PERFORMANCE TESTING OF A NEW DRYING KILN AT A SAWMILL FOR AIRFLOW AND MOISTURE CONTENT

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ABSTRACT

*The performance of a new drying kiln at a sawmill in Kumasi was determined by carrying out tests on the airflow in the kiln which had been loaded with lumber, and monitoring the distribution of the final moisture content of the lumber after the termination of the kiln-drying. The contents of the kiln were 16 packages, made up of 13 packages of 25 mm thick Wawa (*Triplochiton scleroxylon*), one package of mainly 83 and 25 mm thick Celtis (*Celtis mildbraedii*), and two packages of 25 mm thick Ceiba (*Ceiba pentandra*) and Chenchen (*Antiaris africana*) boards. The air speed was measured at various locations in the loaded kiln using an anemometer. The moisture content was monitored mainly on the Wawa boards using an electrical resistance-type moisture meter. The air speed varied from 0.1 to 1.7 m/sec, and averaged 1.01 m/sec for the whole charge. The active airflow through the lumber packages was 39,138 m^3/h, and the air leakage from the fans was 23,097m^3/h. The air leakage was moderate, and the active airflow was not high enough. The fan capacity was insufficient to enable uniform final moisture content to be achieved for the drying of the Wawa, a species with high initial moisture content. The final moisture content for the Celtis varied from 12.6 to 25.5 %. There were many drying defects in the dried Celtis boards, clearly indicating that it is inadvisable to mix different species and thicknesses in the same kiln load. The average final moisture content of 12.3 % for the Wawa was above the average of 10 % usually found in Wawa contracts. The standard deviation of 1.01 % was too high. The kiln needs to be set slightly below the desired final moisture content for export orders.*

Keywords: Airflow, Moisture content, Lumber stacking

INTRODUCTION

Forest product exports in Ghana represent about 12 % of total export of goods. However, a large portion of the wood exported from Ghana is in the form of logs (about 55 to 65 %) and rough lumber (about 32 to 47 %). Their unit value prices are very low compared to those for tertiary products such as furniture components, flooring, or profile boards (Ofori , Adams & Ofosu-Asiedu, 1993). In addition, the forest industry depends mostly on very few established species, the so-called 'noble' species.

To prevent over exploitation of specific species, and to increase domestic processing in the mills, the Ghana Timber Export Development Board has imposed some restriction on the raw volume of certain species being exported - Afrormosia (*Pericopsis elata*), Utile (*Entandrophragma utile*), Hyedua (*Guibourtia ehie*), and Odum (*Milicia excelsa*). The sanctions apply only to green and air-dried material but not to lumber which is kiln-dried, moulded, profiled or processed in any other way. The Government has also imposed forest improvement levies on the export of green and sawn timber taken from those species and on green wood of Kusia (*Nauclea diderrichii*), Ayan (*Distemonanthus benthamianus*), Guarea (*Guarea cedrata*), Afzelia (*Afzelia africana*), Canarium (*Canarium schweinfurthii*) and Yaya (*Amphimas pterocapoides*).

The trend in export of wood from Ghana now is the gradual shift from exportation of round logs to an increasing domestic processing of timber into lumber, dimension parts, veneer and plywood, chipboards and other finished products (such as furniture, cabinets, mouldings, floorings, doors, wood carvings, and other handicrafts). For many end uses and secondary manufacturing processes, lumber should be well dried to avoid undesirable effects such as excessive shrinkage, warping, splitting and checking, stain and decay. The improper drying of the wood or lack of any controlled drying would diminish its acceptance both for local use and for export.

Since drying improves wood quality and maximum value-addition is the target for the wood industry, kiln-drying is being encouraged. However, there has been a number of claims on kiln-dried lumber over the past months. The reasons for the claims were due to blue and brown stain, borer attack, and large moisture content variation (i.e. too high standard deviation).

