THE USE OF ENERGY IN THE DRY KILN

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When Charlie asked for the title of this talk, we discussed what general subject matter he wanted covered and we decided on "The Use of Energy in the Dry Kiln." Possibly a better name would be "Where the Energy Goes."

A simple answer to this question is, the energy eventually goes into the air around us. However, that doesn't tell us much about dry kilns. So, I hope to walk us through some basic calculations which allow us to:

1) Take a look at heat required to dry a charge of lumber. We will break the total heat required into categories and arrive at basic calculations that should serve as a "guide to follow" in making these calculations on your own kiln.
2) Develop energy cost for each of the categories above in order to attain a better appreciation of the cost.
3) Develop the energy cost for drying lumber using various fuel costs.

GENERAL - HEAT REQUIRED

As it relates to a dry kiln, energy comes in two forms--heat and electricity. Generally, the heat enters the kiln as steam and the electricity is used for moving the air through the lumber, returning the condensate and compressing instrument air. Both forms of energy have a known cost.

THE ENERGY USED IN A DRY KILN CAN BE SEPARATED INTO THE FOLLOWING CATEGORIES

1. Heat required to raise the temperature of the kiln equipment and air up to the operating temperature.
2. Heat required to raise the temperature of the wood up to the operating temperature.
3. Heat required to raise the water in the wood up to the operating temperature.
4. Heat required to separate the water from the wood. (The heat of wetting.)
5. Heat required to evaporate the water.
6. Heat required to raise the outside air temperature during venting.
7. Heat required to make up for heat losses through walls, roof, floor, cracks at doors, cracks at vents.
8. Heat lost through steam leaks, malfunctioning steam traps, and other problems.
9. Electrical energy used for fans, condensate pumps and air compressor.

KILN ENERGY WORK SHEET

Assumed Data

Kiln	=	D.T. x 104' long prefab alum
Lumber	=	180,000 bd. ft. 2" hem-fir
Green M.C.	=	90%
Dry M.C.	=	15%
Ambient Temp	=	40°
Schedule	=	230°F D.B., 180°F W.B. for 55 hours
Heat Up Time	=	3 hours (55 - 3 = 52 hours of drying)

1) HEAT REQUIRED TO RAISE THE TEMPERATURE OF THE KILN, EQUIPMENT AND AIR UP TO THE OPERATING TEMPERATURE.
Basic formula for determining the heat required is: lbs. (of material) x specific heat (of material) x difference in temperature = heat required

Item	Material	Lbs.	x	Specific HT	x	Temp Rise	=	Heat Required
Alum Skin	Alum	5,500		.226		190		236,170 BTU
Fin Pipe	Steel	45,000						
Structure	Steel	30,000						
Trucks	Steel	7,200						
Bunks	Steel	7,200						
Rail	Steel	4,160						
		93,569		.11		190		1,955,404 BTU
Floor	Concrete Top 2"	90,900		.156		130		1,843,452 BTU
Air	Air/Water	5,344		----		190		264,523 BTU
								4,299,553 BTU

2) HEAT REQUIRED TO RAISE THE TEMPERATURE OF THE WOOD UP TO THE OPERATING TEMPERATURE.
Basic formula applies, but first determine the weight of the bone dry lumber.

$$\text{Wt. of Wood} = \frac{.38\ (\text{SP.Grav.}) \times 62.4}{12} \times 180{,}000 \text{ bd. ft.}$$

Wt. of Wood = 355,680 lbs. bone dry wood
355,680# x .35 (Sp. Heat) x 140°F = 17,428,320 BTU

3) HEAT REQUIRED TO RAISE THE TEMPERATURE OF THE WATER UP TO OPERATING TEMPERATURE.
Basic formula applies, but first determine the weight of the water. Since moisture contents are on a dry basis, the weight of water = weight of wood x green M.C.

Wt. of Water = 355,680 lbs. x .90
Wt. of Water = 320,112 lbs.

All the water in the wood must be heated up to the wet bulb temperature. The specific heat water = 1.

320,112# x 1 (Sp. Heat) x 140°F = 44,815,680 BTU

4) HEAT REQUIRED TO SEPARATE WATER FROM THE WOOD (THE HEAT OF WETTING).

When wood absorbs moisture from the air, heat is given off. This absorbing only occurs below the fiber saturation point, and is greatest at 0 M.C. Since this is a fairly complicated topic by itself, and the net effect is small, it can be neglected for our purposes.

5) HEAT REQUIRED TO EVAPORATE THE WATER IN THE WOOD.

