Moisture Movement Through Concrete Slabs

Research done 30 years ago helps answer some questions being asked today

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After you've installed concrete floors, have you received complaints from owners about wet, curled or loose floor coverings or blistered coatings? These problems, caused by moisture movement through concrete slabs, have increased in the last 10 years due to increased use of fast-track construction methods and changes in the chemistry of floor-covering adhesives. And it's likely that these problems will increase as owners demand faster completion of their buildings, shortening the drying time of concrete before floor coverings or coatings are applied. Also, environmental legislation that places restrictions on adhesive solvents makes the adhesives more water-sensitive.

In 1965, Portland Cement Association researcher Harold Brewer studied moisture movement through concrete to answer questions about water flow through residential basement slabs. His work can be used to answer some basic questions about the drying of commercial and industrial floor slabs. Brewer's original moisture-flow data were reported in grains of moisture per square foot per hour but can be converted to the measure commonly used today—pounds per 1,000 square feet per 24 hours.

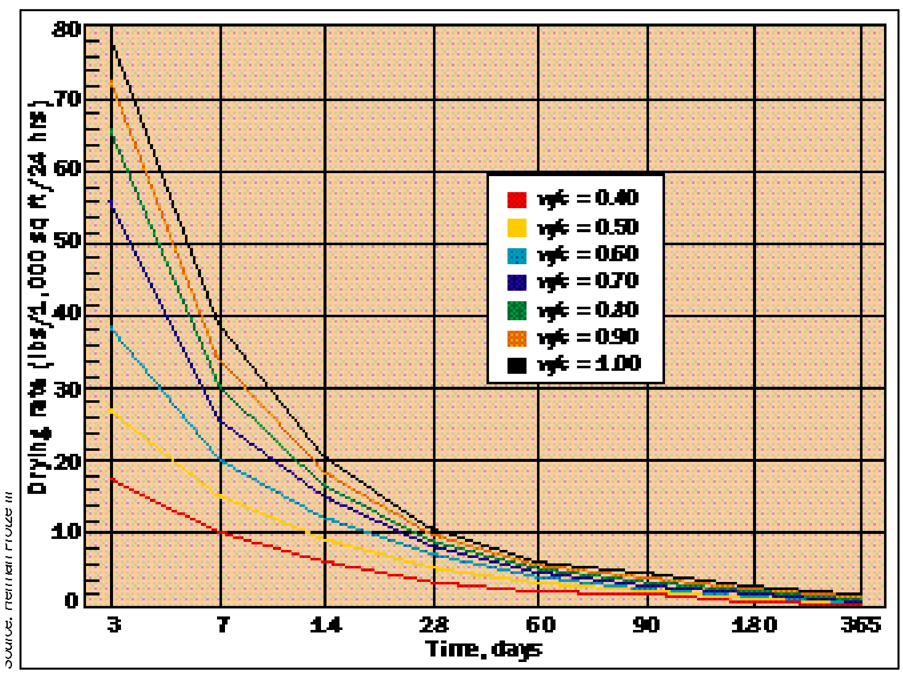


Figure 1. Drying rates for 4-inch-thick concrete specimens exposed to air at 73°F and 50% relative humidity.

Most manufacturers of floor coverings and adhesives recommend installing an impermeable floor covering only when moisture flow is less than 3 lbs/1,000 sq ft/24 hrs. With this value as a reference, Brewer's work provides some interesting answers to the following questions.

1. Is 3 lbs/1,000 sq ft/24 hrs an achievable moisture requirement? If so, how long does it take?

Figure 1, derived from Brewer's original work, shows how long it takes 4-inch-thick concrete specimens, with water-cement ratios from 0.40 to 1.0, to reach a given water-vapor emission rate. The specimens were sealed at the bottom to prevent contact with water or water vapor, and dried at 50% relative humidity and an air temperature of 73°F. All the curves show the same trend—an initially high vapor-emission rate that lowers appreciably as it falls below 10 lbs/1,000 sq ft/24 hrs.

