Technical Notes on Brick Construction

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EFFLORESCENCE
CAUSES AND MECHANISMS
PART I OF II

Abstract: It is important for designers to understand the various types of efflorescence which can occur and to have at least a basic knowledge of the factors influencing the appearance of efflorescence on brick masonry. This *Technical Notes* covers the often very complicated mechanisms leading to the formation of efflorescence, including the probable sources of soluble salts as well as the sources of moisture needed to activate these salts. Information is presented as to the composition of each known type of stain, along with research references describing conditions necessary to cause these stains to appear.

Key Words: **admixtures**, carbonates, chlorides, **condensation**, manganese, **masonry units**, **mortar**, **rain water**, silicates, **soluble salts**, sulfates, trim, vanadium.

INTRODUCTION

Efflorescence is a crystalline deposit of water-soluble salts on the surface of brick masonry. The principal objection to efflorescence is its unsightly appearance. Although efflorescence is unsightly and a nuisance to remove, it is usually not harmful to the brick masonry.

Efflorescence is usually white in color; however, all white stains on brick masonry are not necessarily efflorescence. Also, certain vanadium and molybdenum compounds, present in some ceramic units, may produce a green deposit, commonly referred to as "green stain". Occasionally, "brown stain" may occur, resulting from deposits of manganese compounds.

Under certain specific circumstances and conditions, it is possible for the crystals of efflorescence to form within the bodies of the units. When this occurs, it is possible that the pressure of crystallization and growth of the crystals may cause cracking and distress to the masonry.

This *Technical Notes* addresses the mechanisms of efflorescence, including possible sources of salts and of water. The purpose is to provide a basic understanding of the phenomenon of efflorescence for the design professional, specification writer, contractor or owner. *Technical Notes* 23A Revised will present recommendations on how to prevent the occurrence of efflorescence, and serve as a guide for its investigation, identification and elimination.

MECHANISMS OF EFFLORESCENCE

The mechanisms of efflorescence are many and often complicated. However, simply stated, water-soluble salts in solution are brought to the surface of the masonry and deposited there by evaporation. The salt solutions may migrate across surfaces of units, between the mortar and units, or through the pore structure of the mortar or the masonry units.

There are certain simultaneous conditions which must exist in order for efflorescence to occur. Soluble salts must be present within or in contact with the masonry assembly. These salts may be present in the facing units, backup, mortar ingredients, trim, etc. There also must be a source of water and it must be in contact with the salts for sufficient time to permit them to dissolve. The masonry must be such that the migration of salt solutions to the surface, or other locations, occurs in an environment which is conducive to the evaporation of water.

It is apparent, from the above discussion, that if masonry could be constructed to contain no water-soluble salts, or if no water were permitted to penetrate the masonry, efflorescence would not occur. However, in conventional masonry exposed to weather, neither of these conditions can exist. Consequently, the practical approach to the elimination of efflorescence is to *reduce* all contributing factors to a minimum.

Sources of Salts

The chemical composition of efflorescent salts is usually alkali and alkaline earth sulfates and carbonates, although chlorides have also been identified. The most common salts found in efflorescence are sulfate and carbonate compounds of sodium, potassium, calcium, magnesium and aluminum. Chlorides may also occur as efflorescence. This is usually a result of the use of calcium chloride as a mortar accelerator, contamination of masonry units or mortar sand by sea water, or the improper use of hydrochloric acids in cleaning solutions.

Efflorescence is further complicated by the many available sources of soluble salts. Soluble salts may be present in the masonry units, in the mortar, or may result from rain water or ground water, or other sources as discussed hereafter.

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Masonry Units. Since efflorescence appears on the face of the wall, it is often erroneously assumed to be the fault of the brick. This is not usually the case. There are, however, soluble salts present in many of the units that make up a wall assembly.

Brick - Because of the composition of the raw materials and the high temperatures associated with the manufacturing process, it is possible for soluble phases to exist within the finished brick. If water is absorbed by such products, the soluble salts enter into solution and efflorescence may be formed as evaporation takes place from the surface of the brick.

