KILN HEATING AND CONDENSATE HANDLING SYSTEMS

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A couple of winters ago at an eastern Oregon dry kiln operation, the kiln operator, prompted by -20 F outside air temperatures that had added 20-30% to his drying times, used the steam pressure regulator on the kiln's main steam line to increase the header pressure from 100 psig to 150 psig. He reasoned that the added steam temperature, from 338 F to 366 F, would help him put more heat to the kilns and make up for the lagging production. The next few days he stood around in the bitter cold scratching his head wondering why his dry kiln performance had gotten worse. Let's examine in detail the principles and properties of steam to discover how the increased steam temperature actually provided less heat to the kiln's drying process.

First let's review the definitions of temperature and heat. Temperature is the degree of hotness with no implication as to the amount of heat energy (BTU's) available. Heat is the amount of energy (BTU's) available with no regard to temperature. When operating a dry kiln do we say we want to temperature the kiln or do we want to heat the kiln? We say we want to heat the kiln which means adding the maximum BTU's we can to the circulating air while maintaining a desired temperature. Since we agree that heating the kiln is the objective of our actions how do we maximize the heat to our kiln coils with each pound of steam delivered? Referring to the saturated steam tables (Figure 1) we see the latent heat (available heat delivered when a pound of steam changes to a pound of water at the same temperature) at 100 psig to be 880 BTU/lb. and at 150 psig to be 857 BTU/lb. The effect of increasing the steam temperature at our eastern Oregon kiln operation actually reduced the effective heating value of each pound of steam by 3%. The latent or available heat (BTU's) is reduced as the steam temperature/pressure is increased. Therefore, one should run the steam temperature/pressure as low as possible to maintain the desired kiln air temperature to maximize the heat (BTU's) delivered to the kiln coils.

Reducing the available heat to the kiln coils was not the only negative effect of increasing the steam pressure at our eastern Oregon kiln operation. Referring to Figure 2 (percentage of flashed steam) we see that the percentage of flashed steam has increased from 13% to nearly 17% with a 100 psig to 150 psig increase in steam header pressure due to the increased trap discharge temperature. The condensate return lines handle both water and flash steam and because the volume of flash steam is many times greater than the volume of the condensate we estimated that the 4% increase in flashed steam in the condensate piping reduced the maximum volume of condensate evacuation by nearly 20%. The observed effect was a very substantial increase of flash steam vented from the below grade return condensate receiver vent with a slight pressurization of the receiver tank. The reduced condensate liquid carrying capacity of the return condensate lines due to the increase flashed steam in the lines plus the back pressure resulted in a 30-40% water logging of the center reheat coil as observed with a Hughes Probeye infrared scanner. The infrared scanner gives you an image of an object using the heat

