Kiln Upgrade Case Study: Turn-of-the-Century Brick Kilns replaced with a Quick-dry Partial Vacuum System at Steinway & Sons

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ABSTRACT

Piano manufacturer Steinway & Sons is currently in the process of upgrading the aging kiln system at their American production facility in Astoria, Queens, New York. Because the pianos require tight tolerances for wood board moisture, the drying process for the raw wood purchased by the facility must be carefully controlled.

The existing process uses the plant's original turn-of-the-century brick masonry kilns. Although the structures are sealed, insulated, and well maintained, the process is inherently inefficient. Low-pressure steam – both live steam injection and dry heat via steam coil – is used as a heat source. Ventilation dampers are used to discharge warm air and humidity periodically, resulting in high thermal losses. Depending on the wood type and product specifications, the cycle of steam injection and ventilation can last for up to 5 weeks, compared to only 4-5 days with the new kilns.

The kilns are being replaced by partial vacuum kilns which create a partial vacuum, reducing the heating requirements and increasing the speed of moisture removal. Heating inputs are so low that hot water can be used in place of steam.

This presentation will provide a walk-through of the design, installation, and commissioning process of installing the new system. It will focus on the "lessons learned" and challenges through each stage of the process, beginning with the retrofit options and the decision tree leading to the switch to the partial vacuum system. The various design options and heat sources will also be discussed.

Introduction

Steinway & Son's (Steinway) is a piano manufacturer with production facilities located in Astoria, Queens, New York, and Hamburg, Germany. The piano making process is complicated and requires exacting precision and finesse. However, at times, technology can supplement and enhance even the most time-trusted production methods, and changes are needed for Steinway to remain at the forefront of a competitive industry. One such advancement currently being implemented at Steinway's Astoria campus is a replacement of the century-old kiln-drying process.

All wood used by Steinway for manufacturing must be conditioned within certain moisture content tolerances to ensure proper assembly and prevent shrinking or warping of the pianos as they age. Due to capacity constraints and the challenges faced with the existing equipment, wood arrives either green or pre-dried (at an off-site kiln facility). The green wood must be dried in one of four aging traditional brick kilns. Two of the kilns are shown in Figure 1. The kilns measure approximately 20 × 20 feet and are 25 feet high.

Figure 1. Kilns #3 and #4 at Steinway & Sons.

The kilns are controlled for both temperature and humidity throughout the drying process, which is complicated and involves several steps. The objective is to reduce the amount of moisture in the material to a specific level over a period of time. In order to achieve the desired moisture content, and at the right speed, a mix of dry heat (provided by a steam coil), live steam injection, and ventilation is required. The process involves a repeating series of stages, as follows:

Dry heat is added to a kiln to increase the temperature of the air, and thus its ability to hold moisture is increased. This causes the moisture in the wood to move (through evaporation) into the air until a balance is achieved. This balance is referred to as the equilibrium moisture content (EMC).

After the balance is achieved by heating the kiln to the desired temperature, no additional evaporation of moisture out of the wood will take place. The roof vents are opened, rejecting the warm, moisture-laden air, and drawing cooler, dryer air into the kiln.

The sudden inrush of dry air can create rapid evaporation on the surface of the wood, faster than moisture can be drawn from the interior of the wood to the exterior. If the gradient between the wood's interior and exterior moisture content becomes too great, there is a potential to create an undesirable effect known as "checking." Checking renders the product useless for production. To prevent this, live steam is injected to keep the exterior of the wood moist enough to prevent too steep of an internal moisture gradient from developing.

The process repeats, with additional dry heat added to the kiln. Each cycle, the EMC of the wood decreases, until the final specified level is achieved.

A typical cycle can last for up to 4 to 5 weeks depending on the kiln charge (loading), starting and ending moisture contents, and weather conditions. Each of these variables adds to uncertainty as well as scheduling and production challenges to ensure that the product is ready as needed. In some cases, Steinway must plan months in advance to ensure they have the proper wood ready for production. While not a major challenge due to the large amount of storage space available on-site, this does result in large amounts of capital held as inventory. Use of the vacuum kilns will allow for just-in-time production and less stored inventory. Figure 2 provides a schematic illustration of a typical drying kiln.