In regard to brick which contain water-soluble salts formed during firing, Brownell (W.E. Brownell, ìThe Causes and Control of Efflorescence on Brickworkî, Research Report No. 15, Structural Clay Products Institute, 1969) states: "Products such as these will show efflorescence when placed in distilled water, even though all precautions are taken to eliminate outside contamination."

Brick units with low efflorescence potential are readily available in all parts of the United States and Canada. The potential for masonry units to effloresce may be easily assessed by the efflorescence test in ASTM C 67, Standard Methods of Sampling and Testing Brick and Structural Clay Tile.

Backup - Masonry materials used as backup or inner wythes of masonry walls may contain large quantities of soluble salts. These units may contribute to efflorescence on the face of the wall, if sufficient water is present to dissolve the salts and pathways are provided for the solution to reach the masonry surface.

A comparison of the various types of concrete masonry units with structural clay tile was made by Young (J.E. Young, “Backup Materials as a Source of Efflorescence,” Journal, American Ceramic Society, 40 (7), 1957). Young measured the soluble salts content and efflorescent tendencies of each of the various units in his experiments. It was found that concrete products contain two to seven times as much soluble material as the fired clay material.

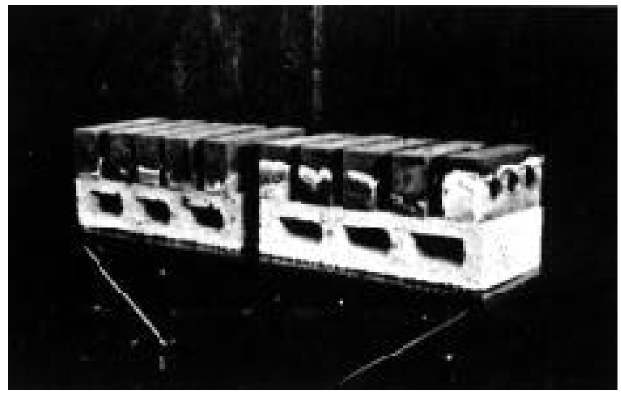
Figure 1 illustrates the transfer of soluble salts from backup units to facing brick. This result was obtained by placing the backup block in pans of water with five brick on top of each block, as shown. The brick had previously been subjected to the efflorescence test and showed no efflorescence. The potential for backup units to effloresce can be determined by using the same efflorescence test method which is used for facing brick.

Trim - Building trim, such as caps, coping, sills, lintels, keystones, etc., are often of materials other than fired clay products. These items can be natural stone, cast stone, precast concrete, etc., which may contain soluble salts. Such materials may contribute significantly to efflorescence on the face of adjacent brickwork.

Mortar. Mortar can be a significant contributor to efflorescence. As Brownell states:

"The primary and most obvious source of contamination of otherwise efflorescence-free brick is the mortar used in wall construction. The mortar is in intimate contact with the brick on at least four and sometimes five sides. It is applied to the brick in a wet, paste-like condition which provides ample moisture for the transfer of soluble salts from the mortar to the brick. If any appreciable soluble material is present in the mortar, it will be carried into the brick proportionately to the amount of moisture transferred.

"The simplest case of soluble salt contamination of efflorescence-free brick is the migration of 'free-alkali' solutions from the mortar to the brick. This situation is not only the simplest mechanism, but it is also the most common. In the trade, it is known as 'new building bloom'."



Showing Migration of Soluble Salts from Backup to Facing Brick
FIG. 1

Cement - The water-soluble alkalies common in mortars are sodium and potassium. Alkalies available in portland cements vary from one source to another, ranging from approximately 0.02 percent to 0.90 percent by weight of the cement. A survey of masonry cements indicates a range of alkali from 0.03 to 0.27 percent by weight of the cement.

It is suspected that the sulfate content of the cement may be as significant as the alkali content in contributing to efflorescence. Modern cement manufacturing methods which attempt to achieve energy conservation may result in larger quantities of sulfates in the finished products.

