

# Some observations on the impact of a low solubility ionic solution on drying characteristics of a model porous medium

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**Abstract:** We study the impact, on the drying rate, of the presence of suspended elements, such as calcium sulfate ions with a low solubility, in porous media interstitial fluid. In order to single out this process in the complexity of a porous medium, we look at the phenomena through drying in a simple capillary. We first show that in such a capillary the drying process characteristics vary depending on the wettability characteristics. Typically the drying rate is much smaller with hydrophobic surface since the air-liquid interface tends to withdraw inside the medium, while there remains a continuous liquid film up to the entrance in the case of hydrophilic surfaces. Then it appears that an ionic solution dries slower than a pure liquid, because the crystals formed along the capillary walls tend to induce a dewetting of the surface, pushing inwards the first liquid-air interface from which most evaporation occurs. An experiment with a model colloidal suspension further illustrates this mechanism: the accumulation of solid particles along the wall forms a deposit which also pushes inwards the first liquid-air interface from which evaporation takes place. Finally we look at the impact, on the drying characteristics, of the presence of different additives in the ionic solution.

## 1. Introduction

Salt presence and crystallization in building materials are responsible for major damages of modern structures (Liu et al. 2014) and cultural heritage (Sawdy et al. 2008). Similar effects in rocks can alter CO<sub>2</sub> injectivity (Peysson et al 2011) and are at the origin of various geomorphological processes (Rodriguez-Navarro and Doehne 1999). For example ions dissolved during imbibition can then, during drying, reach the solubility limit and precipitate as crystals below (subflorescence) or above (efflorescence) the sample free surface. In the case of crystallization, these crystals may clog the porous structure (Espinosa-Marzal and Scherer 2013, Derluyn et al. 2013), and leading to flakings and crumbings (Kramar et al. 2010) or a reduction of the compression strength of the material (Foraboschi and Vanin 2014). The mechanisms at the origin of these damages have been discussed: crystallization pressure thanks to solid volume change from thenardite to mirabilite (Scherer 2004, Flatt 2002, Schiro et al. 2012, Flatt et al. 2014, Tsui et al. 2003), supersaturation. It was also acknowledged that the remaining liquid films can play a significant role on crystallization processes (Espinosa-Marzal and Scherer 2010). Extensive studies (Rodriguez-Navarro et al. 1999, Schultz and Schlünder 1990) show the variety of crystallization patterns observed depending on solution properties (salt type and additives). Also it was finally pointed out (Rodriguez-Navarro et al. 1999, Shahidzadeh-Bonn et al. 2010, Desarnaud et al. 2013) from detailed information concerning salt and damage localization, that possible damages critically depend on the localization of salt crystals which requires the description of the dynamics of salt transport, spatial distribution and crystallization hence the drying mechanisms.

For efflorescence the basic theoretical concepts of salt transport resulting from water flow during drying were confirmed by following the salt distribution by MRI (Pel et al. 2004, Petkovic et al. 2010). It was then shown that crystals deposited at the sample free surface behave as a porous medium which pumps the liquid and brings ions around the most external liquid-air interface to form new crystals thanks to its smaller pore structure (Veran-Tissoires et al. 2012, Sghaier and Prat 2009). A recent study showed in addition that the structure of the efflorescence layer can evolve with successive imbibition-drying cycles, which successively modifies the drying rate (Desarnaud et al. 2015). Microtomography observations of the three phases around the sample top provided a detailed description of the process, which makes it possible to establish a model of crust formation dynamics as a function of drying rate (Norouzi Rad et al. 2015). Besides it was shown that some unexpected effects (in drying rate variations) can result from the interplay between the crust width and the evaporation conditions (Gupta et al. 2014a, Gupta et al. 2014b).

