Structural Heat Loss
Influence on Curing Efficiency

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Introduction

Our petroleum fuels are a limited resource and are rapidly being depleted. We can anticipate price increases until the demand decreases. Transportation is the biggest consumer of petroleum fuels and is the dominant force in the market. Tobacco growers must pay the price set by this industry as long as they use petroleum fuel to cure their tobacco.

The Department of Energy (DOE) has established a program to guide us through the transition phase from a petroleum fuel based energy economy to a coal-nuclear-renewable resources based economy. The central element of Phase I of the DOE program is conservation. It is completely appropriate then to consider the role of conservation in tobacco curing. Specifically, this report deals with the reduction of heat lost from the barn during the curing process.

The consumption of fuel for curing will be discussed as gallons of LP gas equivalent per pound of marketed leaf. Fuel oil has 140,000 BTU/gal and LP gas has 91,000 BTU/gal. A gallon of fuel oil has the same energy as 1.54 gallons of LP (GLP). A tobacco cure which used 148 gallons of fuel oil, used 228 gallons of LP gas equivalent. Suppose 2800 pounds of leaf were marketed from this barn, then the ratio is

$$\frac{228}{2800} = 0.08 \text{ GLP/lb marketed leaf.}$$

If the total fuel consumed in an individual barn during a season is divided by the total leaf marketed from that barn, then this ratio is called the seasonal average. Many growers average 0.15 GLP/lb marketed leaf in their barns over the entire season. This relatively high consumption results from:

1. Poor cure management--venting more air than is required to dry tobacco
2. Improper adjustment of burner--direct-fire LP gas burners typically operate in the combustion efficiency range of 85-90 percent, and indirect-fired fuel oil burners typically operate in the combustion range 75-80 percent

3. Poor maintenance of equipment--excessive air leakage resulting from poor sealing of the foundation slab, and leakage around the doors where the gasket material has been torn away
4. Structural heat loss--lack of insulation under the concrete foundation slab, and in the side walls and roof of the barn

Suppose the inlet and exhaust vents on a tobacco curing barn were sealed and the empty barn was operated over a six day period using the same thermostat settings used for a six day cure. The total fuel consumed for this "empty barn" test could be the energy required during the cure to elevate and maintain the temperature of the barn. This energy is a necessary part of curing since the barn has to be warmed when the temperature is raised to dry the tobacco.

Energy to Elevate and Maintain the Temperature of the Barn

The heat required to elevate and maintain the temperature of the barn during a cure is composed of three parts.

1. Conductive heat loss--heat energy lost through the surfaces of the barn
2. Stored heat--heat energy stored in the structural materials in the barn. Consider, for example, the 4-inch concrete foundation slab under the barn. At the beginning of the cure, the temperature of this slab is approximately the same as the ground temperature, $60^{o}F$. At the end of the cure, it has been heated up to $165^{o}F$, the "killing out" temperature in the barn. A certain amount of heat energy is stored in this concrete.
3. Radiant exchange--heat gain during the day resulting from the sun shining in the barn minus the heat loss at night because the barn is warmer than the night air and it radiates heat energy into the atmosphere

In an insulated barn the percentage of the total in each category is:

$$\text{Total} = \begin{matrix}\text{Conductive}\\ \text{Heat Loss}\end{matrix} + \begin{matrix}\text{Stored}\\ \text{Heat}\end{matrix} + \begin{matrix}\text{Radiant}\\ \text{Exchange}\end{matrix}$$

$$100 = 96 + 4 + (0)$$

The conductive heat loss is by far the most significant term. The radiant exchange is negligible by comparison. It turns out that the heat radiated from the barn during the evening hours is almost equal to the heat gained by the barn when the sun shines on it during the day. Most of the stored heat (approximately 92 percent) is in the concrete foundation slab.

Conductive Heat Loss

A test was conducted on a grower's farm in Tift County, Georgia, to determine the benefit of insulation given typical on-farm conditions. Two LP gas meters were installed on two 126 rack barns. One barn was not insulated or modified in any way. The other barn was a new barn with factory installed insulation. It was installed on a concrete foundation slab insulated from the ground with 1.5 inches of polystrene insulation as shown in Figure 1. A description of the insulation and composite thermal resistance for the major sections of the barn is given in Table 1 for both barns.

The temperature in the delivery and return plenums was recorded during 7 cures in 1977 and 8 cures in 1978. Ambient temperature was recorded in a weather station erected at the site. These temperature recordings were used to calculate the conductive heat loss for each section of the barn shown in Figure 2.

The total LP gas consumption was recorded for each cure in each barn. The leaf from each cure was sheeted, tagged, and weighed as the barn was unloaded. This data was used to calculate the GLP/lb marketed leaf ratio for the individual cures and the seasonal average for both barns. This permits a direct comparison of the performance of the two barns under typical on-farm conditions.

