Are your slabs dry enough for floor coverings?

New test results show that it's difficult to accurately estimate the drying time needed for concrete to reach a specified water-vapor emission rate

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In the United States, most floor covering manufacturers require concrete floors to reach a water-vapor emission rate of either 5 or 3 pounds/1,000 square feet/24 hours before workers can place the floor covering. When the specified emission rate has been reached, as confirmed by a calcium-chloride cup test, installers then place the floor covering. But the time needed to reach the desired rate varies significantly, ranging from two months to many months.

Based on our analysis of existing and new drying data, estimating the required drying time is a difficult task. And if the floor gets wet or is covered during part of the drying period, the task becomes even more difficult.

Two examples

One publication (Ref. 1) shows calculations indicating that a 4-inch-thick concrete slab with a 0.50 water-cement ratio can take 496 days to reach the 3-pound emission level (see "One way to estimate drying time," page **674**). However, that calculation seems to be based on two questionable assumptions:

- A rather low (3 lbs/1,000 sf/24 hrs) *average* water-vapor emission rate during the drying period
- The need to remove all excess (uncombined) water before the emission rate can reach the desired value

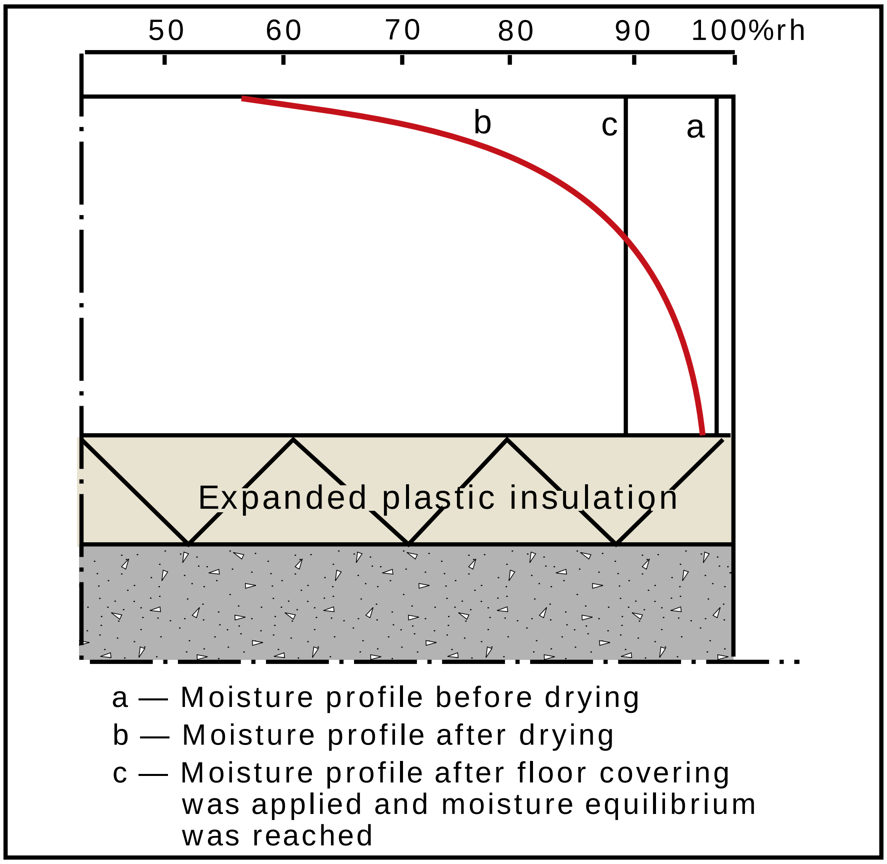
Portland Cement Association researcher Harold Brewer showed that the water-vapor emission rate decreases with drying time for 4-inch-thick concrete specimens with a w/c ranging from 0.40 to 1.0 (Ref. 2). Based on calculations described later, the average emission rate during the time required for Brewer's specimens to reach a 3-pound value was about 8 lbs/1,000 sf/24 hrs (see table below).

