Industrial Tests of Thick Veneer Slicing and Drying Technology

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Contractor

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Industrial Tests of Thick Veneer Slicing and Drying Technology

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Contractor
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EXECUTIVE SUMMARY

The production of thick veneer products has recently become possible through the development of lengthwise veneer slicers said to be capable of slicing veneer products up to 13 mm thick. Recently developed radio frequency (RF) veneer dryers may offer a rapid and economic means of drying such products. Industrial interest in pursuing these new market opportunities has resulted in this study.

The objective of this work was to investigate commercial slicing and RF drying technology for processing aspen and spruce into 6.5 and 8.5 mm veneer. The study examined RF drying, conventional drying and flitch conditioning in terms of their effects on drying times, product quality and final moisture content distribution.

Overall, the results of these tests were very positive. The technical feasibility of slicing and RF drying 6.5 mm thick aspen veneer was demonstrated, given properly conditioned raw material. The RF drying method resulted in final moisture content distributions that are typical of high temperature dried lumber products. A high quality product was produced with the conditioned aspen in these tests; however product suitability for specific end uses must be determined in conjunction with potential customers. Since the test conditions were not necessarily optimal, improvements in both drying times and product quality may well be feasible.

The clear aspen and spruce sample flitches were collected near 100 Mile House, B.C. and sliced in a plant near Boise, Idaho. All the spruce and half of the aspen was conditioned at high temperature and moisture conditions prior to slicing. Some slices were dried in a conventional dryer using a mild schedule while the remainder was dried in a RF dryer.

Veneer slice yield for the aspen and spruce flitches was 86.1% and 80.3% respectively. Target sizes were attained within ±.008 inch. The spruce flitches were overly dry which resulted in lower yields, increased depth of "lathe" checks, and overdrying in the RF dryer. In terms of "lathe" checks, the conditioned aspen produced the best results while the unconditioned aspen had deeper checks, similar to the spruce.

The aspen flitches and slices had high but variable initial moisture contents. Using a conventional kiln dryer, the aspen was overdried and the spruce slightly underdried in 31.5 and 11.5 hours respectively using a mild drying regime imposed by the mill. Drying of 6.5 and 8.5 mm aspen could likely be achieved in 20-24 and 22-28 hours respectively.

A drying curve was initially developed for the 6.5 mm aspen processed in the RF dryer, followed by several drying runs ranging from 5.0 to 7.8 minutes, with the RF power kept constant at 100 Kw. The 6.5 mm aspen reach 16% and 10% moisture content in 6.5 and 7.8 minutes respectively. Drying time to the 12% target is estimated at 7.2 minutes.

Since the two drying methods studied resulted in equivalent final product quality, a choice between the two systems should be based on an economic comparison. This should consider capital costs, energy costs, labour costs and any benefits associated with the short RF drying time.

While the study results were promising, future work should focus on optimizing knife and nosebar settings as well as conditioning procedures. The RF drying of thick veneer could be further refined and the use of increased power and the drying of thicker veneer should be investigated.

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Finally, thanks to the Forintek staff who either participated in or assisted in various ways with this project: Dal Wright, Vit Mlcoch, Peter Tarasoff, Derek Williams (technical support); Don Walser, Graham Mackay (project planning and review); Jean Cook (statistical analysis); and Gay Chan (report preparation).

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1.0 INTRODUCTION

1.1 PROJECT ORIGIN

A Group of 9 businessmen, predominantly from 100 Mile House, (the 100 Mile Group) requested funding from the FRDA II(5) Program - Opportunity Identification, to test the use of local wood species (trembling aspen and white spruce) in a thick veneer slicing machine and a radio frequency veneer dryer.

The 100 Mile Group includes a variety of forest sector enterprises, including a lumber and plywood producer, forestry machinery manufacturers, trade and industry consultants, a log home builder, and a logging contractor. Collectively, they have the capability to 'bring on' a project if a business plan indicates a feasible venture.

The 100 Mile Group has identified a variety of thick veneer products that could be produced by the veneer slicer using local B.C. timber resources. Test samples of veneer, sliced and dried to their specific requirements were needed to investigate potential markets with their existing trade contacts.

At the same time the FRDA II Opportunity Identification Committee had become aware of the broader interests of other potential end users of both the product and the technology. As a result of this interest, this project was developed to address some specific technical questions related to the feasibility of producing thick veneer products.

The study reported here was developed and carried out by Forintek Canada Corp. (as an independent research organization) in consultation with the 100 Mile Group and the FRDA steering committee. It was designed to focus on certain essential facets of the slicing and drying processes.

1.2 THICK VENEER SLICING AND DRYING TECHNOLOGY

1.2.1 Lengthwise Slicing Technology

The lineal slicing of veneers from green wood flitches or boards was first developed in Japan approximately thirty years ago. Two Japanese firms, Marunaka Tekkoshu Inc. and Amitec Corporation (formerly Takekawa Iron Works Co. Ltd.) have developed most of the necessary equipment for a lengthwise veneer slicing plant including veneer slicers, knife grinders, and roller type veneer dryers. This technology was first introduced to North America about twelve years ago.

The lengthwise slicer is reported to have several advantages over the conventional guillotine type slicer: an improved surface quality due to following the grain of the wood, no limitation to flitch length, and a higher yield of veneer since dogging of the flitch is not required. This latter feature has made it practical to use thinner flitches than processed with conventional veneer slicers which slice across the grain.

Over fifty lengthwise veneer slicing plants have been installed in North America, of which nine are reported to be in Canada. The vast majority of these plants produce veneer in conventional thicknesses, seldom exceeding 0.150 inch (3.8 mm). These are used in various applications where laminating of a clear veneer on a solid or composite wood substrate is required. In the western U.S.A., for example, Ponderosa pine is now commonly sliced to produce veneer overlays for door stiles and other millwork products.

More recently, Marunaka has developed a thick veneer slicer capable of slicing up to 1/2-inch (13 mm) thick veneer. This compares to a maximum of about 1/4-inch (6 mm) thick veneer for other models. There have been five such thick slicers sold in North America including one in the western U.S.A. and one in Canada (Quebec). While these thick slicers have a stated maximum thickness of 1/2-inch (13 mm), the quality requirements of most products is said to impose a practical thickness limit of about 3/8-inch (9.5 mm).

A German manufacturer (Linck) has also developed a thick slicing machine in the past few years which is reportedly capable of slicing a maximum of 12 mm thick. The authors are unaware of any installations of this equipment in North America.

The emergence of the thick veneer slicer has created a new opportunity to develop markets for wood products sliced to thicknesses greater than conventional veneer and thinner than sawn lumber. The development of these opportunities is contingent on the ability of the technology to produce products of acceptable quality at competitive costs.

1.2.2 Veneer Drying Technology

Roller-type dryers using hot air to dry the veneer are commonly used by veneer slicing plants, and are usually supplied by the slicer manufacturer. Some plants, however, use kiln chambers in which kiln carts are placed with veneer stacked in layers separated by stickers. The veneer is dried by circulating heated air through the loads, similar to the manner in which lumber is dried.

Recently however, a new radio frequency (RF) veneer dryer has been developed by PMI Production Machinery Inc. of Bend, Oregon. It is being used commercially at a veneer slicing plant to dry veneer sliced to thicknesses from 0.060 to 0.100 inch (1.5 - 2.5 mm). It is claimed to produce a high quality dried product of consistent final moisture content with no wet spots and with a very short drying time. The dryer uses RF energy to heat the green wood and a system of air jets blowing across the veneer surface to remove moisture as it evaporates. The RF energy source and dryer speed can be adjusted to accommodate veneers of different species, moisture content or thickness.

2.0 OBJECTIVES

The objective of the work was to evaluate commercial slicing and radio frequency drying technology for the processing of trembling aspen and white spruce into thick veneer. More specifically, the objectives were as follows:

1. Evaluate the quality of the veneer produced by the slicing equipment under normal process conditions, and in the case of aspen, with and without the usual conditioning process;
2. Evaluate the quality and final moisture content of the veneer dried by conventional drying at Boise, Idaho;
3. Evaluate the quality, drying time, and final moisture content of the veneer dried by radio frequency at Medford, Oregon.

3.0 MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Sample Collection

The main species used in this study was trembling aspen (Populus tremuloides) because of both specific market opportunities identified by the industrial interests supporting this project, and its current under-utilization in British Columbia. The use of the RF drying technology for this species was of particular interest since aspen is known to be a difficult species to dry. White spruce (Picea glauca) was also used for more limited tests due to perceived market potential for thick veneer products from this species.

The aspen and spruce raw material for this study was collected in July in the 100-Mile House area of British Columbia in a four week period prior to the slicing and drying tests. Three-inch thick flitches were sawn at a small sawmill from spruce logs available at the mill yard. These were stored close-piled in a closed shed for a two-week period while suitable aspen was being obtained. Several aspen trees were felled, and transported to the sawmill where they were also processed into flitches for slicing. Some two-inch flitches were accepted due to difficulties in obtaining all 3-inch thick material. All flitches selected for the tests were essentially clear. Some stain was present in a few of the aspen flitches. The number and size of flitches selected are shown below:

Species	Number of Flitches	Size (thickness x width)
Spruce	8	3 x 3 inch
	8	3 x 6 "
	1	3 x 8 "
Aspen	6	3 x 4 "
	12	3 x 6 "
	7	3 x 8 "
	7	2 x 3 "
	4	2 x 4 "
	8	2 x 6 "

The flitches were transported in a covered truck to a Boise, Idaho plant for slicing.

3.2 METHODS

3.2.1 Sample Processing Plan

Sufficient aspen and spruce flitches were produced to provide enough veneer slices to be used in ten different batches or drying runs. These drying runs were designed to examine the effects of several different variables on drying time and final product quality. These variables included the following:

drying method: A conventional batch kiln drying process was used at Boise. The RF drying method was used at Medford, but this dryer was set up to handle a maximum veneer thickness of 6.5 mm.

veneer thickness: Only 6.5 mm slices were required from the spruce, whereas both 6.5 and 8.5 mm slices were required from the aspen. All 8.5 mm slices were dried at Boise.

pre-treatment of flitches: Conditioning of flitches by subjecting them to high moisture and temperature conditions is normal practice prior to slicing. All the spruce and about half of the aspen flitches were conditioned prior to slicing. The remaining aspen flitches were left unconditioned since published literature on rotary peeling of aspen veneer recommends doing so at temperatures from 32° to 70°F (Feihl and Godin, 1975). The resulting ten batch runs were planned as shown below.

Batch Number	Species	Thickness	Conditioning	Drying Method
1	spruce	6.5 mm	yes	conventional
2	"	"	"	RF
3	"	"	"	RF
4	aspen	6.5 mm	yes	conventional
5	"	"	"	RF
6	"	"	"	RF
7	"	"	no	RF
8	"	"	no	RF
9	"	8.5 mm	yes	conventional
10	"	"	no	conventional

For the RF dryer, three extra drying runs were incorporated into the plan, batch numbers 2, 5 and 7. These were to be used as necessary to adjust the RF dryer for both the different species and thicker than normal (1.5-2.5 mm) veneer.

3.2.2 Industrial Test Sites

To carry out the slicing and drying tests, two industrial test sites were required, one capable of thick slicing and the other with the RF dryer described in the introduction.

The thick veneer slicing took place at Quality Veneer near Boise, Idaho, the only such plant in western North America. This plant also dries veneer in a batch-type kiln drying operation which was used to dry the thick veneer. The second co-operating plant was Western Veneer and Slicing near Medford, Oregon which owns the first production model of the Production Machinery Inc. RF veneer dryer.

3.2.3 Conditioning

On delivery of the sawn flitches to the Boise plant, sufficient aspen flitches for batch numbers 7, 8 and 10 were set aside to be left in an unconditioned state. The remaining flitches were placed in a conditioning chamber along with the plant's normal pine raw material to be subjected to heat and moisture in the form of hot water and/or steam sprays at temperatures of 140° - 150°F for a period of approximately 24 hours just prior to slicing. These are the same conditioning temperatures the plant normally uses for ponderosa pine.

3.2.4 Test Slicing of Thick Veneer

The test material was sliced at the end of a normal production shift. Test flitches were removed from conditioning as required to run batches through the slicer. Batch and slice numbers were recorded on all veneer slices as produced, and the batches segregated for drying at Boise or for transport to Medford.

The slicing machine at Boise is calibrated in imperial units and had previously sliced a maximum of 0.187 inch (4.7 mm). For these tests, the green target thickness was set at 0.256 inch for the 6.5 mm veneer and 0.335 inch for the 8.5 mm veneer. This required an adjustment of both the knife (infeed bed height) and nosebar. The spacial relationship between the knife and nosebar is critical to the quality of veneer produced. The settings used for the test were a "best guess" on the part of plant personnel based on their previous experience. The specific settings used by the plant were considered proprietary information, and due to the experimental nature of these tests, not necessarily optimum.

The slicing was done in two steps. First the slicer was adjusted to remove sufficient wood from the bottom of each flitch to develop a clean-cut surface on the full width and length of the flitch. Then the slicer was re-adjusted to the target thickness and slicing proceeded continuously until each flitch was almost entirely converted to veneer slices. As is normal, the uppermost slice or "backing board" was not processed in the slicer due to potential damage to the hold down belt pushing the flitch through the machine. In this test, the "backing board" from each flitch was not recovered.

Immediately after slicing, batches 2, 3, 5, 6, 7, and 8 were carefully wrapped for transport to Medford, Oregon. Ten pieces randomly selected from each batch were weighed before wrapping. These pieces served as control samples to monitor any moisture loss during transportation. Upon arrival in Medford all pieces were stored under ambient conditions and kept wrapped until the RF drying runs were carried out.

3.2.5 Conventional Drying (Boise)

Immediately after slicing, batches 1, 4, 9 and 10 were prepared for kiln drying. Before loading the veneer onto kiln carts, all pieces were marked and weighed. Photo 1 (Appendix 1) illustrates the stickering arrangement utilized for the conventional drying. One-inch stickers were placed at approximately 2-foot intervals in each row.

According to plant personnel, all veneer slices were subjected to a mild drying schedule in order to ensure a high quality of the final product. Information regarding the actual drying schedule utilized as well as the type of conventional dryer was not available.

A moisture content of about 12% was set as the target value. To avoid overdrying and associated loss of quality, plant personnel checked the moisture content at regular time intervals during the drying process using an electric moisture meter. Various pieces located in the upper layers of the veneer stack were checked for moisture content to obtain an average for the stack.

After 11.5 hours, plant personnel removed all the spruce veneer from the dryer since, according to their assessment, most pieces were very close to the target moisture content of 12%. Following the same criteria, the drying of all aspen veneer was stopped after 31.5 hours.

After drying, all pieces were allowed to reach ambient temperature, and moisture content was determined with an electric resistance type moisture meter.

Moisture content measurements were made in three locations along the length of each piece to detect the presence of wet pockets. In addition, all pieces were weighed so that further estimates of moisture contents could be made using the oven dry method.

All pieces were also visually inspected for degrade such as collapse, checks and splits. After inspection, all pieces were wrapped in polyethylene (photo 2) for transport to Forintek facilities in Vancouver for further analysis of moisture content and quality.

3.2.6 Radio Frequency Drying (Medford)

The RF dryer used in the study has a 60 inch wide opening for veneer and a 24 ft long heating zone. The RF generator is power rated at 150 Kw but according to a PMI representative it is oversized for the current production demands. This particular RF dryer normally operates under 100 Kw at this operation. Additional information concerning the dryer can be found in Appendix 2.

3.2.6.1 Development of an Experimental Drying Curve

The main processing variables that could be controlled on the RF dryer were: a) RF power and b) kiln residence time.

Since no previous information on the RF drying of 6.5 mm thick spruce and aspen was available, it was decided that the drying experiments would be carried out using the same RF power level normally used by the plant, that is, 100 Kw. Under this power level, Ponderosa pine veneer, 0.075 inches thick, is usually dried in 45 seconds from an initial moisture content of 30% down to a final moisture content of approximately 8 to 10%.

The remaining variable to be dealt with was kiln residence time which is a function of the conveyor speed. As a starting point, the conveyor speed was set to a value which corresponded to travelling through the RF dryer length in approximately 47 seconds, or at an approximate speed of 31 ft/min.

A total of ten veneer samples were randomly selected from batch 6 (aspen 6.5 mm), weighed, and immediately fed into the dryer (photo 4). After the first pass through the dryer, all ten samples were re-weighed and immediately re-loaded into the dryer for the second pass through. This procedure was repeated ten times. A preliminary drying curve was constructed based on the data points obtained after each pass through the RF dryer. This preliminary drying curve was used to determine the conveyor speed to be used in subsequent drying runs. The preliminary drying curve was developed to estimate drying times in order to avoid overdrying and underdrying. Since at that point the initial moisture content was unknown, the preliminary drying curve was mainly used to determine the moisture loss as a function of time and to indicate sudden changes in the curve which would represent a late stage in the drying process. Changes in the drying curve can be used to optimize drying schedules and to estimate drying times.

All samples used to develop the preliminary drying curve were brought to the Forintek laboratory in Vancouver where ovendry tests were performed in order to accurately determine initial and final moisture contents.

Since it was apparent that the initial moisture content of the spruce was lower than the aspen, it was assumed that the kiln residence time for spruce would have to be considerably shorter than that indicated by the experimental drying curve developed for aspen.

3.2.6.2 RF Drying Runs

The drying test runs were initiated immediately after developing the experimental drying curve. Before each run the ten monitoring samples were weighed to determine whether any moisture loss had occurred during transportation. All pieces were weighed before and after each RF drying run (Photo 3) to accurately determine the actual moisture loss during drying.

The RF dryer was set up to maintain the same drying conditions used for developing the experimental drying curve. The conveyor speed was set up to provide a kiln residence time approximately equal to the estimated drying time obtained from the preliminary drying curve. At the end of the each drying run all samples were weighed and visually inspected for drying degrade. After this preliminary assessment, all batches were individually wrapped and transported to the Forintek laboratory in Vancouver for further analysis.

3.2.7 Quality Assessment

The quality of the sliced veneer was assessed in several ways.

The thickness accuracy of the green sliced veneer was measured by plant personnel at the Boise plant using calipers calibrated in thousandths of an inch.

Veneer smoothness or roughness is a relatively subjective measure of quality. While a veneer-roughness scale has been developed and used for rotary-peeled softwood veneer, it was not considered appropriate for use in this study since all the sliced veneer would meet the smoothest classification on this scale.

3.2.7.1 "Lathe" Checks

The depth of "lathe checks" or "stress cracks" was considered to be one of the most important measures of quality in the thick sliced veneer. To assess the check depth, ten slices from each batch were randomly selected and tested using a method described by Hailey and Hancock (1973).

A dark blue dye was applied across the surface of sample slices at one foot from the end and allowed to penetrate and dry. A smooth saw cut was made across the slices through the blue-dyed section to reveal the depth to which the dye had penetrated the samples via the lathe checks. A visual estimate was then made of the depth of penetration expressed as a percent of veneer thickness (see Photos 5 and 6).

3.2.7.2 Collapse and Splitting

A representative sample from each batch was separated for a detailed analysis of degrade such as collapse and splits. The inspection for degrade concentrated mainly on those samples containing stain since it is known that drying degrade is not unusual in aspen containing appreciable stained areas. This analysis was done to verify whether or not degrade such as collapse and splits would have been influenced by either the drying method or type of treatment.

4.0 RESULTS

4.1 SLICING

4.1.1 Veneer Slice Thickness

The veneer slice thickness measured by plant personnel at the time of slicing, for both aspen and spruce, was as follows:

nominal	target	accuracy
6.5 mm	0.256 inch	± .008 inch
8.5 mm	0.335 inch	± .008 inch

This represents the maximum deviation from the target thickness. The thickness variation in the thick-sliced veneer exceeded the ± .003 inch which the plant claims is normal for thinner veneer. It is quite possible that the thickness variation could be improved upon with optimization of the knife and nose bar positions.

4.1.2 Veneer Recovery

The actual production of green veneer slices by batch is shown in Table 1.

TABLE 1. Veneer Slice Recovery			
Batch Number	Species	Slice Thickness	Number of Slices
1	Spruce	6.5 mm	80
2	"	"	80
3	"	"	-
4	Aspen	6.5 mm	88
5	"	"	44
6	"	"	44
7	"	"	43
8	"	"	42
9	"	8.5 mm	35
10	"	"	56

Total spruce slices - 6.5 mm = 160
Total aspen slices - 6.5 mm = 261
Total aspen slices - 8.5 mm = 91

Veneer recovery was estimated on the basis of the number and thickness of veneer slices recovered by species in relation to the volume of sample flitches processed. The veneer recovery on this basis was estimated using the formula:

$$\% \ Recovery = \frac{Number\ of\ slices \times slice\ thickness}{Number\ of\ flitches \times flitch\ thickness} \times 100$$

The veneer recoveries estimated using this formula were as follows:

$$\underline{spruce}: \ \frac{160 \times .256}{17 \times 3} \times 100 = \underline{80.3\,\%}.$$

$$\underline{aspen}: \ \frac{(261 \times .256)}{(25 \times 3)} + \frac{(91 \times .335)}{(19 \times 2)} \times 100 = \underline{86.1\,\%}.$$

At the time of slicing, it became apparent that some of the spruce flitches had become too dry to process effectively. Near the end of the spruce sample, excess splitting occurred as a result of the dry wood. The remaining material was left unsliced, which accounts for the lower yield obtained.

No such problems occurred with the aspen flitches, and the aspen yield is therefore more indicative of the veneer recovery that is obtainable.

It should also be noted that no veneer was recovered from the "backer board" from each flitch in this test. In an operating plant this can be done by reprocessing the backerboard through a planer or belt sander if it is thick enough to do so. If this were done with the test material the aspen veneer recovery could be increased to as high as 93.6 percent.

The actual veneer yield obtainable is dependant primarily on the relationship between flitch and veneer thicknesses, and the variability in flitch thickness. In an operational situation there may be opportunities to specify flitch thicknesses which will maximize recovery. This was not attempted in these tests.

4.2 DRYING TEST RESULTS

4.2.1 Conventional Kiln Drying (Boise)

The results of the conventional kiln drying runs are shown in Table 2.

The initial moisture content of the spruce was too low to slice satisfactorily. While the spruce dried to 13.7% moisture content in 11.5 hours, and would require a few more hours to reach the 12% target, the results cannot be used to predict drying times for the high moisture content spruce required for a normal slicing operation.

All three batches of aspen had high and quite variable initial moisture contents. This is typical of fresh-cut aspen. The drying time of 31.5 hours was longer than required to reach the 12% target moisture content. A final moisture content of about 8% was reached for all three aspen batches, and very uniform final moisture contents were obtained. While actual drying conditions inside the kiln were not available, the long drying times may have allowed for equalization of the final moisture contents at the end of the drying period. The type of treatment (conditioned versus unconditioned) does not appear to have affected the final moisture content distribution.

TABLE 2. Results of Conventional Kiln Drying Runs - Boise

Batch No.	Species	Treatment	Drying Time	Initial Moisture Content				Final Moisture Content			
				Avg.	Max.	Min.	Std. Dev.	Avg.	Max.	Min.	Std. Dev.
S6B1	spruce	cond.	11.5 hr.	22.5	42.9	13.7	5.7	13.7	17.0	11.5	1.1
A6B4	aspen	cond.	31.5 hr.	126.8	163.4	81.1	12.1	7.4	9.3	6.2	0.6
A8B9	aspen	cond.	31.5 hr.	103.5	133.5	74.3	20.3	9.0	11.3	7.7	0.7
A8B10	aspen	uncond.	31.5 hr.	107.1	151.2	78.2	19.6	7.5	9.0	6.2	0.6

On the basis of results obtained from these tests, it is expected that times to dry green aspen of 6.5 and 8.5 mm thickness to the 12% target would be 20-24 hours and 22-28 hours respectively in the conventional kiln.

Frequency distributions of initial and final moisture contents for all four batches dried at Boise are contained in Appendix III. These clearly illustrate the wide range of initial moisture contents and the uniformity of the final moisture contents. This suggests that no relationship exists between initial and final moisture contents for the test material. While results from the regression analyses were mixed in this regard, it seems safe to conclude that no such relationship exists. This is desired since the objective is to attain a reasonable final moisture content distribution regardless of a wide distribution in initial moisture contents. Figures illustrating these results are also shown in Appendix III.

