchasers have requested that tobacco be cured and sold by stalk position. This can be accomplished by a minimum of 5 harvest/cure cycles. Harvest leaves as follows 1) crop the bottom 2 to 3 leaves called primings, 2) harvest the next 3 to 4 leaves denoted by lugs, 3) gather the next 5 to 6 leaves labeled cutters, 4) crop the next 5 to 6 leaves characterized as leaf and 5) harvest the top 4 to 5 leaves designated as tips. Figure 1 shows a graphic of stalk position.

Tobacco can be harvested by hand or machine. Hand harvesting causes less damage to the tobacco and there is less foreign material (such as sand and sucker) in the cured tobacco. Machine harvest can be accomplished by using defoliators (multiple harvest during the season) and cutter bars (last over or harvest last two stalk positions the same day).

Several factors can influence the maturity and harvest rate. Tobacco grown with recommended fertilizer requirements will tend to ripen normally and produce sufficient pounds. Because of the dirt and closeness to the soil it is recommended that sand lugs (first 2-3 leaves to ripen) not be harvested using machines. Lower stalk tobacco contains more moisture on a percentage basis than the upper stalk tobacco. Therefore, the primings should be harvested when the leaf is dry. Timely harvest is essential to obtain a quality leaf for market. Harvest primings when the leaves appear to be the same color as those of field peas. Another indicator of ripeness is to hold the leaf up in sunlight and visually look for uniform color (pale green) throughout the leaf.

Figure 1. Flue Cured Stalk Positions

HARVEST ONLY MATURE, RIPE LEAVES

Tobacco leaves reach full maturity a few days before ripening. Mature leaves exhibit a slight yellowing and puckering between veins and break off the stalk easier than immature leaves. Fully mature leaves cure easily, and the quality, color, and weight are usually good. The best quality cures occur when the tobacco is allowed to mature in the field. The stages of maturity are premature, mature, ripe, and overripe. Tobacco harvested in the ripe stage may be cured to give better color, quality and weight than tobacco harvested in the overripe stage. Overripe tobacco does not color, yield, or sell as well as tobacco harvested and cured at proper maturation. You should let the tobacco mature and ripen, but not become too ripe before removing leaves from the stalk.

WHEN TO HARVEST

Care should be taken when harvesting drought stressed tobacco. The middle and butts of the tobacco
leaf will appear to be ripe according to color. But actually, the leaf has not fully matured. Let the leaves
stay in the field rather than trying to color them in the barn. But if this type of tobacco is harvested
remember to maintain moisture levels in the curing barn high and keep dry bulb temperatures just above
(3-5°F) outside temperatures. Once the leaf has yellowed then raise temperature fast enough to fix color
and start drying the leaf.

CONTAINER LOADING

Since the introduction of the bulk curing barns, there have been problems with properly loading the bulk
containers. It is difficult to get laborers to load containers uniformly, including racks, big boxes, or
medium-sized boxes. When packing containers, make sure there are no air tunnels or packed lumps of
tobacco. Spread tobacco evenly over the entire container as it is being filled. Lumps or wads of tobacco
cause tight spots and the tobacco will not cure properly. Fill the corners and edges of bulk containers
first and pack slightly more then the center. Unless there is uniform airflow to all leaves in the container,
there will be leaves or pockets of leaves that do not cure.

The type and condition of the tobacco determines to a large extent how tight the tobacco can be packed
in bulk containers. Primings and lugs, if harvested, should not be packed at all. Just enough tobacco to
fill the containers will result in the best cures.

