# CALCULATING KILN SCHEDULE CHANGES

George Bramhall
Western Forest Products Laboratory
Vancouver, British Columbia

The modification of schedules to meet new conditions is traditionally a trial-and-error process. Because it is difficult in most kilns to monitor average moisture content (mc) during drying, there is a high probability that when the charge is removed the final mc will be either too high, in which case the lumber will not conform to standards, or too low, in which case drying times will be unnecessarily long, and there will be an increased possibility of degrade.

In another article (1), the author describes how the mc required to pass standards can be estimated if an operator knows both the average moisture content and percent non-conforming in his present production. This article describes how to attain that moisture content by the modification of kiln schedules, provided that drying is limited to "conventional" or "low-high" schedules, including step-wise and continuously changing schedules. High-temperature drying involves different principles and the procedures described here do not apply.

The concept involved is that a specific amount of "drying effort" is required to dry from a given initial to a given final mc and, provided the drying characteristics of the species are known, that value can be calculated (2). Any setting of dry-bulb temperature (dbt) and wet-bulb temperature (wbt) provides a specific amount of drying effort every hour, and this also can be calculated. When the total drying effort produced by the schedule equals that required by the lumber, the lumber will have reached the desired final mc. Since the drying rate is also affected by factors not involved in these calculations, the time estimates for any chosen schedule are approximate only. Differences between kiln operations, e.g. air velocity, sticker thickness, lumber thickness and schedule type, will result in consistent differences between predictions made and results actually obtained. These can be corrected for, and subsequent predictions made more reliable, by calculating a "kiln factor", and applying this to subsequent calculations.

At this time, tables have been calculated for only 2-in. lumber of western white spruce, lodgepole pine and alpine fir. To use the system, it is necessary to know the initial mc of the lumber and the final desired mc. Where the initial mc is not known, an average value characteristic of the species may be used without a great deal of error. For spruce, lodgepole pine and alpine fir these values are 50, 60 and 80 percent, respectively.

The amount of drying effort required to dry from a given initial to a given final mc is determined from the appropriate species table (Tables 2 to 4) by subtracting the drying effort of the initial mc from that of the final mc.

The amount of drying effort produced per hour for given settings of dbt and wbt are found from Table 1 by subtracting the vapor pressure of the wbt from that of the dbt. Where a setting is held for several hours, the drying effort of that setting is found by multiplying by the number of hours. The drying effort for the entire schedule is found by adding the effort of the various settings. Because equalization and conditioning periods do not dry the lumber significantly, these should not be included in the calculations.

The kiln factor for any kiln is found by dividing the drying effort of a schedule used in that kiln (Table 1) by the effort determined from the difference of initial and final mc of the charge dried by that schedule (Tables 2 to 4). This is later used to multiply the values of Tables 2 to 4 to get the proper value for that kiln.

A series of examples is provided.

1. Assume you are using the following schedule, and are able to dry lodgepole pine from 45% to 12.7% in 54 hours.

| | |
|---|---|
| 180 - 160 | 10 hrs. |
| 190 - 160 | 20 hrs. |
| 200 - 165 | 24 hrs. |

What is the drying effort of your schedule?

Using Table 1 to obtain drying effort produced per hour, substract the vapor pressure of the wbt from that of the dbt and multiply by the number of hours the settings are held.

| Settings | Drying effort | x time |
|---|---|---|
| 180-160 | 518-327 = 191 | x 10 = 1910 units |
| 190-160 | 644-327 = 317 | x 20 = 6340 |
| 200-165 | 795-368 = 427 | x 24 = 10248 |
| Total drying effort produced by schedule | - | 18498 units |

2. What drying effort is required, according to Table 3, to dry lodgepole pine from 45% to 12.7% mc?

| | |
|---|---|
| Drying effort at 12.7% | 24340 units |
| Drying effort at 45% | 2916 |
| Drying effort required to dry lumber | 21424 units |

3. What is the kiln factor for your kiln?

$$\text{kiln factor} = \frac{18498}{21424} = 0.86$$

4. You wish to dry your lumber in 48 hours to 13.0% mc. How can this be done?

(a) First find the drying effort required in your kiln, using Table 3 and the kiln factor.

| | |
|---|---|
| Drying effort at 13% | 23482 units |
| Drying effort at 45% | 2916 |
| Difference | 20566 units |

Multiply by the kiln factor 0.86 = 17687 units, which is the drying effort required for your kiln.

