Moisture Effects on Flooring Systems

Moisture related problems in flooring are more prevalent today than they used to be. Several factors are responsible for that and perhaps the most prevalent are:

1) Fast track construction resulting in reduced slab drying time prior to flooring installation
2) Construction specifications for on grade slabs
3) Increased use of light weight concrete on above grade slabs
4) The use of non-vented pans in concrete construction

All of these factors contribute to the increased permeability, moisture content and/or moisture flow through concrete. When determining a quantifiable rate of moisture flow through concrete the calcium chloride test procedure appears to be the most reliable test available. Manufacturers of most floor coverings feel that vapor emission rates from concrete slabs of greater than *3 pounds/1000 square feet/24 hour period* as measured by the calcium chloride method are sufficient to cause flooring problems. They therefore recommend that flooring materials not be installed unless some remedial action to reduce the rate of vapor emission has been accomplished.

We receive more questions about moisture related flooring issues than any other aspect of our business. When we make technical flooring presentations, questions regarding moisture often spark the most discussion. It is obvious that the whole moisture issue as it relates to flooring is very misunderstood. We hope to share with you some information and experiences that will help put moisture related flooring problems in perspective.

Initially we approached the moisture issue with a mindset that all things wet were in liquid form. When we saw a floor blister, typical of moisture problems, we would penetrate it in some unceremonious fashion and quickly move away as water was propelled skyward; a result of the pressure that had developed within the blister cavity. Through our ignorance, we referred to this phenomenon as “hydrostatic pressure”. Our original conclusion was that “water” could only be forced through concrete as a result of some unseen force akin to putting a fire hose under a slab. As moisture related problems became more prevalent, many people had no clue as to the real problem and consequently promoted more misinformation through ignorance and/or denial. The result has been confusion and, for an industry that responded to the problem too late, a slight lack of credibility for those who are looking for solutions.

We now know that moisture problems are not necessarily caused by hydrostatic pressure. In fact I suspect it seldom occurs that way. Some people still believe that an on or below grade slab exhibiting a moisture problem must have water in direct contact with the slab underside. They expect to find “pooling” or running water far in excess of maximum soil retention levels. While such situations are possible and may occasionally exist, core sampling through the slabs in most cases does not reveal wet or saturated soil. While it is true that the underside of the slab has to be in contact with a moisture source in order to transmit it, it is not necessary that it be in excess.

Never have we seen a river run through it. Our experience has shown that moisture problems can occur in slabs that are not in direct contact with soil but rather reside several feet above. In these circumstances the environment below the slab is very damp and enclosed. Even these conditions provide enough humidity to supply the slab with an adequate moisture source for problems. *In reality, moisture vapor transmission through the slab is the issue, not hydrostatic pressure or pooling*.

Another misunderstanding is that moisture problems will not occur if there is a "vapor barrier" in place beneath the slab. It is not unusual to find a "vapor barrier" when a core sample is taken through a troubled slab. *In fact, most slabs that have problems also have a "vapor barrier" that was installed at the time of construction*. Conversely, we have experience with aged slabs that did not have "vapor barriers" installed originally and which even now show low permeability and no evidence of moisture problems.

According to some researchers, true and effective vapor barriers do help. H.W. Brewer studied vapor emission from concrete as early as 1965. He demonstrated a dramatic *reduction in both the rate of vapor emission and moisture saturation in concrete samples poured directly on vapor barriers when compared to those with no vapor barrier*. While true barrier materials are available, they are very costly and difficult to put in place. Due to practical field conditions, conventional "vapor barriers" essentially become ineffective as true barriers the day they are installed. There are obvious requirements in almost every slab for column footers as well as electrical, plumbing and other penetrations through the underside of the slab. These penetrations are holes in the barrier and as such violate the "barrier" concept. Further, unless all seams are overlapped and sealed, the seams themselves represent another potential for violation. Ultimately, puncture damage do to normal abuse and wear at the time the concrete is placed may be the largest single factor leading to ineffective vapor barriers. Some within the industry have suggested that vapor barriers may be better referred to as vapor retarders. When selecting vapor retarders you need to pay particular attention to several factors:

1) Toughness to reduce puncture
2) Type of material to reduce the rate of deterioration
3) The permeability of the retarder itself
4) Sealing techniques at the seams and penetrations

It appears from most studies that anything that reduces direct contact of water with the underside of the slab helps reduce subsequent moisture problems.