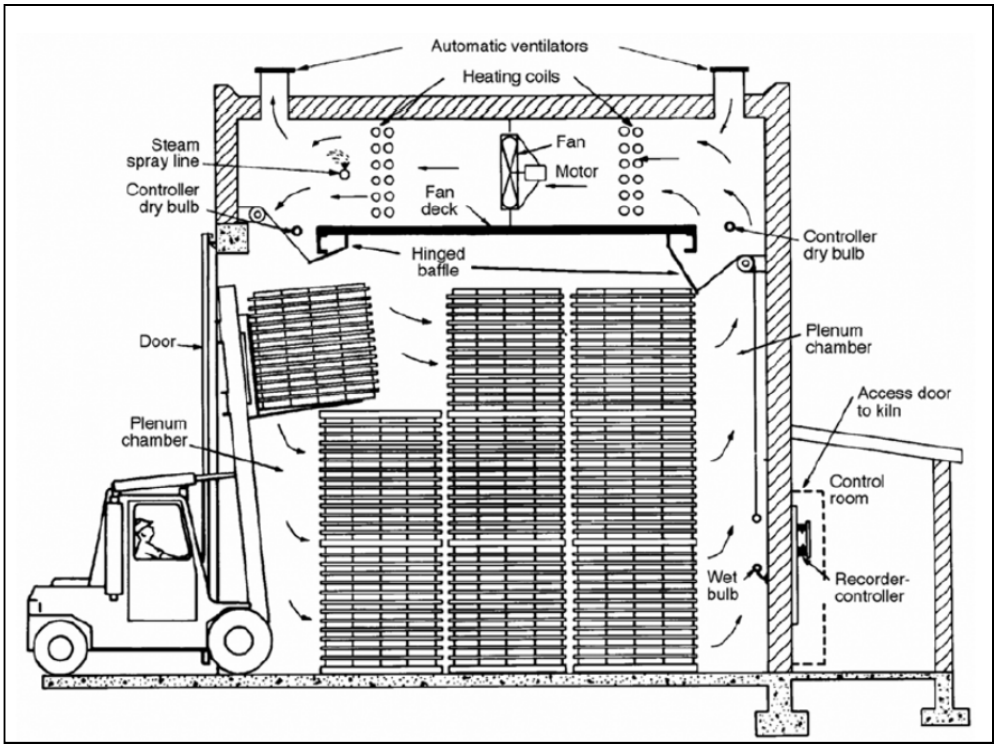

Figure 2. Generic traditional wood-drying kiln. *Source*: UAM 2010.

The wood is loaded on pallets by forklift into the kiln. The heat is provided via a steam heating coil, the moist-air psychrometric conditions are sensed by interior wet- and dry-bulb sensors, moisture is added if needed by a steam spray line, and large fans circulate the air inside the kiln. Additionally, each kiln has hatches that vent kiln air from time to time depending on the internal air conditions. Overall, there are two energy sources in this process: electric energy for the circulation fan and natural gas (thermal) for the steam production via the facility's two steam boilers.

The existing brick kilns have several sources of thermal and electric energy losses and inefficiencies including:

- Shell and infiltration losses through the doors, roof, and walls (thermal)
- Ventilation losses from the exhausted warm, moist air (thermal)
- Live steam injection, of which both the sensible and latent energy is lost from the system during ventilation (thermal)
- Circulation fans in each kiln (electric)

Furthermore, due to the kilns' large volume, permeable envelope, and thermal mass, they must be kept warm throughout the winter in order to prevent long start-up times, which delay production. This creates an extra thermal load and loss for the facility during the winter. Of the total energy consumed by the kiln, only about 5% is the theoretical energy needed to remove the moisture from the wood. The remaining 95% is caused by various losses throughout the process.

Technological Assessment

An initial assessment was performed to review potential savings from restoring or upgrading the existing kilns through measures such as weather stripping or additional insulation. However, due to the magnitude of the inefficiencies noted between the required thermal energy for physically drying the wood and that consumed by the kiln, it became apparent that a step-function increase in efficiency was required, and that this would likely only be achieved through a change in production method or technology. Steinway quickly settled on the partial vacuum kiln option after witnessing a similar system in action at another wood manufacturing company.