Good quality, upper stalk, dry tobacco can be packed to a density of 15 lb/cu. ft. and get good results.
Remember that the density of tobacco may increase from morning to afternoon. Tobacco is usually
turgid (swollen with moisture) in the morning, but it may be completely wilted in the afternoon. Do not
pack wilted tobacco as tightly as turgid tobacco. Containers should fit snugly together so air does not
pass between them. A board or other materials should be used to block air movement between the doors
and the outside container.
GUIDE FOR BULK CURING

Curing develops and preserves the potential quality, flavor and aroma of tobacco. Once the tobacco is in the curing barn, a concerted effort to bring the tobacco to a brilliant color (lemon orange) should be made. Once the desired color is achieved, dry out the leaf to preserve that color. Color is important. It indicates the degree of chemical changes that have taken place, and is used as an index of leaf quality. It is estimated that 75 percent of the market value of the leaf is based on the color.

Closely monitor tobacco throughout the curing process to check on temperature, humidity, and condition of tobacco. Look through observation ports at periodic intervals to check the wet-bulb, dry-bulb thermometer and the color changes taking place. Place the wet-bulb, dry-bulb thermometer under the tobacco near an observation port so it will not be necessary to open the doors.

I. START UP:

Close air intake dampers before heater is turned on. Turn heater on and raise temperature to yellowing range gradually. Temperature should not be raised more than 5°F at any one jump. Allow about 30 minutes between temperature rises to provide time for curing air to become humid. If tobacco has free moisture on the leaves at harvest, operate the fan for 12 to 24 hours with vent open to dry the surface before the heater is turned on.

II. YELLOWING:

Yellow at a dry-bulb temperature of 95° to 105°F and wet-bulb of 93° to 97°F. To maintain high humidity and prevent color setting before it is desired, dampers should be almost closed. Maximum drying short of color setting is desirable; however, for fuel economy and for the best cure. Dampers should, therefore be "cracked" open to the maximum extent short of color setting, especially when using boxes. Venting or moisture removal during yellowing will aid air movement through the boxes during leaf drying. Tobacco that is sappy or high in moisture requires considerably more moisture removal before color setting than does drought or low moisture tobacco.

III. WILTING:

Some wilting occurs before the end of yellowing at the 105°F dry-bulb temperature, but most of the wilting should take place as the dry-bulb temperature advances from 110° to 118°F. The rate of temperature advance from 105° to 110°F should be 1° to 1.5°F per hour and wet-bulb of 100°F. During the wilting phase, the tobacco loosens considerably and the air can move through readily. Do not advance the temperature beyond 118°F dry-bulb temperature until wilting is 100 percent complete.

IV. LEAF DRYING:

Raise dry bulb temperature 2° per hour to 135°F. Leaf drying is the most critical period of the cure. Time is required for moisture removal to keep up with temperature increases. If tobacco gets too hot, water scalding or sweating will occur.

Ventilation of outside air into the barn should increase during this stage of curing to maintain proper wet-bulb temperature. When the curing temperature is raised above 118°F, the dampers should be open enough to hold wet-bulb down to 100°F. The more the dampers are opened, the lower will be the wet-bulb temperature. Keep dampers open enough to hold wet-bulb temperature of 100° to 105°F throughout leaf drying (100°F for the first 24 hours and 105°F for the final stages). For diseased or extra thin tobacco, a lower wet bulb (90° to 100°F) may produce a brighter cure.
Wet-bulb temperature is the same as the leaf temperature until the leaf has dried. The leaf cell breaks down and browning or scalding occurs at a leaf temperature of 113°F. Thus, the wet-bulb temperature should never be allowed to exceed 110°F until the leaf lamina is completely dry.

V. STEM DRYING:

Raise temperature gradually for stem drying. After leaf is essentially dry, temperature should be raised gradually (2° to 3°F per hour) to 165°F for stem drying without sponging or scalding.

Close dampers gradually during stem drying. Maintain damper opening sufficient to hold wet-bulb temperature down to 110°F during the first 12 to 18 hours of stem drying. Dampers are usually closed completely about the time the leaf is completely dry and the temperature has reached 165°F.

