Oscillation drying of beech timber – initial experiments

G. Milić[1], B. Kolin[2]

University of Belgrade, Faculty of Forestry, Department of Wood Processing, Kneza Višeslava 1
11000 Belgrade, Serbia
[1] gmilic@sbb.co.yu, [2] branko.kolin@gmail.com

ABSTRACT

The paper shows the results obtained by drying 38-mm thick beech timber, namely one control test run under usual, conventional drying schedule and four test runs dried under the same schedule but with oscillations of equilibrium moisture content. During oscillation drying, temperature curve was identical with the temperature curve in the control test run, and the values of equilibrium moisture content oscillated according to previously set amplitudes and frequencies. Oscillation amplitudes were ±10% in the first two test runs and ±20% in the second two test runs compared to the value anticipated in the schedule. Duration of each oscillation was 3 h in the first and third test runs and 6 h in the second and fourth test runs. Special addition to the manufacturer's software was developed for the realization of these oscillations. When comparing the results, drying time (for the same intervals of initial and final timber moisture content), energy consumption and drying quality were taken into consideration. Drying quality was determined at the end of each test run (both before and after conditioning), and based on the value of final timber moisture content, distribution of moisture content across thickness and gap size. Drying time was shorter in all four test runs with oscillations, and energy consumption was lower than in the conventional test run. Slightly shorter drying period was recorded in test runs with oscillation frequency of 3 hours compared to the test runs with 6 hour oscillations. Final timber moisture content was almost even in all test runs. Profiles of moisture content across timber thickness were also similar in the test runs, but the biggest difference between core and surface at the end of drying was achieved in the test run without oscillations. Before conditioning, average gap value of over 2 mm was recorded in all test runs, but the biggest average value was recorded in the test run without oscillations.

INTRODUCTION

Timber drying in conventional kilns, regardless of its disadvantages (first of all the duration of the process), is still the dominant method of timber drying. The reasons why other methods have not taken the primary position are different, but the most important ones are the prices of investment and exploitation, and the complicated and expensive maintenance of installations. For this reason, the improvements in conventional drying are still explored. The improvements refer primarily to potential shortening of the process, and one of theoretically possible enhancements is the application of the so-called oscillation drying.

The term oscillation drying covers a form of conventional drying in which, in determined time intervals, air parameters in the kiln are oscillated in comparison to the previously set scheduled parameters. This includes oscillations of temperature or relative air humidity, but also the simultaneous oscillations of these two parameters. The theoretical analysis shows that, by applying oscillations, some improvements can be expected from the aspect of drying duration

(Salin 2003). Experimental research, however, shows contradictory results. In most of the investigations, especially the earlier ones, only the temperature oscillations were applied (Langrish *et al*. 1992). Later investigations used also EMC oscillations. Sackey *et al*. (2004) report that temperature oscillations in thick hemlock timber drying led to reduced drying time, and wet-bulb temperature oscillations led to uniform moisture content distribution per thickness. Terziev *et al*. (2002) conclude that "oscillation drying is neither faster nor better with regard to drying quality than the conventional drying of 50-mm thick Scots pine planks." Welling *et al.* (2003) investigated the application of EMC oscillations in drying 30-mm pine and 60-mm beech and obtained reduced drying time and more uniform moisture content distribution per thickness. Apart from Welling *et al.*, consistent researches of oscillating regimes are very rare in hardwood drying, where potential saving in drying time would be much more significant. In hardwoods, the same saving percentage as in softwoods would lead to reduced drying process for several days, which would, together with the unchanged or better drying quality, mean also a great cost saving. This research of EMC oscillations in beechwood drying is the first step in this direction in Serbia, and it is a part of the research which will also include temperature oscillations, as well as the combination of these parameters, first in the laboratory kiln, and then in industrial kilns.

MATERIAL AND METHODS

The research was done on 38-mm thick beech timber. Five drying cycles were performed in laboratory kiln, capacity 0.8 m^3. The kiln was equipped with 2 reversible fans, 2 measuring points for temperature and EMC, and 8 probes for measuring wood moisture content. In all test runs, timber was dried from green state to 9% moisture content, measured with the probes in the kiln. The length of all boards was 2.1 m, and they were sawn 2-3 days before drying, from the logs of similar diameters and from the same location. In each test run, 30 boards were selected and stacked in the central part of the stack to be used for the assessment of drying quality at the end of the process. The first drying cycle was performed by the schedule for 38-mm thick beech timber, which is common in Serbia (Table 1).