As expected, when more kilns are commissioned, the claims on kiln-dried lumber will increase. For the companies involved, the situation is serious, as it will affect their credibility as reliable kiln-dried lumber suppliers. The main reasons for the expected increase in claims on kiln-dried lumber include incorrect stacking and handling of green or wet lumber into packages, incorrect stacking of the lumber packages in the kiln, and incorrect storing and handling of kiln-dried lumber. Another reason is that during the procurement of dry kilns, the fan and heat exchanger capacities in the kilns are underestimated either by the kiln manufacturer or the purchaser. This may probably be due to lack of knowledge of the moisture content of the species that are likely to be dried in the kilns.

Circulation of air within a kiln is important for supplying heat of vaporization and carrying moisture away from wood as well as for maintaining uniform conditions within the kiln (Eckelman & Baker, 1976). The airflow through the packages of lumber in a kiln is the only means of transferring thermal energy, heat, from the heat exchangers to the lumber. The efficiency in this operation determines the quality of the drying of the lumber. The higher and the more uniform the air speed is, the more uniform the drying result will be (Salmon & McIntyre, 1969; Pratt & Skinner, 1971).

A good fan system should be able to give an air speed of approximately 3 m/sec through packages of 50 mm softwood lumber. This will normally give an air speed of around 2 m/sec when drying 25 mm boards (Bramhall & Wellwood, 1976; Dijkstra, 1984; Pratt, 1986). Air speeds lower than these will result in lower quality drying when the same drying schedule is applied (ie. same climate and drying time).

Wood is dried to a moisture content that is compatible with subsequent processing operations and the use of the final product. Uneven moisture content refers to a condition where individual boards in a kiln charge have a level of moisture content that deviates greatly from the target moisture content (Steinmann, 1994). Variations in the moisture content of timber can be problematic. For convenience, dried lumber has traditionally been described by the average moisture content of a kiln load after drying. Increasingly, this 'average piece' description has been proving inadequate. For example, the dryness of the 'average piece' is irrelevant when individual pieces of the timber are to be glued together; each piece must be adequately dry for proper bonding with the glue (NZFRI, 1989).

The two most commonly used variables in statistical process control in lumber drying are average of the data and the spread of the data, as indicated by the standard deviation. In some hardwood installations, not only the average final moisture content is specified in a purchase order, but also the standard deviation must be under a certain value, typically 0.6 % moisture content (Wengert & Denig, 1995).

In order to determine the performance of a new drying kiln at a sawmill in Kumasi, tests were carried out on the airflow in the kiln which was loaded with lumber. The moisture content of the lumber was also recorded after termination of the kiln-drying.

MATERIALS AND METHODS

Tests were carried out on the airflow in a new conventional drying kiln loaded with lumber. The assessment of the performance of the drying kiln was carried out with 16 packages in the kiln. Thirteen of the packages were 25 mm thick Wawa (*Triplochiton scleroxylon*) boards. Unfortunately, the middle stack contained one package of mainly 83 and 25 mm thick Celtis (*Celtis mildbraedii*), and two packages of 25 mm thick Ceiba (*Ceiba pentandra*) and Chenchen (*Antiaris africana*) boards. These three packages were not box-piled, a prerequisite for proper kiln-drying.

The 25 mm Wawa boards had been stored prior to kiln-drying in the open for sometime. The plant operator used a dry-kiln climate of 60 °C dry bulb temperature and equilibrium moisture content of 14.5 %.

Airflow

An anemometer with a 12 mm impeller which gives readings in meters per second (m/sec) at an accuracy of 0.1m/sec was used for the measurements. The air speed was measured at the top of the lumber stacks (between the lumber and the intermediate ceiling), at the sides, between and underneath the packages. The air speed was also measured at three different places in each package: in the second sticker space from the top and from the bottom, and in the middle. All the readings were taken at the leeward side of the lumber where the air speed was at its lowest, and the wet bulb depression was also low (i.e. high relative humidity), and the risk for fungal attack was highest.

Moisture Content

Due to time constraints, the moisture content was sampled only at the top and the bottom packages on the left side of the kiln, seen from behind. An electrical resistance-type moisture meter was used. As the distribution of the air speed was relatively uniform, except at the bottom, the result will still give an acceptable indication of the total situation.

Readings were taken from the mid-length of the boards at about 10 and 40 mm depths for the 25 and 83 mm thick boards respectively. An intensive moisture content measurement was carried out on the 25 mm Wawa boards. The middle stack containing one package of mainly 83 and 25 mm Celtis and two packages of 25 mm Ceiba and Chenchen were not intensively sampled.