As shown in Table 1, water-cement ratio has a marked effect on the drying time needed to reach an emission rate of 3 lbs/1,000 sq ft/24 hrs. For bottom-sealed concrete specimens with water-cement ratios between 0.40 to 0.60, increasing the water-cement ratio 0.10 increases the drying time significantly (a 78% increase from 0.40 to 0.50 and a 43% increase from 0.50 to 0.60). Above a water-cement ratio of 0.60, an increase of 0.10 increases the drying time about 13%.

Table 1. Drying Time, in Days, at 73°F and 50% Relative Humidity For a 4-Inch-Thick Specimen to Reach 3 lbs/1,000 sq ft/24 hrs

Water-Cement Ratio	Bottom Sealed	Bottom Exposed To Water Vapor	Bottom In Contact With Water
0.4	46	52	54
0.5	82	144	199
0.6	117	365	>> 365
0.7	130	>> 365	>> 365
0.8	148	>> 365	>> 365
0.9	166	>> 365	>> 365
1.0	190	>> 365	>> 365

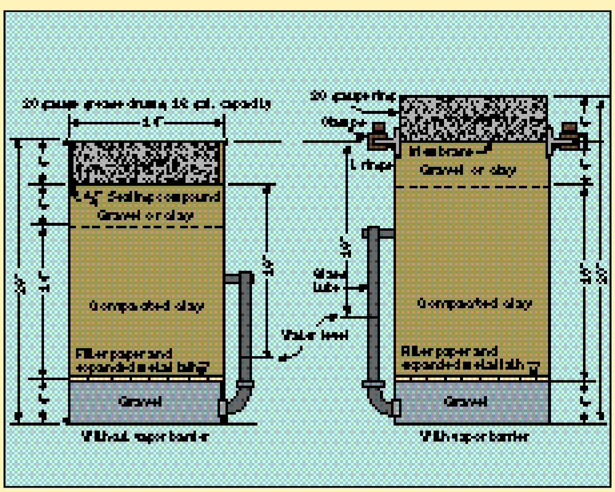
Brewer also tested specimens with the bottom exposed to water vapor or in contact with water. For concrete with a water-cement ratio of 0.40, these exposures didn't significantly affect the drying time. However, at higher water-cement ratios, the effect was dramatic. For a specimen with a 0.50 water-cement ratio, exposing the bottom to water vapor increased drying time two months. And the specimen in contact with water needed nearly four more months of drying time than the bottom-sealed specimen. For water-cement ratios above 0.60, specimens exposed to water or water vapor still hadn't reached 3

Brewer's Test Specimens and Procedures

Brewer used three different types of test specimens and procedures to obtain his data. The test specimens and procedures used in the first series were similar to those used in studies by Forest Products Laboratory, Madison, Wis. The second series of tests was conducted using a procedure suggested by Building Research Advisory Board Subcommittee II on Admixtures. The third series of test specimens and procedures was developed by Brewer to better correlate some of the variables included in the first two test series and to clarify inconclusive data. The test specimens and procedures are summarized below. See Brewer's paper for more details.

Series 1

Metal containers 26 inches tall and 14 inches in diameter were painted with rust inhibitor and fitted with glass water-column gauges. A 4-inch-thick layer of coarse gravel was placed in the bottom and covered with expanded metal lath and filter paper to provide a water reservoir to facilitate water adjustments. The containers were filled with clay soil compacted at optimum moisture content to maximum density. Half of these containers had a 4-inch-thick layer of ⅜- to 1-inch gravel and two layers of cheesecloth above the soil. Ten of the 24 containers had a 4-inch-high metal extension that clamped over vapor retarders of 4-mil polyethylene or 55-pound roofing felt.



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Series 1. Forest Products Laboratory moisture migration apparatus.

Four-inch-thick concrete specimens 13½ inches in diameter were cast in the top of each container. These specimens were made with both normal-weight and lightweight concretes with a wide range of cements. One specimen from each concrete was cast on the soil and another was cast on the gravel. A ¼-inch annular space between the concrete and painted metal container was filled with an asphaltic rubber sealing compound after the concrete hardened.