Do not exceed 165°F during stem drying. Sugars caramelize and leaves turn red at excessively high temperatures. The following temperature schedule (dry-bulb, wet-bulb) should prove effective with normal, good quality tobacco. The time can change according to the condition of the tobacco when it begins the cure. Factors which affect time required for curing in certain phases are maturity of tobacco, stalk position of the leaf, the use of ripening agents and weather condition at harvest.

![Bulk Curing Schedule for Mature, Ripe Tobacco](image-url)

Fig. 1. Bulk Curing Schedule for Mature, Ripe Tobacco
DEVIATIONS IN CURED TOBACCO

IMMATURE AND SLICK

Immature, slick tobaccos are described by the trade as lacking in grain and other elements of quality. The surface of the leaf is smooth - does not have the desirable crepe-like texture, and the leaf is papery, with little or no elasticity or oiliness. Such tobaccos lack richness of color, are deficient in aroma, and have a flat undesirable taste. They may be compared with fruits that have been harvested green and allowed to ripen in storage - the "field-ripened" flavor is not there. This condition is associated with such factors as (1) improper fertilization, (2) close spacing or too high topping, with attendant shading and greater competition for plant food, water and sunlight, and (3) excess rainfall or over-irrigation, which leaches out the fertilizer and upsets normal growth processes. These conditions often cause yellowing before ripening, and harvesting of immature leaf. Varieties differ in their tendency to produce tobacco of this type.

GREEN

Green color in the cured leaf results from a failure to break down all the chlorophyll during the curing process. There are several causes of green tobacco:

(1) Harvesting the leaves before they are ripe, as when too many leaves are pulled at once. Tobacco leaves sometimes acquire a faded-out yellow color, suggesting ripeness, which is not true ripeness.

(2) Severe drought conditions, which prevent ripening. Leaves that are harvested under such conditions will generally cure with a greenish cast.

(3) Excessive nitrogen supply, which prevents proper ripening. Tobacco grown with too much available nitrogen will cure out green or brown.

(4) Insufficient yellowing of the leaves before drying.

There are other deficiencies associated with the green color, and such tobacco has a harsh, bitter taste. Lighter shades of green will improve on aging, but pronounced green grades are most undesirable.

SPONGED

The term "sponged" is used to designate those well-grained, porous, overripe tobaccos of a dull, grayish-brown color. This type of cured leaf is caused by allowing tobacco of good quality to become overripe in the field, or by holding low temperatures too long in the early part of the curing process. If the moisture in the leaves is not removed fast enough, sponging is likely to take place - resulting in grayish and brownish blotches on the leaf surface. In normal curing, the color breakdown proceeds from green to yellow. By drying, the color may be fixed at either of these stages. In the case of sponging, the color breakdown has gone beyond the yellow stage to the gray or brown stage. Color, alone, is not the basis for designating tobaccos as sponged - some brown tobaccos may be slick, dead, "toady," or otherwise very undesirable. Slight sponging may not result in serious detriment to quality.

TOADY

The toad is considered by many to be one of nature's ugliest creations. Evidently, men of the tobacco trade had this animal in mind when they selected the term "toady" to describe a very undesirable type of cured leaf. Such tobaccos are characterized by a slick, dense, sometimes thick and leathery, leaf of a nondescript smutty, grayish-brown color. Toady leaves have no grain and are very compact. They are
abnormally high in sugar content. They are usually soggy, but may be dry-natured and starching. The cause of toadiness is not fully understood. However, certain varieties tend to produce higher proportions of this type of leaf than others. It has also been observed that in seasons of high rainfall or following over-irrigation, some toady tobacco may be found in all varieties. The practice of overcrowding curing barns, which prevents rapid drying, seems to favor the development of this condition in tobaccos that have the tendency toward toadiness.

MOISTURE RUN BACK

The presence of dark or reddish areas along the upper portions of the leaf midrib and larger lateral veins is known as "moisture run back" or "circle stem". It is caused by lowering the temperature after the blade of the leaf is dry, but before all moisture has been removed from the midrib. The moisture in the midrib seeps back into the leaf, causing a dark area. Refiring and drying the midrib will not remove the discoloration, but will put the tobacco in safe keeping condition. Run back will not occur if the curing unit is fired continuously until the entire leaf is dry.