For example, for plasters, after the chemical (dissolution-precipitation) hydration reactions which typically occur in less than one hour and allow to get the basic solid porous structure of the material, a significant excess of water has than to be removed from the (saturated) freshly formed porous structure. However, at the end of the initial hydration process (due to precipitation of dihydrates) the interstitial solution is saturated with ions ( $\text{Ca}^{2+}$ ,  $\text{SO}_4^{2-}$ ), which can then precipitate as gypsum crystals and accumulate in some regions as soon as some water is extracted by evaporation. Thanks to the high dry rates we are working with, the advection is higher than the diffusion (i.e. the Peclet number is larger than 1), hence salts are transported towards the free surface (Sawdy et al. 2008) and then can either crystallize inside the plaster or move outside, towards the substrate (Petkovic et al. 2007). It was also suggested that this salt crystallization leads to the formation of a structure inside the plaster, whose characteristics depend on the drying rate and in turn impact the drying rate (Vosten and Hersfeld 1976, Seck et al. 2015). From Magnetic Resonance Imaging and X-Ray Microtomography measurements it was recently shown (Seck et al. 2016) that crystals deposit around the air-liquid interface the closest to the sample free surface, which induces an apparent recession of this interface towards the interior of the sample and the distribution of crystals deposited during evaporation essentially depends on the history of saturation. It was then suggested that the drying dynamics results from vapor diffusion through the less porous layers of crystal accumulation below the sample free surface. This in particular makes it possible to predict the dramatic decrease of the drying rate after successive imbibition-drying cycles (Seck et al. 2016).

A more detailed view of this process would be useful to fully understand the physical effects at work. In that aim it can be instructive to use a simpler porous structure. For example, with a sintered packing of glass beads initially saturated with a low concentration ionic solution (gypsum saturated solution:  $\text{SO}_4^{2-}$ ,  $\text{Ca}^{2+}$ , with a mass concentration  $\approx 2.65$  g/l) and submitted to a given air flux a drop of the drying rate may be observed from the beginning of the drying process (Seck 2015), whereas with pure water filling the medium and identical air flux, the drying rate remains constant down to low saturation. Finally it requires 27 h to get a saturation of 20% with the ionic solution whereas it requires only 16 h with pure water. This confirms that gypsum ions ( $\text{SO}_4^{2-}$ ,  $\text{Ca}^{2+}$ ) crystallization can by itself affect the drying characteristics of a porous medium.

An even more model porous structure can be useful to get a detailed view of the dynamic process at the local scale. Recent observations (Rufai and Crawshaw 2017) of drying of NaCl solutions in a micromodel directly show that crystallization tend to blocks some paths, which decreases the drying rate. Other experiments in other types of 2D (Eloubaki et al 2011) or 3D (Hidri et al. 2013) model porous media showed that the drying rate can be affected by efflorescence mechanisms. Drying of NaCl salt solutions has even been studied in simple tubes: an experimental study was carry out with 1 mm

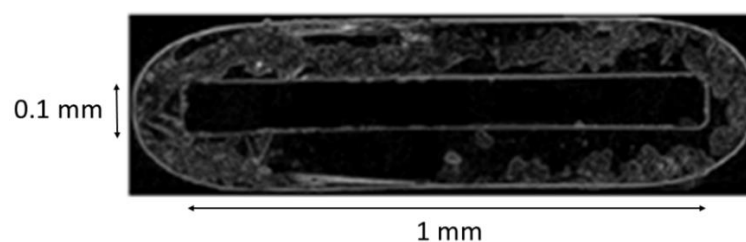
cylindrical tubes, and the process of crystallization and deposit was modelled (Naillon et al. 2015); the patterns of salt crystallization from droplets and in square tubes were also reviewed (Shahidzadeh-Bonn et al. 2008). The same process, but now in tube with cross-square section, which leads to considerable change due to the persistence of liquid films along the corners, was modelled (Camassel et al. 2005).

Here we focus on the drying of ionic solutions of low solubility, from capillaries exhibiting characteristics such that they reproduce some critical aspects of drying of porous media: the geometry consists in a thin channel with a rectangular section, open on one side (left hand side in the figures of this paper), so that capillary effects remain dominant during most of the drying process, as in a porous medium (Keita et al. 2016), and it is generally possible to follow the evolution of the air-liquid interface in time. In this context we will review some observed patterns but we will not attempt to understand the mechanisms of crystallization or deposit at a local scale, and the origin of these patterns; instead we will mainly concentrate our attention on the impact of these phenomena on the drying rate of the whole system.