Insulation of Foundation Slab

The foundation slab was insulated from the ground as shown in Figure 1. A sheet of solid polyethylene film (3 mil) was placed on the sand and the polystrene board was placed on it. Another sheet of polyethylene film was placed over the board and the edges of the bottom and top sheets were glued together to seal the polystrene board in a water-tight envelope.

A 1.5 thick polystrene board with a thermal resistance R=6 was used. For comparison the thermal resistance of 3.5 inches of fiberglas typically used in the walls for home construction is R=11. The board was sized to allow a 6-inch wide footing to support the foundation frame of the barn. In other words there was a 6-inch wide space between the form and the insulation board around the entire periphery.

The manufacturer of the polystrene board states that the concrete can be poured directly on it without the polyethylene film. Also, some dealers are installing the slabs with the insulation under the entire slab. No provision is made for a footing. It is possible that these procedures can be used satisfactorily.

Results

The calculated conductive heat loss from the various sections of the two barns are given in Table 2. These results are the average gallons of LP gas per cure used to replace conductive heat loss during the 1977 and 1978 seasons. The combustion efficiency was measured on site by the manufacturers field service engineer and found to be 87.5 percent in the insulated barn. This figure was used to convert the calculated heat energy losses to gallons of LP (GLP) equivalent for both barns.

It is evident that insulating the barn from the ground gives the greatest savings. The reduction in heat loss resulting from placement of 1.5 inches of polystrene board under the concrete foundation slab was found to be 22 GLP in 1977 and 20 GLP per cure in 1978. (In 1977 the average marketed leaf per cure was 2173 lbs in the insulated barn and 1924 lbs in the uninsulated barn. In 1978 the average was 1887 lbs in the insulated barn and 1625 lbs in the uninsulated barn.) Placing insulation in the side walls and doors saved 8 GLP per cure in 1977 and 5 GLP per cure in 1978. Insulating the return plenum saved 17.5 GLP per cure in 1977 and 13 GLP per cure in 1978. The total savings resulting from insulation averaged 50 GLP per cure in 1977 and 38 GLP per cure in 1978.

The difference in saving during 1977 and 1978 was due to differences in the curing schedules used and differences in the ambient (outside) conditions. Management of the curing was left in the hands of the grower. Differences in the tobacco and its response to the curing environment, caused the grower to select slightly different curing schedules during 1978. The range of total saving, 38 to 50 GLP per cure (Table 3), is realistic for on-farm equipment which is insulated as described in this report and is operated with good management procedures.

A comparison of the measured fuel consumption and the calculated conductive heat loss is given in Table 4. In the uninsulated barn the conductive heat loss averaged 39 percent of the total LP gas burned for 6 cures in 1977 and 32 percent for 7 cures in 1978. In the insulated barn the average conduction heat loss was 13 percent for 6 cures in 1977 and 16 percent for 8 cures in 1978. Comparing the total measured fuel consumption, the insulated barn used 16 percent less fuel during the 1977 season and 21 percent less during the 1978 season.

The best comparison of the two barns can be obtained by evaluating the GLP per lb marketed leaf ratios shown in Table 5. The savings in the insulated barn averaged 17 percent during the 1977 season and 19 percent during the 1978 season.

Discussion

There is a great deal of interest in insulating existing barns. There are firms which will foam or blow insulation in the wall cavity of tobacco barns. This can be effective if the right material is used by a reputable company. There are reports that certain materials gasify and disappear in one or two seasons.

Some growers have had polyurethane foam sprayed on the entire interior, from the concrete foundation slab, up the side wall, across the roof, and down the opposite wall to the foundation slab. This material has a good insulation rating and it also seals cracks in the barn. Reports are that it adhers well and is not readily torn off the wall when the racks are loaded in the barn. Care should be taken to clean surfaces before applying the material. Growers should be sure to obtain the fire retardant formulation of the material. It is almost impossible to avoid an occasional spark in a direct-fired barn.

Two potential problems must be considered if the polyurethane foam is applied to the foundation slab as well as the side walls and roof. The resultant layer of insulation on top of the concrete pad will reduce the cross sectional area of the delivery plenum in an updraft barn (return plenum in a downdraft barn) and may restrict the flow of air in the barn. The material cannot be applied smoothly and the resulting rough surface will create swirls and eddys in the airflow. In addition, if the insulation absorbs water when the barn is brought into order, then it must be dried out during the next cure. This represents an energy investment and is a disadvantage. ~~The application of foamed in place insulation on the concrete foundation slab is not recommended.~~

The best way to insulate the foundation slab from the ground is as shown in Figure 1. If it cannot be done in this way, then the foam method is an alternative. Before proceeding, however, the barn manufacturer should be contacted to determine if the addition of the foam will significantly effect the airflow in the barn. Also, it is adviseable to check a piece of the foam to determine how much water it will absorb.