Lime - Various investigators disagree as to the possible contribution of lime to efflorescence. It has been demonstrated that lime, clay or sand additions to a mortar mix-do not generally contribute to efflorescence (T.J. Minnick, “Effect of Lime on Characteristics of Mortar in Masonry Construction,” Bulletin, American Ceramic Society, 38 (5), 1959.) In fact, these ingredients tend to dilute the deleterious effects of a high alkali cement.

On the other hand, lime is relatively soluble. Its presence may serve to neutralize sulfuric acids generated within the masonry. However, a cleaning solution containing hydrochloric acid can produce very soluble calcium chloride which can migrate to the surface. Nevertheless, lime in mortar is very important in establishing good bond to brick units, and thereby increases the water resistance of the masonry.

Sand - Sands used in mortar are primarily silica, and as such they are not water-soluble. Sands, however, may be contaminated with material which will contribute to efflorescence. This contamination may include: sea water, soil runoff, plant life and decomposed organic compounds, among others. Any of these may contribute to efflorescence.

Miscellaneous Sources of Salts. In addition to the mortar and units placed in the masonry, there are other outside sources of soluble salts that may contribute to efflorescence. Some of these are discussed here.

Admixtures - A wide variety of admixtures for masonry mortars is available to the masonry industry. Most of these products are proprietary and their compositions are not disclosed. In general, they are classified as grinding aids, air-entraining agents, water repellents, wetting agents and accelerators.

The effects of these admixtures on the properties of mortar are generally limited to flow, water retentivity and strength. Little information is available as to their effect on bond, either between mortar and brick or between mortar and reinforcing. In addition, there is some evidence, based largely on field experience, that certain admixtures may reduce the bond between mortar and brick. This reduction in bond may make masonry walls more vulnerable to water penetration.

For these reasons, admixtures with unknown compositions are not recommended for use in mortars unless it has been established by experience or laboratory tests that they will neither materially impair mortar bond nor contribute to efflorescence.

Calcium Chloride - Calcium chloride is sometimes added to mortar as an accelerator as permitted by ASTM C 270, Specification for Mortars for Unit Masonry. Calcium chloride and compounds containing calcium chloride should not be permitted in masonry containing metal anchors or reinforcing, as corrosion of metal embedded in mortar will occur when exposure conditions are favorable.

If calcium chloride is used, it should be limited to an amount not to exceed 2 percent by weight of the portland cement or 1 percent of the masonry cement (usually about 50 percent portland cement) content of the mortar. See *Technical Notes* 1. Normally, this amount of calcium chloride will not contribute materially to efflorescence.

Ground Water - Soluble salts in soil are dissolved by water which penetrates the ground. Consequently, most ground water contains a high concentration of these salts. When the earth is in contact with the masonry, ground water may be absorbed by the masonry and may rise, through capillary action, several feet above the ground. An accumulation of salts in the masonry is then possible.

Atmosphere - It has been reported by some investigators that sulfurous gases in the atmosphere may contaminate the brickwork. (F.O. Anderegg, "Efflorescence," ASTM Bulletin No. 195, 1952). This situation over a period of time will cause disintegration of the mortar joint surfaces. These acids may also attack the components of the brick itself. The reports of such instances are infrequent and are limited to highly industrial areas and coastal regions.

Sources of Moisture

As previously discussed, the mechanism of efflorescence is dependent upon the presence of free water in the masonry to dissolve the available soluble salts. Some of the sources of free water are discussed in the following paragraphs.

Rain Water. The primary source of moisture for the occurrence of efflorescence is rain water which penetrates or comes in contact with masonry. The exposure of masonry to rain water varies greatly throughout the United States. Rain water exposure is very severe on the Atlantic Seaboard and Gulf Coast where rains of several hours duration may be accompanied by high winds. Rain water exposure is moderate in the Midwest and Mississippi Valley where wind velocities are lower. Rain water exposure is slight in arid areas of the West. Exposure area may be defined roughly in terms of wind pressure and annual precipitation. The maps in Fig. 2 indicate geographic areas of high wind pressures and heavy precipitation. A Driving Rain Index, which differs from the maps in Fig. 2, has recently been proposed. See Table 1 and Fig. 2 of *Technical Notes* 7 Revised.