BARN SCALD

Dark, chocolate-colored areas on cured leaves, or brown scald, may result from excessive humidity in the curing barn. This condition is usually caused by over-crowding in the barn and inadequate ventilation. The leaves are cooked, rather than dried, when the temperature is raised. Brown scald will also occur in properly loaded barns if killing heat is applied before drying is complete. A set green color, or green scald, may develop in the leaf tips if flash heat occurs before the tobacco is yellowed.

SWELLED STEM

After colors have been developed and the leaf partially dried, at low temperatures ranging from 130 to 145°F, the remaining moisture is removed at "killing out" temperatures of approximately 170°F. Failure to remove all moisture from the midrib leaves it soft, pliable and larger than when dry. Temperature may be too low or held too briefly. Such incompletely-dried midribs are called "swelled stems or "not killed out". Swelled stems usually mold in storage and may be the cause of considerable loss through damage to the surrounding tobacco.

ENERGY EFFICIENT CURING PRACTICES

1) Stop hot air leaks - check door gaskets and structure for cracks. Strips of thick pile carpet can be used.

2) Ventilate only enough to hold humidity down - the wider the vent opening, the more fuel is required. Utilize a wet-bulb thermometer to monitor humidity in the barn.

3) Tune up the fuel burner - periodic maintenance and adjustment is required for efficient operation.

4) Harvest only ripe tobacco - shorter curing time mean less heat loss and more efficient curing. Let tobacco ripen in the field. Do not try to color green, immature tobacco in the barn.

5) Load racks and boxes uniformly - uniform loading with no "tight spots or loose spots" assures even drying and less energy usage.
6) Assure an air seal round each rack or box - a small crack between boxes or racks reduces ventilation efficiency to large degree. Make sure all the air goes through tobacco not around the ends. Utilize boards wrapped with burlap sheets.

7) Add insulation - well-insulated walls, roof and floor can save 10-20 percent of fuel consumed per cure.

8) Use a Curing Guide - "Guide for Bulk Curing Tobacco" can be obtained at the County Extension Office. Each tobacco barn should have one (11"x17") poster near the control box.

ORDERING TOBACCO

Paul E. Sumner

When curing is over and the stems have been killed, the moisture content of the leaves is near zero. At this stage, the leaves and stems are too brittle to handle, so enough moisture must be added to the leaf to bring the moisture content up to about 15 percent. The leaves are then pliable and can be easily handled.

The best way to add moisture back into tobacco is when the temperature of the leaf is high (165°F). The furnace is turned off and a hollow cone spray nozzle operating at 100 psi, if possible, is inserted into the air stream around the furnace. A cured barn of tobacco can be made easy to handle in one to two hours. Table 1 lists different types of hollow cone nozzles and hours of operation to add moisture to cured tobacco.

<table>
<thead>
<tr>
<th>Nozzle Type</th>
<th>Pressure (PSI)</th>
<th>2 hrs</th>
<th>4 hrs</th>
<th>6 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX-3</td>
<td>40</td>
<td>8</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>TX-4</td>
<td>40</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>TX-6</td>
<td>40</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D1-13</td>
<td>40</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D3-13</td>
<td>40</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D1-23</td>
<td>40</td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D2-23</td>
<td>40</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TX-3</td>
<td>100</td>
<td>6</td>
<td>3</td>
<td>2</td>
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<td>TX-4</td>
<td>100</td>
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<td>TX-6</td>
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<td>D1-13</td>
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<td>D2-13</td>
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<td>D1-23</td>
<td>100</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