Gage Pressure		Absolute Pressure PSIA	Steam Temp. °F	Heat of Sat. Liquid btu/lb	Latent Heat btu/lb	Total Heat of Steam btu/lb	Specific Volume cu ft/lb
Inches of Vacuum	29.743	0.08854	32.00	0.00	1075.8	1075.8	3306.00
	29.515	0.2	53.14	21.21	1063.8	1085.0	1526.00
	27.886	1.0	101.74	69.70	1036.3	1106.0	333.60
	19.742	5.0	162.24	130.13	1001.0	1131.1	73.52
	9.562	10.0	193.21	161.17	982.1	1143.3	38.42
	7.536	11.0	197.75	165.73	979.3	1145.0	35.14
	5.490	12.0	201.96	169.96	976.6	1146.6	32.40
	3.454	13.0	205.88	173.91	974.2	1148.1	30.06
	1.418	14.0	209.56	177.61	971.9	1149.5	28.04
PSIG	0.0	14.696	212.00	180.07	970.3	1150.4	26.80
	1.3	16.0	216.32	184.42	967.6	1152.0	24.75
	2.3	17.0	219.44	187.56	965.5	1153.1	23.39
	5.3	20.0	227.96	196.16	960.1	1156.3	20.09
	10.3	25.0	240.07	208.42	952.1	1160.6	16.30
	15.3	30.0	250.33	218.82	945.3	1164.1	13.75
	20.3	35.0	259.28	227.91	939.2	1167.1	11.90
	25.3	40.0	267.25	236.03	933.7	1169.7	10.50
	30.3	45.0	274.44	243.36	928.6	1172.0	9.40
	40.3	55.0	287.07	256.30	919.6	1175.9	7.79
	50.3	65.0	297.97	267.50	911.6	1179.1	6.66
	60.3	75.0	307.60	277.43	904.5	1181.9	5.82
	70.3	85.0	316.25	286.39	897.8	1184.2	5.17
	80.3	95.0	324.12	294.56	891.7	1186.2	4.65
	90.3	105.0	331.36	302.10	886.0	1188.1	4.23
	100.0	114.7	337.90	308.80	880.0	1188.8	3.88
	110.3	125.0	344.33	315.68	875.4	1191.1	3.59
	120.3	135.0	350.21	321.85	870.6	1192.4	3.33
	125.3	140.0	353.02	324.82	868.2	1193.0	3.22
	130.3	145.0	355.76	327.70	865.8	1193.5	3.11
	140.3	155.0	360.50	333.24	861.3	1194.6	2.92
	150.3	165.0	365.99	338.53	857.1	1195.6	2.75
	160.3	175.0	370.75	343.57	852.8	1196.5	2.60
	180.3	195.0	379.67	353.10	844.9	1198.0	2.34
	200.3	215.0	387.89	361.91	837.4	1199.3	2.13
	225.3	240.0	397.37	372.12	828.5	1200.6	1.92
	250.3	265.0	406.11	381.60	820.1	1201.7	1.74
		300.0	417.33	393.84	809.0	1202.8	1.54
		400.0	444.59	424.00	780.5	1204.5	1.16
		450.0	456.28	437.20	767.4	1204.6	1.03
		500.0	467.01	449.40	755.0	1204.4	0.93
		600.0	486.21	471.60	731.6	1203.2	0.77
		900.0	531.98	526.60	668.8	1195.4	0.50
		1200.0	567.22	571.70	611.7	1183.4	0.36
		1500.0	596.23	611.60	556.3	1167.9	0.28
		1700.0	613.15	636.30	519.6	1155.9	0.24
		2000.0	635.82	671.70	463.4	1135.1	0.19
		2500.0	668.13	730.60	360.5	1091.1	0.13
		2700.0	679.55	756.20	312.1	1068.3	0.11
		3206.2	705.40	902.70	0.0	902.7	0.05

Figure 1. Properties of saturated steam.

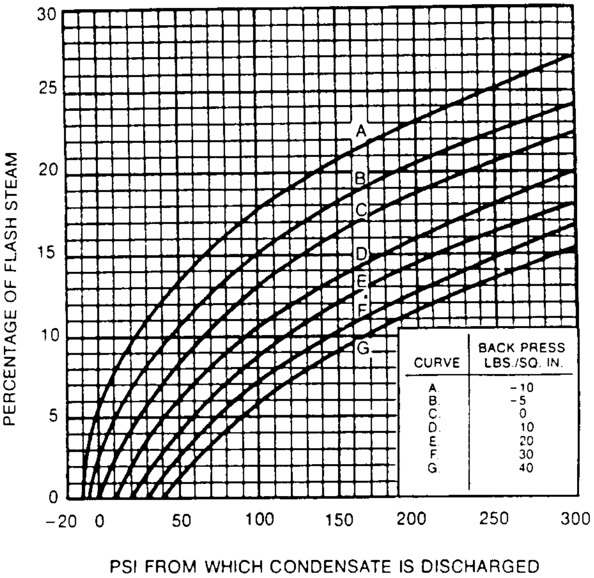

Figure 2. Percentage of flash steam formed when discharging condensate to reduced pressure.

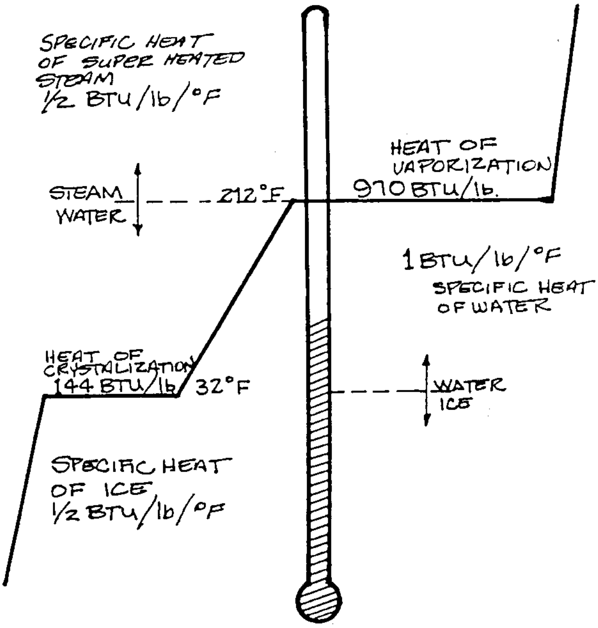

Figure 3. Heat input/output properties of water at atmospheric pressure.