## 2. Materials and methods

We performed drying experiments with 5 cm long hollow tubes manufactured with borosilicate glass with a rectangular section. The internal width and thickness of the tube are respectively 0.1 and 1 mm; the corners of the section are slightly rounded (see Fig.1).

Once saturated with a liquid, the capillary is held horizontally and glued at one of its extremity with Loctite® epoxy quick set glue, drying taking place from the other extremity. With hydrophilic surface, filling the tube with a solution is readily obtained by putting one of its extremity with the liquid, which, due to capillary effects, penetrates and fills the tube. With hydrophobic surface it is necessary to inject the liquid with a syringe from one of the tube extremity. Then the open tube end is exposed to a stagnant air atmosphere at ambient temperature (25°C, 50% RH), and evaporation starts. With a Carl Zeiss Microscopy® device we follow the drying process by taking successive top view images.



**Figure 1:** Cross-section of the tube.

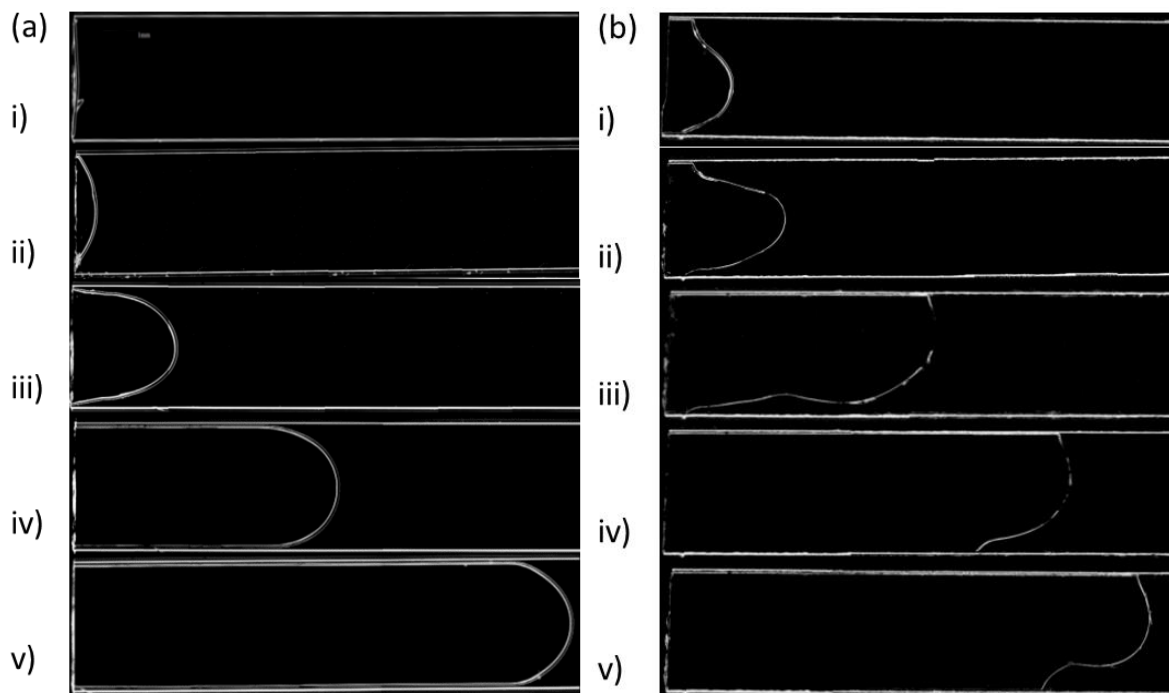
When conducting test with hydrophilic tubes, the interior of the capillary tube is cleaned with nitric acid at 50% then rinsed with pure water. This allows to get a hydrophilic surface, with a 0° contact angle with pure water (about 9° with the sulfate calcium solution). When conducting tests with hydrophobic tubes, the surfaces were prepared differently by placing a silane solution (obtained by mixing 0.01 g of trichlorosilane with 10 mg of octane) inside the tube during one day, which induces a solvent-based salinization reaction (Brzoska et al. 1994). The solution is then removed and the tube is dried. This allows us to get a hydrophobic surface, with a 120° contact angle with pure water.