Several researchers have shown that moisture distribution in a drying slab isn't uniform (Refs. 3, 4, 5). Moisture content of a drying concrete slab can be much lower at the top surface than in the middle of the slab (Fig. 1). Thus it's possible to

Water loss to reach 3 lbs/1,000 sf/ 24 hrs

Initial w/c	Average emission rate, lbs/1,000 sf/24 hrs	Water loss, lbs/sf	Water reduction, % of initial water content	Final w/c
0.40	6.8	0.3	12.4	0.35
0.50	7.4	0.6	19.4	0.40
0.60	7.9	0.9	24.6	0.45
0.70	9.1	1.2	26.9	0.51
0.80	9.3	1.4	27.5	0.58
0.90	9.4	1.6	27.8	0.65
1.00	9.3	1.8	28.3	0.72

Note: Results for 4-inch-thick specimens moist cured for seven days then dried at 73°F and 50% relative humidity.



Reference 3

Figure 1. Moisture distribution shifts when a concrete slab receives an impervious floor covering. Note that the relative humidity before drying was about 98%. After drying from the top only, surface RH was about 50% but concrete at the bottom was still at 98% RH. After the floor covering was applied, surface RH jumped to about 90%.

rate curves he developed (Ref. 7). These curves, with units converted to lbs/1,000 sf/24 hrs, allowed us to calculate water loss for each of Brewer's specimens using a seven-step procedure (Fig. 3).

For each original w/c, we calculated a final ratio by dividing the remaining mix water by the cement content. We also expressed water loss in pounds per square foot of surface and as a percent of the initial mixing water. Using total water loss and drying days required to reach the 3-pound limit, we then calculated the average emission rate. The table on page **671** shows how these four quantities varied with initial w/c. The water loss is measured from the end of the seven-day moist curing period to when the concrete achieved a water-vapor emission rate of 3 lbs/1,000 sf/24 hrs.

Water loss to reach a desired emission rate varies

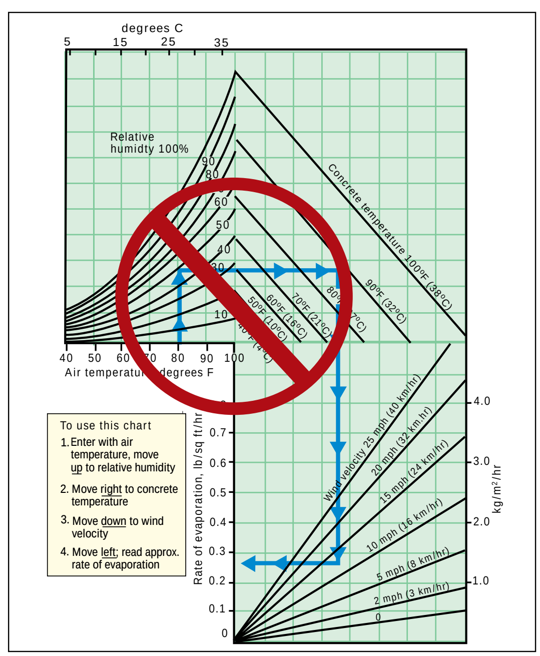
As expected, water loss increases as the concrete's w/c increases. There isn't a constant final w/c or percent of initial mixing water that corresponds with the time at which concrete reaches a desired reach a 3-pound emission rate, as measured by the calcium-chloride cup test, long before all the uncombined water has left the slab.

An article in another publication (Ref. 6) suggests that the nomograph commonly used to predict evaporation rates from fresh concrete (Fig. 2) can be used to estimate the drying rate for hardened concrete. This is an erroneous approach since the nomograph gives evaporation rates from a surface *on which free water is present*.

Brewer's data also indicate that meaningful estimates from this nomograph are unlikely. His specimens were dried at 73°F and 50% relative humidity, with no wind. Using the nomograph to predict the evaporation rate under these conditions yields a rate of 0.02 lbs/sf/hr, which corresponds to a vapor-emission rate of 480 lbs/1,000 sf/24 hrs. For concrete with a w/c of 1.0, Brewer's highest measured vapor-emission rate was 80 lbs/1,000 sf/24 hrs after three days of drying. Use of the nomograph also assumes that the evaporation rate never decreases with time and is independent of the w/c. Brewer's work showed that neither of these assumptions is true.

Concrete moisture content at the 3-pound emission rate

Does the amount of water in the concrete pores have to reach some critical level before the desired surface emission rate is achieved? We used Brewer's data to study this question by calculating water loss based on drying-



American Concrete Institute

Figure 2. This nomograph for predicting evaporation rate from a fresh concrete surface should not be used to predict drying rates from hardened concrete surfaces.