The rate at which to add moisture to the leaf depends mainly on the method selected to add moisture to the barn and on the condition of the tobacco itself. A barn of 3,000 pounds cured tobacco requires about 50 gallons of water to bring the leaf into order. Running the fan with the dampers wide open usually brings the tobacco in order overnight. There are many spray-injection systems that can bring a barn of tobacco in order in a few hours. If there is a floor in the curing barn, water can be poured onto the floor.
No matter which method is selected, do not apply the water directly to the leaf or to the heat exchanger/furnace. Putting water on a hot heat exchanger can cause cracking. Water on a mild steel heat exchanger can cause rusting. The ordering method to use depends on the equipment available and how quickly you need to get the tobacco in order. The use of high pressure (2,000 psi) mist systems and steam are both being evaluated for their usefulness in this process.

RETROFITTING TOBACCO CURING BARNs

Paul E. Sumner, Grant Ellington (NCSU) and J. Michael Moore

Recent research has shown that a class of carcinogenic (cancer-causing) compounds known as tobacco specific nitrosamines (TSNAs) may be formed in flue-cured tobacco leaves during the curing process. These compounds are not found in green (uncured) tobacco. Present research suggests that TSNAs are formed through a chemical reaction between nicotine and other compounds contained in the uncured leaf and various oxides of nitrogen (NOx) found in all combustion gases, regardless of the fuel used. Eliminating NOx compounds in the curing air by using a heat exchanger system has been shown capable of reducing TSNAs to undetectable levels in cured tobacco. The direct-fire curing systems currently in use in most U.S. curing barns are considered to be the major factor contributing to elevated levels of TSNAs in U.S. flue-cured tobacco. Further, there is no known fuel treatment or burner design that can eliminate these nitrogen compounds from combustion gases without the use of a heat exchanger (found in all indirect-fired systems). It is believed that reducing the levels of TSNAs in tobacco products would reduce some of the health concerns associated with tobacco use. An indirect-fired system passes the combustion gases through a heat exchanger and out of the barn, thereby preventing the mixing of flue gases with curing air. Systems with the combustion entirely outside the barn and that conduct the heat to the barn with hot water or steam have proven entirely satisfactory for reducing TSNAs and are acceptable. Research during the 2000 curing season has shown that converting from direct- to indirect-fired curing can reduce levels of TSNAs in cured leaf to below detectable levels (less than 0.1 part per million).

OLDER BARNs

Most bulk curing barns built before the mid-1970s were indirect-fired. They had a heat exchanger and flue that directed the combustion gases out of the barn (fuel oil burners). A number of these barns are still in use. Some tobacco samples taken from these older indirect-fired barns during the 2000 curing season were found to have very low to undetectable levels of TSNAs. This does not mean that all older heat exchanger barns will produce satisfactory tobacco. Some samples taken from other older indirect-fired barns were found to have TSNA levels approaching those found in direct-fired barns. This suggests that the heat exchangers and flues in these barns may have cracks or holes that allow combustion gases to escape into the barn. This is unacceptable. Growers planning to use older heat exchanger barns should closely inspect them for leaks by using smoke bombs or lights. Your oil or gas dealership representative may be able to help you with this inspection. It is necessary to completely replace the heat exchanger and/or the burners if the old ones are no longer in good working order or cannot be repaired.

MAKING YOUR OWN RETROFIT

After evaluating the design, price, and availability of commercial retrofits, some growers built their own or contracted with a local fabrication shop to build units for them. All of these homemade units tested so far have proven satisfactory in lowering the levels of TSNAs in the cured leaf. Additionally, many are relatively efficient in terms of fuel use and apparently have good airflow characteristics. Unfortunately some homemade units have proven uneconomical due to a less than adequate heat exchange area. Stack
temperatures (the temperature of the flue gases at a point just as they exit the heat exchanger) have exceeded 1000°F in some cases, allowing most of the heat to escape the barn. Other homemade units have experienced warping and cracking where poor design or material selection did not allow for thermal expansion during firing. If you build your own, be sure to use a design and materials proven reliable in the severe thermal cycling conditions of a curing barn.