Moisture movement was determined by measuring the water required to maintain a water surface in the glass column 16 inches below the bottom of the concrete slab. Tests were continued for 16 months, when stable moisture flows were obtained. These specimens were tested in a 73°F and 30% relative-humidity environment.

Series 2

Galvanized 14-quart pails, coated with epoxy resin, were fitted with two openings and a metal screen covered by filter paper upon which concrete was cast. A concrete specimen cast in the upper portion of a pail could be tested either with water in contact with the bottom of the sample or with the bottom exposed to water vapor. Five concrete mixes of different water-cement ratios were tested, with and without vapor barriers of polyethylene, 32-mil ABS plastic or 55-pound roofing felt.

Specimens with water-cement ratios of 0.45 and 0.55 were first exposed to water vapor for 50 days in a 73°F and 30% relative-humidity environment. Freshly lbs/1,000 sq ft/24 hrs when the study was discontinued after a year.

2. How do capillary breaks or vapor barriers affect vapor-emission rate?

To study the effect of granular capillary breaks and vapor barriers (or vapor retarders), Brewer placed a 4-inch-thick concrete specimen with a 0.70 water-cement ratio on the following bases:

- Bare soil (clay compacted at optimum moisture content to maximum density)
- A 4-inch layer of ⅜- to 1-inch gravel over the compacted clay
- Two different vapor barriers

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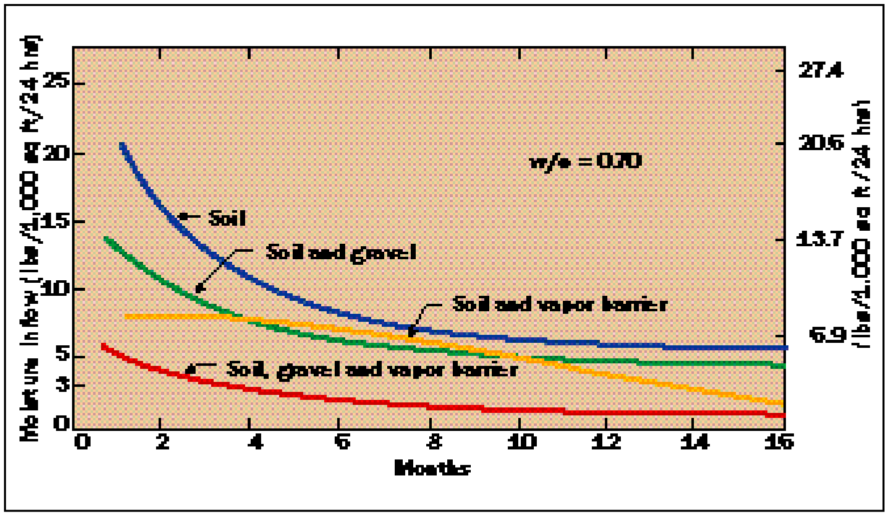

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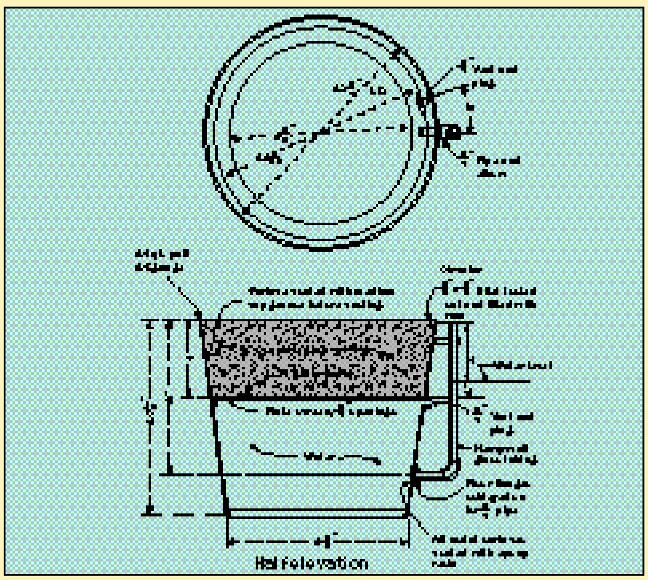
Figure 2. Effect of gravel and vapor barriers on the moisture inflow of 4-inch-thick concrete specimens with a 0.70 water-cement ratio.