Measurements made in three locations along the length of each sample found no wet pockets in any of the batches dried in the conventional drier at Boise.

4.2.2 Radio Frequency Drying (Medford)

4.2.2.1 Experimental RF Drying Curve

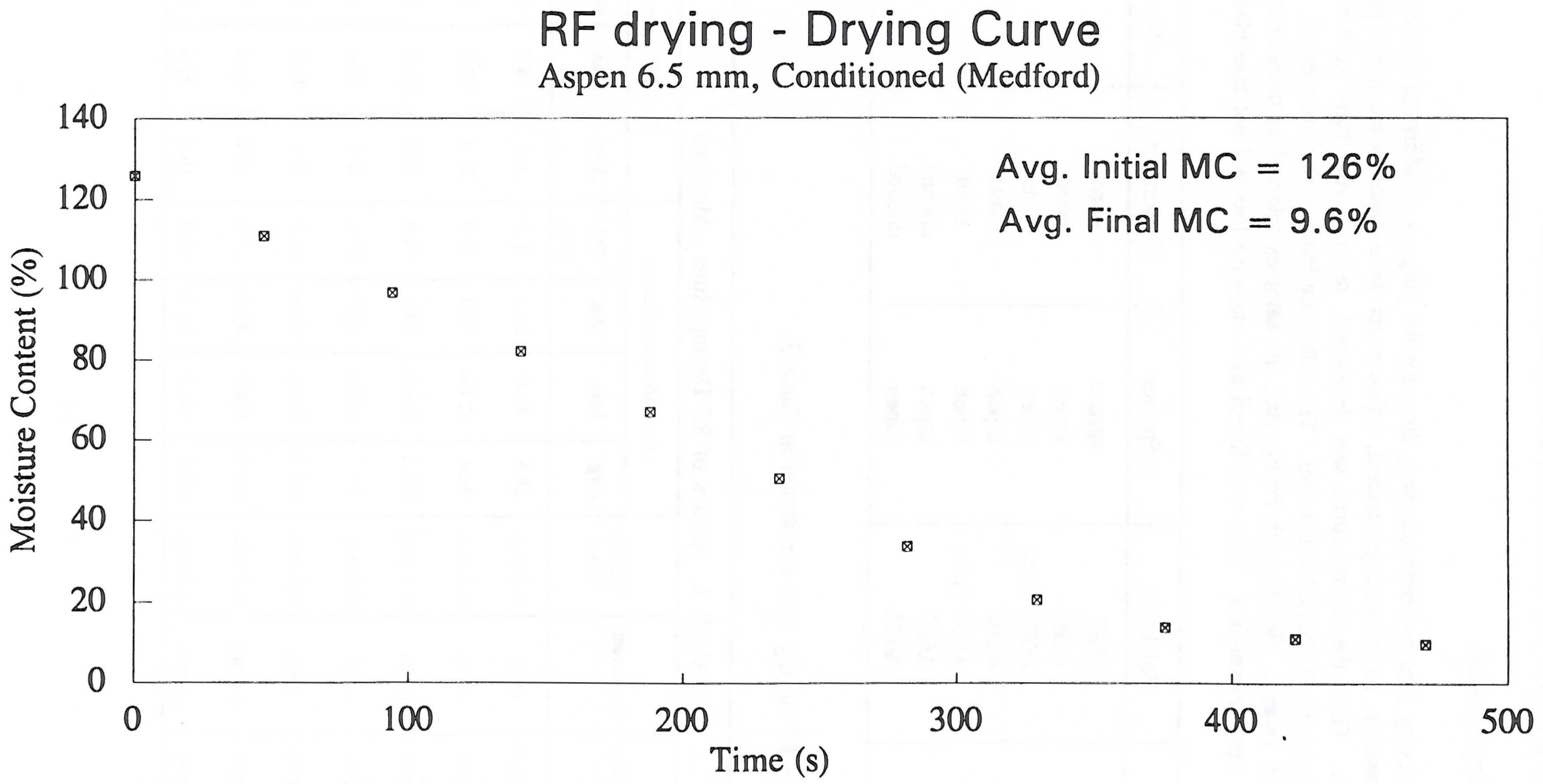
Before carrying out the RF drying runs, an experimental drying curve was developed to provide preliminary information regarding drying times and quality. Figure 1 illustrates the experimental drying curve developed.

Samples from batch A6B6 (Aspen, 6.5 mm, conditioned) were used to develop the drying curve. The total residence time was about 470 seconds (approximately 7.8 min.). All samples involved in the experiment were weighed after each 47 second pass through the dryer and, therefore, the drying curve accurately represents the overall moisture loss during the drying process.

As can be seen from Figure 1, the decrease in moisture content from the initial value of 126% to about 22% was reasonably linear. In practical terms this means that the rate of moisture removal (%/min) was constant until the average moisture content reached a value close to 22%. It took approximately 5.3 min to get down to that value.

The total drying time of 7.8 min was considered to be too long and based upon this preliminary assessment, it was decided to try shorter drying times as discussed below.

According to the RF dryer manufacturer, Ponderosa pine and Douglas-fir 3.8 mm thick veneer, with moisture contents ranging between 25 and 30%, take approximately 35 to 38 seconds to dry down to 12 to 16%. This represents about 10% of the total time that was required to dry aspen 6.5 mm thick with an initial moisture content of about four times greater. In practical terms it means that



Drying curve developed at industrial site
Fig. 1

it took twice as long to dry aspen 6.5 mm thick when compared to the reported drying times for Douglas-fir 3.8 mm thick if the same moisture content basis is used. This is thought to be a species effect, as aspen is known to dry much slower than spruce and pine.

4.2.2.2 RF Drying Runs

Initially, six RF drying runs had been planned, three for the purpose of adjusting the dryer and three "data" runs. However, as the tests proceeded, adjustments were made to the initial plan to fit the evolving situation. Once the drying curve was developed, seven drying runs were made, two of which were sub-samples of planned batch runs. The following batches were processed. All of these runs used 6.5 mm veneer. Before each drying run, the samples selected to monitor moisture loss during transport were re-weighed. This established that moisture loss did not take place in transit.

Run No.	Batch No.	Species	Treatment	No. of pcs.
1	S6B2	spruce	cond.	80
2	A6B5	aspen	cond.	22
3	A6B5 (sub)	aspen	cond.	22
4	A6B6	aspen	cond.	34
5	A6B6 (sub)	aspen	cond.	10
6	A6B7	aspen	uncond.	43
7	A6B8	aspen	uncond.	42

The results of the RF drying runs are shown in Table 3.

TABLE 3. Results of RF Drying Runs - Medford

Batch No.	Species	Treatment	Drying Time	Initial Moisture Content				Final Moisture Content			
				Avg.	Max.	Min.	Std. Dev.	Avg.	Max.	Min.	Std. Dev.
S6B2	spruce	cond.	4.0 min.	28.8	49.6	21.1	5.7	8.1	18.7	6.3	1.6
A6B5	aspen	cond.	5.0 min.	96.6	129.6	62.3	19.9	21.5	32.0	9.0	7.5
A6B5 (sub)	aspen	cond.	6.5 min.	107.1	129.6	79.7	14.0	15.0	22.7	9.0	3.8
A6B6	aspen	cond.	5.0 min.	85.7	160.4	48.7	27.3	25.2	32.0	7.8	8.9
A6B6 (sub)	aspen	cond.	7.8 min.	127.3	160.4	107.0	15.2	9.6	18.0	7.8	3.2
A6B7	aspen	uncond.	6.5 min.	104.3	124.5	83.0	11.0	16.0	21.3	8.3	3.0
A6B8	aspen	uncond.	6.5 min.	112.5	136.3	86.6	12.9	16.4	22.3	8.7	4.0

Although the drying time for the spruce was reduced to 4.0 minutes, the slices were still overdried due to the low initial moisture contents. Since flitches with higher initial moisture contents should be used, these drying results are not indicative of what can be expected on an operational basis.

A total of six aspen drying runs were made, two of which were subsamples of other runs. Based on the preliminary results from developing the drying curve, drying times of 5.0 minutes were tried initially, and subsequently extended to 6.5 minutes as it became apparent that the shorter time was inadequate to reach the 12% target final moisture content.

The initial moisture contents for the aspen runs were high and quite variable, similar to the material dried at Boise. Final moisture contents attained related directly to drying times. Batches dried for 5.0 and 6.5 minutes were underdried, averaging about 22% and 16% final moisture content respectively. At a time of 7.8 minutes, a final moisture content of about 10% was reached. From these data a drying time of about 7.2 minutes is estimated to reach the 12% target.

Since the RF dryer was run at a power level of 100 Kw, but is capable of 150 Kw, reductions in drying time may well be possible at higher power levels. This approach to drying time reduction would have to be weighed against any effects on veneer quality.

It is apparent from Table 3 that batches dried for the longest time attained the most uniform final moisture contents. Frequency distributions of initial and final moisture contents for the batches dried by RF are contained in Appendix IV. Again, regression analyses were performed to determine whether any relationship exists between the initial and final moisture contents. As with the Boise drying runs, the results of these analyses were mixed. It is concluded that no such relationship can be established based on the study data. Figures illustrating these results are shown in Appendix IV.

The conditioning treatment does not appear to have had an effect on either drying rates or final moisture content distribution in the RF drying process. Also similar to results at Boise, wet spots were not evident in the aspen processed in the RF dryer.

4.2.3 Comparison of Drying Results

The large difference in drying times between conventional and RF drying methods was anticipated at the outset of this study. While the aspen dried in the chamber kiln at Boise appears to have a more uniform final moisture content, this result must be interpreted with caution. One reason for this difference may be the lower moisture content to which slices were dried at Boise. Also, equalization at the end of the cycle may have contributed to the uniformity in final moisture content at Boise. The final moisture contents for the RF dryer do not reflect any equalization which would inevitably take place subsequent to drying.

The lack of wet spots in the aspen dried at both locations may reflect a lack of "wet-wood" in the test material, which was largely sapwood. Wet-wood, which leads to wet spots in dried products, is normally encountered in the transition zone between heartwood and sapwood.

For the aspen dried with both drying methods, very little relationship could be found between the initial and final moisture content distributions. In many cases, pieces with the highest initial moisture contents ended up with moisture contents among the lowest in the batch.

4.3 QUALITY AFTER DRYING

4.3.1 "Lathe" Checks

The evaluation of the depth of "lathe" checks was performed on 10 samples from each batch of dry veneer at the laboratory. The results are shown in Tables 4 and 5. The depth of checks is a subjective visual estimate of the proportion of the slice thickness to which the checks extend, expressed as a percent of the thickness. Due to the subjective nature of the assessment method, a statistical analysis is inappropriate. However, a few broad conclusions appear to be valid.

First, by comparing the average values for the 6.5 mm spruce and conditioned aspen in Tables 4 and 5, it is confirmed that the drying method had no obvious effect on the depth of checks. From the three aspen batches in Table 4, it would also appear that the veneer slice thickness (6.5 vs 8.5 mm) did not have an effect on check depth. However, conditioning the aspen appears to have significantly reduced checking relative to the unconditioned aspen. This latter observation is supported by the average values in Table 5 for conditioned and unconditioned aspen.

The spruce samples exhibit deeper lathe checks than conditioned aspen of the same thickness. This is believed to be a result of the dryness of the spruce at the time of slicing. The veneer slicer manufacturer's representative recommends that flitches for slicing be no less than 22% moisture content. By comparison, over 42% of the spruce dried at Boise and almost 25% of the spruce dried at Medford were of lower moisture content.

Management at the slicing plant have indicated that three main factors affect the depth of checks: conditioning reduces it, high moisture content reduces it, and thicker veneer increases it. Only the latter effect is not substantiated by the results of this study. However, it is reasonable to expect deeper checks in thicker slices.

It is expected that check depth in the spruce can be reduced significantly by processing flitches at higher moisture content. A reduction in check depth may also be possible through optimizing the conditioning process and optimizing the knife and nosebar settings on the veneer slicer.

4.3.2 Collapse and Splitting

Since visual inspection of the aspen slices showed some evidence of collapse and associated splitting in stained areas, a more extensive evaluation of available samples was made. The results of this degrade analysis is presented in Table 6. Since some samples had been used for separate market-related studies at this point, a reduced number of samples were evaluated.

TABLE 4. Depth of Lathe Checks, Expressed as a Percent of Thickness, in Batches Dried at Boise (Conventional)

Batch No. Species Thickness Treatment	1 spruce 6.5 mm cond.	4 aspen 6.5 mm cond.	9 aspen 8.5 mm cond.	10 aspen 8.5 mm uncond.
	60	50	40	80
	30	20	20	60
	30	30	30	70
	60	30	20	70
	60	30	20	60
	50	40	40	60
	70	20	20	70
	60	25	20	60
	60	20	20	80
	50	25	30	60
Average (%)	53	29	26	67

TABLE 5. Depth of Lathe Checks, Expressed as a Percent of Thickness, in Batches Dried at Medford (RF).

Batch No. Species Thickness Treatment	2 spruce 6.5 mm cond.	5 aspen 6.5 mm cond.	6 aspen 6.5 mm cond.	7 aspen 6.5 mm uncond.	8 aspen 6.5 mm uncond.
	70	10	40	30	50
	60	15	10	40	70
	60	20	30	35	50
	50	20	10	30	50
	50	30	40	50	50
	70	40	30	60	50
	40	10	30	5	70
	40	30	20	45	70
	40	10	10	25	60
	50	10	20	40	50
Average (%)	53	20	24	36	57

Note: Depth of checks based on visual assessment.

TABLE 6. Analysis of Defect Occurrence in Stained Wood Areas.

		Stain Present		Defects in Stained Area		
Batch Number	Number of Samples	No	Yes (%)	Checks Number (%)	Collapse Number (%)	No Defects Number
CONVENTIONAL DRYING - BOISE						
S6B1	74	54	20 (27)	0 (0)	5 (25)	15
A6B4	86	53	32 (38)	21 (66)	31 (97)	0
A8B9	15	14	1 (7)	0 (0)	1 (100)	0
A8B10	24	15	9 (38)	3 (33)	7 (78)	2
RF DRYING - MEDFORD						
S6B2	35	22	13 (37)	0 (0)	0 (0)	13
A6B5	42	18	24 (57)	6 (25)	21 (88)	3
A6B6	41	16	25 (61)	1 (4)	24 (96)	1
A6B7	41	21	20 (49)	4 (20)	12 (60)	8
A6B8	40	27	13 (33)	0 (0)	7 (54)	6

A statistical evaluation was carried out to determine any significant differences in these results. Most pieces of aspen with stained areas also had collapse. Aspen veneer slices that were conditioned showed a higher incidence of collapse when compared to unconditioned slices. No significant difference in degrade pattern is discernable between the two drying methods. The high incidence of collapse in stained areas of aspen points out the difficulty of achieving acceptable final product quality in this material. These results correspond to those previously found by Mackay (1975) who investigated the properties of discoloured aspen wood. Whether these defects appeared in the veneer during drying or during subsequent storage, as is known to happen with this species (Mackay, 1976) is not known.

5.0 CONCLUSIONS

Overall, the results show that conditioned aspen can be successfully sliced to 6.5 mm and 8.5 mm thicknesses in terms of the yield and quality of the dried product. Unconditioned aspen produced poorer quality. The R/F veneer dryer provided good drying results for the 6.5 mm slices, as did the conventional lumber dryer for both thicknesses.

The aspen flitches processed were of high, but quite variable moisture content. Drying time in the conventional dryer was excessive (31.5 hours) and could likely be reduced to 20-24 hours for 6.5 mm veneer and 22-28 hours for the 8.5 mm veneer to meet the 12% target moisture content. In the RF drying runs, 6.5 mm aspen reached 16% moisture content in 6.5 minutes and 10% moisture content in 7.8 minutes. Drying time to the 12% target is estimated at 7.2 minutes. Conditioning of flitches did not affect the drying rates for the veneer.

Veneer slice recovery from the aspen flitches was 86.1% in the test. The slice thickness was on target ±.008 inch which is considered acceptable. The depth of "lathe" checks in veneer appeared to be acceptable in the case of conditioned flitches, but to be excessive in the case of the unconditioned flitches. Acceptability of the thickness variation and lathe checks should be viewed in the context of final product specifications and the intended end use. Stained aspen wood should be avoided due to the high occurrence of collapse and checks in the stained areas.

The spruce flitches processed in this study were overly dry, which contributed to lower slicing yields, increased depth of "lathe" checks and overdrying in the RF dryer. It is expected that these results could be improved significantly by maintaining flitches at higher moisture contents.

Since a choice between the two drying technologies cannot be made on the basis of the quality of the final product as observed in this study, production requirements and an economic comparison should be used for this purpose. Drying times for both RF and conventional drying methods can be used to determine dryer size requirements. The economic analysis should include the capital costs of both RF and batch kiln dryers of the same daily capacity, the energy costs for dryer operation, any expected differences in labour costs, and any perceived benefits of reduced inventory or just-in-time delivery associated with the short RF drying times.

6.0 RECOMMENDATIONS

The results obtained in this study must be viewed in the context of their exploratory nature. Since the plants had no previous experience slicing and drying the 6.5 and 8.5 mm veneer from aspen and spruce, optimum results could not be expected.

In spite of this, good results were obtained, particularly for the conditioned aspen. If improved slicing accuracy and veneer quality are required, two processing variables should be explored further. First, an attempt should be made to optimize the knife and nosebar positions for the thick veneer. The second item to determine is the optimum conditioning time and temperature for each species.

In terms of drying, it should be relatively easy to determine the appropriate drying times for 6.5 mm and 8.5 mm veneer in the conventional dryer based on the results of this study. While estimated drying times for the RF dryer have been made for aspen, these could be further refined. Also, the RF power can be adjusted upward in an effort to reduce drying time. This is worth exploring further, taking into account the resulting quality of the final product. The tests reported here were limited to 6.5 mm due to mechanical constraints imposed by the set-up of the RF dryer. It may be feasible to test dry thicker veneer using a PMI proto-type dryer set up for this purpose under a more controlled set of test conditions.

7.0 REFERENCES

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APPENDIX 1

STUDY PHOTOGRAPHS

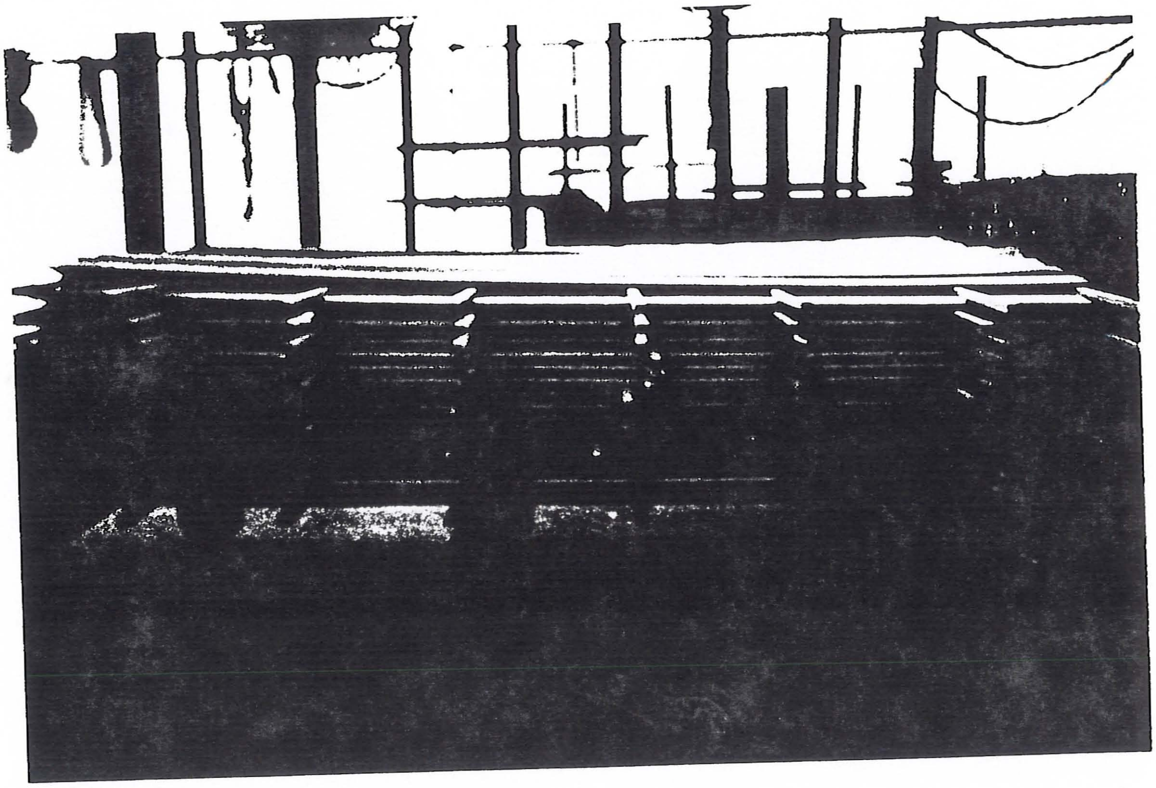


PHOTO 1. Veneer slices stacked for conventional drying (Boise).

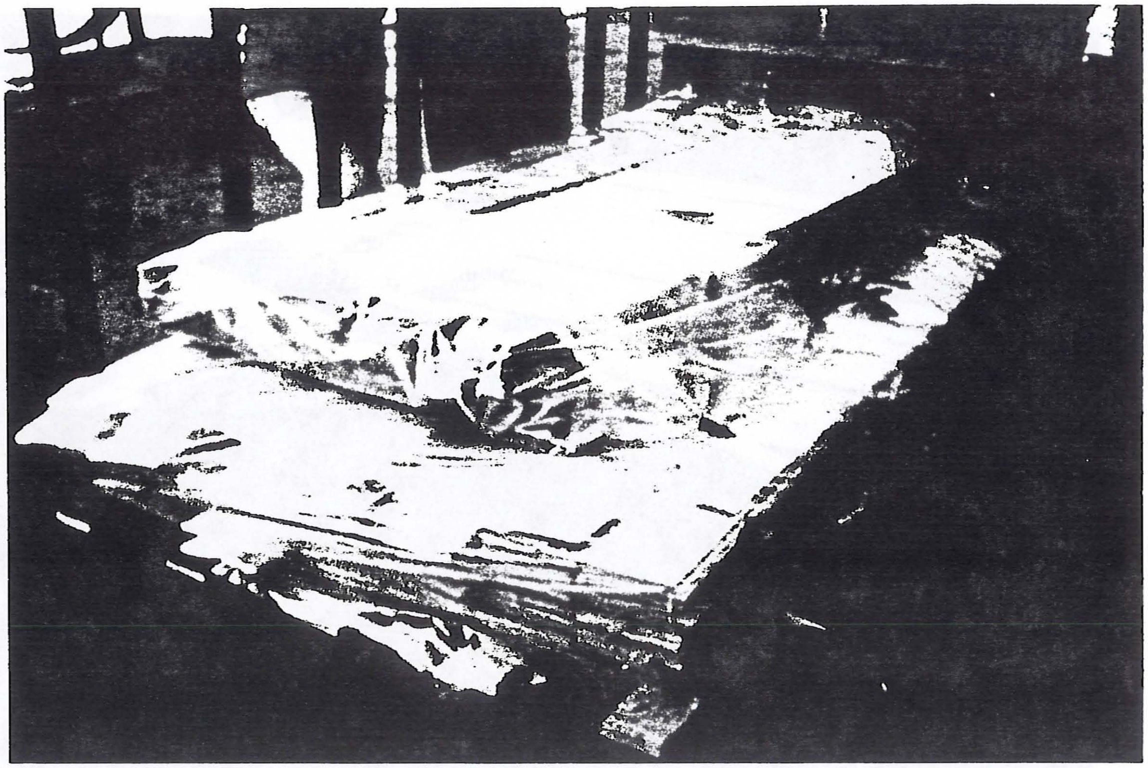


PHOTO 2. Green veneer sliced in Boise wrapped for transport to Medford.