CONSIDERATIONS FOR SELECTING THE RIGHT RETROFIT FOR YOUR BARNs

With the many different retrofit designs on the market and the limited time available to make a decision, choosing the best one for your particular situation may be difficult. Further, some companies that contract directly with growers to purchase their tobacco may specify which barn and/or burner system must be used. Other buying companies have stated that they have no preference as long as the system substantially reduces the levels of TSNAs in the tobacco and otherwise complies with the specifications and recommendations of the Tobacco Leadership Group. In either case, growers who anticipate contracting, now or in the future, should ask potential buyers about any such specifications.

Experience during the 2000 - 2001 curing season has shown that the place to start looking for a suitable retrofit is with the manufacturer of your barns. This company should have more detailed information on the heat and airflow characteristics required to give a satisfactory cure with your equipment. This has not always been possible, however, since some barn manufacturers are no longer in business or are not offering retrofits at this time. If you find yourself in this situation, you may want to closely review the following points.

FUEL TYPE

LP (liquified petroleum) gas is a by-product of the natural gas industry and consists primarily of propane and butane. It contains approximately 90,500 Btu per gallon. Fuel oil contains approximately 138,000 Btu per gallon. A gallon of fuel oil contains about one and one half times as much energy as a gallon of LP gas. The cost per gallon of both LP and fuel oil fluctuates from season to season and year to year. Because they may be freely substituted in many applications, they do, however, tend to track each other and cost about the same most of the time. Locally, you may be able to find LP gas cheaper than fuel oil (on a cost-per-Btu basis) this year, but next year may be the opposite. The best prices for either type of fuel are to be had by contract buying in bulk lots.

HEAT EXCHANGER COMPOSITION

Commercial heat exchangers for curing barns are presently made of carbon steel, aluminum-coated carbon steel (aluminized steel), one of several grades of stainless steel, or a combination of materials. There are potential benefits and liabilities associated with each. Stainless steel is more resistant to rust and corrosion than carbon steel, so it is less likely to rust or burn out during the expected life of the barn. However, the heat transfer of stainless steel is only about 25 percent that of carbon steel of the same thickness. To compensate for lower heat transfer, a stainless steel heat exchanger would have to be made of thinner material and/or have a greater surface area than one made of carbon steel. On the other hand, a carbon steel heat exchanger could be twice as thick as a stainless steel heat exchanger of the same design and still have better heat transfer characteristics.

A heat exchanger in a bulk curing barn may experience several thousand heating/cooling cycles during a six- or seven-day cure. All metals expand and contract upon heating and cooling, but stainless steel expands and contracts twice as much as carbon steel. Thermal cycling was the prime cause of failure experienced with some stainless steel heat exchangers during the 2000 curing season. No crack failures have been reported with carbon steel heat exchangers. Cracks defeat the purpose of a heat exchanger.
because they allow combustion gases to enter the curing barn and contact the tobacco. Before you select a heat exchanger, be sure to closely question the manufacturer concerning thermal cycling and any report of cracks. Some tobacco samples taken from indirect-fired barns during the 2000 curing season had elevated levels of TSNAs traced to cracked heat exchangers. Use the same method described above for testing older heat exchanger barns if you suspect a cracked new heat exchanger.

AIRFLOW

Any heat exchanger will produce some resistance and therefore reduce airflow through the barn to some extent. While most manufacturers have been careful to avoid designs and installations that restrict airflow, the minimal 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, these problems may be more likely after retrofitting. There are only two remedies for poor airflow. The easiest remedy may be to reduce air resistance by reducing the amount of tobacco in the barn. Often even a 5 or 10 percent reduction can have a big effect on the airflow. The other remedy is to increase the airflow. 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 fan angle will increase the horsepower and hence 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 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. 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 TSNAs in the cured tobacco and completely negates the effects of retrofitting.