emitted from the object. By opening the kiln door and looking at the center vertical 15' coil it was obvious 5-6' of the coil was filled with water over the full length of the kiln. That is the top 9-10' of the coil glowed bright white indicating steam condensing, keeping the coil hot, while the bottom 5-6' was dark indicating the presence of, relatively speaking, cold water. Water in the coils essentially eliminates their heating capacity since a change of phase (steam to condensate) can no longer occur on their internal surface.

To summarize the results of the 100 psig to 150 psig supply header pressure increase:

1. Reduced available heat carrying capacity of steam.
2. Increased flash steam in the condensate piping.
3. Reduced condensate carrying capacity of condensate piping
4. Water logging of the kiln coils.

We estimated a 15-20% reduction in kiln heating ability with this header pressure increase.

I encountered a dry kiln operation that was using superheated steam to supply heat to the dry kilns. Superheated steam is great for a turbine/generator operation where the object is to create a "large wind" with a "huge pressure drop" to spin the turbine with <u>no</u> condensate production in the turbine. Superheated steam in kiln coils prolongs the change of phase from steam to condensate where the vast majority of heat is transferred and is a much less efficient kiln heating medium than saturated steam. Superheated steam used for conditioning is a disaster since it would produce a drying condition in the kiln rather than an equalizing and cooling condition provided by saturated, low temperature steam.

With regards to putting frozen wood into a dry kiln. At 50° F, 100 BTU's of heat energy would be required to raise each pound of water in the kiln to 150° F (Figure 3). At -20° F, 288 BTU's of heat energy would be required to raise each pound of water in the kiln to 150° F and because water in the form of ice and snow are often associated with frozen lumber stacks, one can usually count on a warm-up time with frozen material nearly 3 times that of material that goes into the kiln at say 50° F. When we take into account the properties of water and steam it is very understandable why kiln schedules need to be longer during freezing winter conditions as compared to the warm summer months.

Last winter at a Willamette valley dry kiln operation I was handed a handful of broken stainless steel pieces that resembled a beat-up bucket trap rebuild kit. The kiln operator explained that ever since the master mechanic had removed his below grade return condensate receiver and condensate transfer pump ("to eliminate maintenance") he was experiencing impaired dry kiln heating problems and had to re-kit his bucket traps each 6-9 months. To be clear, the modifications made to the kiln condensate return piping resulted in the traps piped to collection manifolds and those manifolds piped directly to the boiler room elevated feed water storage tank over 100 yards away. In other words, the steam traps were also to act as the condensate pumps to pump the condensate through an elevated line to an elevated tank about 20' in the air located at the boiler house over 100 yards from the kilns. Because of initial kiln coil water logging problems it was decided to increase the boiler operating pressure from 125 psig to 175 psig to increase the pressure differential needed to better force the condensate to the receiver in the boiler room. Lifting a couple of boards to expose the condensate trap pit I was greeted by the loudest rattley-bang sounds of metal striking metal that would best be described as a body and fender works hammer mill. The steam traps were engaged in very accelerated self destruction. Have you ever taken a 20' vertical length of 2" pipe filled with water and tried to blow the water out of the pipe from the bottom with compressed air? It doesn't work so well! Imagine the violence at the bottom of the same pipe if you could use rapidly expanding hot steam! Well that is similar to what was occurring in our valley mill steam traps. The condensate passing to the traps was about 375° F as it moved out of the trap to where we had 20 psig of back pressure that water found itself instantly about 110° F over the boiling point (Figure 1). About 15% of the superheated water (Figure 2) violently expanded to steam, the mini explosion blasting back against the needle/seat and other moving parts of the trap. These mini-explosions with resulting water hammer occurring several times a minute made it necessary to rekit the traps often as they beat themselves to pieces.

Although the conditions at the valley mill were extreme, the same principles apply in varying degrees of seriousness to any dry kiln return condensate configuration where steam traps are expected to behave like pumps and transfer liquid up to any elevated receiver. The correct configuration is the receiver located below the trap discharge manifold so gravity will aid coil/trap evacuation (Figure 5). The condensate is then pumped from this below grade tank back to the boiler room.