Without an adequate barrier to restrict moisture contact with the slab, moisture in the vapor phase will continue to move through the slab toward the slab surface. Many people reading this can relate to a common everyday occurrence at their own home that demonstrates this point. If you have a heavy door mat on a concrete step at your back door, move it aside and observe the area that <u>was</u> immediately under the mat. You will probably notice that the concrete under the mat is darker than the surrounding concrete. The concrete is darker in color because it is damp. Moisture vapor moves upward through a designated area of concrete at a relatively even rate. The moisture vapor that moves through the uncovered concrete, the area <u>not</u> under the mat, can freely evaporate as it reaches the surface. Because moisture freely evaporates as it reaches the surface, the surface appears dry. Moisture vapor continues to migrate upward through the covered concrete at the same rate as for the uncovered concrete. The mat however traps the moisture vapor at the concrete surface where it collects between the mat and the concrete, unable to evaporate. If the mat were your flooring material and the back step your facility; you would have a moisture problem. This phenomenon of moisture migration was observed in the study referenced earlier. Brewer demonstrated no reduction of moisture inflow to the bottom side of slabs, regardless if the slabs were coated on top or not. He further demonstrated that coated samples had an increase in moisture saturation, proving that moisture continues to "inflow" in slabs even though subsequent "outflow" is blocked.

Water sources generally fall into one of two classifications: a) natural, such as rainfall or underground springs and b) man made such as irrigation and broken pipes. One man made water source often ignored comes from within the concrete itself, namely, porous aggregate used in lightweight concrete. The porous aggregate absorbs water during the mixing process but does not release water during the curing process at the same rate as the surrounding sand/cement matrix. Long after hydration is completed and the water of convenience has evaporated, excess water from within that aggregate is still being released and therefore evaporating. The process is probably enhanced by vapor drive and if the vapor pressure differentials increase after flooring installation, the problem is exaggerated. We have seen through core analysis that water in porous aggregate is still present for up to 5 years after slab placement. In one example, an above grade light weight concrete slab was left uncovered for two years before applying a low permeability floor covering. Moisture problems appeared in less than one year after the floor covering was installed. Subsequent core analysis revealed saturated aggregate. This condition was further aggravated by the use of non-vented pans.

The components of concrete are sand, stone, cement and water. Water is both an essential component of concrete and the route of the moisture issue. Water is required to hydrate the cement and ultimately for strength throughout the life of the concrete. The amount of water required for the hydration of one pound of dry cement powder is 0.30 pounds, which represents a water/cement ratio of .30. That is a small amount of water, and when mixed with the sand and stone as well as the required one pound of cement to produce concrete would yield a mix too dry to place. For this reason more water than that simply required to hydrate cement is added to the concrete mix to make the mix "workable". This excess water is referred to as the water of convenience. After the initial concrete pour, the excess water evaporates from the mix. As a basic principle, water occupies space. When it leaves its *space* it leaves a void and the void is referred to as porosity. Further, as the water evaporates it creates capillaries through which the vapor travels. The porosity in concrete is commonly referred to as *permeability*. Studies have shown that as water cement ratios increase gradually, the resulting concrete permeability increases dramatically. It is critical to maintain low water cement ratios in order to reduce concrete permeability.

Moisture vapor migration through the slab is a direct function of permeability of the concrete and the primary route for migration is the capillaries we just described. The key factor influencing moisture migration through the capillaries is the differential in vapor pressure between the underside of the slab and the area above the slab. In an environment with a temperature of 55 degrees and a relative humidity of 100%, the vapor pressure is about 0.214. In an environment with a temperature of 70 degrees and 50% relative humidity the vapor pressure is 0.181. (*See Chart Below*) The area described above with a vapor pressure of .214 represents the average condition found below an on grade slab. The area represented in the .181 vapor pressure represents the condition found within a typical building envelope. By the natural laws of physics, moisture will drive from the area of higher pressure to the area of lower pressure in an attempt to equalize the two. The effects of moisture content below the slab, permeability of the concrete and the alkalinity of concrete combine to increase the water content of the slab. This available water has been described as the *fuel for vapor transmission*. The difference in vapor pressures drives the moisture toward the surface or area of lower pressure. Vapor pressure has been descried as the *engine for vapor transmission*. Assuming moisture and vapor pressure differentials are constant at any given time, the rate at which the moisture is transferred to the negative pressure side is a function of number of capillaries available for transport. Capillaries have been referred to as the *fuel lines for vapor transmission*. Obviously, if we can reduce the overall number and size of the fuel lines we can reduce the effectiveness of the engine.