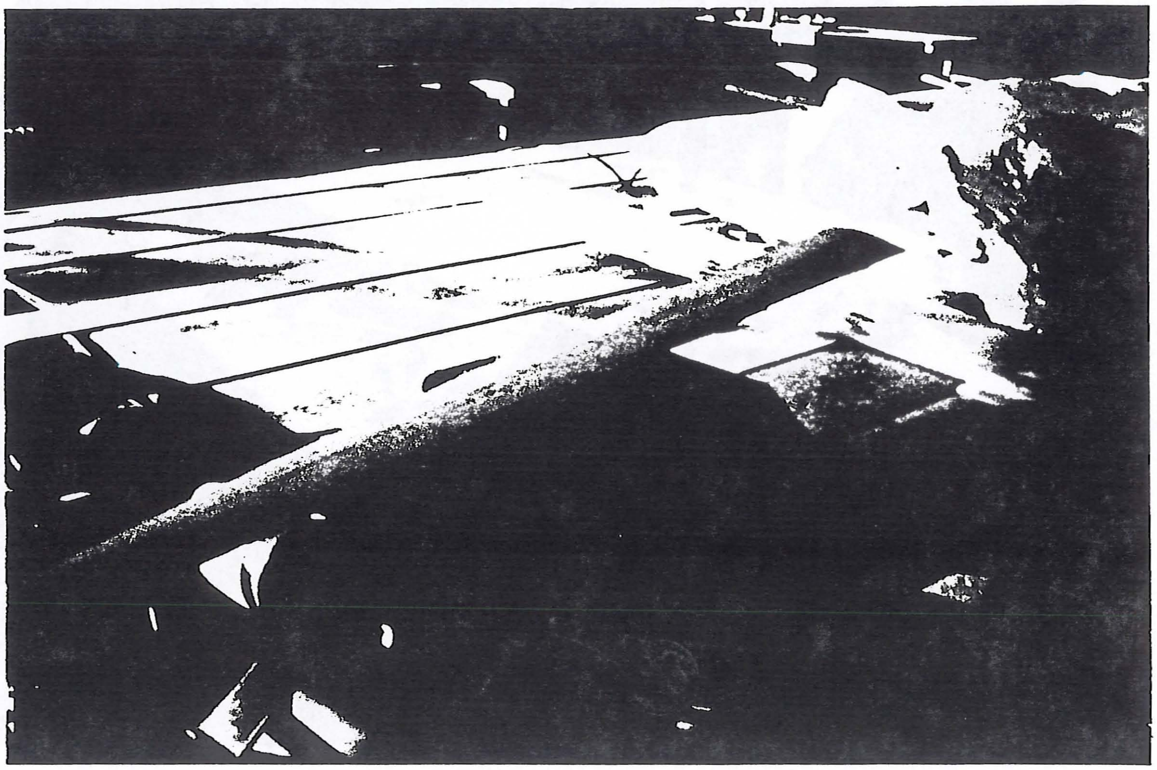


PHOTO 3. Weighing veneer slices before RF drying (Medford).

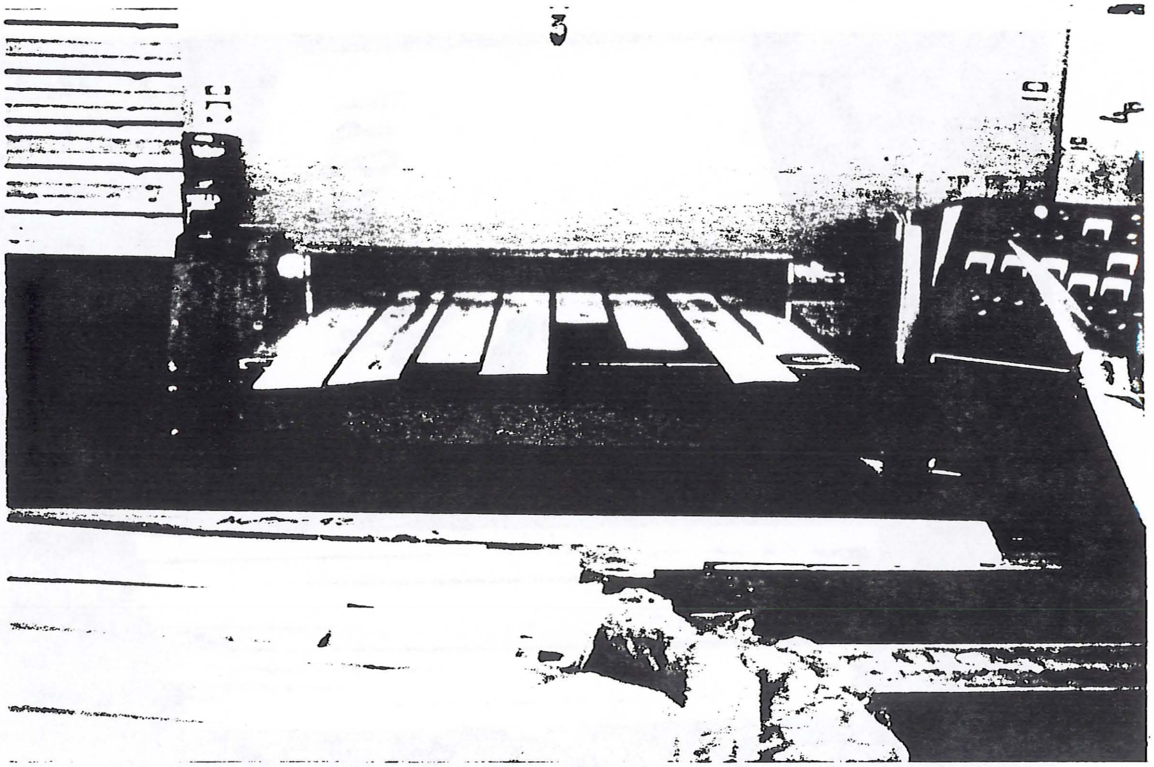


PHOTO 4. Developing the experimental drying curve for 6.5 mm aspen in the RF dryer.

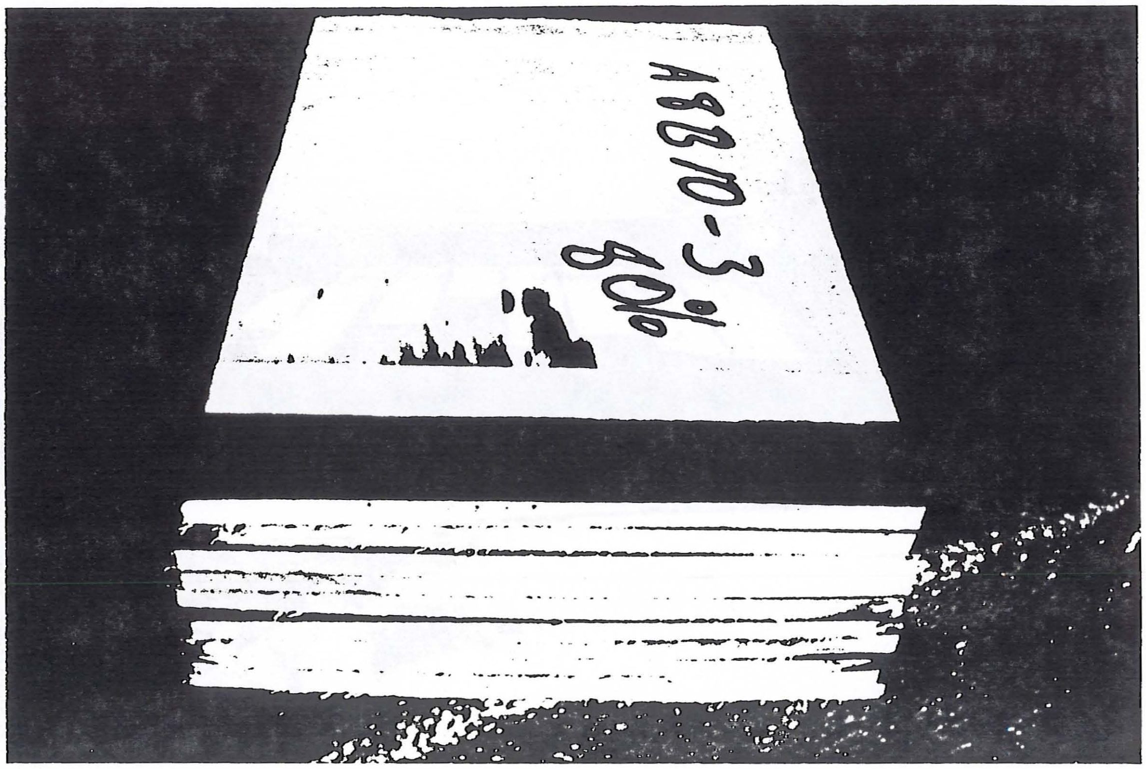


PHOTO 5. Determining lathe check depth in 8.5 mm unconditioned aspen.

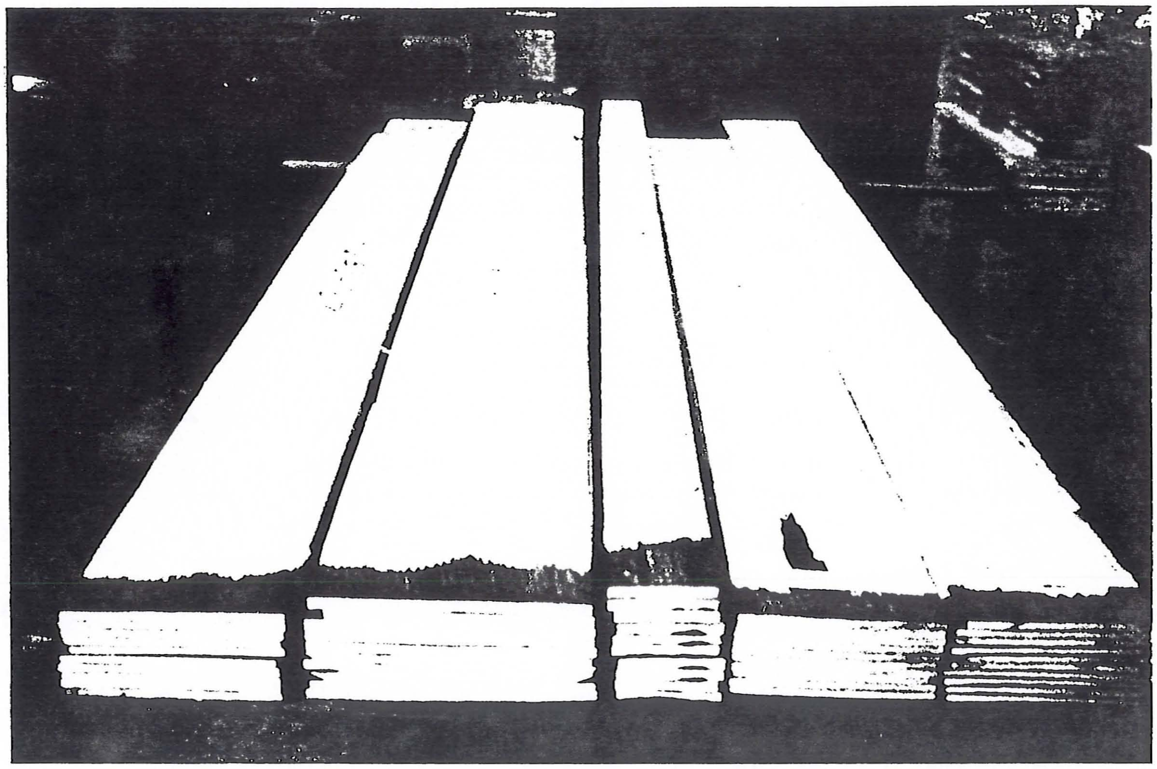


PHOTO 6. Determining lathe check depth from slicing.

APPENDIX II

RF DRYER AND VENEER SLICER LITERATURE

SAVES YOU MONEY

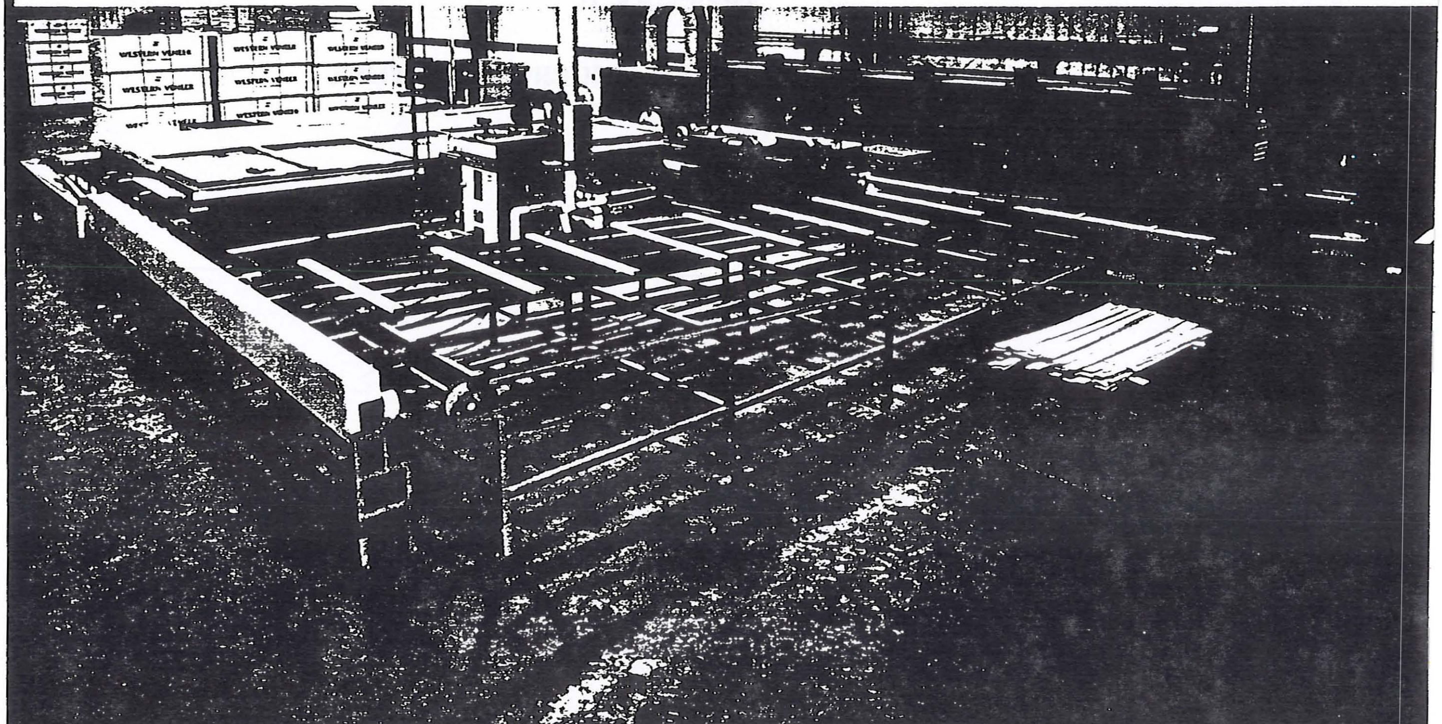
SAVES YOU TIME

SAVES RESOURCES

SAVES ENERGY

NO RE-DRY · NO WET SPOTS · NO PITCH PULL
NO CASE HARDENING

PMI DRY-TECH RADIO FREQUENCY VENEER DRYER



PRODUCTION MACHINERY CAN PROVIDE COMPLETE VENEER PRODUCTION SYSTEMS

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MACHINERY
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P.O. BOX 1222 · BEND, OR 97709
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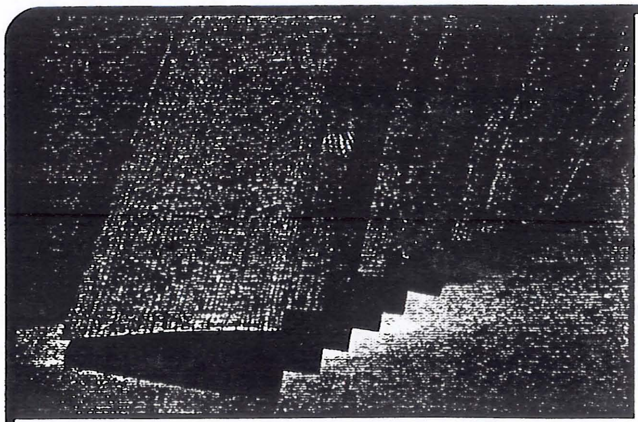

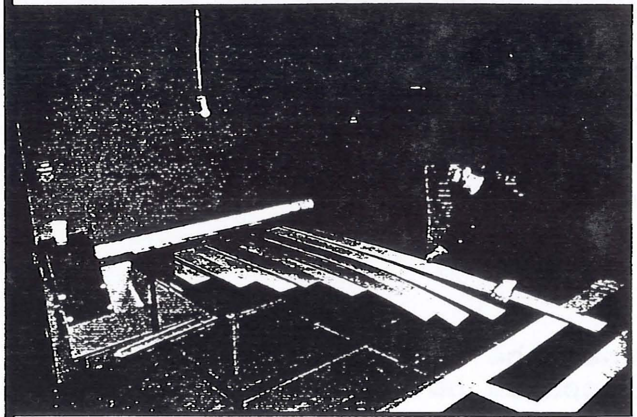

A Better Product In 1/2 The Time

The PMI DRY-TECH Radio Frequency Veneer Dryer is engineered with one goal in mind: ***Quality.***

The veneers you see coming out of your DRY-TECH dryer will be bright, lively, pliable and flat. They will be consistent in moisture content from side-to-side, end-to-end, piece-after-piece.

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Operation of the dryer is simple and safe. Drying is controlled by time of exposure, easily adjusted by the operator.

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Radio Frequency energy is the clean, quiet, economical method of drying veneers. No over drying or burning, no underdrying or wet spots. Lower temperatures mean less pitch pull.

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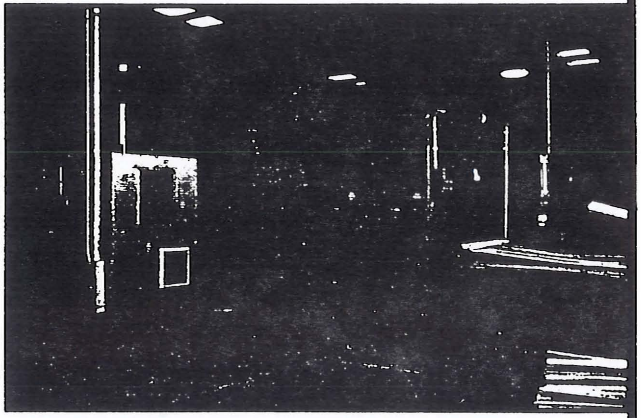
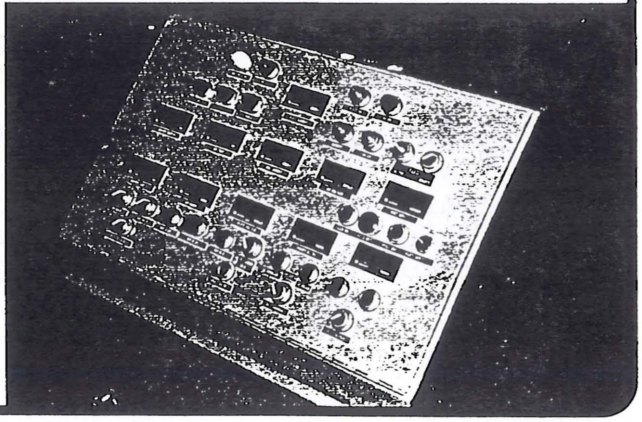




VENEER DRYING WITH RADIO FREQUENCY

When WWII soldiers discovered they could heat their C-rations in front of the radar antenna they were using they probably had no idea how widespread this form of energy transfer would become in the next fifty years. The microwave oven has become a standard appliance in every household, convenience store, coffee room and dormitory.

Industrial use of this method of heating things has grown at the same time. Radio Frequency (RF) has been used to heat items to working temperatures, melt chemicals, speed evaporation, cure adhesives, and other applications. One popular application involved the curing of glue to bond pieces of wood together. A natural consequence of this process was the heating of the wood and subsequent drying of it as water was released from the wood cells.

Enter the slicer:

It has been learned over the years that the best slicing of veneer can be accomplished when the wood is hot and wet. Both conditions contribute to the smoothness and consistency of the cut. The heat and moisture can be imparted to the wood in a conditioning system. Unfortunately these attributes are not desired in the final product, and re-drying of the veneer is necessary.

Traditionally veneers have been dried by nature, stacked about the area and eventually drying, or force dried in an electric or gas fired dryer. The former method is slow and inconsistent, and wasteful of space. The latter method is faster, but expensive, potentially dangerous, operates at temperatures higher than the wood can tolerate, and also uses considerable space. Plywood manufacturers were some of the first to dry bundles of veneers with RF, heating the bundles with large rooms of RF generating equipment.

PMI has developed a continuous system to dry wood veneers with RF energy. **This system operates at lower temperatures, in a smaller floor space, and provides a consistent moisture content and quality that is unmatched by any other drying method.**

A primer on the RF principle: Friction creates heat. Electricity passing back and forth through the filament of a lightbulb 60 times a second causes the molecules of tungsten to heat up and glow. Part of the heat escapes as light. The same principle applies to food you place in your microwave oven, except the energy is transmitted through the air in your oven rather than through wires. When RF energy is used to dry wood we use a frequency that is much higher than that used in light a bulb, but lower than that used in a microwave oven.

The moisture in the wood becomes more active as it heats and migrates to the surface of the veneer. It must be removed from the surface immediately to allow more moisture to come to the surface. Thus the drying process involves two steps: Heat the water molecules, and then remove them from the wood surface. With RF this becomes a simple process. The RF energy is attracted to the water molecules in the wood because they are a path of least resistance to ground. When the water reaches the wood surface it is removed by a system of air jets blowing heated air across the surface.

The results:

In extensive testing PMI has arrived at the proper balance of time, RF energy level and forced air temperature and velocity. Our trials have focused on Ponderosa Pine and Doug Fir veneers.

Materials thickness	.050 to .150"
Starting moisture content	25 to 30%
Staring veneer temperature	ambient to +30
Time in dryer	35 to 40 sec.
Air temperature in dryer	300 to 350° F
Moisture content after drying	12 to 16%
Veneer temperature after drying	140 to 150° F

As the veneers return to ambient temperature the moisture content will continue to drop. After approximately two minutes the MC reading will drop to 8 to 10%.

Capacity: The Dry-Tech dryer with a 60" wide drying zone, running at 30 FPM can dry 150 sq. ft. of veneer per minute.

Production rate: (Per 400 minute shift)

Veneer width: Length:	4"	5"	6"	8"	12"
5'	36000	28850	24000	18000	12000
6'	30000	24000	20000	15000	10000
7'	25700	20603	17150	12850	8500
8'	22500	18000	15000	11250	7500

RF Advantages:

*** Approximately 1/3 the amount of floor space required.
***The quality and Moisture content are more consistent.
***There is no wood damage or marking.
***Power control is easy and instantaneous.
***Operating temperature is low, less wood damage.
***Release of air contaminants is minimal.