Experience with retrofitted barns during the 2000 - 2001 curing season has shown that vent settings may need to be altered to maintain the proper wet-bulb temperature. Although a few growers reported that the same or slightly less vent opening was required during leaf drying, many needed somewhat more opening to compensate for the air resistance of the heat exchanger. After a cure or two, most growers were comfortable with the new vent settings and pleased with the results. The use of wet-bulb thermometers and curing charts are helpful in determining the optimum vent openings at various stages of the cure.

HEATING SYSTEM EFFICIENCY

The barn heating system consists of a burner and a heat exchanger. The direct-fired gas and oil burners used in curing barns before the retrofit project are very efficient because all the heat produced mixes freely with the curing air. There is no heat exchanger to direct the products of combustion along with some lost portion of the heat out of the barn. Since some heat loss is unavoidable with a heat exchanger, it is very important to gain as much efficiency as possible to control fuel costs. Energy efficiency, by definition, is the percentage of total energy inputted into the system that is put to practical use. In a burner/heat exchanger system, efficiency is complicated by the combination of many interrelated factors.

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 portion 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 one or two percent.
The 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 smoke. The smoke being partially unburned fuel. 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 considerably reduce heat exchanger efficiency. 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 be best achieved with a combustion analyzer. Combustion analyzers range in price from $500 to $5,000, are quick and easy to use, and can save a grower hundreds to thousands of dollars per year in wasted fuel. Some fuel dealers and retrofit manufacturers have these instruments for use in adjusting the burners of retrofitted barns. In addition, your local Cooperative Extension agent has access to combustion analyzers and can test your barns at no cost.

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 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 (Btu/hr) by the burner greatly influences the efficiency of a particular heat exchanger. A burner operating at a high capacity can easily overwhelm a modest heat exchanger designed for a smaller burner. 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 early part of leaf drying (barn temperature between 125°F and 135°F) is the part of the cure when the barn requires the most heat. 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 minutes is probably operating at too high Btu/hr setting and inefficiently overwhelming the heat exchanger. Further, in the short time the burner is operating, the heat exchanger may be getting too hot, inducing severe thermal stresses in the metal and ultimately shortening its life.

CURING EFFICIENCY

While heating system efficiency is the combined efficiency of the burner and heat exchanger, curing efficiency takes into consideration the entire process of tobacco curing. In essence, barn 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). 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 (Btu/hr) to the curing barn as was delivered by a direct-fired system will necessarily require more fuel. In fact, many growers have reported using slightly more fuel. Others, however, reported no increase in fuel use or even that their retrofitted barns used less fuel. There are several possible explanations, with the most likely being that many of the direct-fired burners needed maintenance and adjustments.

One of the quickest and easiest ways to check the efficiency of a burner and heat exchanger is to measure the temperature of the flue gases. To get an accurate reading, you can make a small hole (about 5/16-inch) in the flue at a point just as it comes from the heat exchanger. This opening may be conveniently plugged after the test with a short 3/8-inch bolt. Because the hot flue gases quickly cool as they pass up the stack, taking the temperature at the top will give an erroneously low temperature. Likewise, simply measuring the temperature of the metal flue itself will yield a temperature much lower than that of the flue gases. With the barn warmed to a moderate temperature (140°F) and the Btu/hr output of the burner adjusted so that it can complete the cure in a reasonable time, the ideal stack temperature for LP should be 350°F to 400°F. If you measure the stack temperature before the barn warms up or if the Btu/hr output of the burner is adjusted too low, the reading may be in error.

**CAREFUL INSTALLATION IS IMPORTANT**

Not all retrofits will properly fit all barns. Proper selection, planning, and installation should reduce the probability of poor airflow and of too little or too much heat, as well as the possibility of explosions and barn fires. Some heat exchanger surfaces may exceed 1200°F, but wood ignites at approximately 450°F. It is very important to make sure that all wood is a safe distance from heated metal surfaces.