The following method has been used by a grower to install insulation in the side walls of an existing uninsulated barn. The tier rails were removed and a saw cut was made along the line of the top tier. (The saw was set to cut through the plywood only.) The plywood was then loosen from the wall and bent down so that the insulation could be installed in the wall cavity between the studs. It was then nailed back into place and the tier rails replaced. The doors were insulated in a similiar manner. The polystyrene board was used rather than fiberglas batts because it was easier to insert it behind the plywood.

To insulate the roof of an existing barn, it is a simple matter to place insulation between the rafters and nail strips of wood underneath to hold it in place. In insulating the roof section over the furnace, it is again important to not reduce the plenum area to the point where the airflow is restricted.

Summary

Insulating under the foundation slab of a bulk curing barn can save 20 to 22 gallons of LP gas equivalent per cure. Placing insulation in the wall cavity and between the rafters can save an additional 18 to 25 gallons of LP gas equivalent per cure. The total savings calculated for factory insulated barn on an insulated foundation slab in comparison with an uninsulated barn of the same capacity, ranged from 50 gallons of LP gas equivalent per cure for 6 cures during the 1977 season to 38 gallons per cure for 7 cures during the 1978 season. These savings were calculated for actual conditions measured on the Talley Farm in Tift County, Georgia.

Table 1. Comparison of thermal resistance in major sections of the barns.

Uninsulated Barn

Barn Section	Insulation	Composite Thermal Resistance $(R, \frac{F^o}{BTU/h \cdot ft^2})$
Foundation Slab	None	0.4
Side Walls and Loading Doors	1.5 in. Air Space	3.6
Roof	None	1.5
Furnace	None	0.8

Insulated Barn

Barn Section	Insulation	Composite Thermal Resistance $(R, \frac{F^o}{BTU/h \cdot ft^2})$
Foundation Slab	1.5 in. Polystrene Board	6.0
Side Walls and Loading Doors	1.5 in. Fiberglas	6.2
Roof	1.5 in. Fiberglas	5.6
Furnace	1 in. Fiberglas	3.9

Table 2. Calculated conductive heat loss during 1977 and 1978 seasons on the Talley farm in South Georgia.

Uninsulated Barn

Section	Average GLP Equivalent* per Cure	
	1977 (6 Cures)	1978 (7 Cures)
Delivery Plenum (Below Drying Floor)	29	29
Curing Compartment	14	12
Return Plenum (Above Tobacco)	23	20
Furnace Room	4	2
TOTAL------------------	70	63

Insulated Barn

Section	Average GLP Equivalent* per Cure	
	1977 (6 Cures)	1978 (8 Cures)
Delivery Plenum (Below Drying Floor)	7	9
Curing Compartment	6	7
Return Plenum (Above Tobacco)	5.5	7
Furnace Room	1.5	2
TOTAL--------------------	20	25

* 87.5% Combustion Efficiency or 84.5 MJ/GLP

Table 3. Heat loss reduction in insulated barn relative to uninsulated barn.

Season	Average GLP Equivalent per Cure		
	Uninsulated	Insulated	Saving
1977	70	20	50
1978	63	25	38

Table 4. Comparison of calculated conductive heat loss and measured fuel consumption on the Talley Farm during the 1977 and 1978 seasons.

Uninsulated Barn

Season	Average GLP Equivalent* per Cure		
	Total	Heat Loss	Heat Loss (%)
1977 (6 Cures)	178	70	39
1978 (7 Cures)	199	63	32

Insulated Barn

Season	Average GLP Equivalent* per Cure		
	Total	Heat Loss	Heat Loss (%)
1977 (6 Cures)	149	20	13
1978 (8 Cures)	158	25	16

* 87.5% Combustion Efficiency or 84.5 MJ/GLP

Table 5. Petroleum fuel consumption on the Talley Farm during the 1977 and 1978 seasons (GLP/lb marketed leaf).

1977 Season

Cure No.	Uninsulated Barn	Insulated Barn
1	.139	.120
2	.129	.085
3	.097	.082
4	.100	.084
5	.071	.074
6	.073	.049
7	.057	.060
Average	.095	.079

1978 Season

Cure No.	Uninsulated Barn	Insulated Barn
1	.153	.127
2	.129	.102
3	.117	.085
4	.091	.079
5	.075	.079
6	.104	.072
7	.095	.078
8	--	.079
Average	.109	.088

