MC based or time based drying schedules? Calculation of the influence on final MC variation

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ABSTRACT

The quality of dried softwood timber depends of course on the drying process performance and in batch kilns especially on the drying schedule. In the Nordic countries the drying schedule is almost always a time based schedule, i.e. the target climate is defined as a function of drying time. The basic idea is that the average properties of each batch (same wood species and board dimension) are almost constant and when a suitable drying schedule has been found, then it can be used repeatedly without changes. In continental Europe the target climate is very often defined as a function of the actual average MC of the batch. The basic idea here is to adapt the schedule according to the real properties of each batch. This is a correct approach, but the problem is to measure the average MC accurately during the process. This is normally done by pairs of electrodes driven into a limited number of boards for electric resistance measurements. Each board has however individual properties and the measured MC differs normally from the average MC of the batch. In addition the MC value based on the electric resistance is not fully reliable. This introduces a stochastic element in the performance of the kiln control system. The aim of this paper is to analyse the accuracy of the MC based schedule control and compare it to the time based schedule approach. The analysis is performed using a simulation program for the drying process. Virtual boards with different properties (initial MC, heartwood content, density and 'dryability') are generated using a random number generator. It has been taken into account that the properties mentioned are not statistically independent. In this way a batch of timber is generated and the drying of each board is simulated in order to get the individual final MC and further the MC standard deviation for the whole batch. The MC based drying schedule is applied according to the calculated MC of a few randomly selected boards. The influence on the final MC variation, by the number of boards selected for MC estimation, can thus be determined, as well as the influence of some other features. The results are then compared to the corresponding results for a similar kiln using a time based drying schedule.

INTRODUCTION

Using simulation models for the prediction of the outcome from softwood drying processes has been a standard procedure for a long time already. The basic method is to predict the average result for the whole load in a batch kiln as a function of timber dimension, drying schedule etc. This approach does not give any value for the spread in the results, such as the final MC standard deviation. This limitation can be solved by performing simulations for each piece of a large group of boards, where each board is given different properties according to the real variation in practice. This method has been described and used in (Salin, 2002). The properties varied are: initial MC, density, heartwood content and "dryability" (diffusion coefficient and related parameters). These variables are considered the most important for softwood drying processes and also sufficient for a reasonably reliable calculation. It should be observed that these variables are not independent of each other. This is encountered for in the method described in (Salin, 2002). In this way a batch of "virtual" boards is created and drying of each of these is simulated according to different drying schedule types and approaches.

MC BASED DRYING SCHEDULE

An MC based drying schedule means that the climate in the kiln is a function of the measured (estimated) average MC in the batch. The average MC is in practice based on the electric resistance measured by pairs of electrodes driven into a number of boards in the batch. There are several ways to do this by measuring the resistance at different depths, for instance close to the surface and/or at the depth believed to represent the average MC of the board etc. Such solutions can improve the reliability of the measurement. In the following theoretical calculations it is however assumed that the MC measurement is 100% exact all the way for each board selected.

The example used in all the following simulations is characterized as follows. Scots pine (*Pinus silvestris*) 50 x 150 with an average initial MC of about 73 % and density 430 kg/m^3 (abs. dry/green volume) is dried to either 16 % or 12 % in a batch kiln. The drying schedule used has a constant dry bulb temperature of 80^{o}C and a decreasing wet bulb temperature and the air velocity between board layers is 4 m/s. Initially a time based schedule was chosen that gives a rather rapid drying, but with a stress development (for all boards) clearly below the threshold value for checking. This time based schedule was converted to an equivalent MC based schedule by investigating the MC development in a board with *average* properties when dried with the time based schedule. Due to the relatively high temperature, rapid drying and no final conditioning, the spread in the final moisture content is high – which makes comparisons easier.

The simulations are performed for batches of 200 virtual boards. This number represents a rather small kiln but is chosen for computational reasons. The final MC distribution for these 200 boards should however represent a rather good approximation of the distribution from a full size kiln. Consider as an example that three virtual boards are randomly chosen for control of the MC based schedule (resistance electrodes). A typical final MC distribution for one single batch is shown in Fig.1 for a 16% MC target and in Fig.2 for a 12 % target.