RESULTS AND DISCUSSION

Airflow (Air Speed and Fan Capacity)

The distribution of the air speed at the rear side of the kiln is shown in Fig. 1. The air speed varied from 0.1 to 1.7 m/sec in the different packages. The lowest and highest average air speed in each individual package were 0.0 and 1.4 m/sec respectively. The average air speed for each package varied from 0.8 to 1.4 m/sec. The average air speed for the whole charge was 1.01 m/sec. There was no significant difference in the average air speed from the top to the bottom packages, except in the area in the 'shadow' from the 83 mm Celtis where there was no or very low airflow.

The average air speed of 1.01 m/sec, and the lowest and highest average air speed in each individual package of 0.8 and 1.4 m/sec respectively, show that the airflow through the lumber is on the lower side. This will not lead to uniform moisture content in the charge, especially when drying species such as Wawa and Ceiba with high initial moisture content.

Calculations on air leakage and active airflow through the lumber packages are shown in Tables 1 and 2. The air leakage above the stacks (13,608 m^3/h) was too high. It was about 59 % of the total airflow leakage. In any kiln the circulating air always has a tendency to by-pass the timber through spaces inadvertently formed above, below or along the load. This short-circuiting should be minimized. The kiln should be loaded as high as possible to avoid capacity loss and, in this particular case, poor circulation due to the big gap between the timber and sub-ceiling. Flow over the load leading to poor circulation is most effectively prevented by using ceiling-hinged baffles arranged so that their free end rests on top of the load (Bramhall & Wellwood, 1976; Pratt, 1986).

Total airflow from fan or fan capacity is the sum of the total air leakage and the active airflow through the lumber packages. Thus, the fan capacity is 23,097 m^3/h + 39,138 m^3/h =

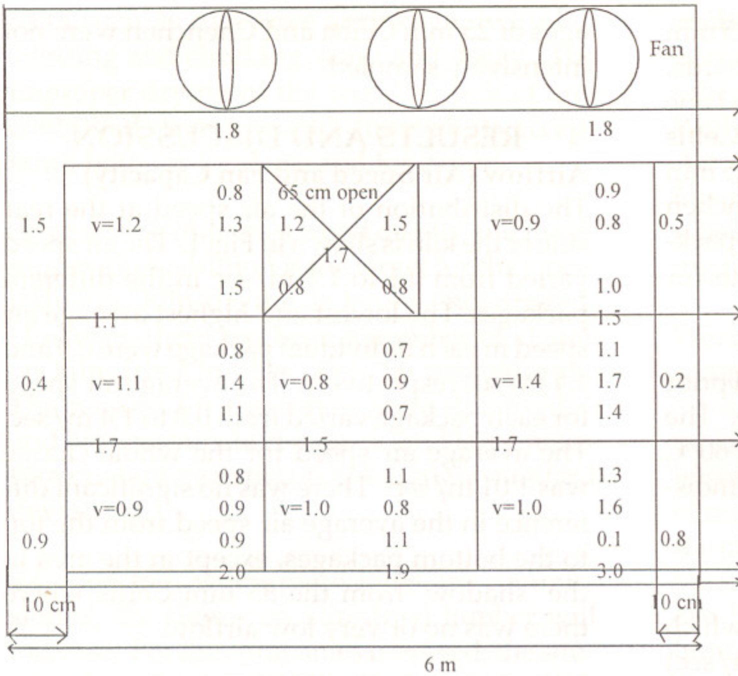

Fig. 1. Distribution of air speed at the rear side of the kiln.

Legend:

	1.5	- Air speed on top of package
	1.1	- Air speed in sticker space, 2nd from top
V = average air speed in the package	v=1.0 0.8	- Air speed in the middle
	1.1	- Air speed in the sticker space, 2nd from bottom
	1.9	- Air speed below package

Air speed in meters per second	m/sec
Sticker thickness	25 mm
Number of stickers per package	24
Lumber thickness	25 mm
Bolster thickness	50 mm
Maximum package/stacking width	6 m

62,235 m^3/h. The air leakage (representing 37 % of the total airflow) was not high, thus indicating that the stacking of the lumber packages in the kiln was very good. At higher air speed, one must expect a higher percentage of leakage, as the dynamic pressure increases, and air forces its way through more places where it is stagnant when drying smaller dimensions.