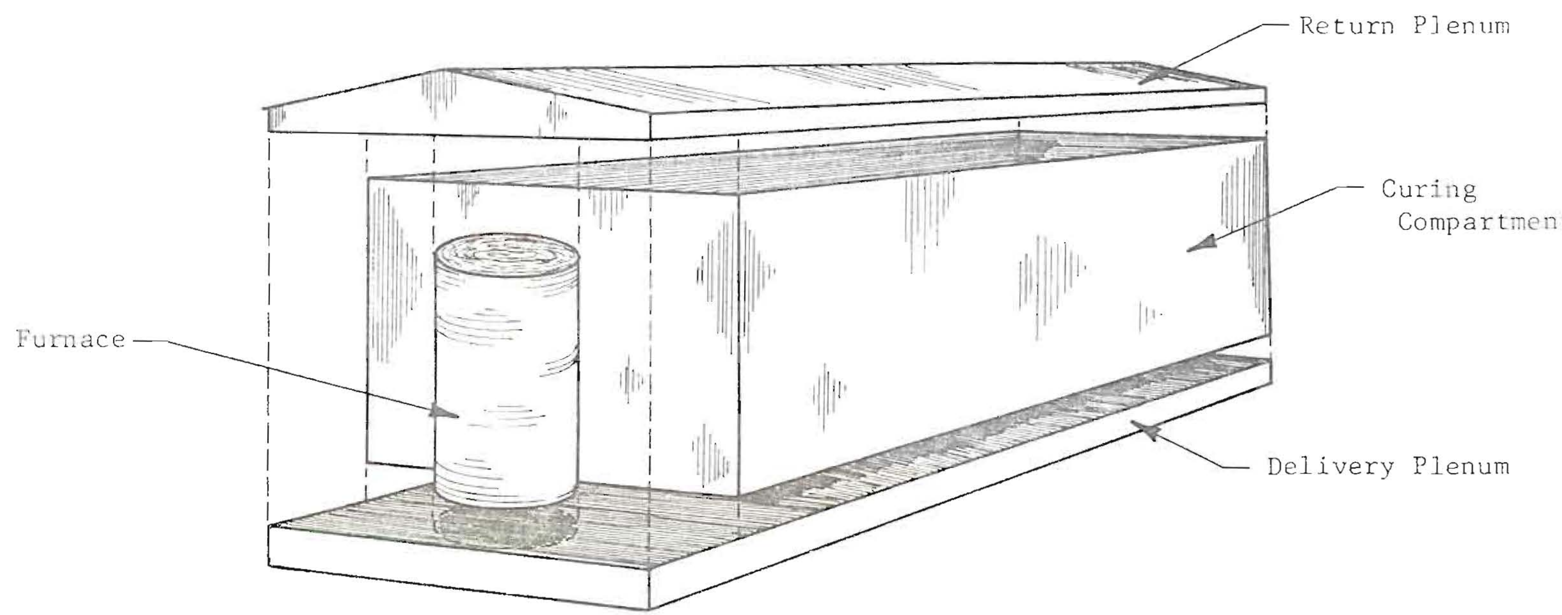

Figure 1. Exploded view showing sections of a bulk curing barn.

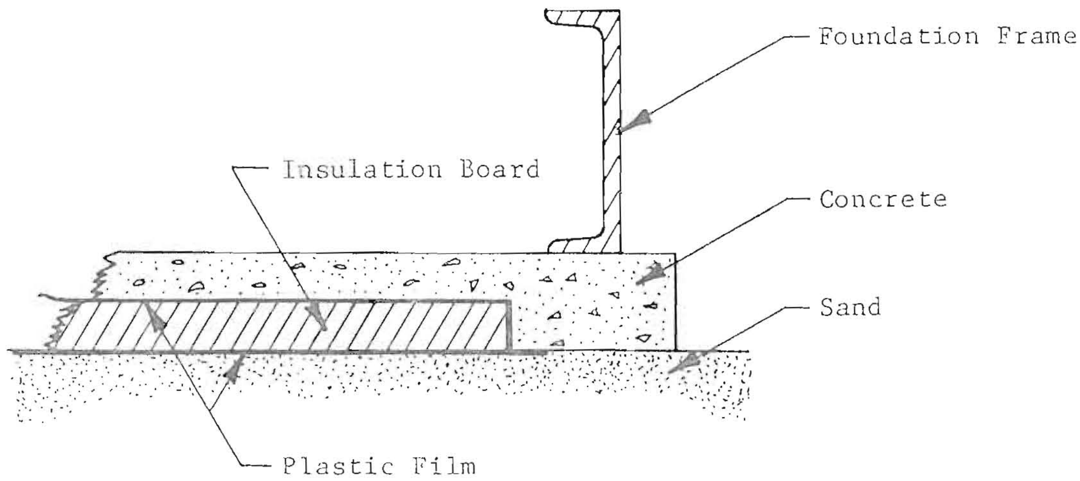

Figure 2. Insulation of foundation slab from the ground.
(All dimensions in inches.)