Table 1: Conventional drying schedule (beech, 38 mm)

MC (%)	temp. (°C)	EMC (%)
60	37	15
55	38	15
50	38	14.6
45	38	14
40	38	13.6
35	40	13.1
30	43	12.1
25	47	9.2
20	52	6.8
15	58	5.4
10	62	4.4
5	62	4.4

In the other four test runs, the oscillations of equilibrium moisture content were done according to previously set amplitudes and frequencies (Table 2).

Table 2: Amplitudes and frequencies of EMC oscillations in five test runs

Test run	Amplitudes (% relative)	Frequencies (h)
I (conventional)	-	-
II (oscillation)	±10	3
III (oscillation)	±10	6
IV (oscillation)	±20	3
V (oscillation)	±20	6

As for test runs with oscillations, e.g. in test run II, the preset EMC value was, in relative sense, by 10% higher than the value in the conventional schedule for the period of 3 hours, and then by 10% lower for the period of 3 hours (Table 2). Thus in the initial stage of drying, the upper value of EMC was 16.5%, and the lower value was 13.5%, while in the final stage of drying the value ranged from 4.8% in plus stage to 4.0% in minus stage. The temperature curve in test runs with oscillations was identical to the curve in the conventional test run. To realize the EMC oscillations in the previously set amplitudes and frequencies, it was necessary, in cooperation with the kiln manufacturer, to create an addition to the software whose simple activation leads to oscillation drying. Additional software enables the input of duration of the first and the second stages, and the deviation values of EMC and temperature in the first and in the second stages previously set in percents, compared to the existing ones in the conventional schedule.

Before drying, the selected 30 boards were weighed with a digital balance. The boards were stacked in the kiln so that the distribution of 30 control boards was uniform in all test runs. For monitoring the wood moisture content in each test run, the probes were driven into the boards at the same places. At the end of drying, the conditioning stage lasted for 16 hours, under the temperature of 62°C, and EMC 11%. After the active stage of drying (before the conditioning stage), four test specimens were sliced from each of the 30 control boards and marked A, B, C and D (Fig. 1). Prior to slicing, the board mass was measured and, in addition to end sealing, 40 cm was rejected in order to eliminate the faster end drying influence. Test specimens marked A and D were used for the measurement of final moisture content by gravimetric method (EN 13183-1). Simultaneously, initial moisture content of beech timber was determined based on the final moisture content and board mass before and after drying. Test specimen B was used for gap measurement, which is a measure of case-hardening in wood according to ENV 14464. Gap values were measured immediately after slicing, as well as after climatization of 48 hours. Five lamellae were sliced from test specimen C and their moisture content was measured gravimetrically to determine the moisture content distribution across thickness. Simultaneously, moisture content difference (ΔMC) was calculated as the difference between moisture content in the core (MC of lamella 3) and the mean moisture content in the surface (MC of lamellae 1 and 5).

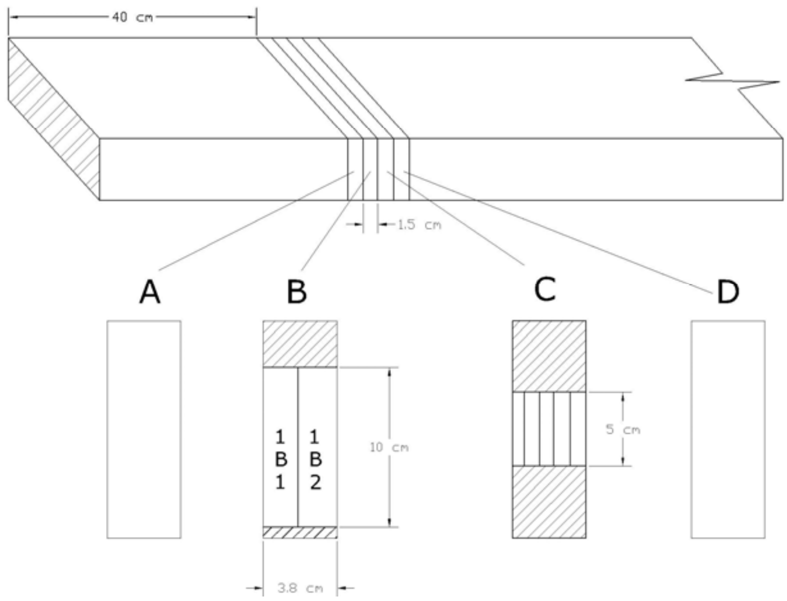


Figure 1: Test specimens and lamellae for determination of final MC (A, D), MC distribution across thickness (C) and gap measuring (B)