(b) Now, find a combination of dbt, wbt and time which will produce approximately 17687 units in 48 hours. Since the method described here gives no indication of how the schedule will affect lumber quality, an operator must use his experience to avoid excessively severe conditions. By starting with the same temperatures as before, and increasing the wet-bulb depression somewhat more rapidly, a satisfactory final mc in the desired time should be obtained with no significant degrade.

| | | | |
|---|---|---|---|
| 180-160 | 8 hrs. | 518-327 = 191 | x 8 = 1528 |
| 190-160 | 8 hrs. | 644-327 = 317 | x 8 = 2536 |
| | | Total at 16 hours | 4064 |

After 16 hrs. drying, 17687-4064 = 13623 units are still required. If these are produced in the remaining 32 hours, this will require 13623/32 = 426 units per hour. If we maintain 160 wbt, the dbt will require a vapor pressure of 327 + 426 = 753, which is between 197 and 198°F (Table 1). So a final setting of 198-160 for 32 hours will complete the schedule satisfactorily. Many other combinations could be found with the same end result.

5. The system can be used with continuously changing schedules, but the drying time must be handled a few hours at a time, averaging the temperature over that period. Five or six hour periods are recommended. With the schedule being used or considered, determine dry and wet-bulb temperatures every 6 hours, take the average for each 6 hour period, and apply these values for the entire 6-hour period. An example is worked out as follows:

(a) If the wet bulb is fixed at 160°F and the dry bulb increases from 180°F at 1°F per hour, how many hours will be required to provide 17687 units to dry lodgepole pine from 45% to 13% in the kiln considered in the earlier example?

| Hours | Settings | Average | Drying effort | Cumulative total |
|---|---|---|---|---|
| 0 | 180-160 | - | 0 | |
| 6 | 186-160 | 183-160 | (554-327) x 6 = 1362 | 1362 |
| 12 | 192-160 | 189-160 | (630-327) x 6 = 1818 | 3180 |
| 18 | 198-160 | 195-160 | (716-327) x 6 = 2334 | 5514 |
| 24 | 204-160 | 201-160 | (812-327) x 6 = 2910 | 8424 |
| 30 | 210-160 | 207-160 | (917-327) x 6 = 3540 | 11964 |
| 36 | 216-160 | 213-160 | (1034-327)x6 = 4242 | 16206 |

(b) Since we are now close to the required value of 17687 units, we can calculate how much more drying is required, and how long this would take at the final setting.

Required amount = 17687 - 16206 = 1481 units
Final setting = 216-160°F or 1097-327 units = 770 units per hour
Time required 1481/770 = 1.9 hours
Total time required 36 + 1.9 = 37.9 hours.

The reliability of the method was checked by comparing predicted and actual drying times of 12 charges of western spruce dried in the WFPL pilot kiln (capacity 7000 fbm) using a velocity of 500 fpm. These charges included step schedules, constantly rising schedules and combinations of both. Data regarding the source of the lumber was not obtainable. It may have varied somewhat in average thickness from charge to charge, affecting drying rate. Most charges were 2 x 8, but some 2 x 6 and 2 x 4 charges were dried. The following table provides initial and final mc, estimated and actual drying times, and error both in hours and percentage. For the sake of brevity the actual schedules are not included.

Much of the error may be attributed to variability of the charges themselves, as for example the proportions of sapwood and heartwood, and the permeability of the lumber. Some results from sampling error in estimating initial and final average mcs. Some error results from simplification of the complex mathematics involved. Nonetheless this method gives a reasonable estimate of the effect of changing kiln conditions, and the expected increases or decreases of drying rate which result.

| Charge | Init. mc % | Final mc % | Est. drying time, hrs. | Actual drying time hrs. | Error hrs. | Error % |
|---|---|---|---|---|---|---|
| 1 | 45 | 15.3 | 45.8 | 51 | -5.2 | -10.2 |
| 2 | 48 | 13.3 | 56.5 | 54 | 2.5 | 4.7 |
| 3 | 56 | 16.4 | 58.8 | 61 | -2.2 | - 3.7 |
| 4 | 52 | 12.2 | 65.6 | 61 | 4.6 | 7.5 |
| 5 | 47 | 13.7 | 60.8 | 60 | 0.8 | 1.4 |
| 6 | 45 | 14.2 | 46.8 | 56 | -9.2 | -16.4 |
| 7 | 33 | 10.3 | 68.8 | 61 | 7.8 | 12.8 |
| 8 | 47 | 11.9 | 55.2 | 60 | -4.8 | - 7.9 |
| 9 | 57 | 16.5 | 48.6 | 48.5 | 0.1 | 0.3 |
| 10 | 48 | 14.8 | 46.1 | 45 | 1.1 | 2.4 |
| 11 | 53 | 15.5 | 70.0 | 60 | 10.0 | 16.7 |
| 12 | 57 | 16.0 | 54.0 | 53 | 1.0 | 2.0 |
| | | | | Total error | +6.5 | +9.6 |

## References


1. Bramhall, G. 1975. Average moisture contents required to conform to the new softwood drying standards. Submitted to Canadian Forest Industries. In press.