Rain water will penetrate all masonry walls to some degree, especially if they are improperly designed or improperly detailed. The craftsmanship employed in the construction of a masonry wall also has a significant effect on the amount of water penetrating the wall. Brick masonry with workmanship characterized by partially filled joints, deep furrowing of the mortar beds and improper execution of flashing and caulking details will be more subject to rain penetration. See *Technical Notes* 7 Revised, 7A Revised and 7B Revised.

Condensation. In addition to rain water and ground water, water may accumulate within the wall as a result of condensation of water vapor. Frequently, efflorescence that appears on masonry walls protected from rain is due to this accumulation of condensed water.

Condensation is usually due to moisture originating inside buildings. Cold outside air, entering a building and heated for comfort purposes, is invariably low in moisture content. Moisture released from cooking, bathing, washing and other operations employing water or steam, and moisture released by exhalation and perspiration of the occupants humidify this air. This gain in moisture content increases the vapor pressure of the inside air substantially above that existing outdoors. This increased pressure tends to drive the vapor outwardly from the building interior through any vapor-porous materials that may comprise the enclosing surfaces.

When vapor passes through porous and homogeneous materials, which may be warm on one side and cold on the other, it may pass through the zone of its dew point temperature without condensing into water. But, if the flow of vapor is impeded by vapor-resistant surfaces at a temperature below the dew point temperature, the vapor will condense on such cold surfaces. This condensed moisture can contribute to efflorescence on the wall surface. See *Technical Notes* 7C and 7D.

Construction. Another source of moisture which may cause "new building bloom" and contribute to future occurrences of efflorescence in a building is the water which enters the assembly during construction. The improper protection of a building during construction may significantly contribute to future problems, including efflorescence. It is at this stage, when interior assemblies are exposed, joints are open and foreign materials are present on the project, that the construction is highly vulnerable to the entry of considerable moisture. Also, in some cases, additional soluble salts from other sources may contaminate the masonry wall assembly.