The airflow in the kiln was unsatisfactory; it seems the fan capacity was on the lower side for drying of 25 mm Wawa and Ceiba. These species normally contain a lot of water, and a good fan capacity is paramount to a good drying result. The average speed of the air through each individual package varied from 0.8 to 1.4 m/sec. However, for 50 mm lumber thickness, the airspeed in the sticker space will, according to experience, be close to 3 m/sec. The middle stack of Celtis lumber is the main reason for the relatively low airflow, especially through the lowest packages.

TABLE 1

Air leakage through the lumber packages

Location	*Air speed (m/sec)*	*Cross-section of airflow (m × m)*	*Airflow leakage * (m^3/h)*
Above the stacks	(1.8 + 1.8) / 2 = 1.8	0.35 x 6.0	13,608
Left side of stacks	(1.5 + 0.4 + 0.9) / 3 = 0.9	0.10 x 1.2	403
Right side of stacks	(0.5 + 0.2 + 0.8) / 3 = 0.5	0.10 x 1.2	216
Bottom of stacks	(2.0 + 1.9 + 3.0) / 3 = 2.3	0.05 x 6.0	2,484
Between 1st and 2nd packages	(1.7 + 1.5 + 1.7) / 3 = 1.63	0.05 x 6.0	1,764
Between 2nd and 3rd packages	(1.1 + 1.5) / 2 = 1.3	0.05 x 5.35	1,252
Opening 3rd row middle	(0.8 + 1.7 + 1.2 + 1.5 + 0.8) / 5 = 1.2	0.65 x 1.2	3,370
Total air leakage			23,097

* Airflow leakage (m^3/h) = air speed (m/sec) × cross-section of airflow (m^2) × 3600 sec/h.

TABLE 2

Airflow through the lumber packages

Location	Air speed in sticker space (m/sec)	Sticker thickness (m)	Stickers per package (no.)	Package width (m)	Airflow through lumber * (m^3/h)
Bottom stack: 1st package	0.9	0.025	24	2	3,888
Bottom stack: 2nd package	1.0	0.025	24	2	4,430
Bottom stack: 3rd package	1.0	0.025	24	2	4,430
Middle stack: 1st package	1.1	0.025	24	2	4,752
Middle stack: 2nd package	0.8	0.025	24	2	3,456
Middle stack: 3rd package	1.4	0.025	24	2	6,048
Top packages	(0.9 + 1.2)/2	0.025	24	5.35	12,134
Total active airflow through the lumber packages					39,138

* Airflow through lumber (m^3/h) = air speed in sticker space (m/sec) × sticker thickness (m) × stickers per package (no.) × package width (m) × 3600 sec/h.

Moisture Content

Table 3 indicates a summary of the moisture content of the boards sampled.

Celtis

The final moisture content for the 25 mm Celtis varied from 12.6 to 16.3 %, and for the 83 mm Celtis from 21.4 to 25.5 %. There were wide splits and checks on the lumber surfaces. The moisture contents and standard deviations were too high and unacceptable. Internal checks, severe warping (in the form of cupping and twisting) were also observed on the Celtis lumber. This clearly indicates that it is inadvisable to mix different species and thicknesses of lumber in a kiln load.

Wawa

The whole lot of Wawa boards was dried to an average final moisture content of 12.3 %, and a standard deviation of 1.01 %. The drying result of Wawa boards was disturbed by a package of Celtis of 83 mm thickness which had been placed in front of a package of Wawa boards, thus preventing a proper airflow through that Wawa package.