A vacuum kiln operates in a fundamentally different way than a traditional kiln. Rather than heat air at atmospheric pressure to temperatures close to 150ºF, the kiln system draws a partial vacuum, reducing the temperature at which water boils, and thus evaporates. Therefore, the same moisture removal can be achieved, but at a significantly lower temperature, requiring much less heat. Steinway was presented with two potential options early in the energy analysis process – a vacuum kiln and a vacuum press. Both operate in a similar fashion, taking advantage of using a system close to a vacuum. The basic vacuum kiln is loaded in a similar fashion to the exiting brick kilns. Wood is stacked in pallets, with a ¼" to ½" slat between each layer of wood for circulation. If the slats are not added, the interior wood will not dry since it does not have sufficient exposed surface area to evaporate moisture from. The vacuum press replaces these wood slats with a special membrane between equal layers of wood. In addition to the vacuum, pressure is applied to the wood to drive out additional moisture into the membrane and ultimately out of the kiln. Although inserting the membrane is faster, it adds a step to Steinway's process, which starts and ends with the palletized wood. This kiln was rejected due to the increased labor costs that would be incurred with the restacking of the product. Figure 3 shows the new kiln during delivery.

Figure 3. The AirVac 4 kiln before installation.

The new kiln is smaller than its predecessor with a 5' × 25' footprint and 5' in height. The mechanics of the vacuum kiln vary slightly from the traditional kiln. Heat can be provided by a variety of sources as either hot water or steam, since the heating requirements are so low – approximately 180ºF and 200,000 Btu/hr for the proposed model. Like its predecessor, the vacuum kiln has air circulation fans – a total of four at 5 hp each to ensure that the wood dries evenly. In addition, a 7.5 hp vacuum pump is used to maintain the partial vacuum in the kiln. Finally, two ½ hp condenser fans allow the moisture in the air to be condensed and expelled from the kiln. The kiln construction involves an airtight seal to prevent infiltration. The tight control of interior conditions reduces the likelihood of checking of the wood, reducing the product that needs to be discarded.

The vacuum kiln is a fundamentally different technology than a conventional kiln. Rather than rely solely on heat delivered at atmospheric pressure, the vacuum kiln offers a redesign that makes use of the physical effects of a vacuum – that liquid will evaporate at a lower temperature. This change in design offers a level of energy efficiency that not even the best maintained conventional kilns can reach. A switch from a conventional to vacuum kiln can result in energy savings of up to 75%.

Energy Analysis

The energy study began with a quantification of the energy used by the existing kilns. Trends were created with the assistance of the Steinway staff to monitor the number and duration of opening of the valves controlling the dry steam, live steam, and roof vents for a period of several weeks. In addition, current transformers (CTs) were installed on each of the kiln fans to measure electric energy use. Two of the kilns utilize one fan each (10 hp), while the other two kilns have three fans each (10 hp per fan). The additional fans allow for increased air circulation and speed up the drying process. However, the process can still take several weeks to complete and the savings pale in comparison to those achieved with the proposed vacuum system.

The two sources of steam use (dry and live) were calculated using orifice and pipe diameters, steam pressure, and enthalpy differences. Table 1 provides a summary of the inputs and results of the steam use. The baseline energy consumption measured to be 1.28 kWh and 0.247 therms per board foot.

Table 1. Total steam energy inputs

Parameter	Heat (dry steam)	Live steam injection
Percent of time open	37%	8%
Total hours per year (1 kiln)	3,215	672
Total annual hours (all kilns)	12,861	2,689
Energy rate (Btu/hr)	310,000	290,000

Steinway has identified a Vacutherm AirVac 4 system to install. Table 2 shows the equipment components for the new kiln and duty cycles provided by the manufacturer.