First determine the weight of the water to be evaporated. Since moisture contents are on a dry basis, the weight of water evaporated = wt. of wood x diff. in M.C.

Wt. of water evaporated = 355,680 x (.90 - .15)

Wt. of water evaporated = 266,760 lbs.

The latent heat of evaporation for various temperatures as follows (W.B. kiln temperature):

Degrees Fahrenheit	BTU/Lb.
140	1014.1
150	1008.2
160	1002.3
170	996.3
180	990.2
190	984.1
200	977.9
210	971.6
212	970.3

Lbs. water x latent heat/# = heat required

266,760 x 990.2 = 264,145,752 BTU

6) HEAT REQUIRED TO RAISE THE TEMPERATURE OF THE OUTSIDE AIR DURING VENTING.

The exhausted air is 230/180^{o}F = 37% RH. It carries approximately 3,800 grains of moisture per pound of dry air. The 40^{o} incoming air brings approximately 28 grains with it.

3800 grains - 28 grains = 3,772 net

$$\frac{\text{\# water evaporated x 7000 grains/\#}}{\text{3772 grains}} = \text{lbs. air exhausted}$$

$$\frac{266{,}760 \times 7000}{3772} = 495{,}048 \text{ lbs. of dry air exhausted}$$

Therefore, an equal amount of 40^{o}F outside air must enter into the kiln and be heated.

The enthalapy of 230^{o} D.B. .5% R.H. air = 62 BTU/#

The enthalapy of 40^{o} D.B. 60% R.H. air = 13 BTU/#

Change in enthalapy = 49 BTU/#

49 BTU/lb. x 495,048 lbs. of air = 24,257,352 BTU

7) HEAT REQUIRED TO MAKE UP FOR HEAT LOSSES THROUGH WALLS, ROOF, FLOOR, CRACKS AT DOORS, AND CRACKS AT VENTS.

Heat Loss Through Walls and Roof

2" thick kiln panel has a U	=	.11
104' D.T. has surface area	=	9000 ft^{2}
Inside temperature	=	230^{o}
Outside temperature	=	40^{o}

Basic formula is:

U x area x difference in temp.	=	heat loss/hr.
.11 x 9000 x 190^{o}F	=	188,100 BTU/hr.
188,100 BTU/hr. x 53 hrs.	=	9,969,300 BTU

<u>Heat Loss Through</u>			
Doors	Total Cracks	=	.8 ft^2
Vents	Total Cracks	=	.5 ft^2
Miscellaneous	Total Cracks	=	.5 ft^2
			1.8 ft^2
Assume a velocity of 700 FPM		=	1,260 CFM
1260 CFM x 60 Min x 52 hrs.		=	3,931,200 ft^3

$\frac{3,931,200}{30\ ft^3/lb.}$ = 131,040 lbs. dry air

At the least, the heat required to heat this air from 40° to 230° is lost.

131,040 lbs. x 49 BTU/lb.	=	6,420,960 BTU
<u>Heat Loss Through Concrete Floor</u>		
Surface area of floor	=	3,536 ft^2
U factor for 4"	=	1.07
Assumed temperature under	=	150°F
Temperature above floor	=	230°
U x area x difference in temp.	=	heat loss
1.07 x 3536 x 80°F	=	302,682
302,682 x 53 hours	=	16,042,125
Total required to make up for losses	=	32,432,385 BTU

8) STEAM LEAKS AND MALFUNCTIONING TRAPS.
Assume 1% of heat required for evaporating water is lost.
.01 x 264,145,752 2,641,457

9) ELECTRICAL ENERGY FOR FANS, PUMPS AND COMPRESSOR.
Assume:

80-HP total x .747 KW/HP x 55 hrs.	=	3,287 KWH
@ .04/KWH	=	$131.47/charge

You will note the BTU/lb. of water evaporated is in the 1500 to 1600 range. This is significantly less than 1800 to 2200 BTU/lb. quoted by authorities on the subject. So we ask, "Where does the additional energy go?" I have some opinions on the subject:

1. The integrity of the building is probably not as good as we think. The "U" factor of the insulation is a value when the insulation is new and dry. I believe this factor is reduced rapidly in use. Also, cracks at doors, vents, and broken door fronts no doubt accounts for a larger loss than assumed here.
2. The heat used in warming the make-up air assumes good D.B./W.B. control. I doubt that it is as stable as we have assumed, which means we are venting air above the W.B. set point which causes additional heat load to make up for overventing.
   We also saw on the chart that as W.B. is reduced, more heat is required to evaporate the water.
   If you think of the normal position of the vents, it's easy to see how inefficient the venting process really is. Fresh air is drawn in on one side, mixed with the kiln air as it goes through the fans, and then at least a portion is exhausted on the pressure side of the fan. Remember we are getting the W.B. reading down on the wall; not up in the vent opening.