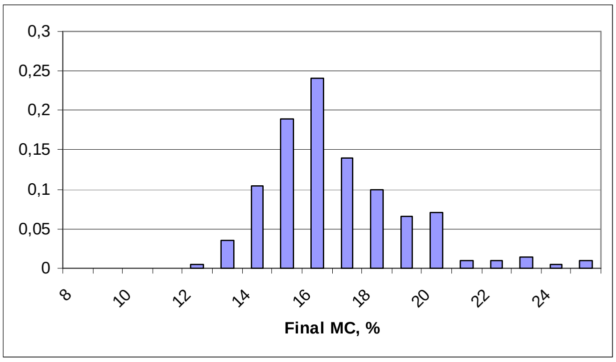

Figure 1. Typical final MC distribution for a single batch of 200 virtual boards. Target 16 % determined from 3 boards.

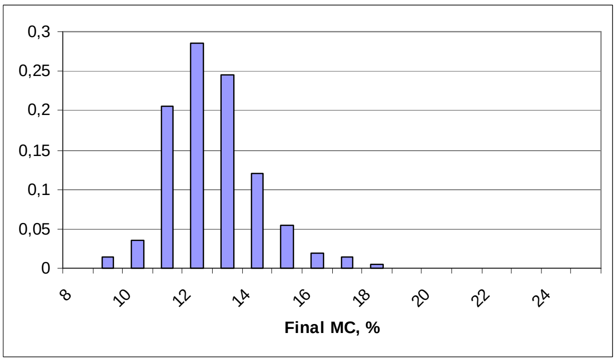

Figure 2. Typical final MC distribution for a single batch of 200 virtual boards. Target 12 % determined from 3 boards.

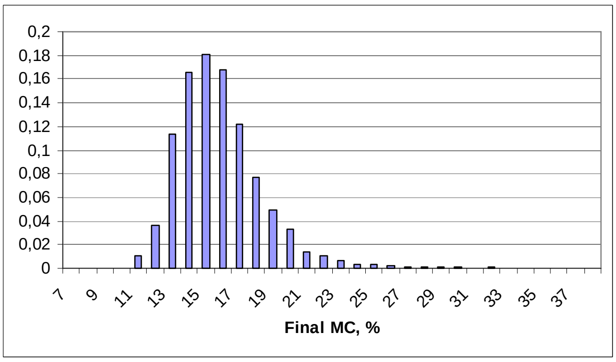

Figure 3. Final MC distribution for 17 batches of 200 boards each. Target MC 16 % determined for each batch from 3 boards.

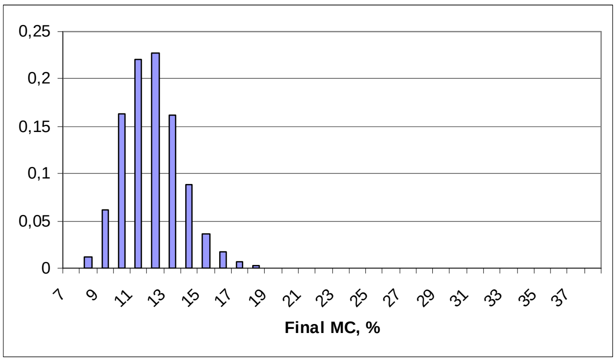

Figure 4. Final MC distribution for 17 batches of 200 boards each. Target MC 12 % determined for each batch from 3 boards.

It is clearly seen in both Figs.1 and 2 that the average MC in the batch is higher than the corresponding target. (Actually these two distributions are taken from the same simulation, where the 16 % target case represents an intermediate result.) This shows that the three boards selected for control, dried faster than the average of the batch. Now if several batches are dried in this way, then some batches are dried too long and some for a too short time. When these batches are combined the overall spread in the final MC will increase. Such a result is seen in Figs.3 and 4 for 17 batches (in total 3400 boards) for MC targets 16 and 12 % respectively. If more than three boards are used for the

estimation
of the average MC in each batch then a narrower overall distribution will of course be the result.