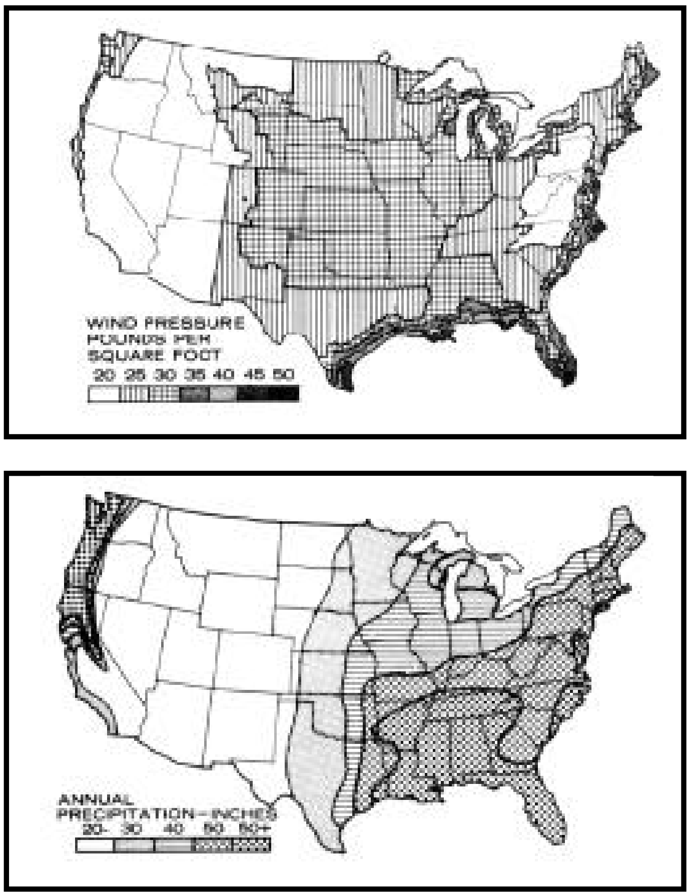


FIG. 2

OTHER STAINS

Stains will occasionally occur on the surfaces of masonry structures other than the fairly common white efflorescence previously discussed. These are carbonate deposits ("lime run"), silicate deposits (white "scum"), "green stains" and "brown stains".

Carbonate Deposits (Lime Run)

Carbonate deposits, if they occur, usually appear as a gray-white, crusty spot in the form of a vertical "run-down" shape on the face of the wall. These deposits are sometimes referred to as "lime run". This is not really correct, and may be misleading, as "lime run" is not directly a result of lime in the mortar. Carbonate deposits nearly always occur at a small hole or opening in the face of the masonry.

The mechanisms of this type of stain are not clearly understood, but are often compared with the formation of stalactites in limestone caves. It is apparent that this deposit/stain requires a great deal of water traveling a similar path over an extended period of time. The water takes any of several calcium compounds into solution, and brings them to the surface of the masonry through the hole. The source of the calcium compounds may be trim, mortar, backup, etc. At the surface, it is thought that the solution reacts with carbon dioxide in the air, thus forming the crusty deposit.

These carbonate stains can be removed using a weak solution of hydrochloric acid, applied directly to the deposit. Care must be taken to properly wet the wall area first and rinse it thoroughly after cleaning. This is especially true when removing carbonate deposits from light-colored brick. See *Technical Notes* 20 Revised. The deposit is likely to reappear unless the water source is stopped.

Silicate Deposits (Scumming)

Silicate deposits, sometimes called "scumming", sometimes occur as a general white or gray discoloration on the face of brick masonry. The discoloration may occur over all of the face of the masonry or sometimes in specific locations of 100 to 200 sq ft (9 to 19 m^2) in area, irregular in shape. Silicate stain/deposits may also occur adjacent to trim elements, precast concrete and occasionally large expanses of glass.

These silicate deposits on brick masonry should not be confused with the "scumming" that occasionally occurs on brick in the manufacturing process. This "scum" will be evident on the brick units in storage before they are placed in the wall.

It is known that there is any number of mechanisms that may precipitate silicate deposits on brickwork. Their specific chemistry, however, is not totally clear. Many of these stains are related to the cleaning of brick masonry with hydrochloric acid solutions, especially if proper cleaning procedures are not carefully followed, i.e., thoroughly wetting the wall, method of applying the cleaning solution and thoroughly rinsing the wall with clear water.

Silicate deposits are very difficult, if not impossible, to remove from brick masonry. They are insoluble in most acids. Often the only practical method of dealing with a silicate deposit is to disguise it and permit it to weather away over time. See *Technical Notes* 20 Revised.

Vanadium (Green or Yellow Stains)

Some structural clay products develop yellow or green efflorescent salts when they come in contact with water. These stains are usually vanadium salts. They may be found on red, buff or white clay products; however, they are most objectionable and more readily apparent on the lighter-colored units. The vanadium salts responsible for these stains have their origin in the raw materials used for the manufacture of the clay products. The yellow and green stains are usually vanadyl salts, consisting of sulfates and chlorides, or hydrates of these salts.

The mechanisms of this type of stain are as follows:

as water travels through the brick, it dissolves both the vanadium oxide and sulfates. In this process, the solution may become quite acidic. As the solution evaporates from the surface of the product, the salts are deposited.

The chloride salts of vanadium require highly acidic leaching solutions, and are usually the result of washing brickwork with acid cleaning solutions. Vanadyl chloride, one of the most prominent stain compounds, forms almost exclusively as a result of washing with hydrochloric acid. As stated by Brownell: “A highly acid condition in the water leaching through a brick is necessary for the promotion of the colored vanadyl salts."