The boards were examined before the conditioning stage, after which the boards were returned to the kiln which was then re-heated for several hours to 62°C, followed by conditioning and cooling. After that, the complete procedure of quality assessment was repeated on all 30 control boards. All parameters had to be determined before the conditioning stage to detect clearly the possible differences which were the consequence of oscillations in the active stage of drying. Drying defects were also controlled visually, such as the surface and end checks and deformations.

Along with drying quality, drying time and energy consumption per test runs were also compared. Drying time was monitored for the same interval of moisture content in all five test runs, whereas the electric energy consumption was monitored for the entire drying cycles.

RESULTS AND DISCUSSION

Fig. 2 presents the drying curves of all five test runs. Compared to the control test run, the oscillations of wood moisture content measured by probes were noticeable, especially in the high zones of moisture content. These oscillations were the direct consequence of EMC oscillations, i.e. the changes of relative air humidity. The value of the oscillations did not affect essentially the drying process itself, all the more because the change of temperature and EMC in that period is very small, according to the previously set drying schedule.

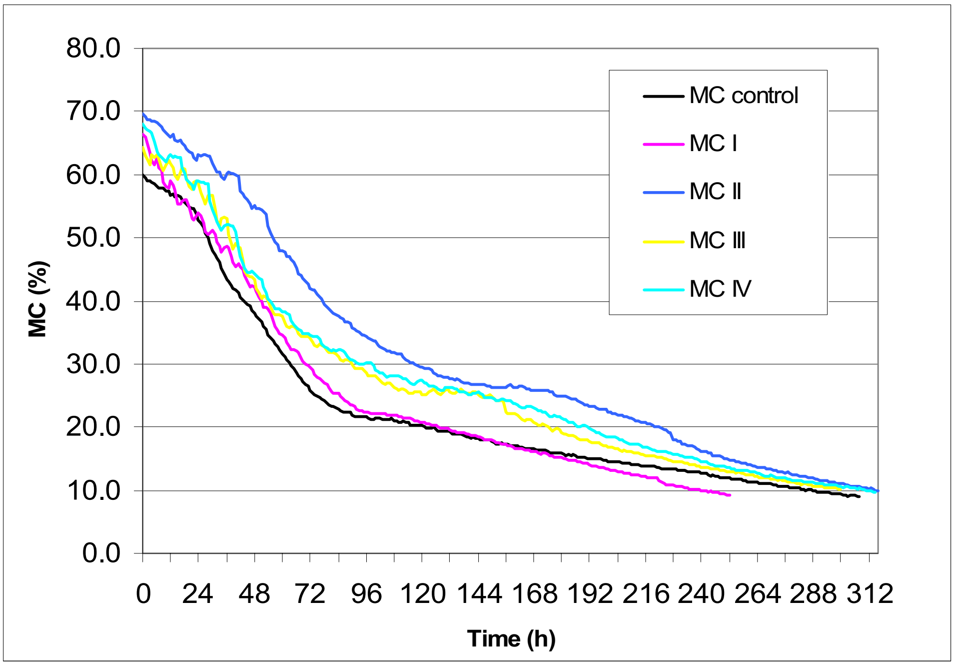
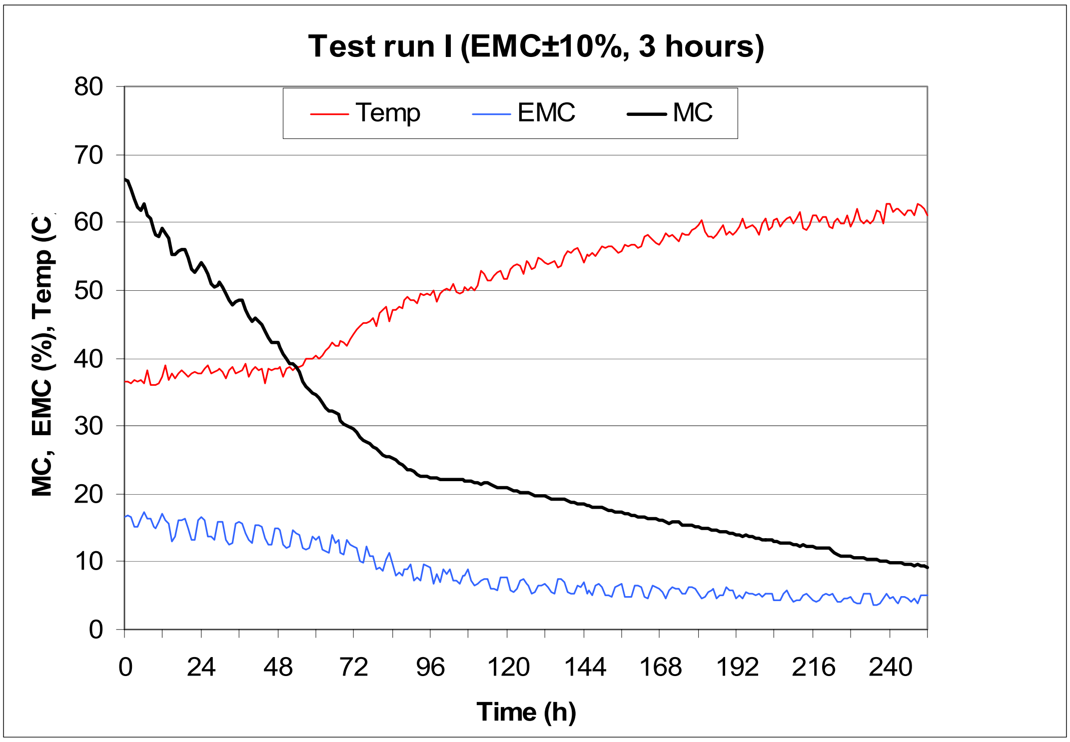
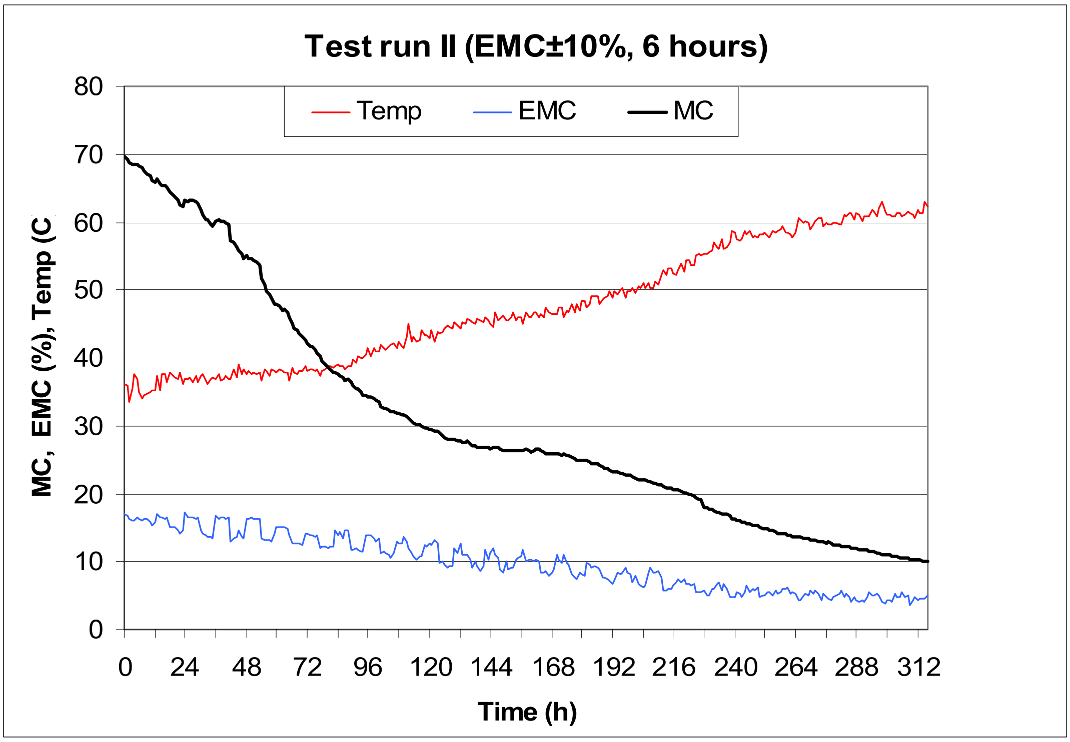
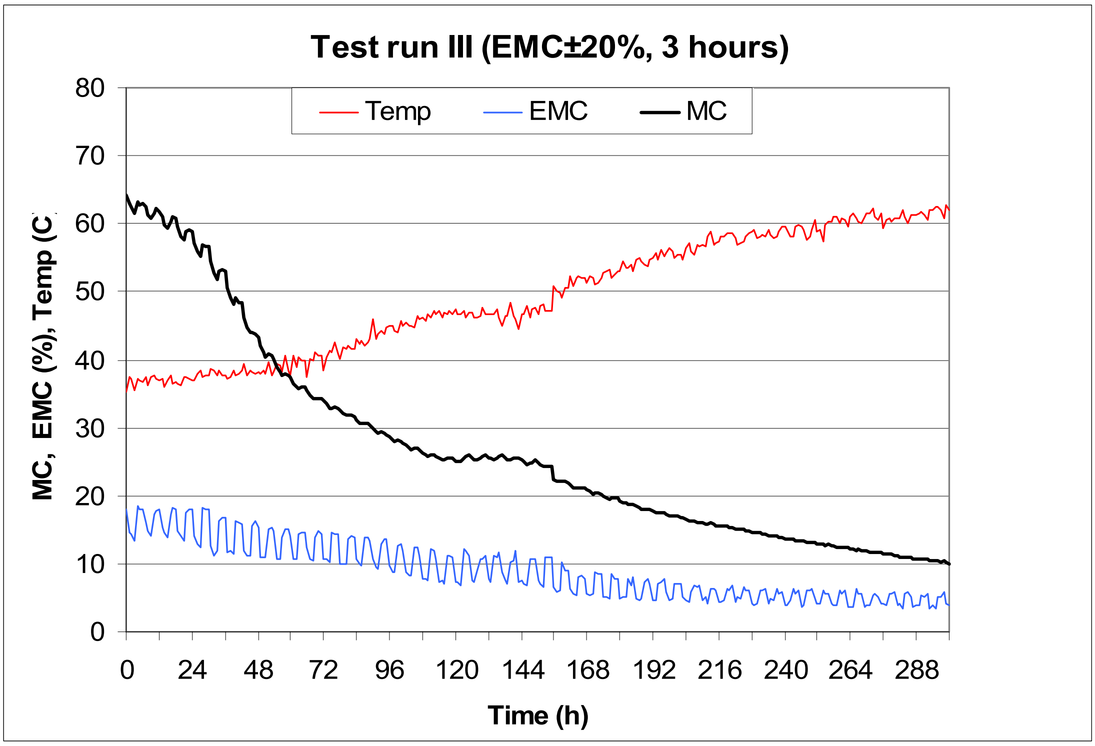