The final MC standard deviation calculated for the total number of boards from 17 batches with different number of control boards is presented in Table 1.

Table 1. Final MC standard deviation when several batches are combined

Number of control boards	Target MC 16 % [%]	Target MC 12 % [%]
1	2,67	1,87
3	2,53	1,72
5	2,52	1,64
10	2,33	1,58
All	2,12	1,48
5, highest and lowest value neglected	2,41	1,57
10, highest and lowest value neglected	2,27	1,55

A perhaps surprising result seen in Table 1 is the relatively small influence the number of control boards has on the standard deviation. An analysis shows that the standard deviation is a combination of two parts; the (rather constant) spread in the final MC in a single batch and the error in the estimated MC based on the control boards. It turns out that the first part is dominating. It should be noticed that the values in Table 1 are rather high, which is due to a rapid drying process, without a conditioning phase.

Although the total number of boards in the simulations is high, a random scattering of the results in Table 1 have to be taken into account. A theoretical estimation of the final MC standard deviation – with some simplifying assumptions – has been performed and is presented in Fig. 5.

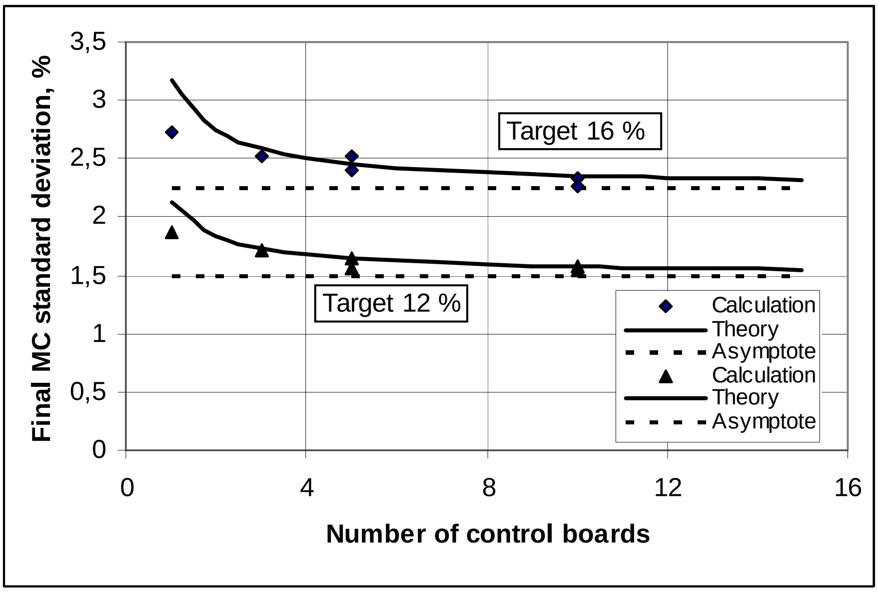

Figure 5. Final MC standard deviation as a function of the number of control boards.

Fig. 5 shows clearly that the number of control boards does not influence the result very much. It is also seen that omitting the highest and lowest measured MC values does not have a significant impact on the standard deviation. This is true in this theoretical case – in practice the main reason is to remove clearly erroneous, unsuccessful measurements. Due to the risk of such measurement failures, the number of control boards should in practice not be too small, perhaps not less than five.

It should be taken into account that the control board measurements were assumed to be absolutely exact in the simulations above. In reality the measurements are far from exact. In softwood boards there are frequently both sapwood and heartwood present in the same board, with different MCs most of the time during the drying process. There is further a steep moisture gradient in the board during drying and it thus very important that the electrodes in a resistance measurement are driven to the correct depth. If it is assumed that the standard error in a single measurement is 2 %-units (Forsén, Tarvainen 2000) then the theoretical curves in Fig. 5 may be extended with a calculation of the influence on the final MC standard deviation. The result is seen in Fig. 6.