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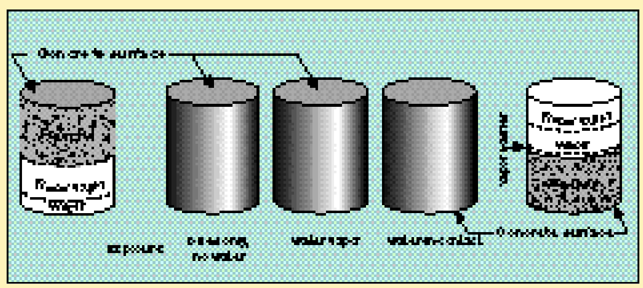
Series 2. Moisture migration apparatus using 14-quart galvanized pail.

boiled and cooled water was added to a depth of 2 inches in the bottom of each pail, leaving an air space between the water and the bottom of the concrete. The glass water columns were capped to prevent moisture loss. After 50 days, the pails were completely filled with water and all entrapped air was carefully removed from beneath the specimens. Testing continued for 165 days in a room at 73°F and 50% relative humidity. Moisture movement was determined by measuring weight loss of specimens exposed to water vapor and by measuring the water added (water inflow) while the specimens were in contact with water.

Concretes with water-cement ratios of 0.68 and 0.99 were tested in contact with water for 138 days. Then a portion of the water was drained, and the specimens were exposed to only water vapor for another year. Companion specimens were exposed to water vapor for 50 days. To obtain an estimate of water loss due to drying only, Brewer cast additional specimens, cured them for seven days and then sealed them on the bottom and sides with several coats of polyester resin. These specimens, stored beside the others in the 50% relative-humidity room, were weighed periodically for 500 days.

Series 3



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Series 3. Sealed 1-gallon paint cans.

Four-inch-thick concrete specimens were cast in the bottom of epoxy-coated triple-seal 1-gallon paint cans (6½ inches in diameter by 7 inches tall) and sealed to the sides of the can. The concrete was cured for seven days, then the can bottoms were cut out to expose the concrete surface. A bead of epoxy resin was added around the top rim so specimen sides weren't exposed to a drying atmosphere. In a room at 73°F and 50% relative humidity specimens were exposed to three conditions: drying only, water vapor and water contact.

Seventeen concretes with water-cement ratios from 0.41 to 0.89 were tested. Several admixtures were used including two air-entraining agents, two calcium-chloride solutions, butyl stearate and two water-reducing agents.

(4-mil polyethylene and 55-pound roofing felt) over the compacted clay

- A combination of vapor barrier and gravel layer over the compacted clay

Brewer introduced water below the clay layer, exposed the top of the concrete slab to air at 73°F and 50% relative humidity and measured moisture inflow instead of outflow.

Because the total moisture leaving a slab surface includes both excess mixing water and moisture entering the concrete through the bottom, initial moisture outflow is always much higher than inflow. If the moisture inflow exceeds 3 lbs/1,000 sq ft/ 24 hrs, then the outflow as measured by vapor-emission rate will exceed this value until all the excess mixing water has exited the concrete. Moisture outflow will approach moisture inflow only after an extended exposure period that Brewer estimated could exceed a year.

As shown in Figure 2, concrete placed directly on a clay soil had the highest moisture inflow. A gravel capillary break reduced the initial moisture inflow by about one-third. Brewer concluded that using a gravel capillary break produced a long-term reduction in moisture inflow of 10% to 25%. However, the moisture inflow was always above 3 lbs/1,000 sq ft/ 24 hrs for a 0.70-w/c concrete placed over a capillary break without a vapor barrier.