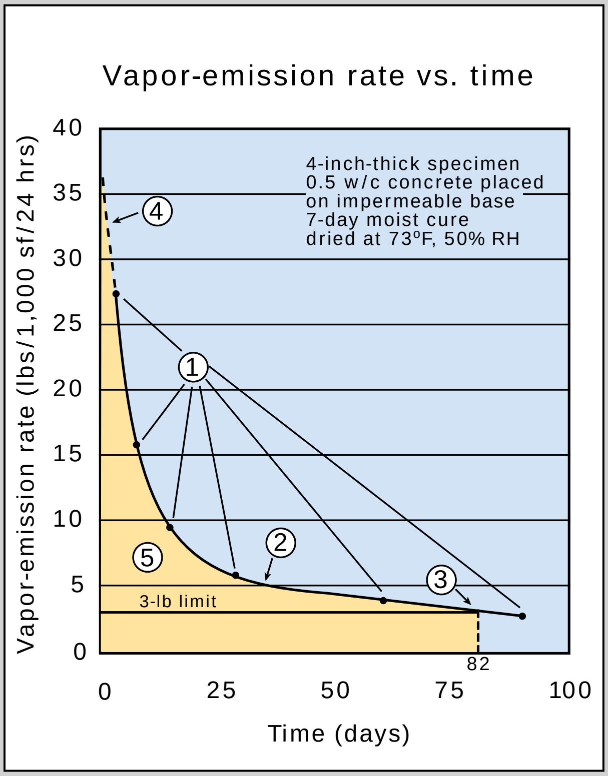


Figure 3. Vapor-emission data from drying concrete specimens can be used to estimate the total amount of water lost in reaching a specified emission rate.

1. Plot original data points in pounds/1,000 sf/24 hrs vs. drying time in days.
2. Determine a best-fit curve for the data points.
3. Determine the time at which the test specimen achieved an emission rate of 3 lbs/1,000 sf/24 hrs.
4. Extend the curve to the left to find the emission rate at the start of the test.
5. Calculate the area under the curve (from the start of drying until the concrete achieves 3 lbs/1,000 sf/24 hrs) to obtain the total water loss in pounds per 1,000 square feet.
6. Calculate the water loss for each test specimen, based on specimen surface area and the results from step 5.
7. Subtract the water loss of the test specimen from the initial mix water to find the remaining mix water.

emission rate.

The calculated water-loss values represent the amount of water lost after Brewer's initial seven-day moist curing period ended and the test specimen achieved an emission rate of 3 lbs/1,000 sf/24 hrs. It was assumed that the seven-day moist curing period did not add or subtract water from the concrete specimen. For concrete with a w/c of 0.40, this assumption could lead to a slight error because the concrete might have absorbed some of the curing water.

To further study the effect of low w/c, The Aberdeen Group performed calcium-chloride cup tests on 3-foot-square concrete test slabs 2, 4, 6 and 8 inches thick and with w/c values of 0.31, 0.37 and 0.40 (Ref. 8). Before testing started, the slabs were cured under plastic sheeting for three days. In drying to a 3-pound emission rate, the 4-inch-thick slab with a w/c of 0.40 lost 0.24 pounds of water per square foot, a water reduction of 7.8%, which corresponded to a final water-cement ratio of 0.37. These test results generally agree with those obtained using Brewer's test data for specimens with a w/c of 0.40.

These curve-fitting and numerical integration results were based on relatively few data points from small specimens in a fairly stable environment. Because of this, the calculated water losses, percentage reductions in water content and final water-cement ratios shouldn't be viewed as exact predictors of what can be expected in an actual floor slab.

Re-wetting effects

Our concrete slabs took only 46 days to reach the 3-pound emission rate required for many floor coverings. To study the effect of re-wetting, we ponded 12.5 pounds of water on the 4-inch-thick slab that had a w/c of 0.40. We removed the water after two hours and measured it. The slab had absorbed 4.6 pounds of water, and as shown in Figure 4, the water-vapor emission rate jumped back to around 15 pounds. It required about five more weeks of drying to again reach the 3-pound

One way to estimate drying time

The basis for drying-time calculations in Reference 1 seems to be that concrete with a w/c of 0.30 would theoretically contain a weight of combined water equaling 0.30 times the cement weight. Water added to raise the w/c above 0.30 is excess water that must exit a slab through the surface. Using this rationale, a cubic yard of concrete with 300 pounds of mixing water and 600 pounds of cement would contain 0.30 x 600 = 180 pounds of combined water and 300–180 = 120 pounds of excess water. A 4-inch-thick slab would contain 12.4 cubic yards of concrete per 1,000 square feet of slab. Thus the excess water would be 12.4 x 120 = 1,488 pounds. If this water dries at the rate of 3 lbs/1,000 sf/24 hrs, total drying time is 1,488 ÷ 3 = 496 days. As noted in the article, two questionable assumptions make this an inaccurate method for estimating drying time.