RELATIVE HUMIDITY (IN PERCENT)

DRY BULB TEMP (IN DEGREES)	100	90	80	70	60	50	40	30	20	10
100	0.948	0.854	0.785	0.663	0.569	0.474	0.379	0.284	0.189	0.095
90	0.698	0.628	0.558	0.489	0.419	0.349	0.279	0.209	0.140	0.070
80	0.506	0.455	0.405	0.357	0.303	0.253	0.202	0.152	0.101	0.051
75	0.429	0.386	0.343	0.300	0.258	0.214	0.172	0.129	0.086	0.043
70	0.362	0.326	0.290	0.253	0.217	0.181	0.145	0.108	0.072	0.036
65	0.305	0.274	0.244	0.213	0.183	0.152	0.122	0.091	0.061	0.030
60	0.256	0.230	0.205	0.179	0.153	0.128	0.102	0.077	0.051	0.026
55	0.214	0.192	0.171	0.149	0.128	0.107	0.085	0.064	0.042	0.021
50	0.178	0.160	0.142	0.124	0.107	0.089	0.071	0.053	0.036	0.018
45	0.147	0.132	0.118	0.111	0.088	0.073	0.059	0.044	0.029	0.015
40	0.122	0.110	0.098	0.085	0.073	0.061	0.049	0.037	0.024	0.012
35	0.100	0.090	0.080	0.070	0.060	0.050	0.040	0.030	0.020	0.010
30	0.080	0.072	0.064	0.056	0.048	0.040	0.032	0.024	0.016	0.008
25	0.063	0.057	0.050	0.044	0.037	0.032	0.025	0.019	0.012	0.006
20	0.052	0.047	0.042	0.036	0.031	0.026	0.020	0.015	0.010	0.005
15	0.310	0.028	0.025	0.022	0.018	0.015	0.012	0.009	0.006	0.003
0	0.018	0.016	0.014	0.013	0.010	0.009	0.007	0.005	0.003	0.002
-10	0.011	0.010	0.009	0.008	0.007	0.006	0.004	0.003	0.002	0.001
-15	0.008	0.007	0.006	0.005	0.005	0.004	0.003	0.002	0.002	0.001

The primary concern of the flooring contractor and end user is how to determine the potential for problems in advance of installation. It is almost a given that a source of moisture to concrete is likely to be available. Further, concrete being what it is, if moisture is available it will likely be transmitted as vapor. There are a number of tests recommended for use with concrete as demonstrated by Rode and Wendler in their article published in Concrete Repair Bulletin, March-April 1996. I caution you that as you read about test methods and procedures you must consider their application to the real issue being measured.

Although we have spent most of this discussion talking about water and moisture, neither is the true affect leading to flooring damage. It should now be obvious that the real problem is *the transfer of moisture vapor, driven by differential vapor pressure from a moisture source through a permeable slab to the area of lower pressure where it is trapped beneath a low permeability flooring material*. Therefore any test that does not measure the transmission rate of moisture vapor through the slab is inconsequential. Actually, the moisture content of concrete means nothing if it is static or in equilibrium with it's surroundings. It is not until a differential vapor drive is established that the state of the moisture becomes dynamic. It is the dynamic state that needs to be measured and none of the tests designed to measure the *moisture content* of concrete measure dynamics. The mat test is indicative of the dynamic state of moisture but it is qualitative by nature and not measurable. Only the calcium chloride test (*ASTM F 1869-98*) seems to measure the dynamics of vapor emission in quantitative terms.

Each industry (to a lesser extent some manufacturers within an industry) is responsible for developing the standards governing the suitable conditions for the successful installation of their flooring type. To a great degree the standards are based not only on the permeability of concrete but also on the permeability of the flooring material and, if applicable, on the sensitivity of recommended adhesives to moisture. Most will state their limits based on the readings as given from the *ASTM F 1869-98* test (calcium chloride vapor emission test) and most stated limits are between 3 and 5 pounds per 1000 square feet per 24 hour period as the maximum allowable vapor emission rate for successful installations. This simply means that vapor emission rates must be at or below those readings or remedial steps must be taken to reduce the emissions prior to installation.

Copies of the ASTM vapor emission procedure are readily available. If you need a source, simply contact us and we will forward a copy to you.