Another major fault of configurations where the condensate receiver is elevated above the steam traps is that a water seal is always present at the trap discharge preventing the evacuation of non-condensable gasses. Air is made up primarily of nitrogen, oxygen and carbon dioxide all of which do not condense (turn to a liquid) at kiln operating or stand-by temperatures. These gasses are dissolved in the boiler feed water and leave the boiler with the steam. Also, when the kiln coil goes cold, a vacuum is formed and air is sucked into the coil from around valve stem seals, leaks, etc. When these gasses enter a steam coil with a water seal on the discharge end they are trapped and accumulate in the coil. When these gasses build up in a steam heating coil several bad things happen. Air can "plate out" on heat exchange surfaces and greatly reduce heat exchange efficiency. As little as 0.5-1.0% by volume air in steam can negatively impact heat exchange efficiency under some conditions by 50%. The presence of air in steam reduces the steam temperature (Figure 4). A steam coil containing steam and air can exchange only that heat that is determined by the partial pressure of the steam, not the total pressure. For example, a 100 psig steam coil with no air present in the steam will have a temperature of 338° F. If that same steam is mixed by volume with 30% air the temperature will drop to 312° F. I use these principles to determine if noncondensable gas problems are occurring in parts of steam systems. That is, by accurately measuring steam pressure and temperature at a suspect part of a system, the pressure should coincide with the measured saturated steam temperature (Fig. 1). If that temperature is depressed I can go to Figure 4 to determine the percent noncondensable gas content at that point.

In addition to insulating heat exchange and depressing the effective steam temperature, noncondensable gasses trapped in a steam coil can cause serious steam/condensate side corrosion problems. Two of the gasses present would be carbon dioxide and oxygen. When steam condenses in the presence of carbon dioxide a very acidic and corrosive solution of carbonic acid is formed. Modern water treatment practices employ the use of neutralizing amines to neutralize the corrosive effects of this acid formation. Neutralizing amines are weak organic bases or alkalies that have similar properties to water in that they vaporize and

AIR STEAM MIXTURE

Temperature reduction caused by various percentages of air at differing pressures. This Chart determines the percentage of air with known pressure and temperature by determining the point of intersection between pressure, temperature and percentage of air by volume. As an example, assume system pressure of 250 psig with a temperature at the heat exchanger of 375°F. From the chart, it is determined that there is 30% air by volume in the steam.

TEMPERATURE REDUCTION CAUSED BY AIR

Pressure psig	Temp. of Steam, No Air Present	Temp. of Steam Mixed with Various Percentages of Air (by Volume)		
		10%	20%	30%
10.3	240.1	234.3	228.0	220.9
25.3	267.3	261.0	254.1	246.4
50.3	298.0	291.0	283.5	275.1
75.3	320.3	312.9	304.8	295.9
100.3	338.1	330.3	321.8	312.4

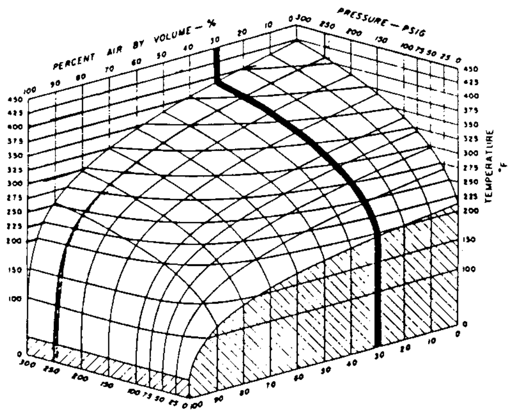

Figure 4. Effect of air mixed with steam in heating coils.

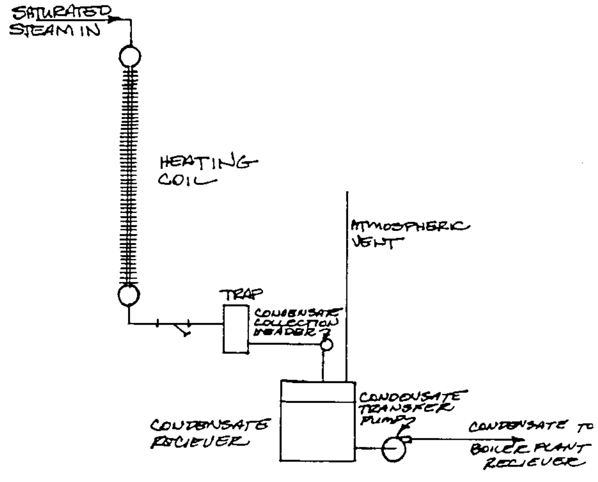

Figure 5. Proper configuration of heat coil, steam trap and condensate receiver.