The two vapor barriers gave similar results, and the curves in Figure 2 represent the averages of both types. Placing a vapor barrier directly on the compacted clay soil reduced moisture inflow. However, it took 13 months for 0.70-w/c concrete placed on a vapor barrier over clay to reach an inflow rate of 3 lbs/1,000 sq ft/24 hrs.

The most effective method for reducing inflow was a vapor barrier over a gravel layer placed on the compacted clay. However, even with this combination, 0.70-w/c concrete took about three and a half months to reach a 3-pound moisture inflow.

Brewer also measured moisture inflow for concrete specimens with a 0.45 water-cement ratio. The specimens were initially exposed to water vapor for 50 days then placed in contact with water for the duration of testing. After seven months, the moisture inflow had stabilized to the following values:

- Without a vapor retarder: 2.4 lbs/1,000 sq ft/24 hrs
- With 4-mil polyethylene: 1.7 lbs/1,000 sq ft/24 hrs
- With 32-mil ABS plastic: 1.0 lb/1,000 sq ft/24 hrs
- With 55-lb roofing felt: 1.0 lb/1,000 sq ft/24 hrs

These results show that if the water-cement ratio is low enough, moisture inflow can be kept below 3 lbs/1,000 sq ft/24 hrs without a vapor barrier. However, even at a low water-cement ratio, a vapor barrier significantly reduces moisture inflow.

Brewer also found that placing concrete on a vapor barrier slightly increases the initial vapor-emission rate (or moisture outflow) from concrete. For specimens placed directly on a vapor barrier, mix-water evaporation at the surface accounts for most of the water loss at early ages. But when a vapor barrier isn't used, some mix water is lost at the bottom, reducing the water content and water-cement ratio in the specimen. At later ages, however, a vapor barrier reduced the moisture outflow of concrete exposed to water or water vapor.

Table 2. Vapor-Emission Rate and Percent Saturation After One Year in 0.50-w/c Concrete

Test Condition	Vapor-Emission Rate (lbs/1,000 sq ft/24 hrs)	Percent Saturation
Water in contact with concrete	2.5	81
Water vapor in contact with concrete	2.3	76
Water in contact with 4-mil polyethylene	1.5	53
Water in contact with 32-mil ABS plastic	1.1	51
Drying only	1.0	50

3. What happens to the moisture content of the concrete when an impermeable covering is placed on the top surface?

Two months before the end of his tests, Brewer coated the top surfaces of some test specimens with a polyester resin. The coating prevented water-vapor emission from the specimens, but the specimens were still exposed to water from below. Measurements indicated no reduction of moisture inflow during this time. However, after weighing both coated and uncoated specimens, Brewer discovered that coated specimens were 64% saturated while uncoated specimens were only 46% saturated. The impervious coating on the concrete surface caused the moisture content to increase, even in concrete placed on a vapor barrier over a gravel layer. Since there was no outflow and the inflow remained the same, moisture accumulated in the slab below the impervious coating.

4. For concrete typically used in commercial and industrial floor slabs, what vapor-emission rates and degree of saturation are possible after the slabs have been exposed for one year to air at 73°F and 50% relative humidity?

Brewer measured the vapor-emission rate and percent saturation after one year for 4-inch-thick concrete specimens with a 0.50 water-cement ratio. Table 2 shows the emission rate and percent saturation for varying test conditions.

Preventing concrete contact with water or water vapor significantly reduced vapor-emission rate and percent saturation. A vapor barrier reduced the emission rate by more than 1 lb/1,000 sq ft/24 hrs and reduced the percent saturation from more than 75% to about 50%. These values are for specimens drying from the top while exposed to air at 73°F and 50% relative humidity.

Reference

H. W. Brewer, "Moisture Migration—Concrete Slab-on-Ground Construction," Bulletin D89, Portland Cement Association, Skokie, Ill., May 1965.

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