Table 2. Vacuum-kiln operating characteristics

Equipment	Quantity	Duty cycle	Voltage	HP	Amperes	kW
Air circulation fans	4	0.63	480	5	6.5	12.2
Vacuum pump	1	0.20	480	7.5	10	1.5
Condenser fan	2	0.50	480	0.5	0.75	0.6

The air circulation fans on the new kilns are expected to operate at full speed half the time and at 25% speed for the other half. The vacuum pump is projected to operate only half the time at 40% speed. The duty cycle fractions are based on post-installation data at another installation of the kiln. Wood types and moisture contents are not expected to differ materially from the operations at Steinway. According to the manufacturer, drying cycles can vary depending on the lumber species, but the typical average is 4 days (96 hours), significantly shorter than the 4 to 5 weeks of the existing kilns. For the types of wood that Steinway dries, and the moisture reduction required, this is a reasonable expectation. The operation of an additional 5 hp condensate return pump was added to account for site-specific conditions to return the condensate to the boiler feed water system. Steinway has identified an outbuilding on the property in which to install the new kiln. Because the new kiln is small, it does not require a standalone structure. By housing the kiln indoors, additional benefits can be realized, since the kiln can now be loaded and unloaded in all weather conditions as the finished wood will be protected from the elements. The existing kilns only had exterior access points, limiting unloading to dry days.

Several options were identified for use as a heat source for the new kiln. A local hot water gas-fired boiler was considered, but it would have required permitting and a gas line. Due to the configuration of the Steinway campus, the boilers are located on the opposite side, and the nearest gas line available was several hundred feet away and would require expensive excavation. Alternatively, the new boiler would have been close to the street front, allowing for new utility hookup. However, this too is expensive, and such an installation can require significant lead time with the local utility. An oil boiler was also considered to avoid the costly gas hookup, but was ultimately rejected due to the high cost of fuel oil, as well as expected permitting difficulties given New York City's strict air-quality requirements. Permitting also prevented the use of a biomass boiler, which could have burned wood scraps generated on-site. The most feasible option was to extend the existing steam lines from an adjacent building, approximately 100 feet from the new kiln. To return the condensate back to the boilers, a condensate return pump would also be installed.

The manufacturer stated that the maximum thermal capacity for this vacuum-kiln is a 200,000 Btu/hr heat rate. The typical drying cycle lasts for about 96 hours, thus the total heat required per kiln per drying cycle is approximately 229 therms, accounting for boiler efficiency and heat exchanger losses between the steam system and hot water kiln. Initial estimates were kept conservative, but the kiln is designed with trending and Internet connectivity so that performance can be monitored in real time.

Electric consumption per board foot was found to drop from 1.28 to 0.39 kWh, a decrease of nearly 70%. Natural gas use consumption decreased by 77% from 0.247 to 0.058 therms per board foot. Utility savings amount to $83,000 per year, in addition to a one-time rebate incentive of $115,000 from local energy efficiency programs. With an estimated total project cost of $675,000, this results in a 6.7 year payback. Table 3 summarizes these results.

Table 3. Savings results summary

Parameter	Traditional kiln	Vacuum kiln
Electric consumption (kWh/bd ft)	1.28	0.39
Natural gas consumption (therm/bd ft)	0.247	0.058
Electric savings (as percent)	70%	
Natural gas savings (as percent)	77%	
Annual cost savings	$83,000	
Installation cost	$675,000	
Potential utility incentive	$115,000	
Simple payback	6.7 years	

Conclusion

The installation of a vacuum kiln at Steinway represents a technology change from the existing wood drying method. The new kilns will offer a number of energy and non-energy benefits. Annual costs savings combined with state and utility energy efficiency incentives yield a payback of just under 7 years. Electric energy savings of 70% are expected while natural gas savings are anticipated to be 77%. Non-energy benefits will improve production efficiency and product quality. Through the increased control the vacuum kiln offers, checking is expected to be reduced, resulting in more usable wood per kiln load. The quicker kiln drying times allow for higher throughput and just-in-time production, reducing the need for stocking of finished product. The small size allows for indoor installation which also facilities all-weather loading and unloading. Drying times per cycle are expected to be more consistent, allowing for better forecasting of production. Finally, the increase in output may allow Steinway the ability to dry more wood at its own facility, rather than purchasing pre-dried wood. This gives Steinway more control of wood quality, as well reducing costs by handling these tasks in-house.

References

UAM (University of Arkansas at Monticello). 2010. *Wood Structure and Forest Products.* http://www.afrc.uamont.edu/pattersond/Coursework/Undergrad/wood_&_water.htm