For additional information contact:
Production Machinery, Inc.
P.O. Box 1222 Bend OR 97709 (503) 382-0298

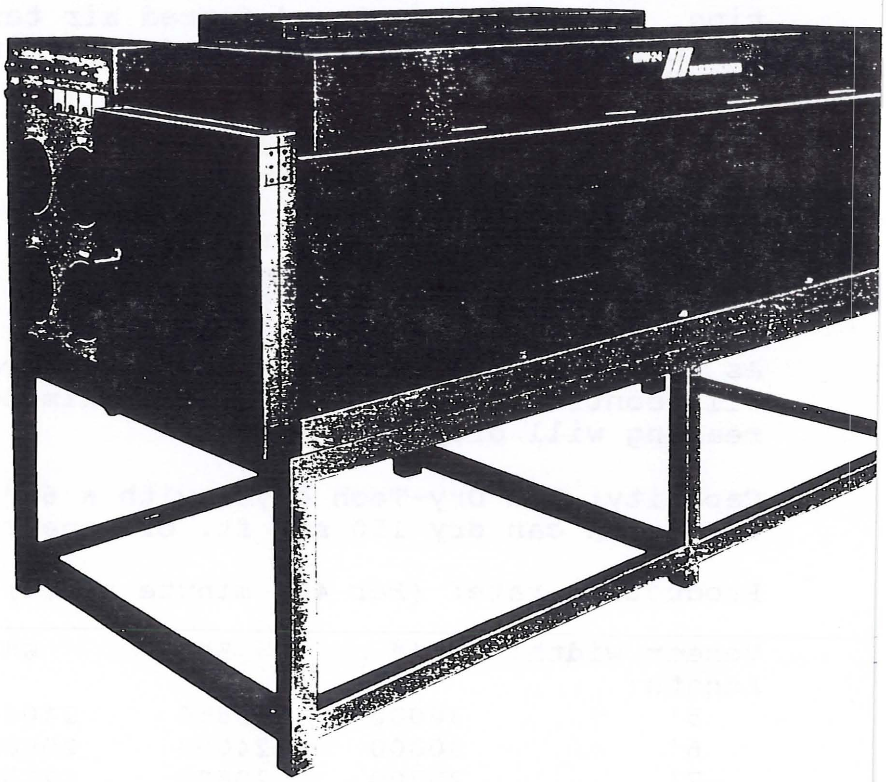
MARUNAKA NEW PRODUCT NEWS

[illegible]

- This system is a micro-wave oscillating device constructed by magnetrons (1.2kW × 4 2,460MHz), air cooling fan (55W × 2) and main power station which is designed to heat mainly timbers to be sliced.
- Heating time a few minutes should be enough (depends on materials and size)
- Output power can be set easily by dials.
- By using plastic case, taking in and out of timbers easily.

[illegible]

Model	MW-24
Oscillating freguency	2460 MHz
Out put power	1.2kW × 4 set
Out put control	variable transformer
Motor for diffusion fan	3W × 2
for magnetron cooling fan	15W/60Hz × 4
for circulation fan	55W/60Hz × 2
Heating capacity (W × L × H)	400 × 2000 × 300mm
Machine size (W × L × H)	1000 × 2400 × 1280mm



MW-24

MICRO-WAVE TIMBER HEATING EQUIPME

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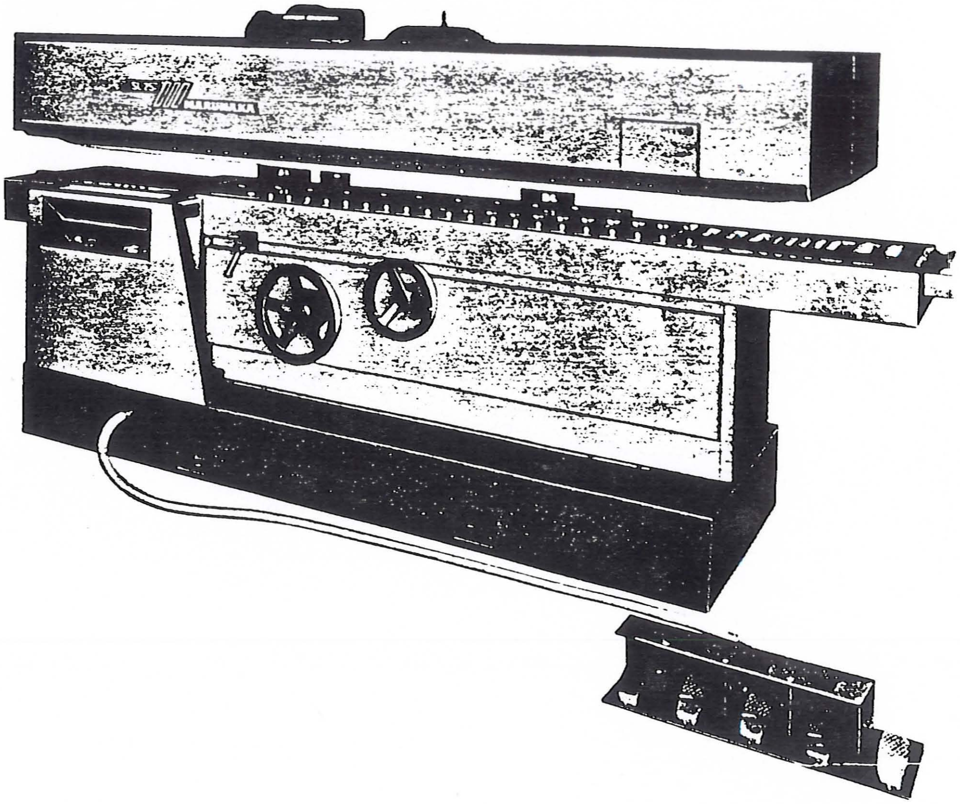
MARUNAKA NEW PRODUCT NEWS

[illegible]

- Lengthways slicer has no limitation on flitch length.
- Powerful motor and build in roller table enable to slice thick veneer smoothly.
- With the microwave timber heating equipment (MW-24) max 13mm thick venner can be sliced. (depend on material)
- Easy and fine adjustment of the knife and nose bar alignment for fine veneer and veneer thickness.
- Compact machine size and easy installation.



Model	SL-20T
Feed motor	15kW/4P
Head elevation motor	0.75kW × 4P
Work capacity	(flitch size)
max. width	200 mm
max. height	250mm
Max. slicing thickness	13mm (depend on material)
Knife bias angle	80°
Table height	830mm
Machine size (W × L × H)	1400 × 3000 × 1750mm
Max. weight	5000kg

Model	SL-25T
Feed motor	18.5kW/4P
Head elevation motor	0.75kW × 2/4P
Work capacity	(flitch size)
max. width	250 mm
max. height	250mm
Max. slicing thickness	13mm (depend on material)
Knife bias angle	80°
Table height	900mm
Machine size (W × L × H)	1350 × 3450 × 1470 ~ 1720mm
Max. weight	6500kg

SL-20T・25T

LENGTHWAYS THICK VENEER SLICER

MARUNAKA TEKKOSHO INC.

APPENDIX III

MOISTURE CONTENT DISTRIBUTIONS AND REGRESSION ANALYSES - CONVENTIONAL (BOISE)

MOISTURE CONTENT DISTRIBUTIONS - CONVENTIONAL (BOISE)

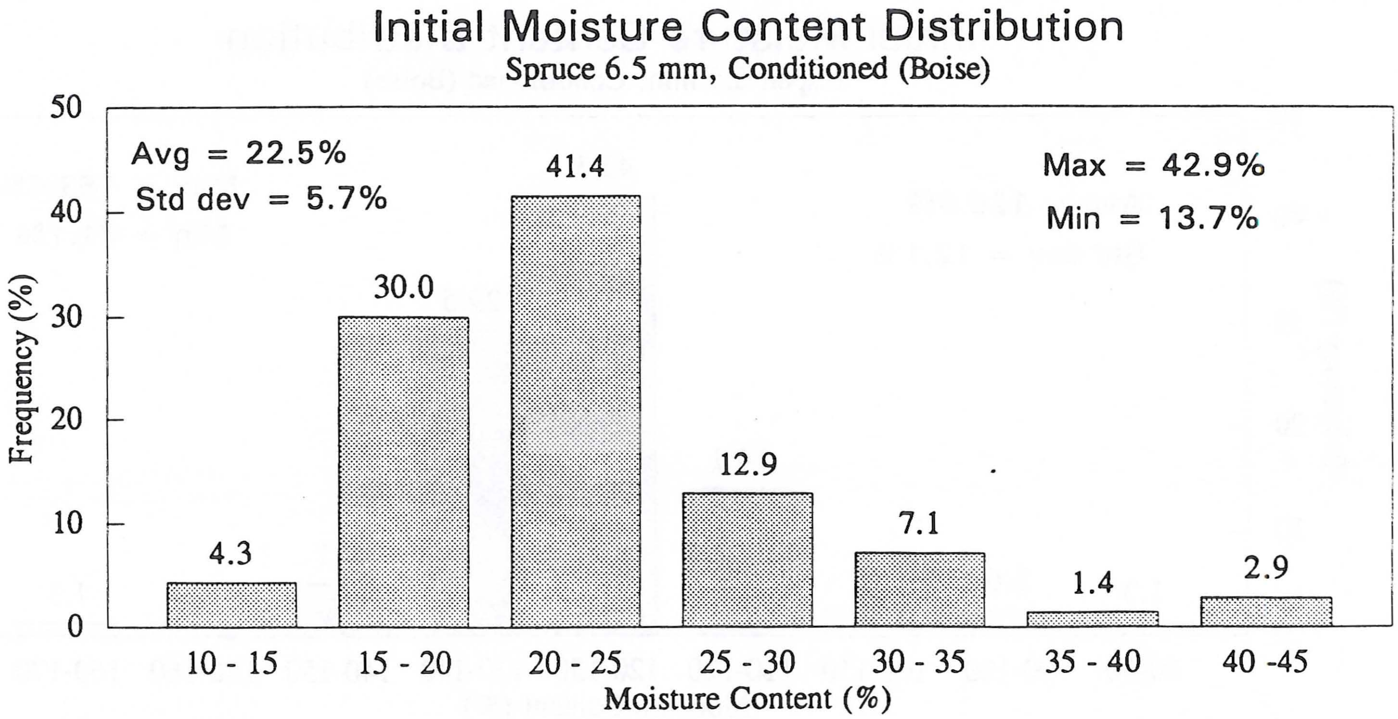
Spruce, 6.5 mm, Conditioned: Figures 2a and 2b illustrate the initial and final moisture content distributions for batch S6B1. As can be seen in Figure 4a, the initial average moisture content was considerably lower when compared to normal freshly cut spruce. Approximately 75% of all samples had moisture content below 25% and only about 4% had moisture contents above 35%. After drying, about 85% of the samples had moisture contents between 12 and 15% and approximately 10% of the samples had moisture contents above 15%. The drying was stopped after 11.5 hours, but could have been extended a few more hours to bring the average final moisture content closer to 12%.

Aspen, 6.5 mm, Conditioned: Figures 3a and 3b illustrate the initial and the final moisture content distributions for the samples from batch A6B4. As can be seen, a considerable spread of initial moisture contents was present although most of the samples fell between 110 and 140%.

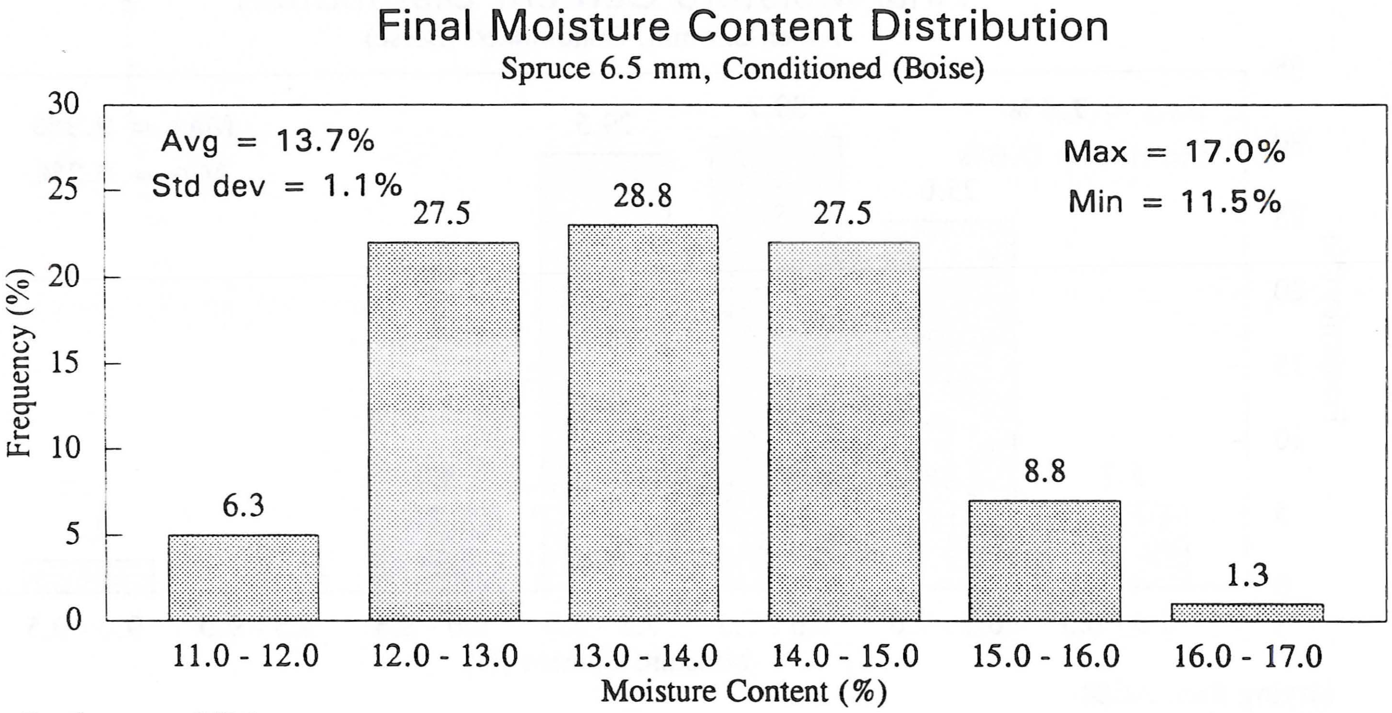
Although the overall average final moisture content was well below the target of 12%, it can be seen from Figure 1 that the moisture content was relatively uniform, that is, within a narrow range (6.2 to 9.3%). Approximately 85% of the samples had a final moisture content between 6.5 and 8.0%. These results clearly indicate that the drying was quite uniform and suggest that the drying time of 31.5 hours could have probably been significantly reduced since all veneer samples were overdried.

Aspen, 8.5 mm, Conditioned: Figures 4a and 4b shows the initial and final moisture content distributions for the samples from batch A8B9. Approximately 50% of the samples had moisture contents below 100% and about 37% had initial moisture content between 120 and 140%. Despite the considerable range of initial moisture content, the final moisture content was uniform. The overall results for this batch indicate that the 8.5 mm veneer samples were slightly less overdried than the 6.5 mm aspen batch, as would be expected. The total drying time of 31.5 hours was excessive and therefore can be safely reduced to attain a target moisture content of 12%.

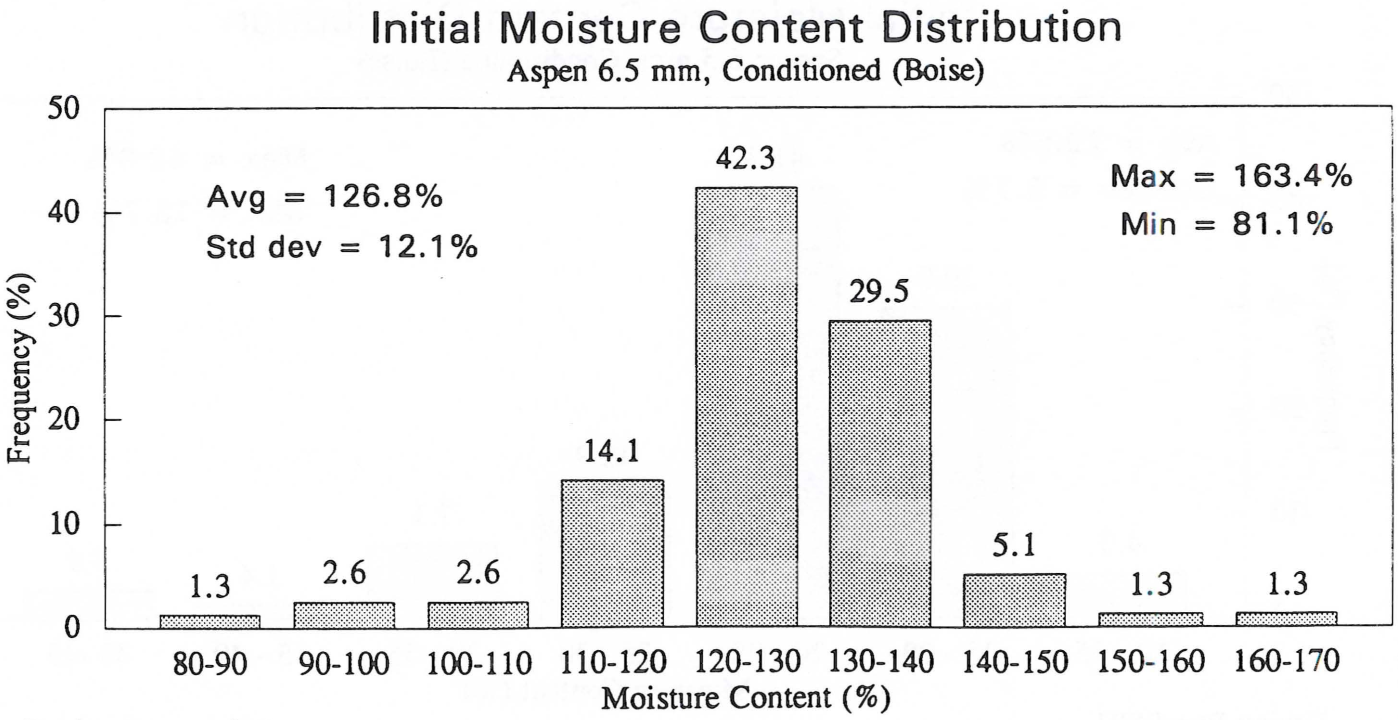
Aspen, 8.5 mm, Unconditioned: Initial and final moisture content distributions for the samples from batch A8B10 are shown in Figures 5a and 5b. Similar to the two previous distributions, the spread of the initial moisture content was large. Approximately 54% of the samples had initial moisture content ranging between 70 and 110% and a significant amount (14%) had moisture contents between 130 and 150%. As for the final moisture content, about 60% of the samples had moisture contents between 7.0 and 8.0%, a very narrow distribution. The average of 7.5% was well below the target of 12% which once again confirms that the total drying time of 31.5 hours was excessive. It seems that the type of treatment did not have any effect on the final moisture content distribution.