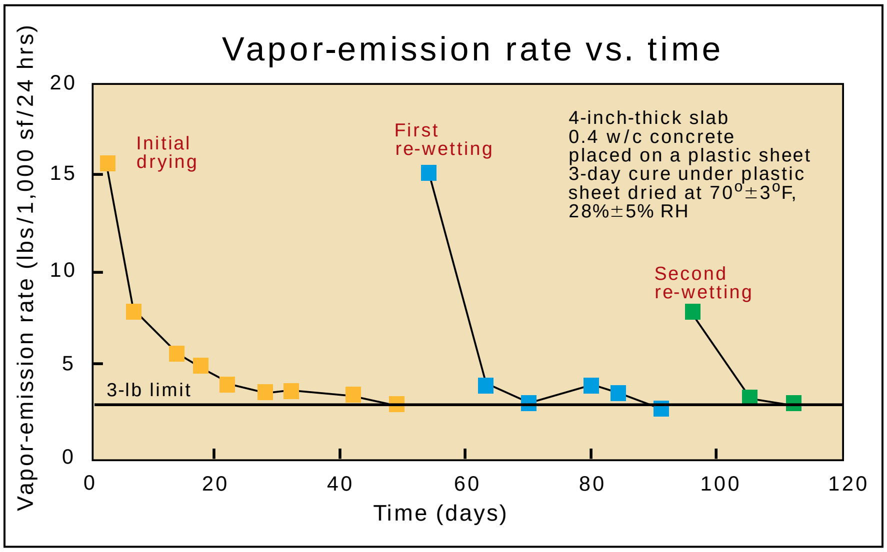


Figure 4. Even with a low water-cement ratio and a three-day cure under plastic sheeting, these slabs took about seven weeks to dry to a 3-pound emission rate. After re-wetting, they required about five more weeks of drying to reach the 3-pound rate. A second re-wetting wasn't as damaging to the schedule.

rate.

At that point we re-wetted the slab with 12.5 pounds of water, this time for six hours, and measured the amount of water absorbed. The absorption decreased to 2.8 pounds, and this time the emission rate jumped to only 8 pounds before returning to 3 pounds in about two weeks. This confirms that re-wetting has less effect as the concrete matures (Ref. 3).

Effects of covering the floor

Hedenblad (Ref. 3) found that after a concrete floor is covered, moisture is redistributed and the concrete's internal relative humidity near the surface increases (Fig. 1). To measure the effect of floor coverings on water-vapor emissions, we allowed a 4-inch-thick slab with a 0.40 w/c and a 2-inch-thick slab with a 0.31 w/c to reach emission rates of 3.0 and 2.6 pounds respectively, while drying from the top only. We then tightly covered each slab with plastic sheeting for 10 days to simulate the effect of adding an impermeable floor covering without any appreciable change in ambient temperature.

On the 10th day we cut two holes in the plastic covering each slab, with each hole just large enough to be covered by the transparent cover for the calcium-chloride test kit. A lab technician glued down the covers with an adhesive and used duct tape to ensure an airtight seal. After 72 hours, the measured emission rates were 3.4 and 3.8 pounds for the 4- and 2-inch-thick slabs, respectively.

The vapor-emission rate for both slabs had risen above the commonly specified maximum value that permits application of the floor covering. Yet no water vapor was visible on the slab surface beneath the plastic sheet. A similar phenomenon could result on a jobsite if a subcontractor stores materials on plastic sheeting or lays plywood on the floor during the concrete drying period. We didn't measure changes in surface pH that may have occurred as the emission rate increased after the floor was covered. However, since pH is a major factor affecting adhesive stability, we plan to run further tests while checking pH changes.

The results of our studies emphasize the importance of protecting drying floors from any moisture source—rain, washwater or spillage by other trades—if project completion schedules are critical and floors will receive a moisture-sensitive covering. They also show that covering the floor, even temporarily, increases the water-vapor emission rate. And both Brewer's and our results demonstrate that it's difficult to accurately estimate the drying time required to reach a specified emission rate.

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