2. Bramhall, G. 1975. A theoretical method to calculate kiln schedule modifications in drying softwood lumber. Submitted to Wood Science. In press.


Table 1. Vapor pressure of water at temperatures from 100 to 239°F (mb).

| Temp. °F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 81 | 83 | 85 |
| 110 | 88 | 91 | 93 | 96 | 99 | 102 | 104 | 107 | 110 | 114 |
| 120 | 117 | 120 | 123 | 127 | 130 | 134 | 138 | 141 | 145 | 149 |
| 130 | 153 | 158 | 162 | 166 | 171 | 175 | 180 | 184 | 189 | 194 |
| 140 | 199 | 204 | 210 | 215 | 221 | 226 | 232 | 238 | 244 | 250 |
| 150 | 257 | 263 | 269 | 276 | 283 | 290 | 297 | 304 | 312 | 319 |
| 160 | 327 | 335 | 343 | 351 | 360 | 368 | 377 | 386 | 395 | 404 |
| 170 | 413 | 423 | 433 | 443 | 453 | 463 | 474 | 485 | 496 | 507 |
| 180 | 518 | 530 | 541 | 554 | 566 | 578 | 591 | 604 | 617 | 630 |
| 190 | 644 | 658 | 672 | 687 | 701 | 716 | 731 | 747 | 763 | 779 |
| 200 | 795 | 812 | 828 | 846 | 863 | 881 | 899 | 917 | 936 | 955 |
| 210 | 974 | 994 | 1014 | 1034 | 1054 | 1075 | 1097 | 1118 | 1140 | 1163 |
| 220 | 1185 | 1208 | 1232 | 1256 | 1280 | 1304 | 1329 | 1355 | 1380 | 1407 |
| 230 | 1433 | 1460 | 1487 | 1515 | 1543 | 1572 | 1601 | 1631 | 1661 | 1691 |

| TABLE 2. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Drying Effort Required for 2-inch Western Spruce (mb-hr)** | | | | | | | | | | |
| **mc** | **0** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** |
| **10** | 18599. | 18435. | 18271. | 18109. | 17949. | 17790. | 17632. | 17476 | 17321. | 17168. |
| **11** | 17016. | 16865. | 16715. | 16567. | 16420. | 16275. | 16131. | 15988. | 15846. | 15706. |
| **12** | 15567. | 15429. | 15292. | 15157. | 15022. | 14889. | 14757. | 14626. | 14497. | 14368. |
| **13** | 14241. | 14115. | 13990. | 13866. | 13743. | 13621. | 13501. | 13381. | 13262. | 13145. |
| **14** | 13028. | 12913. | 12799. | 12685. | 12573. | 12461. | 12351. | 12241. | 12133. | 12026. |
| **15** | 11919. | 11813. | 11709. | 11605. | 11502. | 11400. | 11299. | 11199. | 11100. | 11001. |
| **16** | 10904. | 10807. | 10712. | 10617. | 10523. | 10429. | 10337. | 10245. | 10155. | 10065. |
| **17** | 9975. | 9887. | 9800. | 9713. | 9627. | 9541. | 9457. | 9373. | 9290. | 9208. |
| **18** | 9126. | 9045. | 8965. | 8886. | 8807. | 8729. | 8651. | 8575. | 8499. | 8424. |
| **19** | 8349. | 8275. | 8202. | 8129. | 8057. | 7986. | 7915. | 7845. | 7775. | 7706. |
| | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **20** | 7638. | 6988. | 6393. | 5848. | 5350. | 4895. | 4478. | 4096. | 3748. | 3429. |
| **30** | 3137. | 2869. | 2625. | 2402. | 2197. | 2010. | 1839. | 1682. | 1539. | 1408. |
| **40** | 1288. | 1178. | 1078. | 986. | 902. | 825. | 755. | 691. | 632. | 578. |
| **50** | 529. | 484. | 443. | 405. | 371. | 339. | 310. | 284. | 260. | 237. |
| **60** | 217. | 199. | 182. | 166. | 152. | 139. | 127. | 116. | 107. | 98. |
| **70** | 89. | 82. | 75. | 68. | 62. | 57. | 52. | 48. | 44. | 40. |