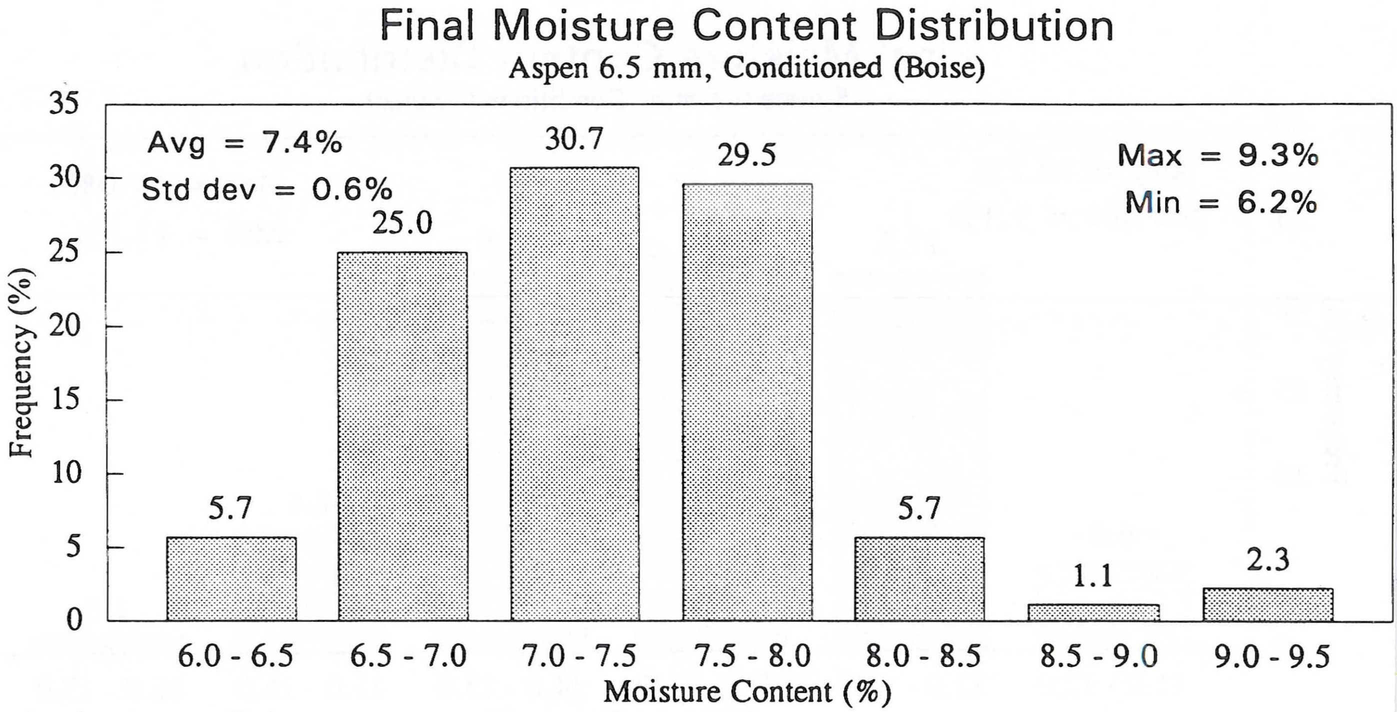
Drying Run S6B1
Fig. 2a



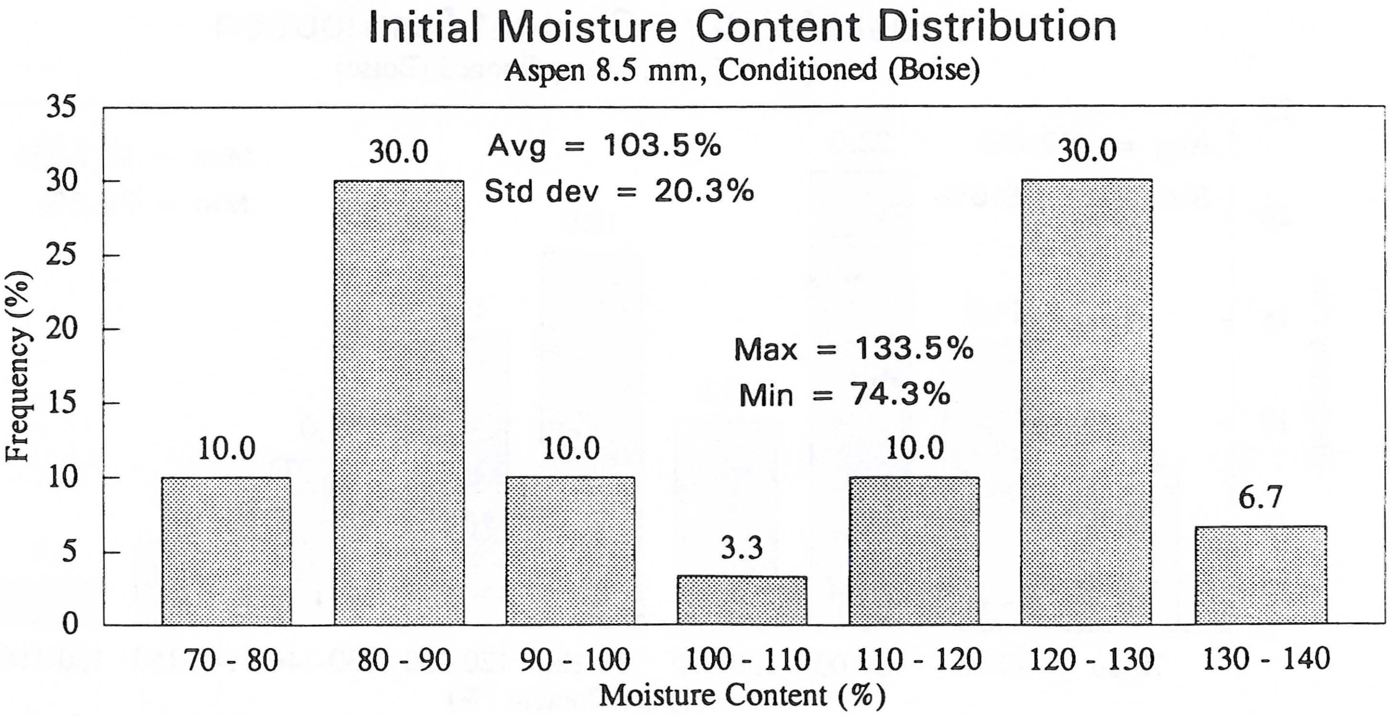
Drying run: S6B1
Fig. 2b



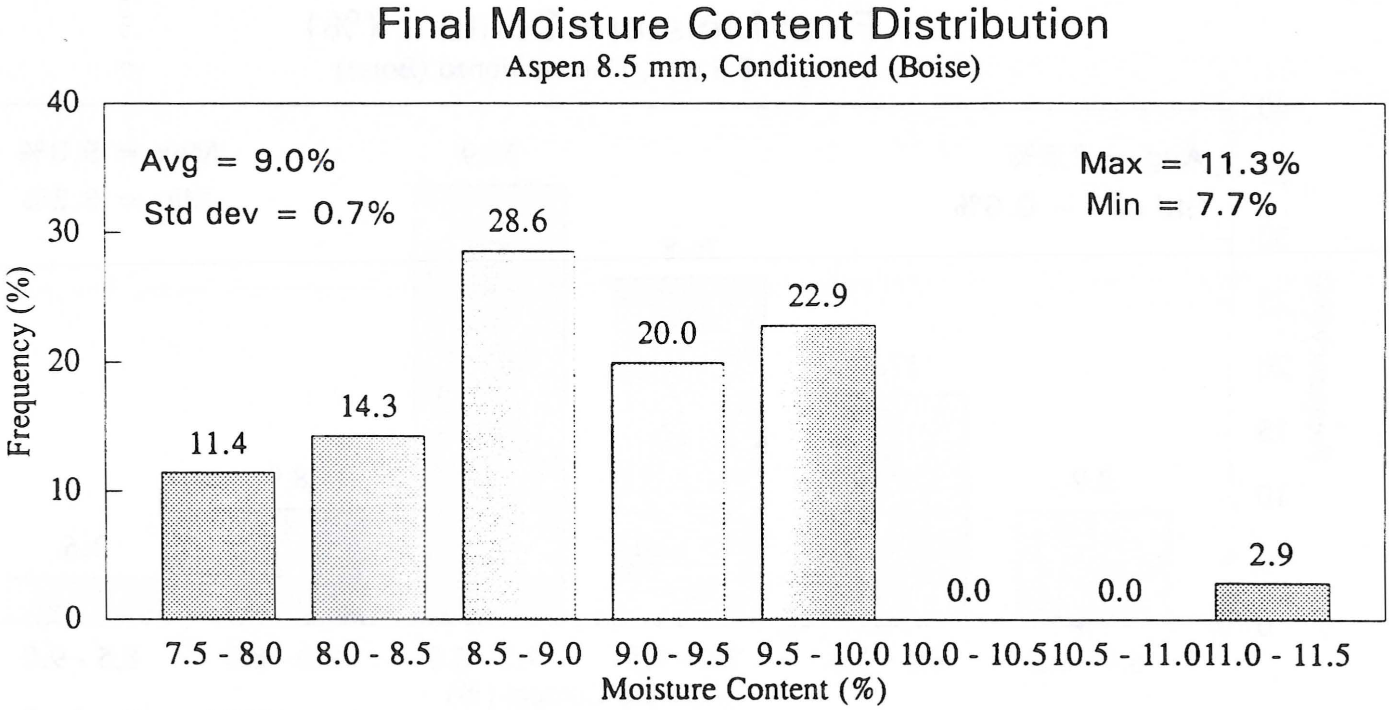
Drying Run: A6B4
Fig. 3a



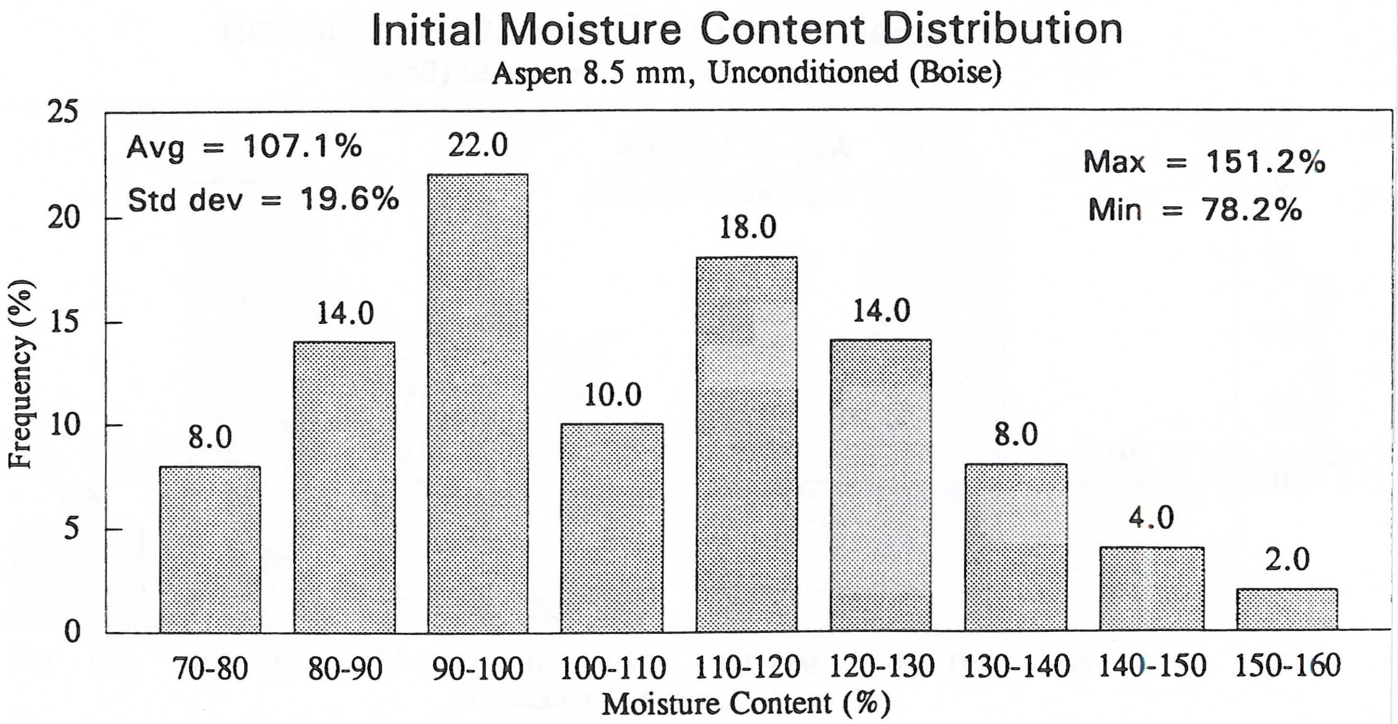
Drying Run: A6B4
Fig. 3b



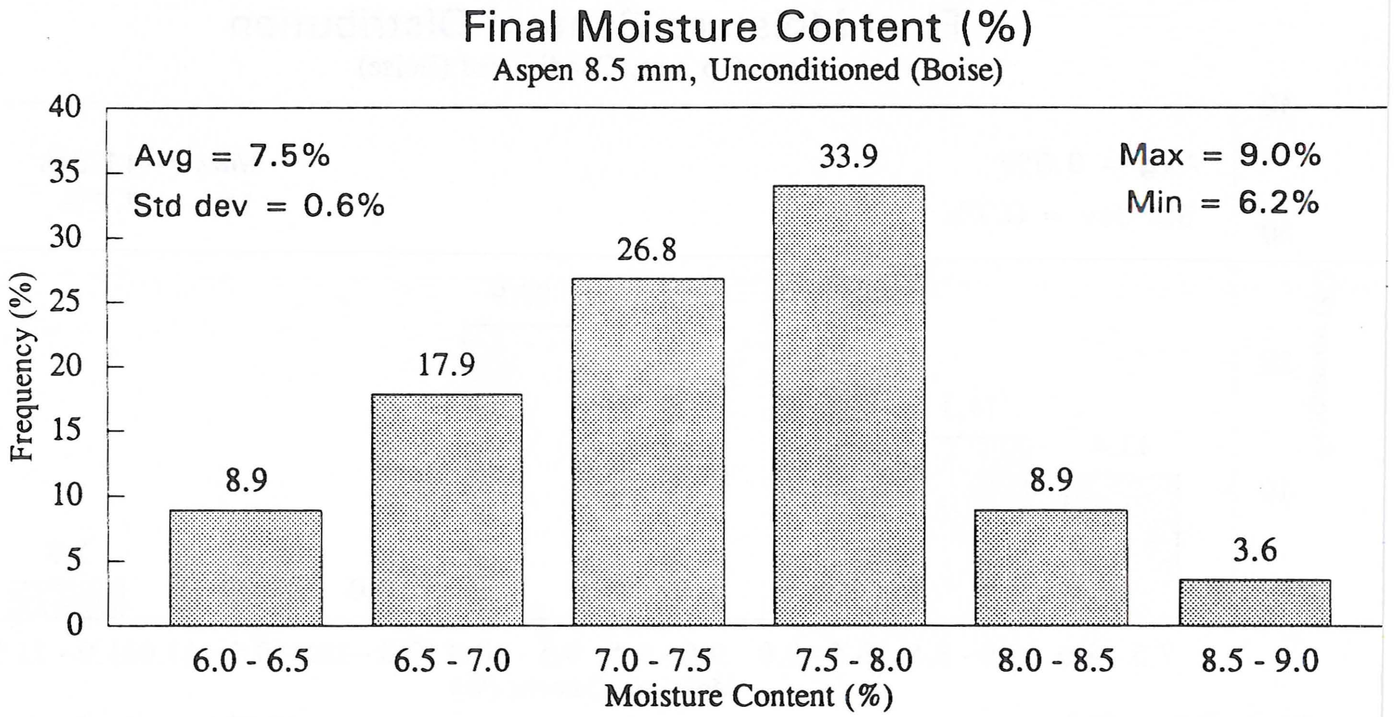
Drying Run: A8B9
Fig. 4a



Drying Run: A8B9
Fig. 4b



Drying Run: A8B10
Fig. 5a



Drying Run: A8B10
Fig. 5b

INITIAL VERSUS FINAL MOISTURE CONTENT - CONVENTIONAL (BOISE)

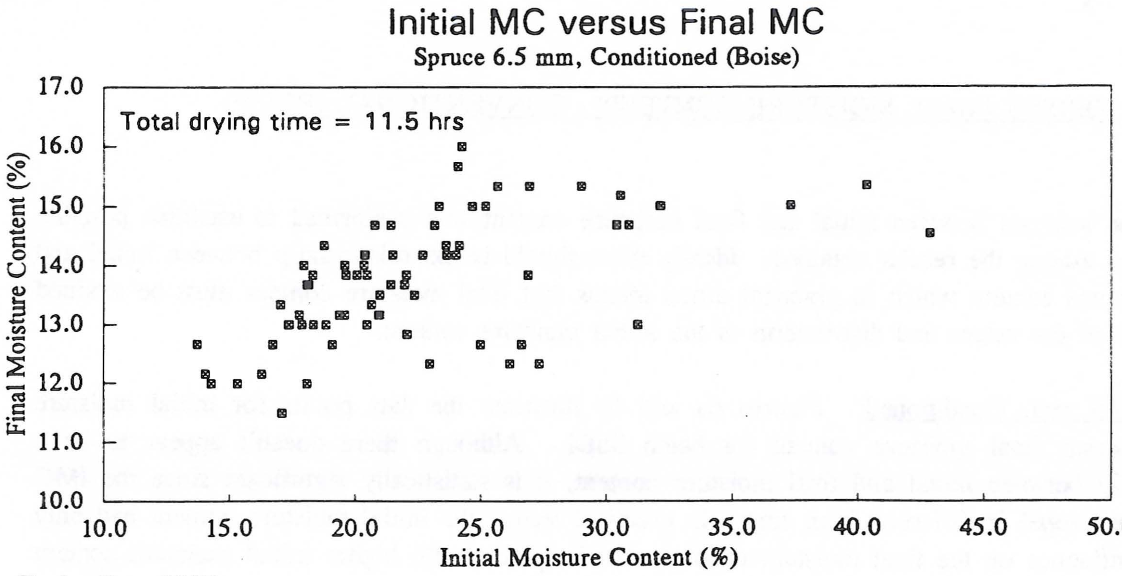
Regression analysis between initial and final moisture content was performed to establish possible differences among the results obtained. Ideally there should be no relationship between initial and final moisture content which in practical terms means that final moisture content must be attained regardless of the values and distribution of the initial moisture content.

Spruce, 6.5 mm, Conditioned: Figures 6a and 6b illustrate the data points for initial moisture content versus final moisture content for batch S6B1. Although there doesn't appear to be a relationship between initial and final moisture content, it is statistically significant since the IMC coefficient (slope) is different from zero. In practical terms, the initial moisture content had only a slight influence on the final moisture content, that is, pieces with higher initial moisture content ended up with higher final moisture content.

Aspen, 6.5 mm, Conditioned: Figures 7a & 7b illustrate the relationship between initial moisture content (IMC) and final moisture content (FMC). The analysis clearly shows that the initial moisture content is not related to the final moisture content. The regression analysis formally confirms this observation. The slope (b) in the relationship FMC=a+b(IMC), is not significantly different from zero. In practical terms, the drying run was uniform and the results illustrated by Figure 7 represent one of the goals of the drying process, that is, to reach a uniform final moisture content. On the other hand, the lower than planned final moisture content may have contributed to a more uniform distribution of the final moisture content.

Aspen, 8.5 mm, Conditioned: The regression analysis for batch A8B9 is illustrated in Figure 8a. In general, the samples from this batch were also overdried (average FMC=9%) but had relatively uniform final moisture content (Figure 8b). The relationship illustrated in Figure 8 shows that there was a significant relationship between initial and final moisture content. Due to probably a few data points, the relationship even suggests that the pieces with higher moisture content ended up with lower moisture values. There is no reason to believe that this would happen under the circumstances imposed by the conventional drying carried out in Boise. Thus, it is safe to assume that the drying of batch A8B9 was quite uniform and there is not enough evidence to conclude that there is a relationship between initial and final moisture content. There are a number of factors related to the wood structure that could be influencing drying rates of individual pieces. These factors are difficult to detect and therefore control in experiments such as those conducted in Boise and probably will always be present in industrial situations.

Aspen, 8.5 mm, Unconditioned: Figure 9a illustrates the data points for the initial and final moisture contents obtained for batch A8B10. The main difference between this batch and the previous one is that all pieces were unconditioned before slicing. The average moisture content for this batch was around 107% which was close to the value of 104% obtained for batch A8B9. Figure 9 clearly shows no relationship exists between the initial and final moisture content. As before, the drying was quite uniform, though this may have occurred because all pieces were overdried (Figure 9b).



Drying Run: S6 B1
Fig. 6a

Regression Analysis

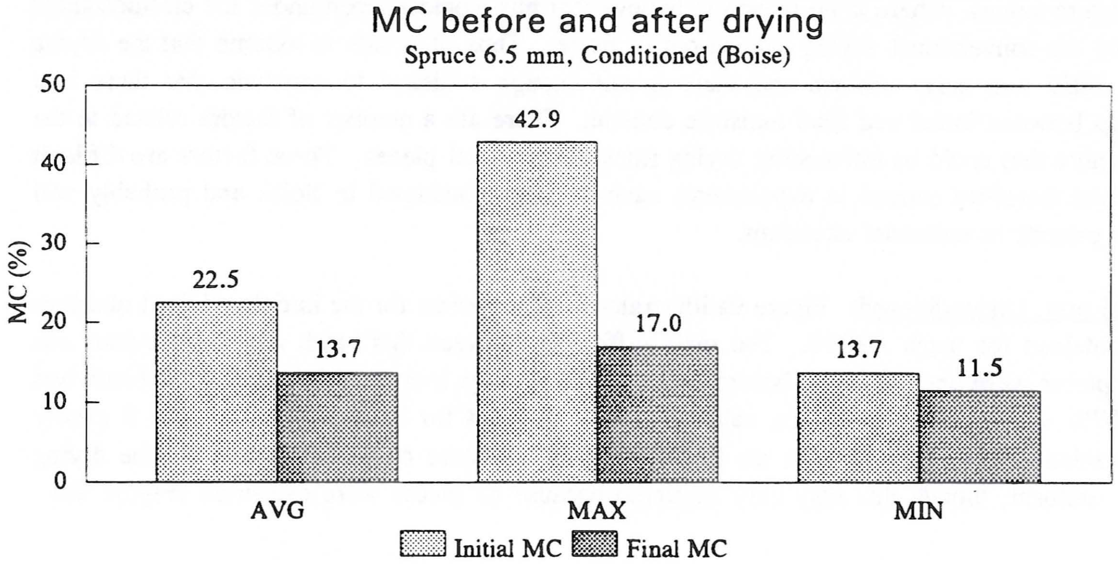
No. of observations	70
Degrees of freedom	68
R square	0.303295
IMC Coefficient	0.100354
Std Err of IMC	0.018445
Constant	11.47153

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

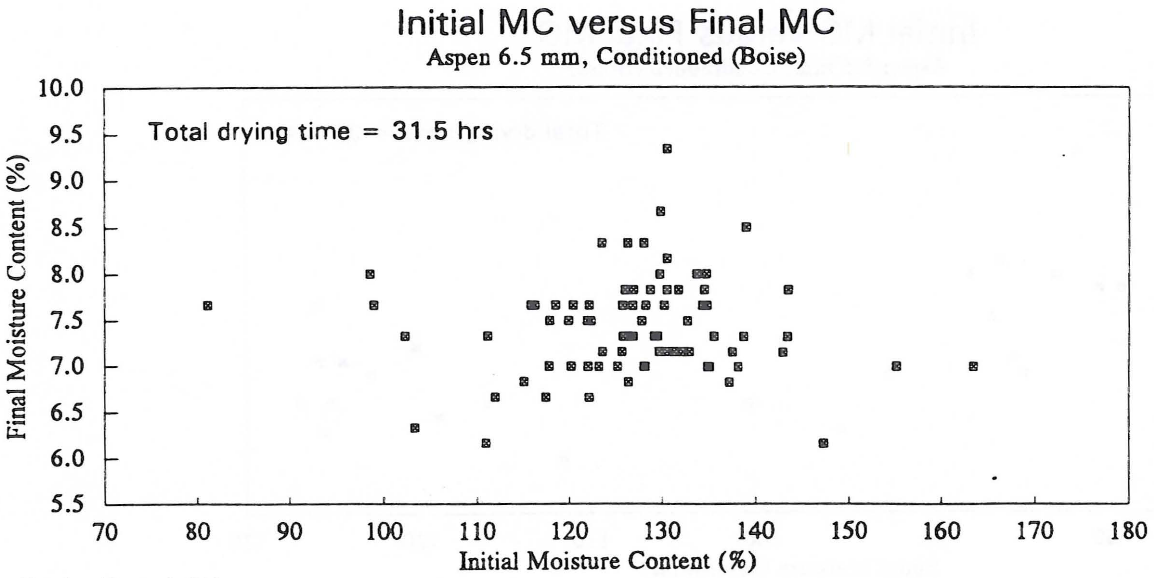
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

0.0635 < IMC Coefficient 0.1372



Drying Run: S6B1
Fig. 6b



Drying Run: A6B4
Fig. 7a

Regression Analysis

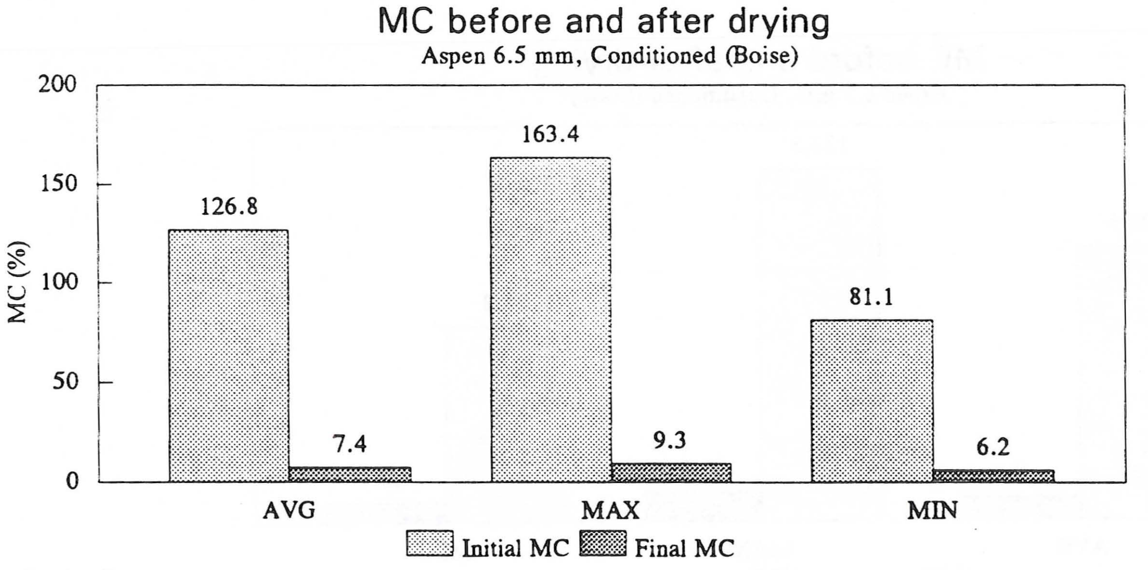
No. of observations	78
Degrees of freedom	76
R square	0.0
IMC Coefficient	0.0008
Std Err of IMC	0.0051
Constant	7.32

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

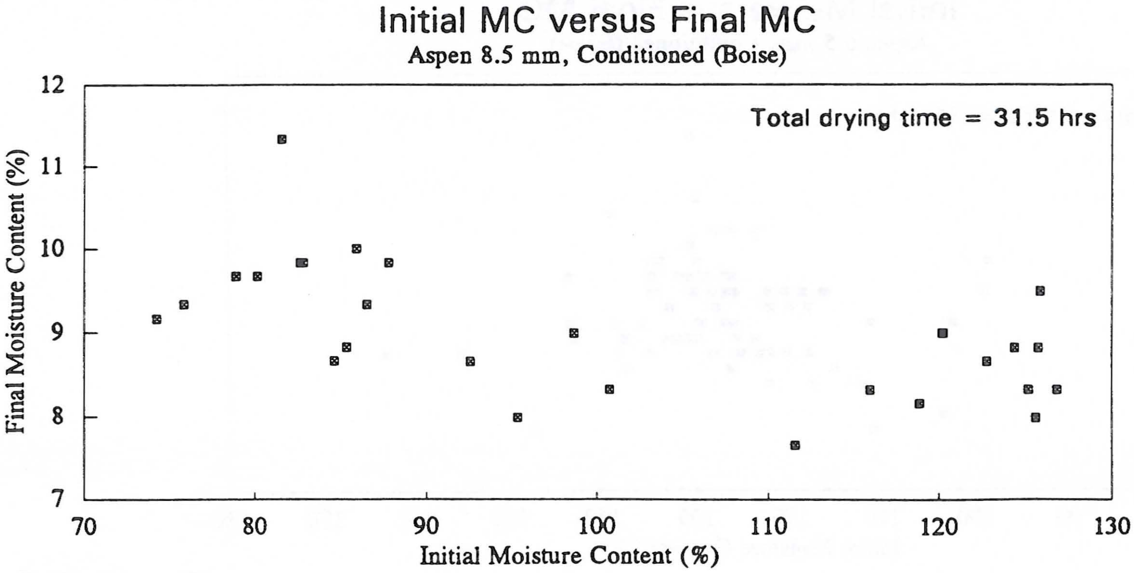
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.0094 < IMC Coefficient 0.0067