The lowest and highest moisture contents for the Wawa package behind the Celtis were 11.8 and 14.8 % respectively. The mean and standard deviation for 19 samples for this lot were 13.0 and 2.30 %. The result for this package cannot be accepted, due to the high average moisture content (13.0 %) and high standard deviation (2.30 %). The mean moisture content is above the average final moisture content usually found in Wawa contracts. These contracts usually call for an average final moisture content of 10 % upon arrival at the customer's place. The standard deviation is far above the international standard (of 0.6 %) for drying quality (Wengert & Denig, 1995). When this lumber is mixed with the other packages of the lot, and the customer carries

TABLE 3

Summary of moisture content of the boards sampled

Wood species		Lumber thickness (mm)	No. sampled	Moisture content (%) Range	Moisture content (%) Mean ± std dev.
Celtis		25	10	12.6 – 16.3	15.4 ± 1.28
		83	12	21.4 – 25.5	22.5 ± 1.39
Wawa	All samples	25	73	11.0 – 14.8	12.3 ± 1.01
	Package with Celtis in front	25	19	11.8 – 14.8	13.0 ± 2.30
	Excluding package with Celtis in front	25	54	11.0 – 13.4	11.9 ± 0.66

out random sampling of the final moisture content, a claim may be put in for high moisture content.

A statistical control of the rest of the lumber (excluding the Wawa package behind the Celtis) shows an average final moisture content of 11.9 % and a standard deviation of 0.66 % for 54 samples. The range of moisture content for this lot was 11.0 to 13.4 %. The mean moisture content is above the average final moisture content of 10 % upon arrival at the customer's place usually found in Wawa contracts. The maximum value is too high. The standard deviation is about the same value as the allowable value of 0.6 % that is found in international standards (Wengert & Denig, 1995). The result for these packages is acceptable in respect of the standard deviation (0.66 %). However, a high average moisture content (11.9 %) may cause problems overseas.

It is recommended that the kiln is set slightly below the desired final moisture content for export orders (eg. 8 %), as lumber usually absorbs moisture when stored in Ghana.

A uniform moisture content could not be achieved because the airflow through the lumber is on the lower side. The package of 83 mm thick Celtis that had been placed in front of a package of Wawa boards prevented a proper airflow through that Wawa package. In addition, the 25 mm Wawa boards had been stored in the open air for some time, and as a very dry climate (dry bulb temperature of 60 ^{0}C and an equilibrium moisture content of approximately 14.5 %) was applied in the kiln, the target final moisture cannot be uniform.

General Stacking Practice

The loading of the kiln with the lumber packages was well done; the good stacking practice led to the very low air leakage outside or at the sides of the packages. Empty spaces between the short packages were filled with stacks of shorts so as to seal off potential air leakage outside the valuable lumber to be dried. Irrespective of the species of the shorts, this practice seals off potential air leakage outside the valuable lumber to be dried. However, care must be taken not to block the airflow through the packages behind. If the airflow is restricted, the attempt is counterproductive.

It must be evident that both the production manager and the kiln attendant have a very important job to do to ensure the final quality of the lumber by supervising proper stacking, and avoid mixing different species and dimensions in the same kiln load. If one is forced to mix dimensions, it must never be on the same horizontal level, and preferably the thicker dimension must be at the bottom, and the thinner boards at the top. But the general rule must be same thickness throughout the kiln.

CONCLUSION

- The air leakage above the stacks is too high. The kiln should be loaded as high as possible to avoid capacity loss and poor circulation because of the big gap between the timber and sub-ceiling. Flow over the load is most effectively prevented by use of ceiling-hinged baffles arranged so that their free end rests on top of the load.

- The good lumber-stacking practise achieved by the kiln operator can be seen from the very low air leakage at the sides of the packages.

- The active airflow in the kiln is unsatisfactory; it seems that the fan capacity is on the lower side for drying of 25 mm Wawa and Ceiba. These species normally contain a lot of water, and a good fan capacity is paramount to a good drying result. The middle stack of Celtis lumber is the main reason for the relatively low airflow, especially through the lowest packages.

- The final moisture content of the charge is unacceptable, considering the high average, and also the high standard deviation. A high average moisture content may result in increased claims on kiln dried lumber by the purchaser. The kiln needs to be set slightly below the desired final moisture content for export orders.

- The production manager and the kiln attendant must supervise proper stacking and avoid mixing of dimensions in the kiln to ensure that the final quality of the lumber meets acceptable standards.

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