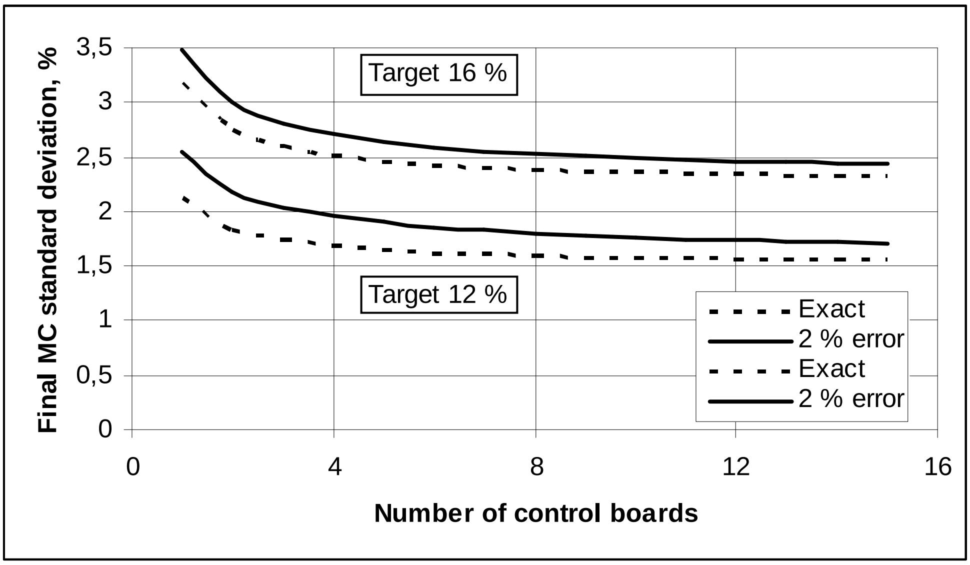

Figure 6. Influence of control board MC measurement error on the final MC standard deviation.

The standard deviation seen in Fig.6 has of course increased, but not so much, i.e. the spread caused by the variation in board properties is still dominating.

TIME BASED DRYING SCHEDULE

The time based drying schedule is based upon the assumption that each batch of boards in the kiln has the same distribution of properties and if the optimal drying procedure is found, then an optimal result will be obtained for each batch. If this really is the case then a level slightly below the asymptotes in Fig.5 would be achieved. This is however not a fair comparison as the main objective with the MC based drying schedule is to adjust the schedule according to the real MC development for each batch. A more reasonable procedure is to analyze how deviations from the assumption that each batch is equal, affects the final MC standard deviation and compare this to the results for a MC based schedule. An MC based schedule will in the long run produce an average MC close to the target but the standard deviation depends on the ability of the control boards to estimate the real MC. For time based schedules the opposite situation is found, i.e. the standard deviation is fairly constant but the average value will deviate from the target as the changed properties of a batch are not taken into account. A comparison between schedule types is thus not very easy. One possibility, which is used here, is to instead of the standard deviation (which is based on the deviation from the *average* value) base the calculation on the deviation from the *target* value. For the MC based schedule the result will in principle be the same, but for the time based schedule the systematic deviation from the target will be included and affects the result.

Three different changes in the batch properties are considered here; a pre-dried batch, a 1^{o}C error in the wet bulb depression and a 1 mm error in board thickness. In the first case it is assumed that the (stickered) batch has been standing outdoors for a longer time than normal before loading into the kiln. Boards with a high initial MC (much sapwood) will dry more during this period than boards with a low initial MC and this feature is included in the simulation. The average decrease of the initial MC for the whole batch is 8,0 %-units in this example. The second case was obtained by decreasing the dry bulb temperature 1°C from the target level, simulating an error in the temperature measurement. Finally in the third case, it is assumed that the green board thickness has increased 1 mm without a change of the drying schedule. The result is seen in Table 2.

Table 2. Influence of a change in batch properties on the spread in the final MC with a time based schedule

	Final MC target 16 % [%]	Final MC target 12 % [%]
Ideal case	2,05	1,48
Pre-dried batch	1,92	1,43
Wet bulb depression error	2,38	1,60
Board thickness error	2,08	1,51

It is seen in Table 2 that the influence of changes in the batch properties or drying conditions on the spread in the final MC (standard deviation in relation to the *target*) is rather small. It is remarkable to notice that in the case of pre-drying the spread actually decreased. This is obviously due to the calculated effect of relatively slow pre-drying at low temperature before the kilning.
If this is true in reality is not known. It could be argued that the changes in batch properties studied in Table 2 are small. On the other hand, at least in the Nordic countries, it is a normal procedure to check the final MC with a hand-held MC meter before emptying the kiln. At that stage fatal errors would be noticed and the MC corrected if possible. It should finally be mentioned that although 3400 boards are simulated for each entry in Table 2, there are still some random scattering in the results.