There was a significant increase in barn fires in 2001. These fires could have been caused by improper installation of the heat exchangers. Inspect your units of any metal surfaces coming in close contact to wood. If you suspect a problem, replace a wooden member with a steel one would be a simple effective solution. Check for any construction debris or materials used during installation that may have been left in the barn. Vent pipes should be extended a minimum of 2 feet above the highest point of the structure. Single wall vent pipe should have a minimum of 18 inches clearance of any wooden material. Double wall vent pipe can have a 3 inch clearance.

Since the purpose of indirect-fired curing systems is to prevent contact of combustion gases with the tobacco in the barn, do not allow exhaust fumes from burners, boilers, tractors, and other equipment to enter the curing chamber. When the intake vents are open, the barn fan can pull the exhaust fumes into the barn and possibly result in increased TSNA levels. Because these exhaust gases have mixed with outside air, the effect on TSNA levels would not be as great as would be expected with direct-fired burners. Nevertheless, this source could be eliminated or reduced by using smokestacks or flues that release the gases well above the barn roof, and by not allowing tractors or other equipment to operate for extended periods near the intake vents of the barn.

**CURING PROBLEMS**

Indirect-fired barns have a drier heat and in some cases less airflow. This has caused frustration during curing. The drier heat results in lower moisture levels within the barn for the same vent settings. A wet-bulb thermometer can be used to monitor the moisture levels within the curing barn. By following a suggested curing schedule such as the one included above and comparing the dry bulb temperature to that of the wet-bulb vent settings may be adjusted appropriately during the cure, especially during yellowing and leaf drying.
You can buy wet-bulb thermometers at most fuel supply dealers, or you can make one at a fraction of the cost. A homemade wet-bulb thermometer designed especially for bulk tobacco barns can be used. Details for construction and a photograph of the homemade wet-bulb thermometer are available at http://www.caes.uga.edu/commodities/fieldcrops/tobacco/

DETECTING HEAT EXchanger Leaks

Nitrosamines in the cured leaf became an issue for growers in late 1999. Since that date all of the flue-cured bulk tobacco barns being used have been updated with indirect fired curing units. These units were built by major tobacco barn manufacturers and local metal shops. The life of these units depends on the metal used and quality of construction.

Two full harvest and curing seasons has past for the retrofitted bulk barns. Tobacco companies have been sampling the cured leaf for nitrosamine levels in the cured leaf. Nitrosamine levels in cured leaf have been greatly reduced. But, there have been cases where high nitrosamine levels were found and the growers were notified of the problem. Some reasons for high nitrosamine levels still being detected in cured leaf are as follows:

1. The flue gas exit point is less than 2 feet above the highest point of the barn. Growers should make sure that flue gases are not allowed to enter the barn through the air inlet vents during curing.

2. The welds in and on the metal heat exchanger may have separated (cracked). This could be a result of thin metal being used, more than one type of metal used, poor welds, and inappropriate bracing. These heat exchangers experience several thousand heating/cooling cycles during a six- or seven-day cure. All metals expand and contract upon heating and cooling.

How Do I Find Cracks?

Use a flash light look at the heat exchanger welds, this may take crawling under the floor and looking down over the furnace area. It will be very hard to examine all of the welds. A better way is use an electronic gas meter to detect carbon dioxide gases (CO₂) being released into the curing air. Recently, North Carolina State University (Grant Ellington) has conducted tests using a commercial gas meter to measure CO₂ in the curing barn. Any CO₂ meter measuring the gas in the range of 0-10,000 ppm can be used. Also, the probe must be placed in the area where the heated air first moves over the furnace. The only requirement is to operate the barn at 120°F for 30-45 minutes. This can be done during the off season. Levels over 1,000 ppm would indicate problems.

If high CO₂ levels or cracks are observed, contact the installer and/or manufacturer of heat exchanger. Under the agreement, they are to repair the unit for three years.