The quality of lumber produced is of major economic concern to all lumber processors. One highly important element of product quality is out-of-specification moisture content. Lumber moisture content may be lower than specified. If it is, it may tend to be brash and it may swell when put into use in atmospheres of higher equilibrium moisture contents. However, the major effect of producing too-dry lumber is the reduction in product value due to checks, splits, warp and other shrinkage effects. Many data have been gathered which show that product value at a low moisture content may be several dollars per thousand board feet less than lumber dried to specification moisture content.

However, the customer most frequently complains about lumber which is wetter than specification. The kiln operator is constantly urged to keep the number of wets to a minimum. The kiln operator looks at the distribution of moisture contents in the green lumber entering the kiln and the tendency is to say that in no way can a uniform moisture content product come out of that material.

Figure 1 is a typical moisture content distribution of lumber charged into a kiln. In this case the product is small log 2x4's (Douglas fir) weighed immediately before being put into the kiln. This population, which is probably large enough to be typical of this source of material, shows an average moisture content (calculated as the total moisture content divided by the number of boards) of approximately 61%. However, the distribution is such that half of the individual boards have moisture contents of 40% or less while the remaining half have moisture contents between 40% and 190%.

This variation becomes even more significant when attention is given to the amount of moisture which is to be removed in the kiln. If the desired kiln dry moisture content is 15%, the change in moisture content of the average population is 46%. Half of the boards will lose 25% or less while the higher 10% of the green population must lose an average of over 110%!! The kiln is being asked to remove many times as much moisture from one board than from another board which may lie next to it in the kiln.

Experience shows that the final kiln dry moisture content of all of the boards in the charge are not exactly the same. However, under good operating conditions, the final moisture contents are much more uniform than would be expected at first thought.

The nature and magnitude of the drying problem faced by the kiln are shown again in Figures 2, 3 and 4. In these figures the moisture contents of individual boards are shown in the two courses of lumber which defines an air slot in the kiln charge. The total length of a bar represents the green moisture content expressed in pounds of water in
that board. The shaded portion of the bar represents the kiln dry moisture content of the board expressed in pounds of water. The unshaded portion of the bar represents, therefore, the number of pounds of water removed from the board during kiln drying. (In these figures the lumber is small log Douglas fir 2x4's eight feet long, stacked twenty four boards to the course. Sticks separating the courses were 0.75 inches in thickness. Stacking was completely random.

Examination of the figures reveals several significant points. First, with random stacking, widely differing drying energy requirements exist board-to-board across the charge. A board with a very high green moisture content may be positioned between two boards with low moisture contents. A board with a low moisture content may lie across the slot from another board with a low moisture content or across from a board with a high moisture content. All possible combinations of high, intermediate and low moisture contents exist between adjacent boards in a course and between corresponding boards on either side of the slot.

Second, it will be noted that the total green moisture contents of the boards which define a kiln charge slot are not equal. Not only does the green moisture content of the charge vary from board to board but the total moisture content varies from slot to slot. In other words, during the drying process different quantities of moisture are removed through different slots.

Third, and most significant, the kiln dry moisture contents are much more uniform than the green moisture contents. In order that this result may be achieved the boards with the higher green moisture contents must lose moisture at faster rates than the boards with the lower green moisture contents under the applied kiln conditions. Therefore, the rate of heat transfer from air to wood must be greater in the case of the initially high moisture content boards than in the case of the dryer boards.

The dry bulb temperature of the air passing through the slot, therefore, does not decrease uniformly with distance. Rather, the temperature profile is jagged. When passing over boards with low moisture contents the air dry bulb temperature changes only slightly; but when passing over the surfaces of higher moisture content boards the temperature decrease is marked. This non-uniform dry bulb temperature drop across the slot has been demonstrated experimentally with thermocouples in the air stream.

It would be very interesting and potentially valuable to have wood surface temperatures and air dry bulb temperatures corresponding to each board along the slot during the drying period. With these data, coefficients of heat transfer could be calculated and a better understanding of the energy-mass transfer mechanisms would undoubtedly result.

It will be noted that the total kiln dry moisture contents of the boards along a slot vary slightly and do not correlate with the total green moisture contents. It is not unusual for higher green moisture content slots to end up with lower kiln dry moisture contents. The correlation for experimental kiln data is shown in Figure 5.

When the relation between the green moisture contents and the kiln dry moisture contents of a large number of boards dried in
commercial kilns is plotted a figure such as that in Figure 6 is obtained. It is seen that there is, indeed, a tendency for high green moisture content boards to yield high moisture content kiln dry boards. However, within the total population the greatest number of "wets" come from green boards with lower moisture contents. Data such as these cast serious doubt on the economic feasibility of segregating western softwoods on the basis of green moisture content in order to avoid the production of "wets" in the kiln dry population.

Some of the familiar broad distribution of kiln dry moisture contents and the costly number of "wets" is unavoidable. However, in many cases the cause of the broad distribution is due to non-uniform kiln conditions which can conceivably be corrected, if identified.

Correctable causes of broad moisture content distributions can be determined best by means of recording and analyzing many moisture contents taken throughout several charges of lumber. This type of data gathering and analysis will show whether certain regions in the kiln are responsible for the higher moisture content boards. The data may show that certain cribs along the track are consistently wetter than others. The lower sections of the charge may be consistently wetter than the upper sections. The centers of the charges may be consistently wetter than the edges. The lumber on one track may be consistently wetter than that in the corresponding position on the other track in a double track kiln.

Armed with the knowledge that there are consistent non-uniformities in the drying performance of a given kiln, attention may then be focused on isolating and correcting the cause. The obvious first things to look for are non-uniformities in dry bulb temperature, air flow and humidity. Corrective action may range from starting a stalled fan, plugging a steam leak, replacing baffles or using improved stacking to redesign of heating or dilution air components.

In most cases the lumber is doing its best to cooperate with the kiln operator in producing uniform kiln dry moisture content product. It needs help, however. The kiln conditions must be maintained as uniform as possible.

One situation which will continue to plague the northwest softwood lumber dryer is the existence of wet streaks such as those found as frequently in western hemlock. It is not uncommon to find boards which have been through the kiln many times which are still marked as "wet" by the unstacker meter.
Total Water in Course
Green  139 lb
Lost   111 lb
Kiln Dry 28 lb

Green  102 lb
Lost   73 lb
Kiln Dry 29 lb
Total Water in Course
Green  128 lb
Lost   102 lb
Kiln Dry  26 lb

Green  154 lb
Lost   126 lb
Kiln Dry  28 lb

Figure 3

Total Water in Course
Green  155 lb
Lost   126 lb
Kiln Dry  29 lb

Green  126 lb
Lost   99 lb
Kiln Dry  27 lb

Figure 4
"Correlations" between green and kiln dry moisture contents - Douglas-fir 2" stock - two kiln charges.

Figure 5

Figure 6