Figure 2: Drying curves for all test runs

Fig. 3 presents individual drying curves of test runs with oscillations, as well as the range of temperature and EMC in time. The variation of temperature compared to the previously set one, which was the consequence of the disturbed balance by EMC oscillations, was low in all test runs and within tolerant limits. In all four test runs in the first 12-24 hours of drying, the previously set EMC values were not realized completely in the "minus stage" (lowering of EMC values). The high initial moisture content of timber and consequently the high evaporation of water from wood at the beginning of drying did not lead to achieving the sufficiently low relative air humidity.


Test run I (EMC±10%, 3 hours)
Temp
EMC
MC
MC, EMC (%), Temp (C
0
10
20
30
40
50
60
70
80
0
24
48
72
96
120
144
168
192
216
240
Time (h)


Test run II (EMC±10%, 6 hours)
Temp
EMC
MC
MC, EMC (%), Temp (C
0
10
20
30
40
50
60
70
80
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (h)



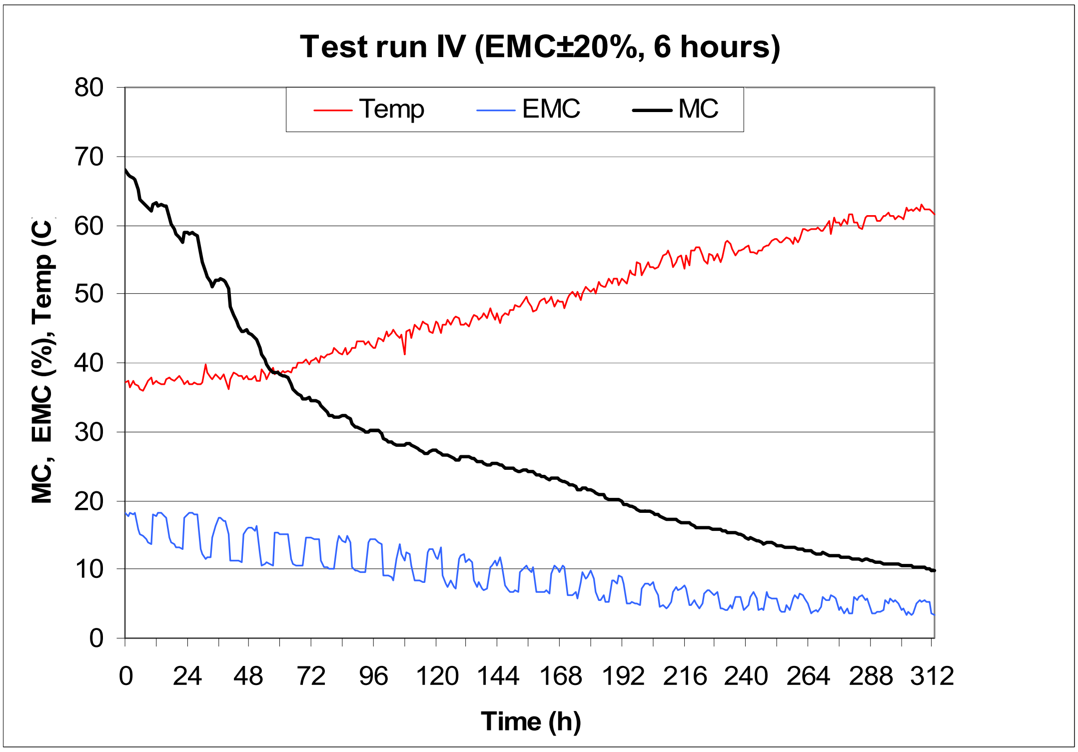


Figure 3: Test runs I-IV with EMC oscillations

Initial moisture content, measured by probes in the kiln, ranged from the average 60.0% in the control test run to 69.7% in test run II (Table 3). Electric moisture meters are not accurate in high moisture contents and, as anticipated (Milić *et al*. 2008), they showed significantly lower values than moisture contents measured by gravimetric method, which were in all test runs on average higher than 80%. It is characteristic that in all test runs, at the end of the drying process and before the conditioning stage, average moisture content measured gravimetrically was lower than the values measured by the probes. To enable the comparison of drying time per test runs, the times were observed in the same intervals of wood moisture content, i.e. in the interval from 60% to 10% measured by the probes. In this interval, test run II, where EMC oscillated by 10% during 3 hours, showed a significantly shorter time than other test runs. The amplitudes of 10% in both cases produced shorter drying times than the amplitudes of 20%. Also, oscillation frequencies of 3 hours produced a shorter drying time than the frequencies of 6 hours for the same amplitude values. Total energy consumption for the entire drying cycle includes the consumption for heating, fan and automatics operation, and it is the highest in the conventionally dried test run. The shortest drying time produced the lowest energy consumption in test run I, while in test run III the consumption was higher than in test runs II and IV, because of the combination of high amplitude and low frequency oscillations.