Drying Run: A6B4
Fig. 7b



Drying Run: A8B9
Fig. 8a

Regression Analysis

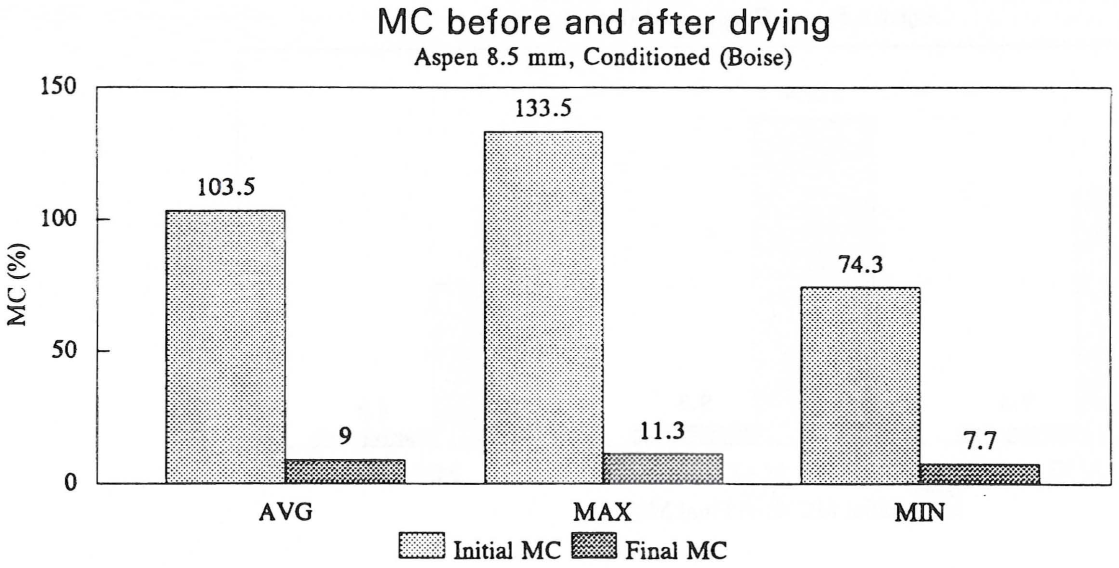
No. of observations	30
Degrees of freedom	28
R square	0.234952
IMC Coefficient	-0.01811
Std Err of IMC	0.006177
Constant	10.89607

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

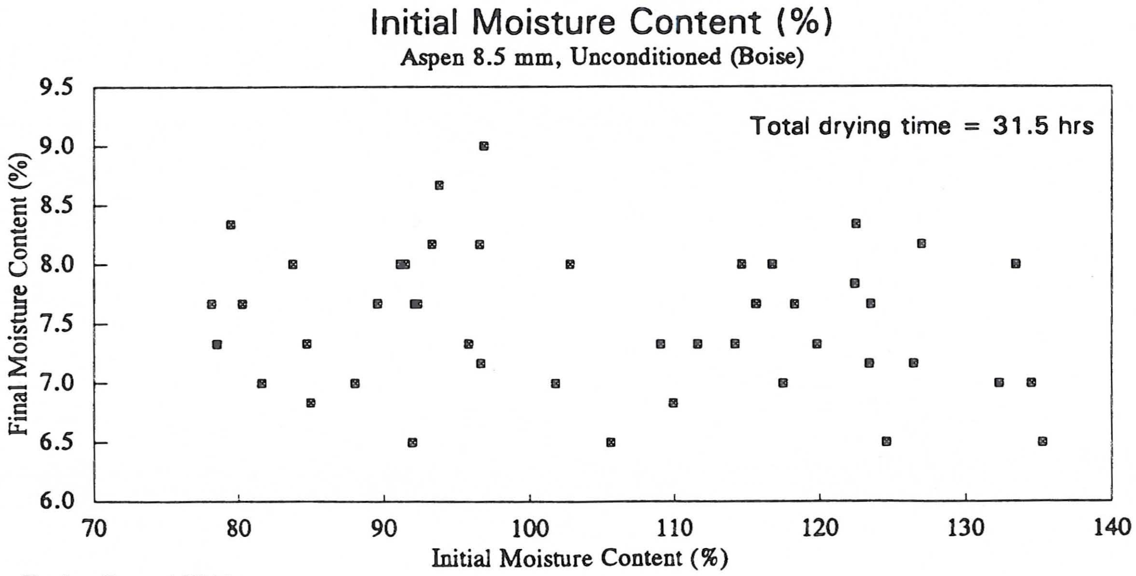
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.0307 < IMC Coefficient -0.0055



Drying Run: A8B9
Fig. 8b



Drying Run: A8B10
Fig. 9a

Regression Analysis

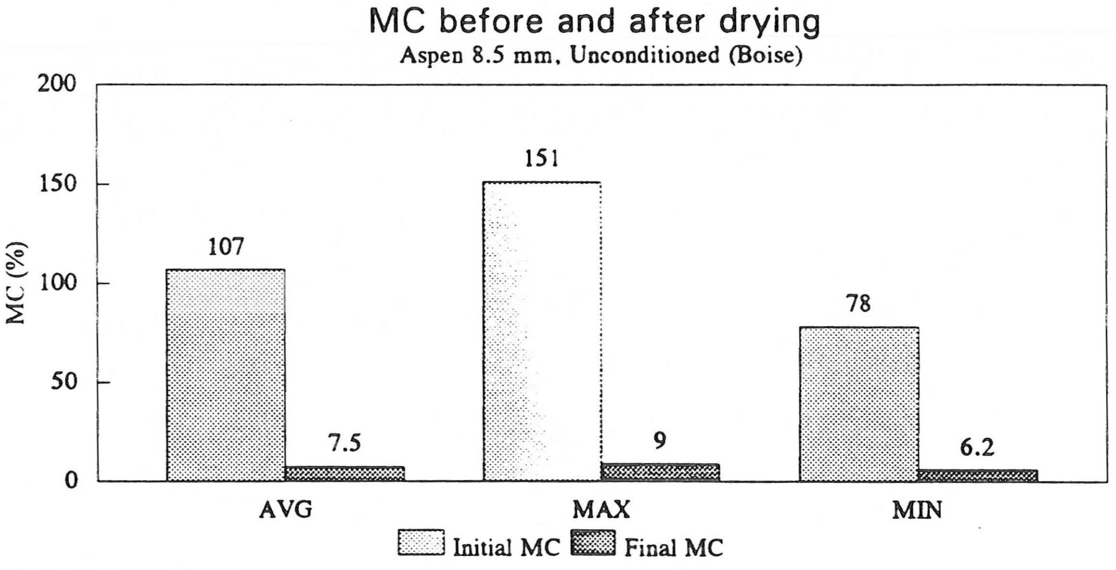
No. of observations	50
Degrees of freedom	48
R square	0.039657
IMC Coefficient	-0.00573
Std Err of IMC	0.004069
Constant	8.116657

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.0140 < IMC Coefficient 0.0026



Drying Run: A8B10
Fig. 9b

APPENDIX IV

MOISTURE CONTENT DISTRIBUTIONS AND REGRESSION ANALYSES - RF DRYER (MEDFORD)

MOISTURE CONTENT DISTRIBUTIONS - RF (MEDFORD)

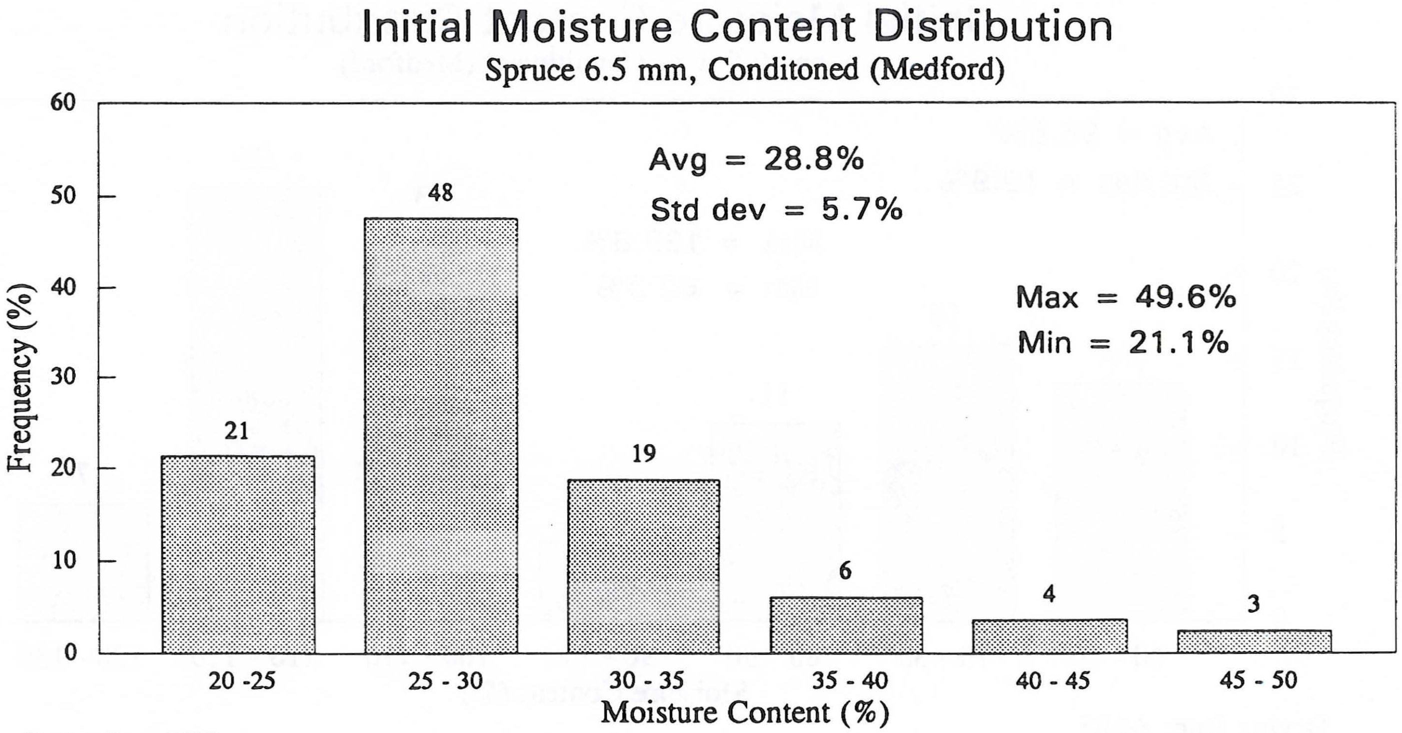
Spruce, Conditioned: Figures 10a and 10b show initial and final moisture content distributions for the samples from batch S6B2. As can be seen, most of the spruce had initial moisture contents varying between 25 and 30%. Only about 7% of all pieces had moisture content above 40%. After drying, the moisture content was quite uniform although lower than the target of 12% as illustrated by Figure 10b.

Aspen, Conditioned: Figure 11a illustrates the initial moisture content distribution for batch A6B5. As shown, the moisture content varied considerably. Approximately 46% of all pieces in the batch had moisture contents below 100% with minimum values as low as 62%. Figure 11b illustrates the final moisture contents. In addition to not having attained the target moisture content of 12%, the final moisture content distribution was also quite variable. Overall, drying of batch A6B5 was not satisfactory.

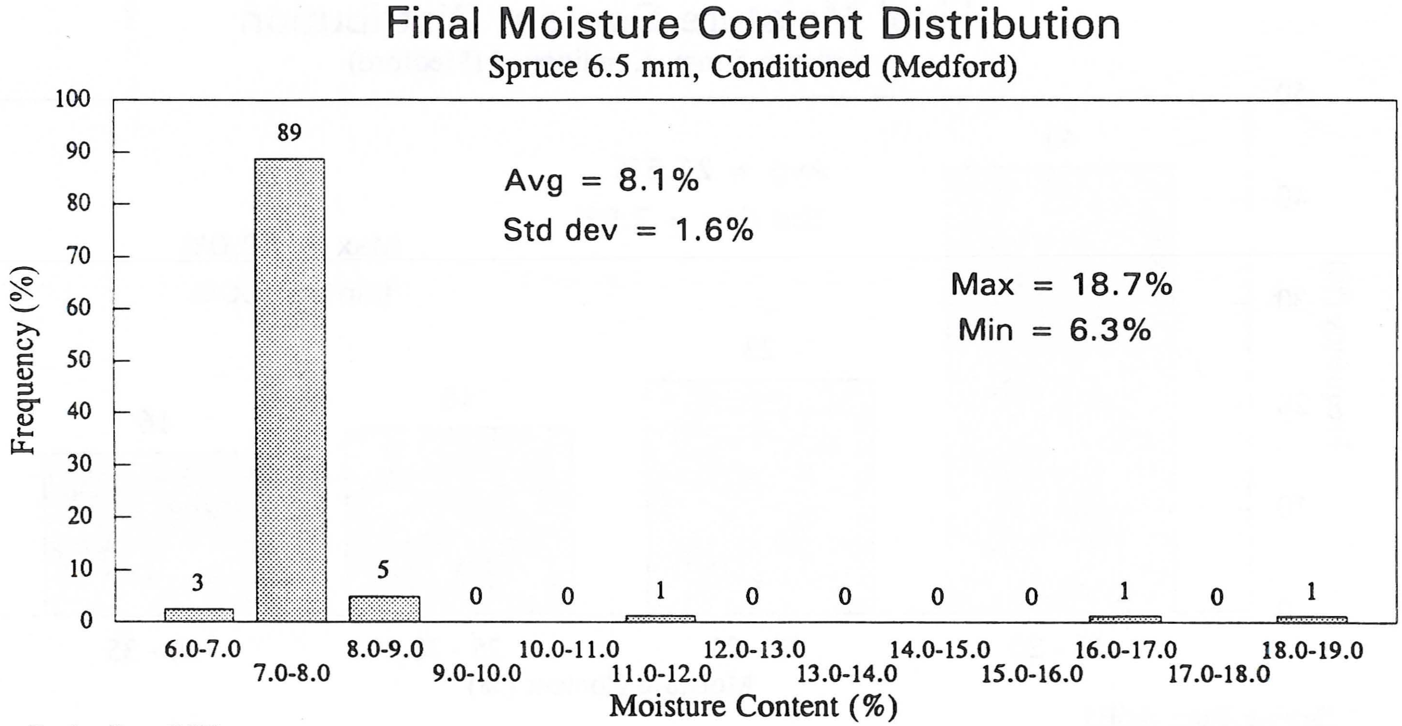
Aspen, Conditioned: The initial moisture content distribution for batch A6B6 is shown in Figure 12a. As before, a wide range of moisture content was found. Although most pieces had moisture contents between 60 and 80%, moisture contents as low as 49% and as high as 160% were also found in the batch. After drying the moisture content was also quite variable and most pieces were underdried, that is, with moisture contents between 25 and 35%, as seen in Figure 12b.

Aspen, Unconditioned: Relative to the previous two batches, batch A6B7 had a somewhat narrower initial moisture content distribution as illustrated by Figure 13a. About 40% of the pieces had moisture contents between 95 and 110%. After drying, most pieces had moisture content values between 10 and 20% and approximately 30% of the samples attained values close to the target moisture content (Figure 13b).

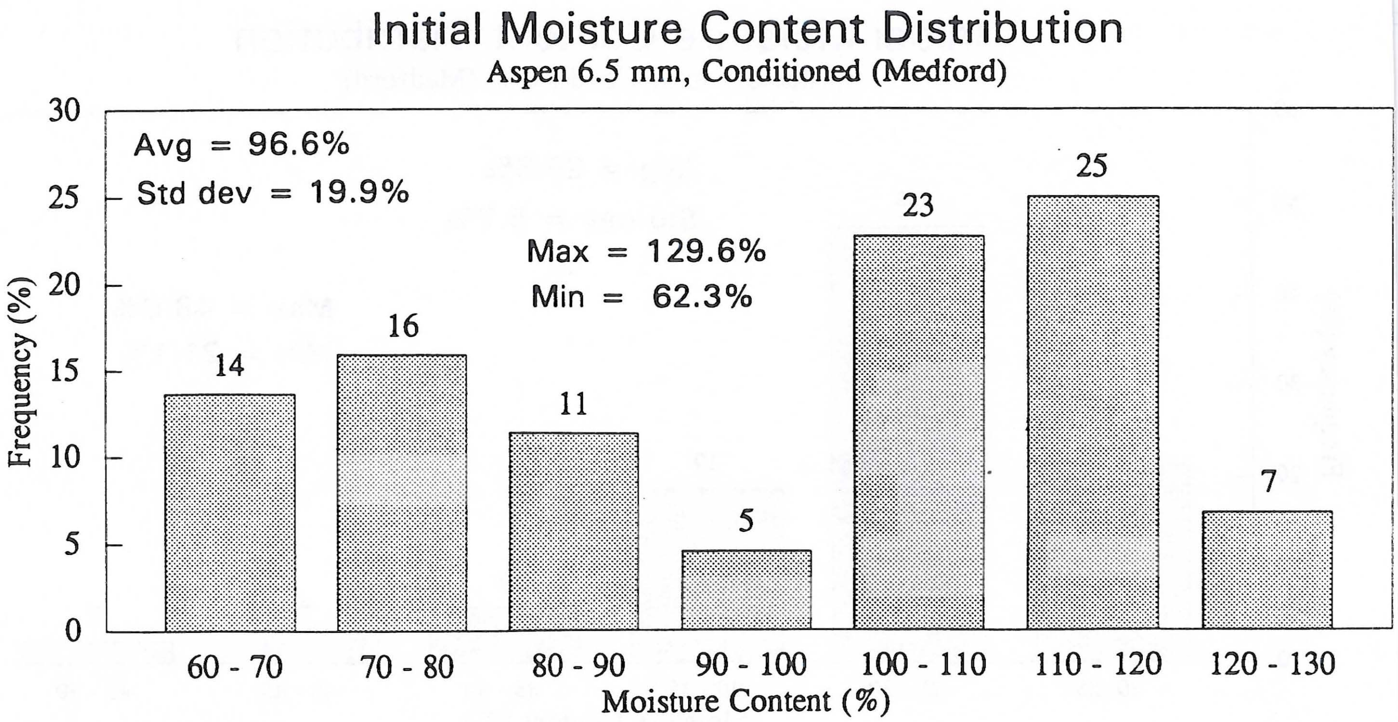
Aspen, Unconditioned: The moisture content distributions for batch A6B8 are shown by Figures 14a and 14b. About 50% of the pieces had initial moisture contents between 100 and 120%, 17% with moisture contents below 100%, and approximately 30% had a moisture content above 130%. Figure 14b illustrates the final moisture content distribution for the batch. As can be seen, more than 65% of the pieces had moisture contents varying between 10 and 20%. About 19% had moisture contents above 20% and approximately 14% were quite overdried with moisture content below 10%. This final variation of moisture content illustrates the difficulty of reducing the spread of values when targeting moisture contents between 10 and 15%.