condense at similar pressures and temperatures and under normal circumstances will condense where the carbonic acid is being formed causing neutralization to occur. However in a steam piping configuration where a water seal prevents the proper evacuation of the noncondensable gasses, the CO_2 can build up to high enough levels where the amount of carbonic acid produced completely overwhelms the available amines' capacity to neutralize it. I have actually read pH's of above 9.0 at the condensate receiver of a dry kiln and pH's of 3.0 (very acidic) coming from a water sealed coil in the same kiln. The effects of corrosion due to elevated noncondensable gas concentrations can be very accelerated and very localized. The kiln in the valley, I described, had persistent and massive failures to the center coil, 5-6' above the bottom header, which corresponded to the water level in the coil where the high carbonic acid concentrations were being formed.

Oxygen is the other corrosive, noncondensable gas. Unlike carbonic acid which causes a general over all corrosive metal wastage, oxygen will cause a severe corrosive pitting of the metal. These gasses if not dealt with properly can jointly act together to produce complete kiln coil failure from the inside out in less than one year.

In a steam/condensate system, oxygen is specifically dealt with by employing filming amines. Unlike neutralizing amines that only neutralize, filming amines actually form a hydrophobic (nonwettable) monomolecular film on the inside of the piping preventing contact with the corrosive gasses, like putting a wax job on your car. As an added benefit, properly applied filming amine improves heat transfer because it promotes droplet instead of film condensation on the heat exchange surface. For those plants employing turbine generators, filming amine is not recommended because of high temperature build-up problems of the filming amine that can occur on turbine blading.

Proper trapping and drainage of condensed steam from a heating coil is imperative to any efficient steam heating application. Remember, water runs down hill, so elevation wise the heat coil is highest with the trap in-between and at the lowest point in the configuration is the vented condensate receiver (Figure 5). Failure to provide this orientation will leave you, with varying severity, to deal with the problems describe above.

I have dealt with noncondensable gas problems of poor heating and corrosion in properly configured steam heating applications. By identifying the problem, using the steam temperature depression method, one can usually cure the negative effects by venting. Noncondensable gasses, depending on low steam velocities or piping configurations, can accumulate and the effects of the accumulation can be completely eliminated by the strategic placement of a noncondensable gas bleed. A very small hole drilled in the correct spot on a steam coil header can dramatically improve the heating performance of that steam coil.

Heating efficiency of the air in a dry kiln begins with the kiln coil. Each coil or fin pipe design has its own heating characteristics which designers refer to as the U-factor. The higher the U-factor the more efficient the coil is in heating the air that passes by it. Characteristics that improve a coil's U-factor are how the fins conduct the heat away from the pipe, how the fins promote a highly turbulent air flow at the pipe and fin surface to maximize intimate heating contact. I have seen kilns where fin pipe has been replaced with regular pipe (no fins), a big drop in U-factor! Keeping the coils clean, free of baked on pitch and wood fiber also dramatically improves kiln heating performance. Coil spacing and total coil surface area also depend on how efficient each individual coil is. How fast a coil will heat the air depends on the inside vs outside temperature or ΔT. The greater the ΔT the faster a given coil will add temperature to the air. One has to balance this concept with the one that says the higher the steam temperature the less heat (BTU's) is carried with each pound of steam.

Airflow in kilns can vary from 200 ft./min. in a old kiln to over 1000 ft./min. in a high temperature kiln. Conventional kilns used for softwood drying have airflows usually between 500-600 ft./min. Air is the medium that is putting heat into the boards and carrying the water out the vents. Proper baffling of the kiln charge, having no space between the packages, and directing all of the circulating air through the sticker space and across the boards will maximize drying efficiency and performance. Higher air velocities cause greater turbulence in the sticker space and on the board surface, causing more efficient heat transfer and a higher rate of moisture removal. At a moisture content of about 25% for most softwood species the surface moisture and moisture between the wood fibers (cells) have been removed, a point referred to as the "fiber saturation point" has been reached, and the remainder of the drying process deals with removing the water that is inside the wood cell walls. Since there is less moisture below the fiber saturation point, because it is more tightly held and is given up more slowly, the air velocity can usually be decreased by 40-60% with no negative impact on the drying time or performance.

In summary, the most productive dry kiln operation combines the most efficient steam heating principles with a properly configured steam/condensate handling system that integrates the best heat exchange and airflow performance to produce the maximum quality and quantity product throughput.