Table 3: Moisture content, drying time and energy consumption for all test runs

Test run	Control	I	II	III	IV
Initial MC (%)	60.0 (88.8)	66.3 (84.8)	69.7 (98.9)	64.2 (84.9)	68.1 (80.2)
Final MC (%)	9.0 (7.4)	9.2 (7.8)	9.9 (7.4)	10.0 (7.8)	9.6 (7.9)
Time of active phase (h)	308	252	316	300	315
Time from 60% to 10% (h)	288	231	275	281	285
Energy consumption (kW)	1104	917	996	1021	946

MC determined by oven-dry method in brackets

The range of the final moisture content after the active stage of drying was similar in all test runs. The analysis of variance shows that there was a statistically significant difference at 0.05 level among the mean values of final MC per test runs. Still, sig. (P-values) were at the threshold level (0.048). Test run IV was the main reason for the significant differences, because it had somewhat higher average moisture content and a lower deviations among the specimens (Table 4). The proof was also the absence of significant differences among the average MCs in the control test run and the first three test runs (sig. value was 0.16).

The highest moisture content difference across thickness after the active stage (before the conditioning stage) was recorded in the control test run (Table 4). The difference among the mean values of ΔMC per test runs is statistically significant. Average gap size before conditioning in all test runs was more than 2 mm, and the highest average value was recorded in the control test run. However, there were no significant differences among the average gap values per test runs.

Table 4: Drying quality for all test runs (before conditioning phase)

Test run	Control	I	II	III	IV
Final MC (%)	7.4 (0.9)	7.8 (0.9)	7.4 (0.9)	7.8 (0.9)	7.9 (0.6)
ΔMC (%)	3.1 (0.9)	2.7 (0.8)	3.0 (0.8)	2.9 (0.6)	2.5 (0.6)
Gap (mm)	2.5 (0.4)	2.4 (0.6)	2.4 (0.6)	2.2 (0.5)	2.2 (0.2)

Standard deviations in brackets

There were no surface and end checks in any test run. There were no visual differences in wood color per test runs.

CONCLUSIONS

For the same intervals of wood moisture content, it can be expected that oscillation drying produces shorter drying time and lower energy consumption than the conventional drying. This research shows a significantly shorter time and lower energy consumption in the test run in which EMC oscillated in the phases of 3 hours and with amplitude ±10%. Drying time in this test run was as much as 20% shorter, compared to the control. Slightly shorter drying period was recorded in test runs with oscillation frequency of 3 hours compared to the test runs with 6-hour oscillations at the same amplitude. A similar conclusion is drawn in the comparison of test runs with the same frequencies, and different amplitudes: test runs with ±10% amplitudes were somewhat shorter than those with ±20% amplitudes.
The average final moisture content per test runs ranged from 7.4% to 7.9%, with similar variations per individual boards. Average moisture content difference across thickness was lower than the control in all test runs with oscillations. The same conclusion is also drawn for gap values.
The initial experiments show that it is possible to expect a shorter drying time in oscillating climates, under the unchanged or better drying quality. Further laboratory tests should be done with temperature oscillations, as well as with the combination of temperature and EMC oscillations. At the same time, some tests are performed on hard broadleaves (beech and oak) in industrial conditions.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Ministry of Science and Technological Development, Republic of Serbia. This work is part of project BT20026.

REFERENCES

EN 13183-1 (2003) Moisture content of a piece of *sawn timber* - Part 1: Determination by *oven dry method*

ENV 14464 (2002) Sawn timber – Method for assessment of case-hardening

Langrish, T.A.G., Keey, R.B. and Kumar, M. (1992) Improving the quality of timber from red beech (*N. Fusca*) by intermittent drying. *Drying Technology*, 10 (4), 947-960.

Milić, G., Vuković, G. and Kolin, B. (2008) Accuracy of moisture content measurements in conventional kilns (in Serbian). *Prerada drveta*, 6 (21-22) (in the press).

Sackey, E.K., Avramidis, S. and Oliveira, L.C. (2004) Exploratory evaluation of oscillating drying for thick hemlock timbers. *Holzforschung*, 58, 428-433.

Salin, J-G. (2003) A theoretical analysis of timber drying in oscillating climates. *Holzforschung*, 57, 427-432.

Terziev, N., Salin, J-G., Söderström, O., Forsen, H., Rosenkilde, A. and Temnerud, E. (2002) Oscillation drying of Scots pine timber. In: *4th European COST Action E15 Workshop*, Santiago de Compostela, Spain

Welling, J., Riehl, T., Kruse, K. and Rose, B. (2003) Verbesserte schnittholztrocknung im frischluft-/ablufttrockner durch wechselklima. Bundesforschungsanstalt für Forst- und Holzwirtschaft. Hamburg.