Since it is almost impossible to totally stop vapor transmission, there are three basic categories for remedial actions to "deal" with it as follows:

1) **Penetrants:** Liquids that penetrate into the concrete and, after reacting with the moisture and alkaline components, form polymerized crystals. The crystalline formation is intended to fill the porosity in the upper levels of the concrete and in turn block the transmission of moisture vapor. These are often referred to as glass membranes and are in the modified silicate chemical family. Our experience with several of these materials has been less than satisfactory. The theory is good. If the concrete is porous and porosity is responsible for vapor transmission then simply fill the porosity and eliminate vapor transmission. In practicality it is not effective. Porosity depends on many variables and will differ between concrete pours. The inability to accurately define porosity within a slab defies the ability to accurately fill that porosity. The result of using Penetrants is a reduced vapor transmission but continued failures that are less exaggerated.
2) **Coatings:** Literally means coatings applied topically to the concrete. The coatings are effective only if they present a lowered permeability that is at once high enough to co-exist with the elevated permeability of the concrete and low enough to bridge the permeability

required by the finish flooring. These coatings are thin, generally mils thick, and if applied too heavily have low permeability themselves. It becomes obvious that the coatings are best suited to concrete with lower emission rates and may best serve as the finish coats. In the final analysis the coating class is not very effective as negative side barriers, must be semi-permeable membranes and as such do not work well in high tech applications as finish coatings.

3) **Membranes:** This can be a misunderstood term. Generally we think of membranes in terms of their positive side potential. The most obvious example of positive side membrane is the application of waterproofing to the outside of a block wall of a below grade basement. In this case the membrane is placed between the substrate (the block) and the source of the water (the soil). The membrane serves as the barrier to water penetration through the block and ultimately into the basement. Not the case here. The membranes described here are "negative side membranes". They are generally cement based or polymer concrete based and are applied to the slab to reduce vapor transmission *after* moisture has entered the slab. In this regard they are on the negative side of the concrete. Due to their chemistry, these materials are compatible with moisture and are not effected at the bond line by differential permeability. They close or reduce capillary size at the concrete interface thereby reducing vapor transfer rates. In addition to reducing the permeability gradient, they appear to absorb moisture within the membrane layer. We have found this treatment to be the most effective.

So far we have presented information on vapor emission through concrete slabs in the conventional concept of moisture related problems. One aspect of moisture that is rarely dealt with is water introduced through the top of the slab. This water is generally a result of normal work procedures requiring wash down or cleaning, especially on a repetitive basis.

Bruce Suprenant, in an August 1998 article published in Concrete Construction, examined some effects of topical water on subsequent vapor emission rates for uncovered slabs. His data demonstrates, among other things, that cured concrete slabs will absorb water topically that subsequently results in increased vapor emission rates. His data is based on a measured exposure for a short periods of time (hours) with some dramatic results. Information regarding the effects of prolonged exposure i.e. years of exposure to wash down procedures was not found. However it is possible, base on Suprenant's information, to predict that absorption from topical moisture does occur and that extended drying periods are required reach compliant vapor emission rates.

Water absorption from topical exposure can occur in areas that have existing flooring systems. The most obvious of these is tile. All tile products have seams or joints. Glazed and quarry tile floors have pronounced joints through which water freely penetrates to the substrate. Although we do not normally associate VCT installations with wet environments, there are a lot of facilities in which wet functions take place over VCT flooring. As seams begin to separate and lift in these systems, water gains free access to the substrate as well. In some instances tile floors are installed over mortar setting beds. The setting bed becomes a sponge, absorbing free water. Another obvious condition is one in which low permeability flooring has been chipped or eroded while wet operations continue. Some resinous floor systems are porous. Just as with concrete, porous flooring absorbs moisture, some of which will be transferred to the covered slab.

The reason for addressing this aspect in the moisture section is that, in renovation, these flooring systems are often removed and resurfaced. Renovation projects are often associated with area shut downs and as such are on fast track timing. Care must be taken to assure that moisture readings are taken and that vapor emission requirements are compliant prior to installation of new flooring systems. Additionally, specifications requiring new flooring to be installed over existing systems are often written to save time and money. Trapped moisture within a system can also react like vapor emission from concrete. Therefore, care must be taken to assure that moisture is not trapped within or under the existing system.

References:

1) Bruce A. Suprenant and Ward R. Malisch, "Are your slabs dry enough for floor coverings?" Concrete Construction, August 1998
2) Bruce A. Suprenant and Ward R. Malisch, "Effect of water-vapor emissions on Floor-covering adhesives", Concrete Construction, January 1999
3) H.W. Brewer, "Moisture Migration-Concrete Slab-on Ground Construction", Bulletin D89, Portland Cement Association, Skokie, IL, May 1965
4) Malcom Rode and Doug Wendler, "Methods for measuring moisture content in concrete", Concrete Repair Bulletin, March-April 1996
5) "Concrete Vapor Emission Control", Revised January 1998, 1530 Old Oakland Road, Suite 120, San Jose, CA 95112