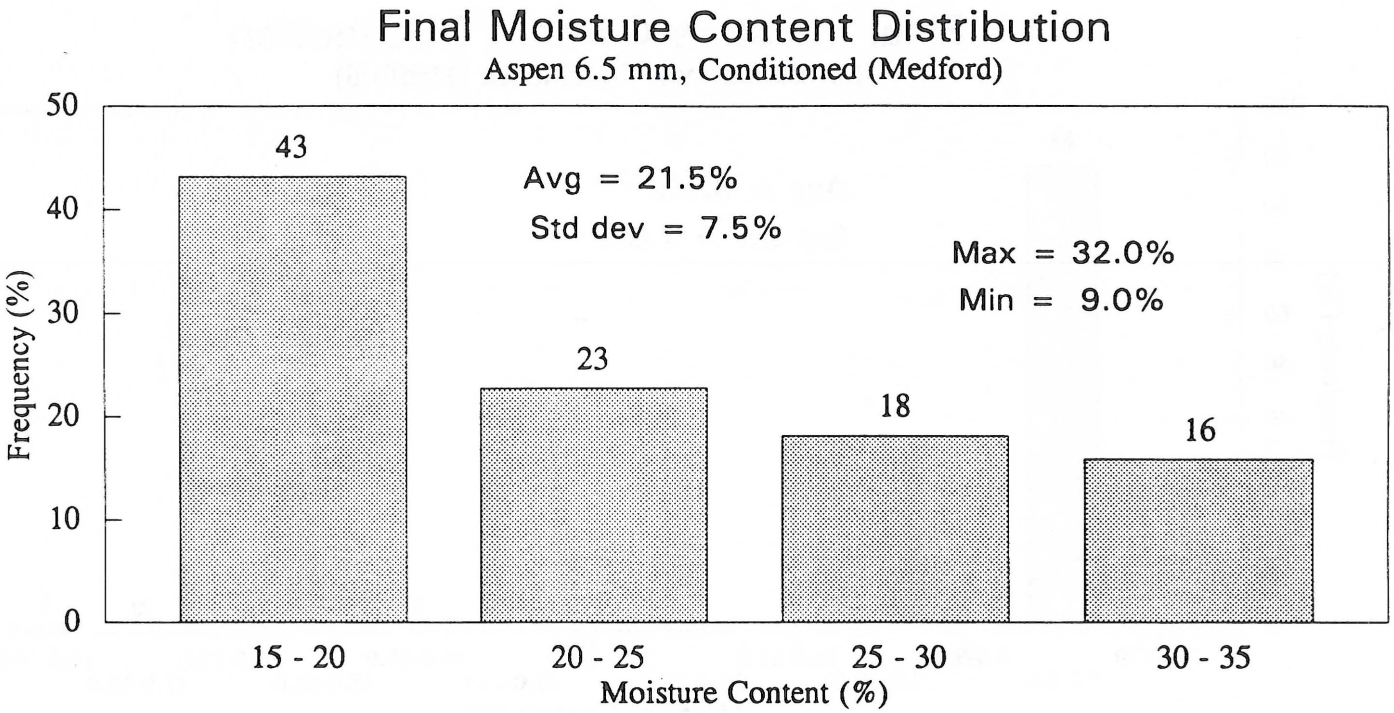
Drying Run: S6B2
Fig. 10a



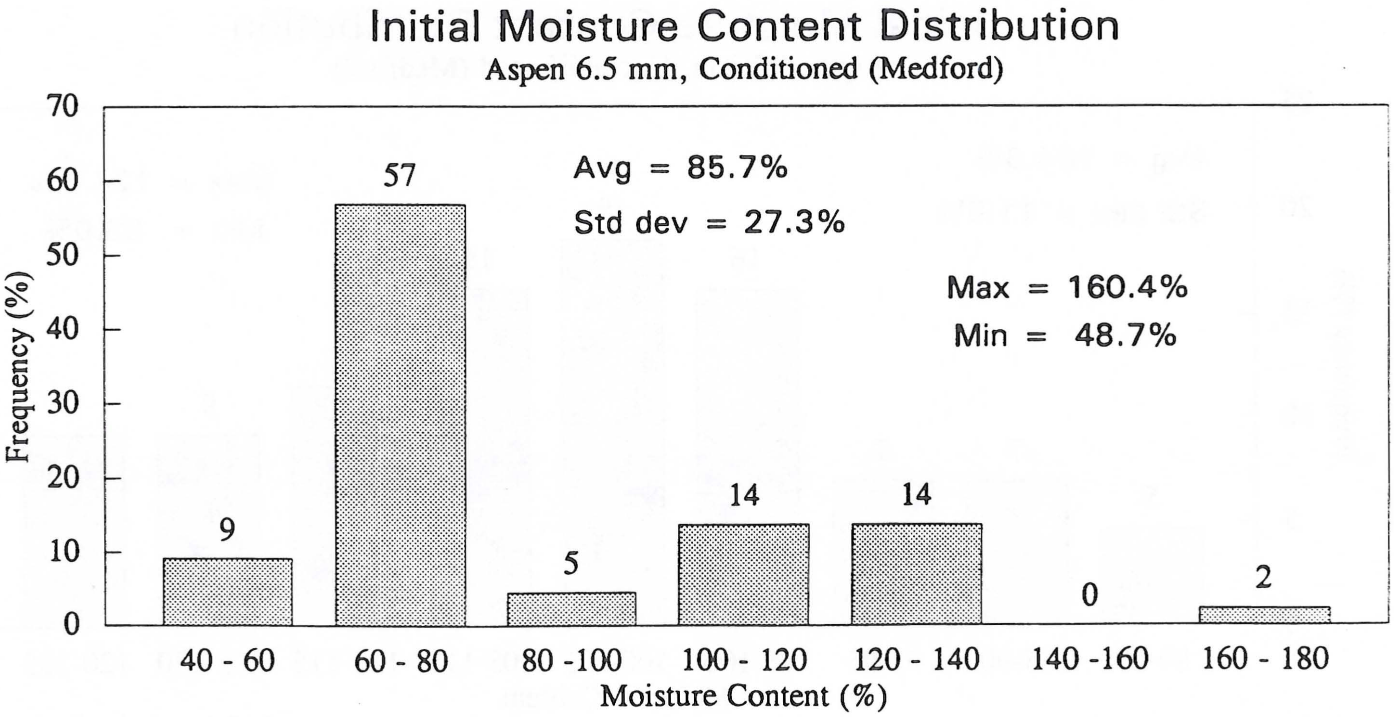
Drying Run: S6B2
Fig. 10b



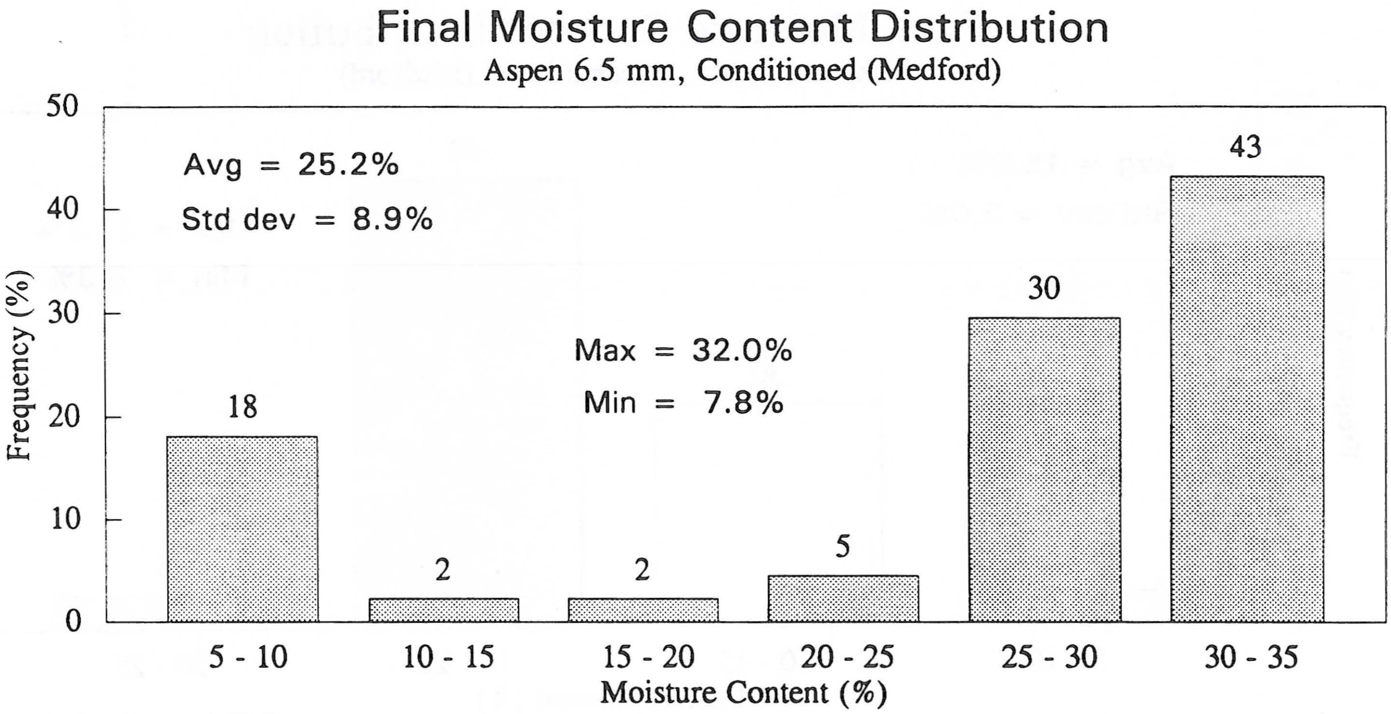
Drying Run: A6B5
Fig. 11a



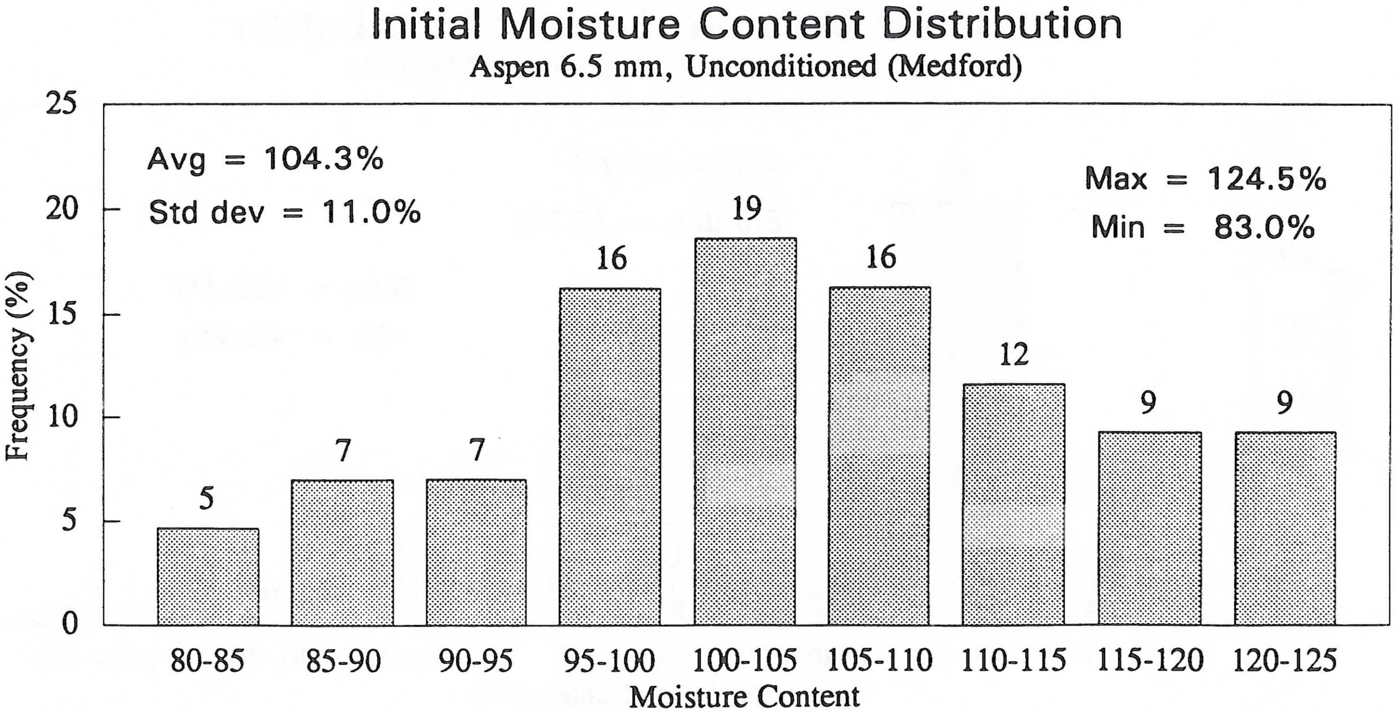
Drying Run: A6B5
Fig. 11b



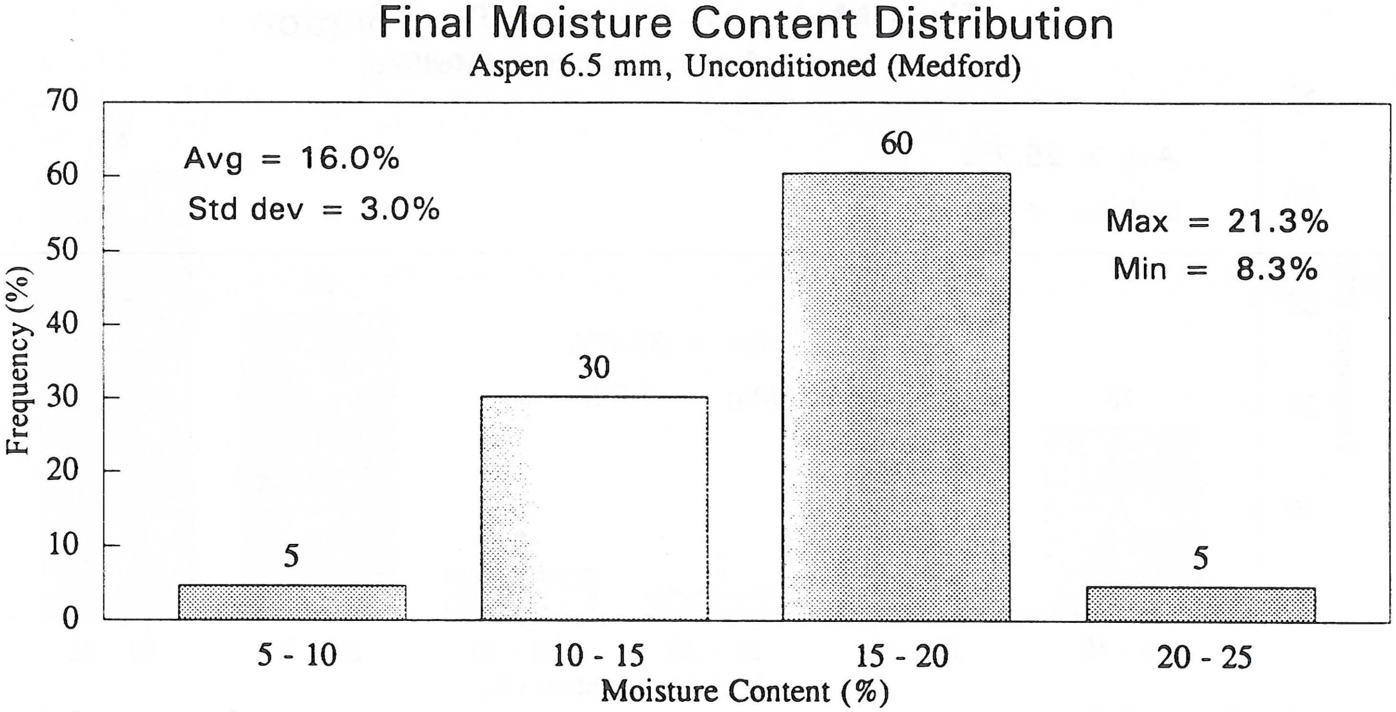
Drying Run: A6B6
Fig. 12a



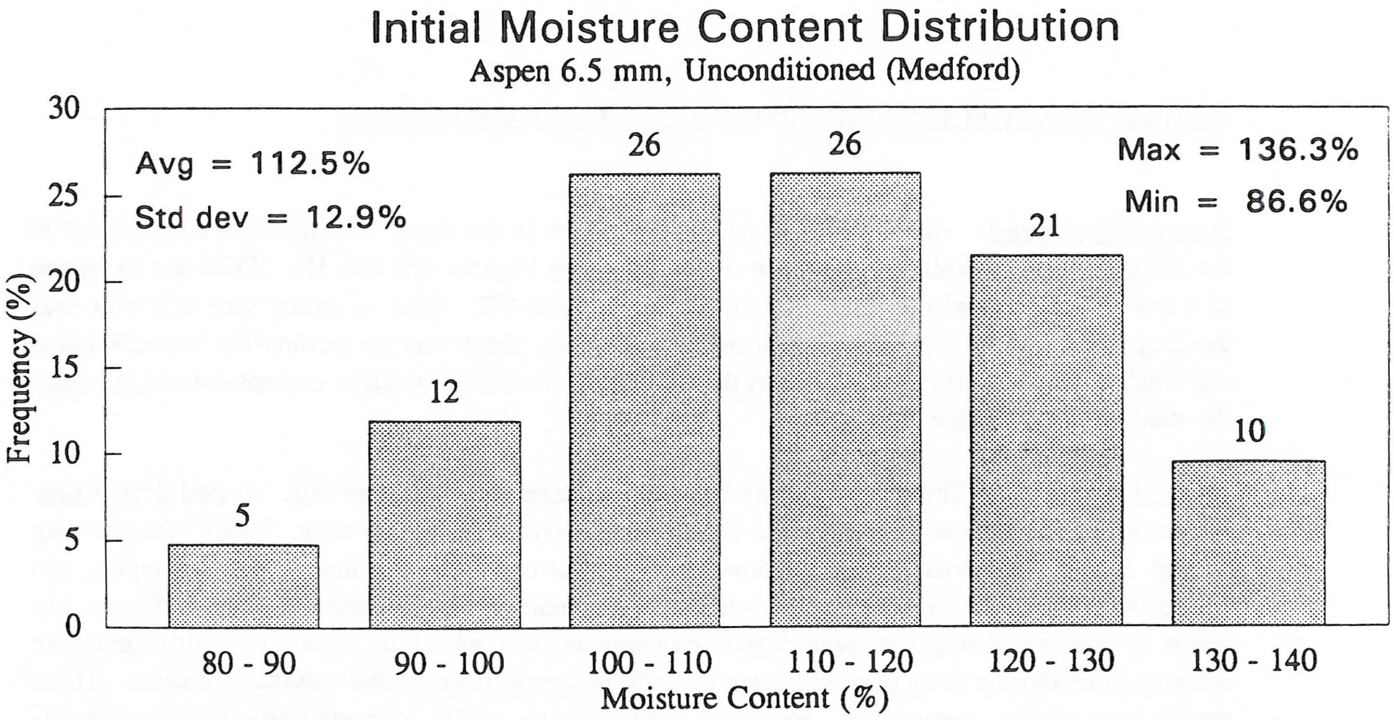
Drying Run: A6B6
Fig. 12b



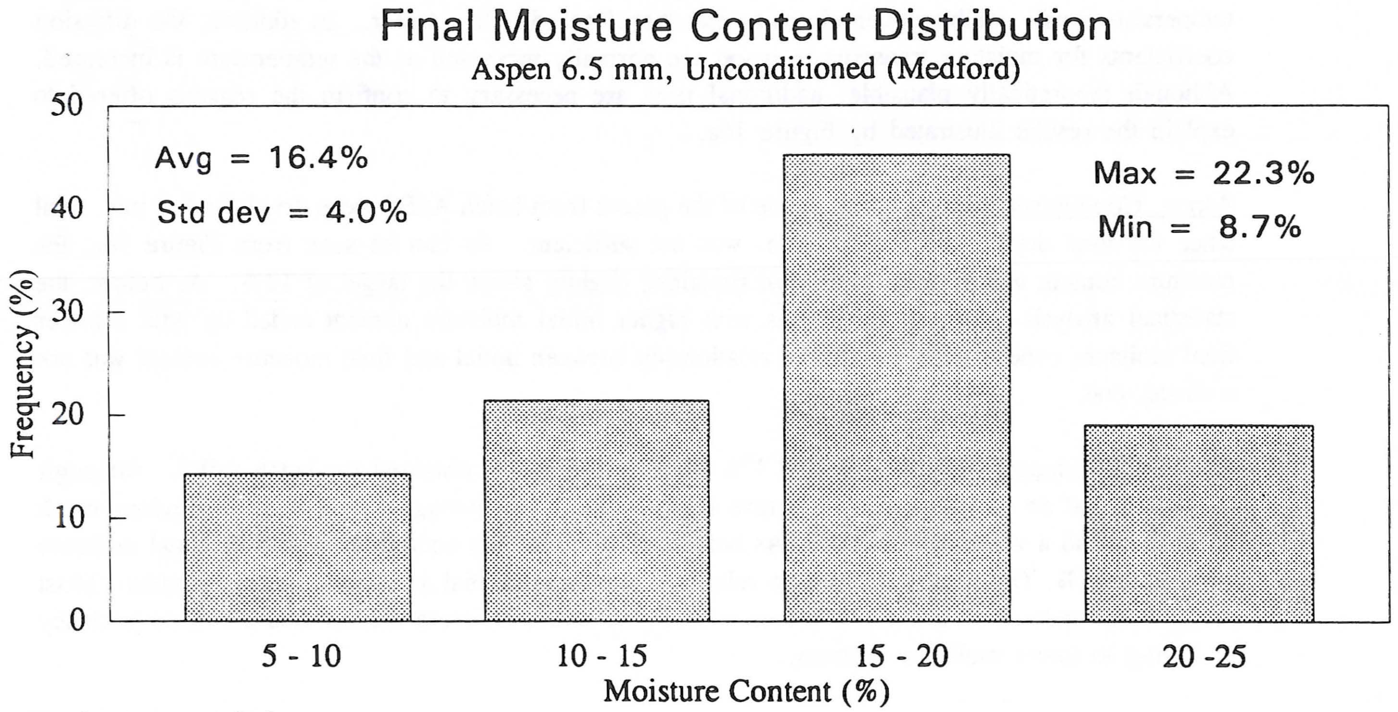
Drying Run: A6B7
Fig. 13a



Drying Run: A6B7
Fig. 13b



Drying Run: A6B8
Fig. 14a



Drying Run: A6B8
Fig. 14b

INITIAL VERSUS FINAL MOISTURE CONTENT - RF (MEDFORD)

Spruce, Conditioned: Although the short residence time in the dryer was intended to dry close to the target of 12%, overdrying did occur as illustrated by Figures 15a and 15b. With the exception of a few points, most pieces were uniformly dried to 6 and 8%. Thus, a drying time of 4 min. was too long and could be significantly reduced. Statistically, there was no relationship between initial and final moisture content, which means that in general the initial moisture content did not influence the final moisture content obtained.

Aspen, Conditioned: The results for batch A6B5 are illustrated by Figure 16a. A total drying time of 5 min. was set to test and verify the experimental curve. As can be seen, 5 min. was not long enough to bring the moisture content down to the target of 12%. The drying was incomplete and a large spread of moisture content was obtained (minimum=9%, maximum=21.5%). Figure 16a seems to indicate that pieces with higher moisture content ended up with lower final moisture contents in relation to the pieces which started with relatively lower initial moisture contents. These results are usually unexpected, especially when drying under conventional drying methods. Nevertheless, RF drying mechanisms may be imposing different drying rates which can be closely dependent on moisture content. For instance, it is known that RF energy is more effective where higher concentrations of water exist. Thus, it could be argued that perhaps those pieces with higher moisture contents develop higher temperatures due to more effective RF energy activity and therefore exhibit faster drying rates when compared to pieces with lower moisture contents. Water at higher temperatures will exhibit lower viscosity and therefore will flow faster. In addition, the diffusion coefficients for moisture transport in wood are normally increased as the temperature is increased. Although theoretically plausible, additional tests are necessary to confirm the reasons offered to explain the results illustrated by Figure 16a.

Aspen, Conditioned (Subsample): Some of the pieces from batch A6B5 were dried for 6.5 min. total since the total drying time of 5.0 min. was not sufficient. As can be seen from Figure 16c, the moisture content values were lower but remained slightly above the target of 12%. As before, the statistical analysis indicated that pieces with higher initial moisture content ended up with a lower final moisture content even though the relationship between initial and final moisture content was not a strong one.

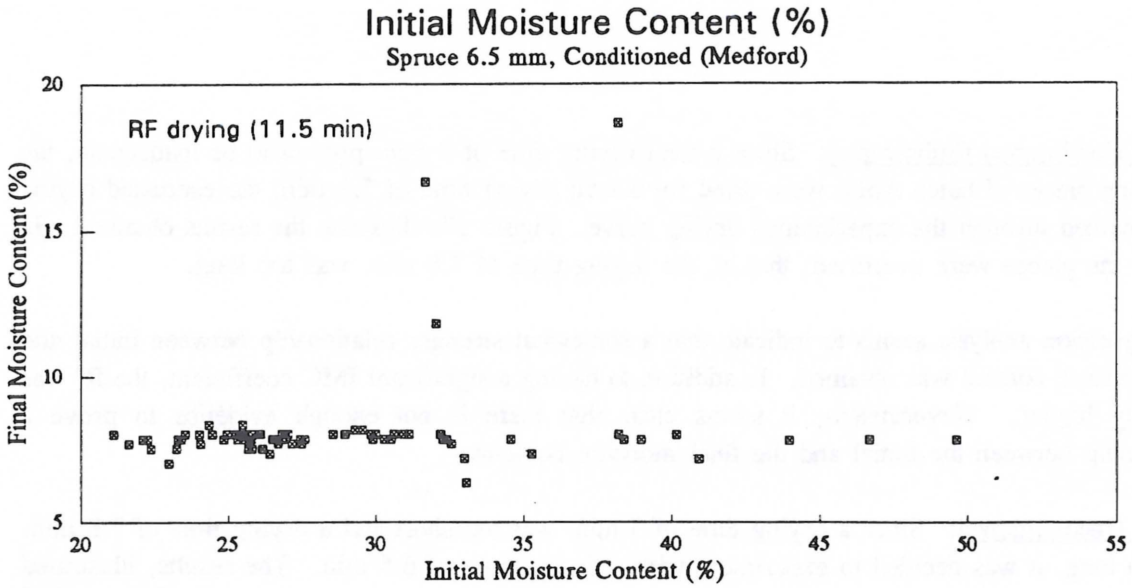
Aspen, Conditioned: Figures 17a and 17b illustrate the results obtained for batch A6B6. Although this batch had an average initial moisture content below the average found for the previous batch (A6B5), it had a wider distribution. As before, 5 min. was not enough to dry to the final moisture content of 12%. The results indicate no relationship between initial and final moisture content. Most pieces were underdried and a few pieces with higher initial moisture content had the same tendency of drying to lower moisture contents.

Aspen, Conditioned (Subsample): Since a total drying time of 5 min. proved to be inadequate, the remaining pieces of batch A6B6 were dried for a total drying time of 7.8 min, the estimated drying time obtained through the experimental drying curve. Figure 17c illustrate the results obtained. In general the pieces were overdried, that is, the drying time of 7.8 min. was too long.

The regression analysis seems to indicate that a somewhat stronger relationship between initial and final moisture content was obtained. In addition to having a significant IMC coefficient, the R^2 was relatively higher. Nevertheless, it seems clear that there is not enough evidence to prove a relationship between the initial and the final moisture contents.

Aspen, Unconditioned: Since a drying time of 5 min. was too short and a drying time of 7.8 min. was too long, it was decided to experiment with a drying time of 6.5 min. The results, illustrated in Figure 18a for batch A6B7, show that an improvement in relation to the previous drying runs was clearly achieved. Final moisture contents ranged from 10 to 20% with an average around 16% (Figure 18b). Although higher than the target of 12%, the distribution of final moisture content was reasonably uniform and the statistical analysis revealed that the final moisture content was independent of the initial moisture content.

Aspen, Unconditioned: Figures 19a and 19b illustrate the data for batch A6B8 dried for 6.5 min.. The overall results confirmed the findings for the previous batch, that is, with an average final moisture content around 16%, most pieces had moisture contents varying between 10 and 20%. As before, the statistical analysis indicated no relationship between initial and final moisture content. The tendency for the pieces with higher moisture content to dry to lower moisture levels was not observed for batches A6B7 and A6B8.