| TABLE 3. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Drying Effort Required for 2-inch Lodgepole Pine (mb-hr)** | | | | | | | | | | |
| **mc** | **0** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** |
| **10** | 35060. | 34534. | 34021. | 33520. | 33031. | 32554. | 32088. | 31633. | 31188. | 30753. |
| **11** | 30328. | 29912. | 29505. | 29108. | 28719. | 28338. | 27966. | 27601. | 27244. | 26894. |
| **12** | 26552. | 26216. | 25888. | 25566. | 25250. | 24941. | 24637. | 24340. | 24048. | 23762. |
| **13** | 23482. | 23206. | 22936. | 22671. | 22411. | 22155. | 21904. | 21658. | 21416. | 21178. |
| **14** | 20945. | 20716. | 20490. | 20269. | 20051. | 19837. | 19627. | 19420. | 19217. | 19017. |
| **15** | 18820. | 18627. | 18437. | 18249. | 18065. | 17884. | 17706. | 17530. | 17357. | 17187. |
| **16** | 17019. | 16854. | 16692. | 16532. | 16375. | 16219. | 16066. | 15916. | 15767. | 15621. |
| **17** | 15477. | 15335. | 15195. | 15057. | 14921. | 14787. | 14655. | 14524. | 14396. | 14269. |
| **18** | 14144. | 14021. | 13899. | 13779. | 13661. | 13544. | 13428. | 13315. | 13203. | 13092. |
| **19** | 12982. | 12874. | 12768. | 12663. | 12559. | 12456. | 12355. | 12255. | 12157. | 12059. |
| | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **20** | 11963. | 11062. | 10262. | 9547. | 8904. | 8325. | 7801. | 7324. | 6889. | 6491. |
| **30** | 6125. | 5788. | 5478. | 5190. | 4923. | 4675. | 4444. | 4228. | 4026. | 3837. |
| **40** | 3660. | 3493. | 3336. | 3188. | 3048. | 2916. | 2791. | 2673. | 2560. | 2454. |
| **50** | 2352. | 2256. | 2164. | 2076. | 1992. | 1912. | 1836. | 1763. | 1693. | 1626. |
| **60** | 1561. | 1500. | 1440. | 1383. | 1329. | 1276. | 1225. | 1176. | 1129. | 1084. |
| **70** | 1040. | 998. | 957. | 918. | 879. | 843. | 807. | 772. | 739. | 707. |

| TABLE 4. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Drying Effort Required for 2-inch Alpine Fir (mb-hr)** | | | | | | | | | | |
| | **0** | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** |
| **10** | 40021. | 39801. | 39583. | 39366. | 39150. | 38935. | 38722. | 38509. | 38298. | 38088. |
| **11** | 37879. | 37671. | 37465. | 37259. | 37055. | 36852. | 36649. | 36448. | 36248. | 36050. |
| **12** | 35852. | 35655. | 35460. | 35265. | 35072. | 34879. | 34688. | 34498. | 34309. | 34120. |
| **13** | 33933. | 33747. | 33562. | 33378. | 33195. | 33013. | 32832. | 32652. | 32473. | 32294. |
| **14** | 32117. | 31941. | 31766. | 31592. | 31418. | 31246. | 31075. | 30904. | 30735. | 30566. |
| **15** | 30399. | 30232. | 30066. | 29901. | 29737. | 29574. | 29412. | 29251. | 29090. | 28931. |
| **16** | 28772. | 28614. | 28457. | 28301. | 28146. | 27991. | 27838. | 27685. | 27533. | 27382. |
| **17** | 27232. | 27083. | 26934. | 26786. | 26640. | 26493. | 26348. | 26204. | 26060. | 25917. |
| **18** | 25775. | 25633. | 25493. | 25352. | 25214. | 25076. | 24938. | 24801. | 24665. | 24530. |
| **19** | 24395. | 24262. | 24129. | 23996. | 23865. | 23734. | 23604. | 23474. | 23345. | 23217. |
| | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **20** | 23090. | 21854. | 20685. | 19578. | 18530. | 17538. | 16600. | 15712. | 14871. | 14075. |
| **30** | 13322. | 12609. | 11934. | 11295. | 10691. | 10119. | 9577. | 9065. | 8580. | 8121. |
| **40** | 7686. | 7275. | 6885. | 6517. | 6168. | 5838. | 5526. | 5230. | 4950. | 4685. |
| **50** | 4434. | 4197. | 3973. | 3760. | 3559. | 3368. | 3188. | 3017. | 2856. | 2703. |
| **60** | 2558. | 2422. | 2292. | 2169. | 2053. | 1943. | 1839. | 1741. | 1648. | 1560. |
| **70** | 1476. | 1397. | 1322. | 1252. | 1185. | 1121. | 1061. | 1004. | 951. | 900. |