I hope this analysis of the dry kiln will help to bring a few basics back into your operation. Many aspects of kiln operation have a direct impact on the cost of drying, and by paying closer attention to conserving your energy, you will help squeeze a few more dollars out of your operation.

COSTS PER CHARGE

	BTU/Charge	%		------- Per 1,000 lbs. of Steam --------				
				@ 5.00		@ 6.00		@ 7.00
1. Heat Kiln & Equipment	4,299,553	1.08		24.43		29.32		34.20
2. Heat the Wood	17,428,320	4.34		99.02		118.83		138.63
3. Heat the Water	44,815,680	11.17		254.64		305.56		356.49
4. Heat of Wetting	--	--		--		--		--
5. Evaporate the Water	264,145,752	65.84		1500.83		1800.99		2101.16
6. Heat Air for Venting	24,257,352	6.04		137.83		165.39		192.96
7. Make Up Losses	32,432,385	8.08		184.27		221.13		257.98
8. Steam Leaks & Traps	2,641,457	.66		15.01		18.01		21.01
9. Electrical	11,202,243	2.79	(0.04)	131.47	(.05)	164.34	(.06)	197.21
	401,222,742	100.00		2347.50		2823.57		3299.64

Lbs. of water evaporated 266,760

BTU/lb. water evaporated $\frac{401,222,742}{266,760} = 1504$

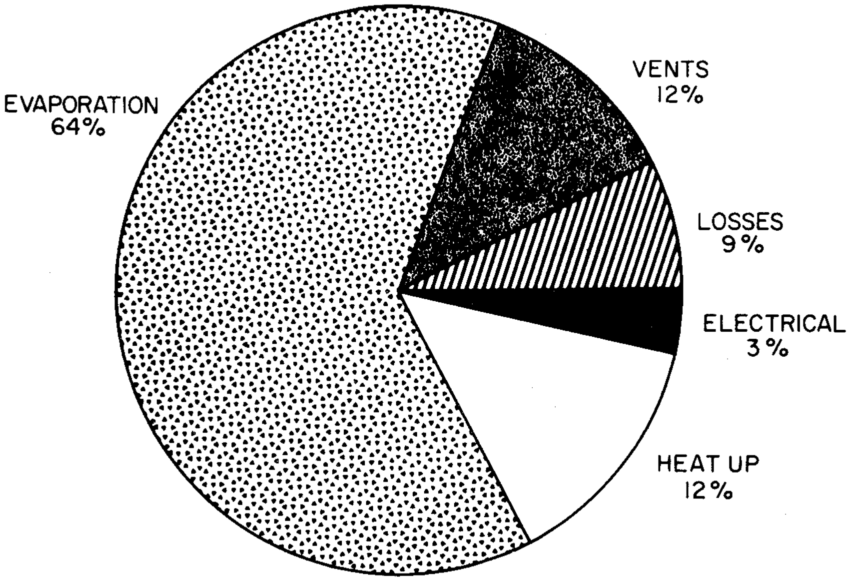
COSTS PER CHARGE
CONVENTIONAL TEMP. 175/145 80-HOURS

		BTU/Charge	%	---- Per 1000 lbs. of Steam ---- @ 5.00	@ 6.00	@ 7.00
1)	Heat Kiln & Equipment	2,100,000	.50	11.93	14.32	16.70
2)	Heat Wood	13,071,240	3.10	74.27	89.12	103.98
3)	Heat Water	33,611,760	7.90	190.58	229.17	267.37
4)	---------------------					
5)	Evaporate Water	269,694,360	63.60	1,532.35	1,838.83	2,142.30
6)	Heat Air for Venting	51,827,662	12.25	294.48	353.37	412.27
7)	Make Up Losses	33,518,637	7.90	190.45	228.54	266.63
8)	Steam Leaks	3,919,942	.90	22.27	26.73	31.18
9)	Electrical	16,294,172	3.85	92.58	111.10	129.61
		424,037,773	100.00	2,409.31	2,891.18	3,370.04

Lbs. of Water Evaporated 266,760

BTU/lb. of Water Evaporated $\frac{424,037,773}{266,760} = 1590$

ENERGY COSTS AT CONVENTIONAL TEMPERATURES



ENERGY COSTS AT HIGH TEMPERATURES