Drying run: S6 B2
Fig. 15a

Regression Analysis

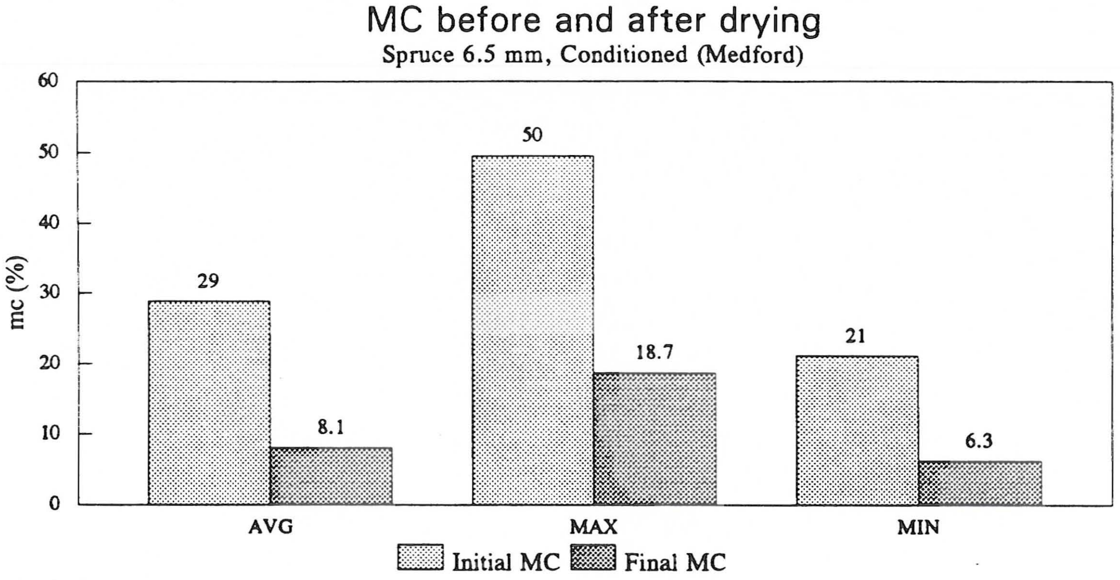
No. of observations	80
Degrees of freedom	78
R square	0.030006
IMC Coefficient	0.049367
Std Err of IMC	0.031781
Constant	6.687216

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

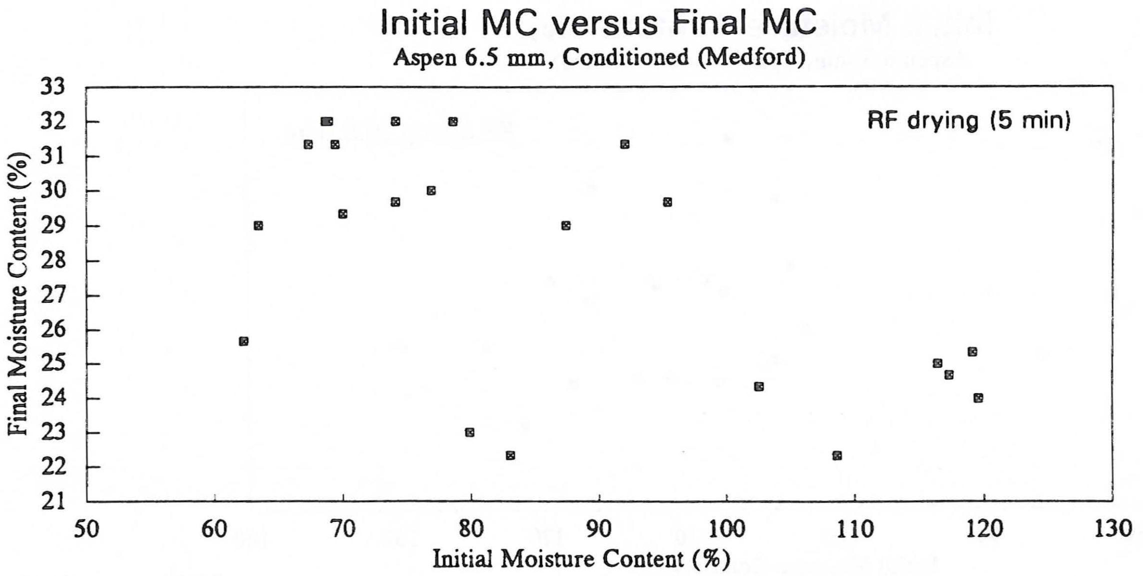
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.0155 < IMC Coefficient 0.1143



Drying Run: S6B2
Fig. 15b



Drying run: A6 B5
Fig. 16a

Regression Analysis

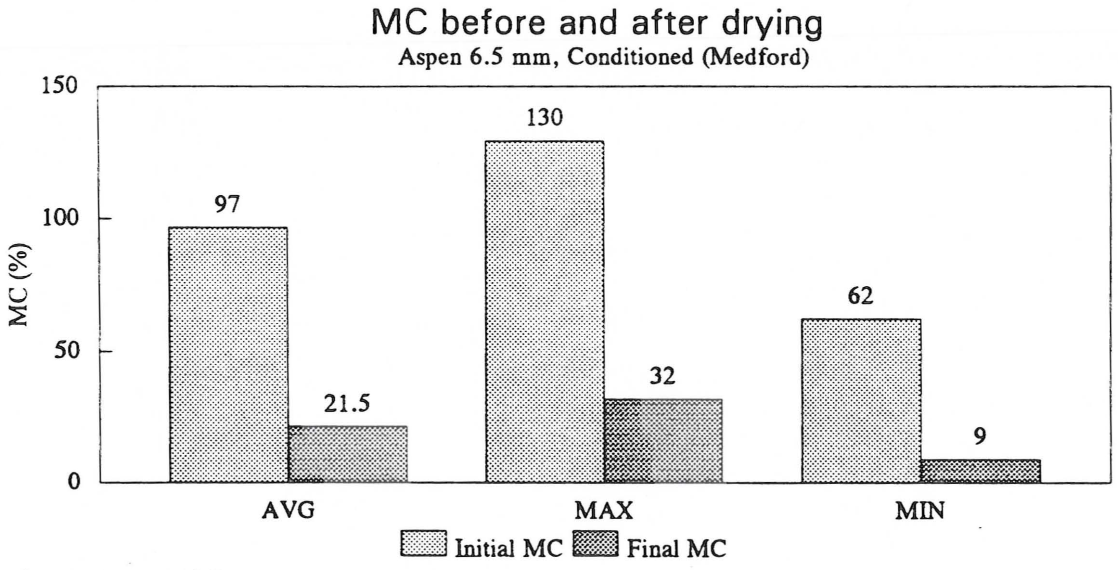
No. of observations	22
Degrees of freedom	20
R square	0.368753
IMC Coefficient	-0.10944
Std Err of IMC	0.032017
Constant	37.39617

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

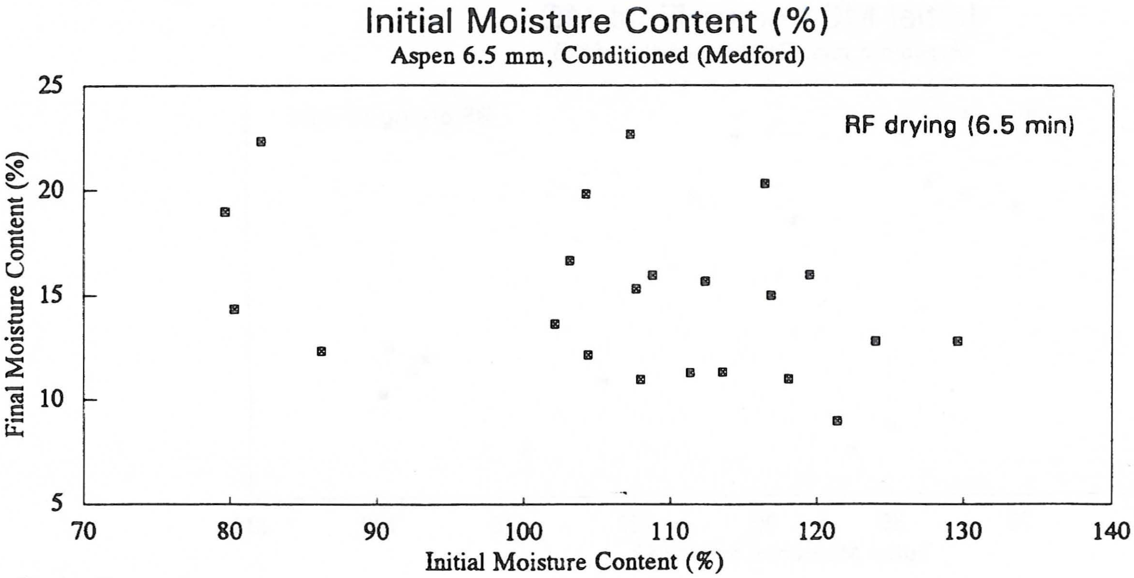
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.1758 < IMC Coefficient -0.0430



Drying Run: A6B5
Fig. 16b



Drying Run: A6B5 (subsample)
Fig. 16c

Regression Analysis

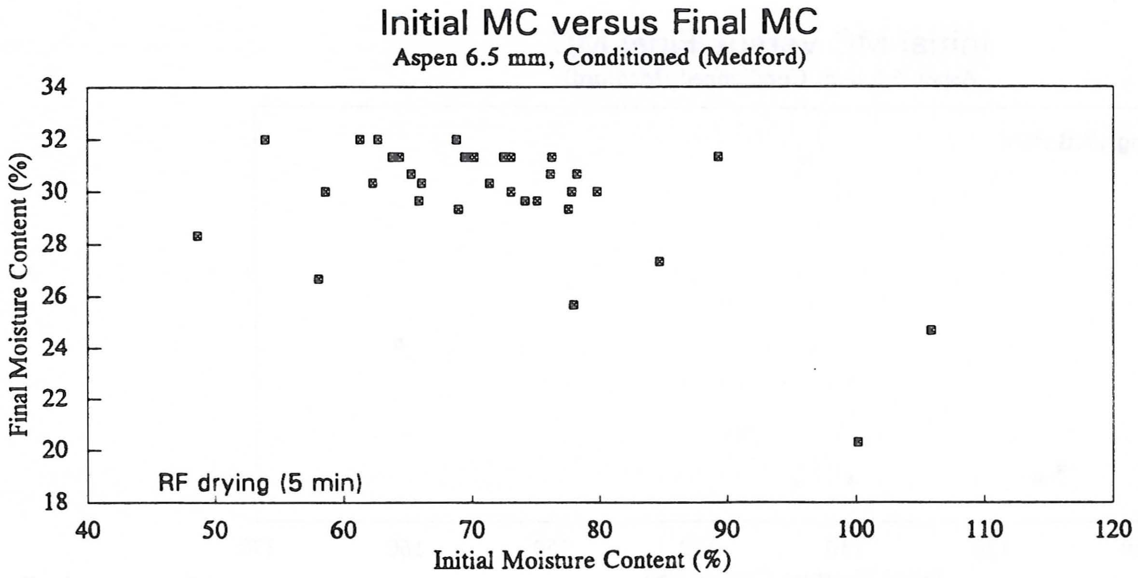
No. of observations	22
Degrees of freedom	20
R square	0.135407
IMC Coefficient	-0.10032
Std Err of IMC	0.056681
Constant	25.77807

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.1981 < IMC Coefficient -0.0025



Drying run: A6B6
Fig. 17a

Regression Analysis

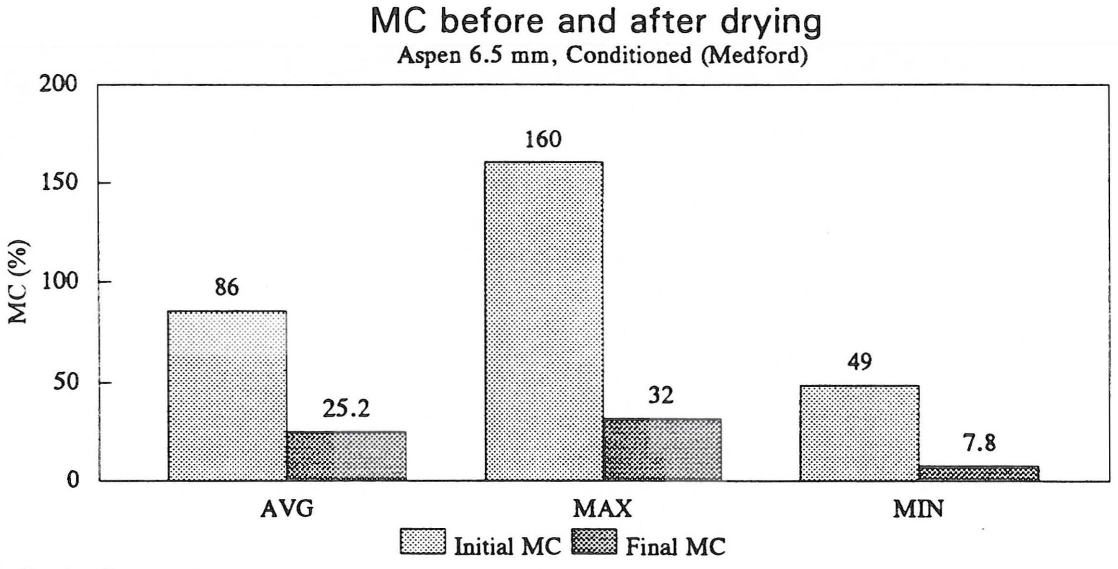
No. of observations	34
Degrees of freedom	32
R square	0.111713
IMC Coefficient	-0.05205
Std Err of IMC	0.025946
Constant	33.64694

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

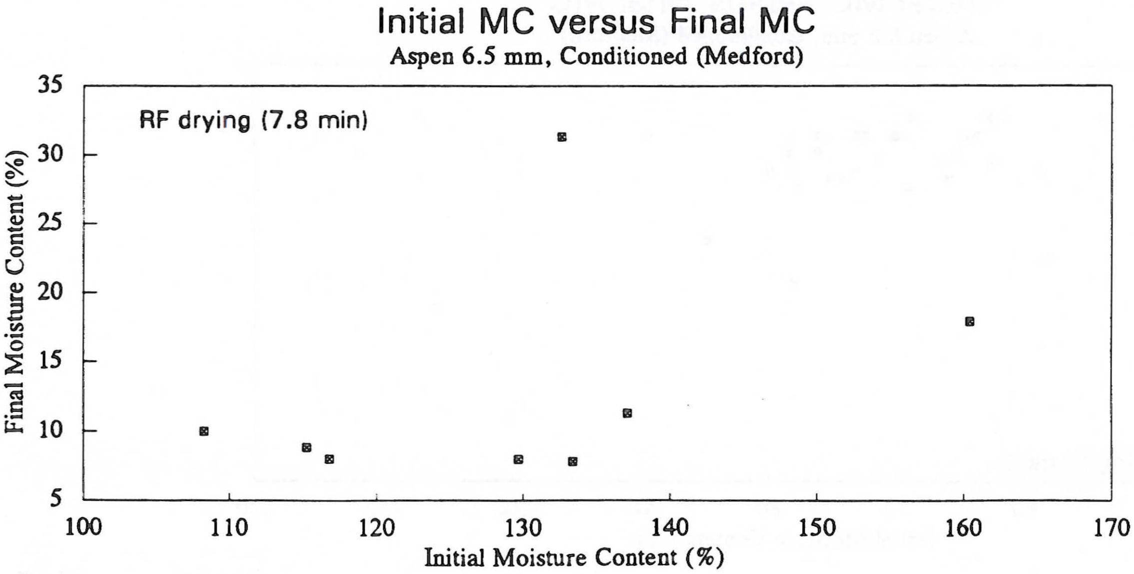
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.1050 < IMC Coefficient 0.0009



Drying Run: A6B6
Fig. 17b



Drying run: A6B6 (subsample)
Fig. 17c

Regression Analysis

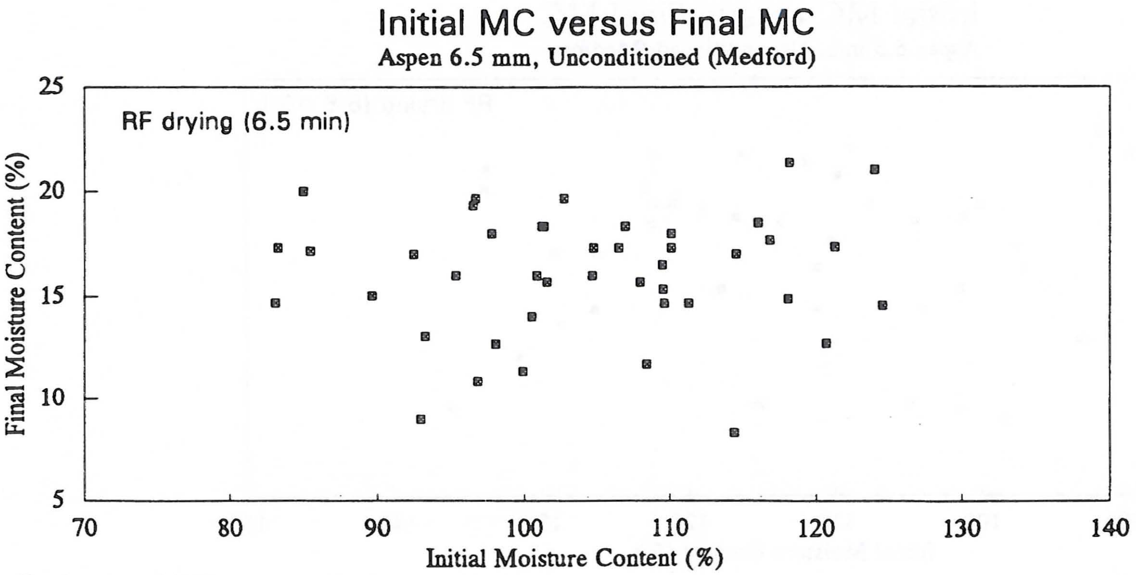
No. of observations	10
Degrees of freedom	8
R square	0.511317
IMC Coefficient	0.142431
Std Err of IMC	0.04923
Constant	-8.45227

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

0.0327 < IMC Coefficient 0.2521



Drying run: A6B7
Fig. 18a

Regression Analysis

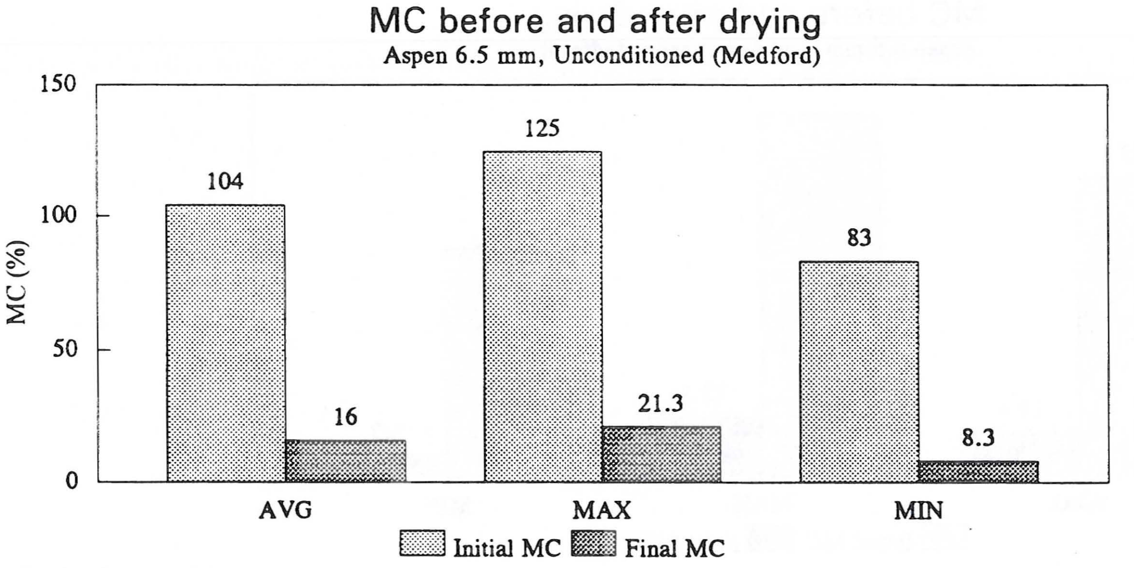
No. of observations	43
Degrees of freedom	41
R square	0.004065
IMC Coefficient	0.01725
Std Err of IMC	0.042168
Constant	14.22476

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

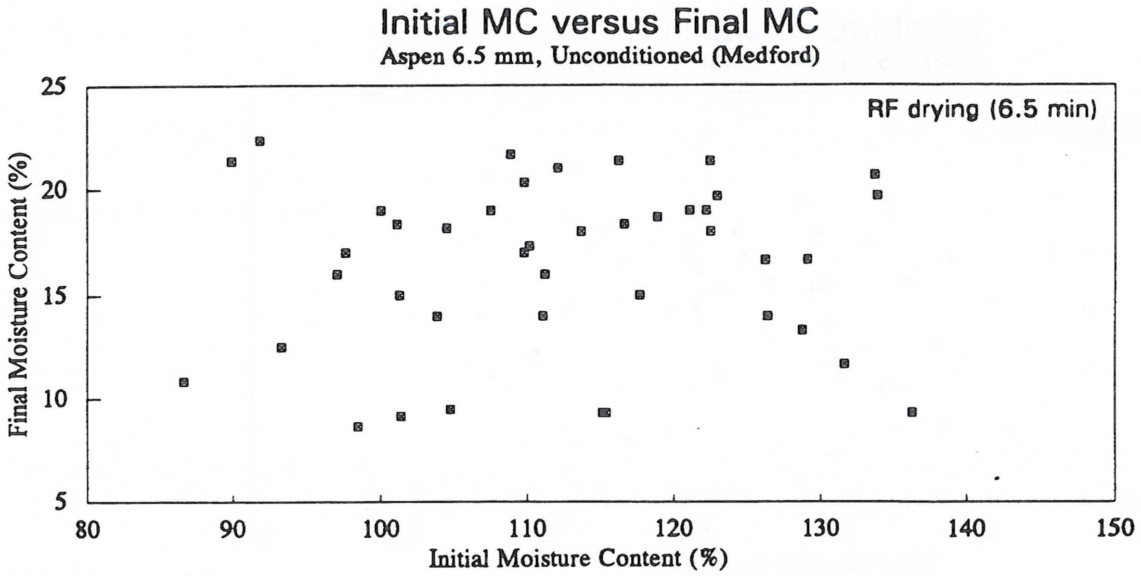
IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.0680 < IMC Coefficient 0.1025



Drying Run: A6B7
Fig. 18b



Drying run: A6B8
Fig. 19a

Regression Analysis

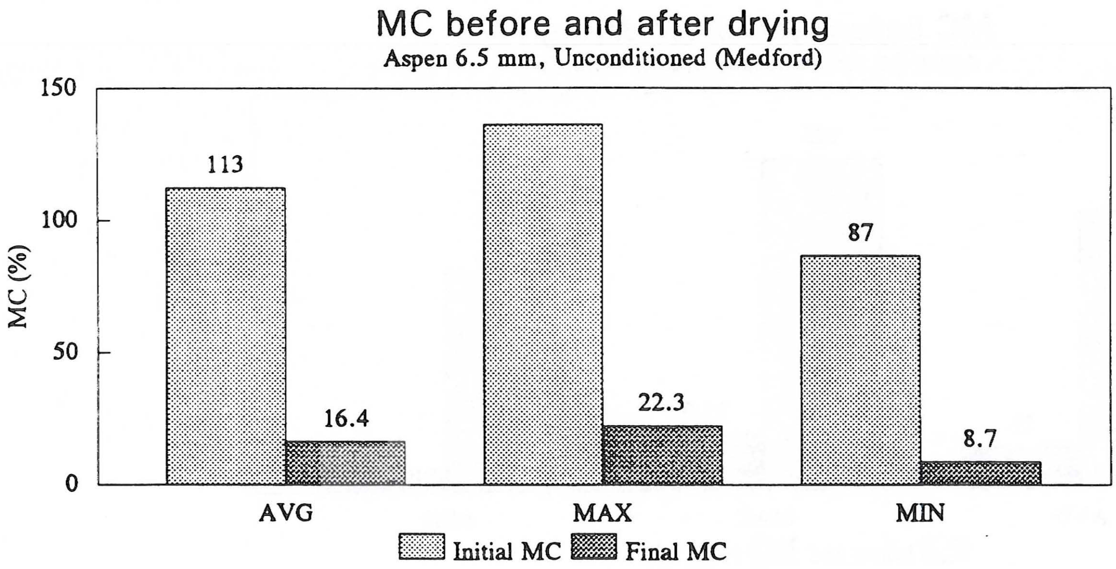
No. of observations	42
Degrees of freedom	40
R square	0.00305
IMC Coefficient	0.017361
Std Err of IMC	0.049628
Constant	14.40825

For Alpha = 95% the confidence interval for the true estimate of the IMC coefficient is given by:

IMC Coefficient ± t 0.0975 x Std Err of IMC

Thus,

-0.0829 < IMC Coefficient 0.1177



Drying Run: A6B8
Fig. 19b