Preventing green stain caused by vanadium is important, since subsequent efforts at cleaning may turn it into a brown, insoluble deposit that is very difficult to remove.

To minimize the occurrence of green stain, the following steps are recommended:

1. Store brick off the ground and under protective covers.
2. Never use or permit the use of acid solutions to clean light-colored brick.
3. Seek and follow the recommendations of the brick manufacturer for cleaning procedures, for all types and colors of brick.

Green vanadium stains can be difficult to remove. Some methods and procedures for the removal of green stain are described in *Technical Notes* 20 Revised. Never attempt to remove green stain with acids.

Manganese (Brown Stain)

Under certain conditions, tan or brown, and sometimes gray staining may occur on the mortar joints of brickwork. Occasionally, the brown stain will streak down onto the faces of the brick. This type of stain is the result of the use of manganese dioxide as a coloring agent in the units. This staining problem is closely related to the general efflorescence problem, since it is the sulfate and chloride salts of manganese that travel to the surface of the brick and are deposited on the mortar joints.

During the brick firing process, the manganese coloring agents undergo several chemical changes, resulting in manganese compounds that are insoluble in water. They have varying degrees of solubility in weak acids. As previously discussed, acid solutions can occur in the brick in a wall. Also, the brick can absorb hydrochloric acid during the masonry cleaning process. It is also possible that in some areas rain water may be acidic (T.J. Minnick, “Effect of Lime on Characteristics of Mortar in Masonry Construction,” Bulletin, American Ceramic Society, 38 (5), 1959.)

According to Brownell: "The manganese sulfate or chloride solutions from the brick will migrate across the mortar joints especially during a period of drying. These acidic manganese solutions will be neutralized by the inherent basic nature of the mortar. Upon neutralization, insoluble manganese hydroxide is precipitated on the mortar joints, and this is converted to brown Mn_3O_4 on drying."

To minimize or eliminate manganese staining, the following are suggested:

1. When a building is under construction using brick colored with manganese, it should not be cleaned with hydrochloric acid without neutralizing the acid during the rinsing operation. Such neutralization will tend to reduce the amount of manganese taken into solution.
2. Application of silicones to brick (if otherwise unobjectionable, see *Technical Notes* 6A) may prevent staining by retarding water penetration of the brick while stored or in service.
3. Always request and follow the advice of the brick manufacturer in cleaning a brown or manganese-colored brick.

The removal of manganese stain is a fairly simple operation, and is described in *Technical Notes* 20 Revised. However, the permanence of the removal is often in doubt. Hence, the prevention of the occurrence of brown manganese stain is of paramount importance.

SUMMARY

This *Technical Notes* has presented a brief description of the causes, mechanisms and sources of efflorescence. *Technical Notes* 23A Revised will address the prevention of efflorescence, a guide for analysis of efflorescence problems and the removal of efflorescent salts from the face of masonry.

The information contained in this *Technical Notes* is based on the available data and experience of the technical staff of the Brick Institute of America. This information should be recognized as recommendations which, if followed with good judgment, should result in brick masonry that performs successfully.

Final decisions on the use of information, suggestions and recommendations as discussed in this *Technical Notes* are not within the purview of the Brick Institute of America and must rest with the project owner, designer or both.

REFERENCES

For further information on the subject of efflorescence, its causes and mechanisms, the following publications may be consulted:

1. T. Ritchie, "Study of Efflorescence Produced on Ceramic Wicks by Masonry Mortars", *Journal*, American Ceramic Society, 38 (10) 1955.
2. W. F. Brownell, J. L. Kenna, and P. P. Wilko, Jr., "Staining of Mortar by Manganese Colored Brick", *Bulletin*, American Ceramic Society, 45 (12) 1966.
3. *Technical Notes on Brick Construction* 20 Revised, Brick Institute of America, McLean, Virginia, Sept/Oct 1977.