CONCLUSIONS

As described above the variation in board properties has a dominating influence on the final MC standard deviation. This means that a surprisingly low number of control boards with an MC based drying schedule is enough, i.e. the benefit of additional control boards gradually disappears in comparison with the total uncertainty. For the same reason, moderate changes in batch properties or drying procedure, together with a time based drying schedule, will not influence the spread in relation to the target MC very much.

If the results are compared to the new standards, it is found that with a MC based drying schedule, the average MC of a batch (200 boards) will occasionally fall outside the accepted range for 1, 3 and 5 control boards. The portion of individual boards that fall within the ranges 12±3,6 % and 16±4,8 % for the MC targets 12 % and 16 % respectively, fulfils the requirement (93,5 %) when several batches are combined, but not for all single batches when the number of control boards is 1, 3 or 5. For time based drying schedules the requirements are fulfilled. These results are based on the assumptions that control board MCs are measured exactly and that the board property distribution is constant. The results for the MC based drying schedule indicate thus that the number of control boards should preferably be ten or more. This is illustrated by Figs.7 and 8.

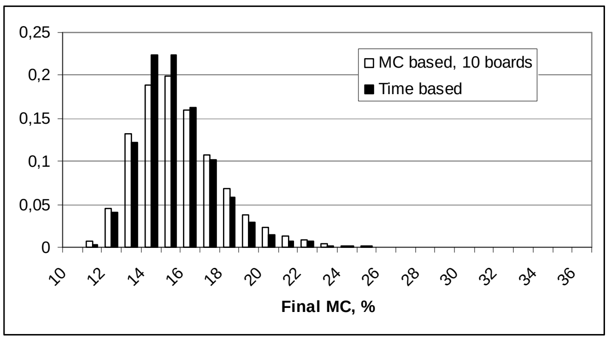

Figure 7. Final MC distributions for a MC based drying schedule with 10 control boards and for a time based schedule. Target final MC is 16 %.

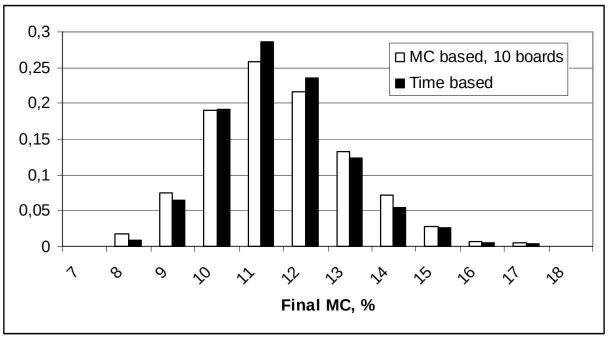

Figure 8. Final MC distributions for a MC based drying schedule with 10 control boards and for a time based schedule. Target final MC is 12 %.

As seen in Figures 7 and 8 the time based drying schedule produces a somewhat narrower distribution in both diagrams, but the overall difference is rather small. The total number of boards in each case is 3400 and in Fig.7 a few boards have a final MC of up to 36 %, but the portion of these extremes is too small to be seen in the diagram.

Taking into account that especially the steep moisture gradient in a board during drying will increase the MC measurement uncertainty – as seen in Figure 6 – it seems that a ten control board requirement is a reasonable target. This indicates also that if a reliable average MC measurement method would be available – that includes an essential part of the whole batch – then the MC based schedule would be superior as it adapts to the real MC development of each individual batch.

On the other hand, in many laboratory tests where matched boards are dried in different batches in order to compare different procedures, using a MC based schedule will introduce an unnecessary random disturbance in the results. In such cases a time based schedule should be used.

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