Different liquid solutions were used. We used pure (distilled) water. We also used an ionic solution, a calcium - sulfate saturated water solution by placing during a few hours 100 g of gypsum powder in 1 l of water so as to obtain a saturated solution (i.e. 2.65 g/l). Note that this rather low solubility can be at the origin of physical trends during drying rather different from those observed with salt solution with much larger solubility such as NaCl. A different ionic solution was obtained by adding citric acid (at a concentration of 10g/l) in calcium - sulphate saturated solution. At last we also changed the wettability of the ionic solution by adding surfactant. In order to avoid any interplay between these surfactants and the crystallization phenomenon, we used non-ionic surfactants, i.e. PEG  $((C_3H_6O.C_2H_4O)_x)$ , number average molecular weight  $M_n \approx 4400$  and Sorbitan esters (Tween 20). They were mixed in a gypsum-saturated solution so as to obtain a 3.3 g/l concentration. The contact angles of the ionic solutions mixed with these surfactants on hydrophilic surfaces is 4-5°.

The order of magnitude of the velocity of liquid transport ( $U$ ) during our tests is a channel length  $L = 2.5$  cm emptied in 200 min, which gives  $2 \times 10^{-6} \text{ m.s}^{-1}$ , so that we have  $UL = 5 \times 10^{-8} \text{ m.s}^{-1}$ , a value much larger than the coefficient of diffusion of any species in water (ions, colloids), smaller than the self-diffusion coefficient of water ( $D = 2.3 \times 10^{-9} \text{ m}^2.\text{s}^{-1}$ ). Note that in some cases the velocity drops to a value about five times smaller but this does not change the conclusion. Thus the Peclet number (i.e.  $Pe = UL/D$ ) is much larger than 1 in all our tests, so that we expect that advection is dominant.

## 2. Results and discussion

During drying of the capillary with a hydrophilic surface filled with water we observe that the air-liquid interface deforms in time. Initially it is perpendicular to the tube axis (see Fig.2a i)), then it progressively curves towards the tube interior (see Fig.2a ii) and iii)). At some time it becomes composed of two interfaces along the sides in the tube direction and one interface with a large radius of curvature at the front (see Fig.2a iv) and v)). This “steady-state” shape remains the same until the end of drying, while the front progressively penetrates deeper in the tube.

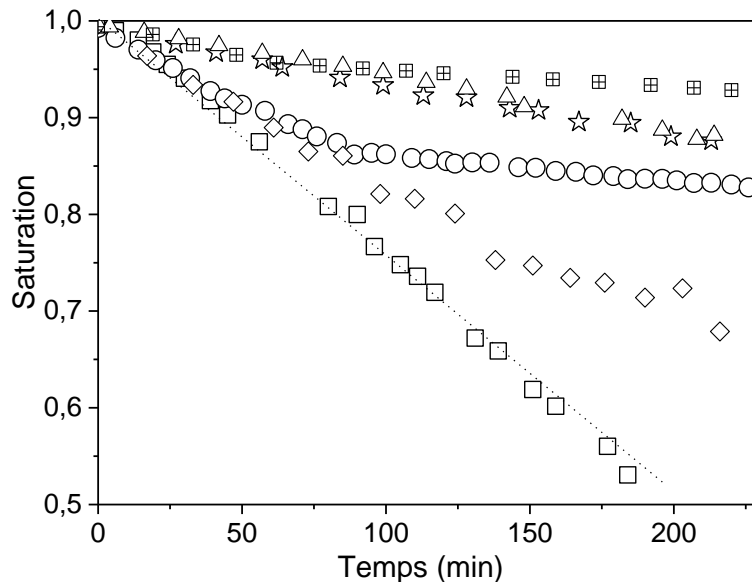


**Figure 2:** Views of the liquid air interface in the main plane of the channel at different times for pure water and hydrophilic surface (a): i) 0, ii) 0.6, iii) 14, iv) 45, v) 80min; or hydrophobic surface (b): i) 6, ii) 33, iii) 45, iv) 89, v) 186 min. (open side: left hand side)

With this tube shape, which has a cross-section close to a perfect rectangle, the interface along the tube sides is so close to the corner that it is not possible to get precise values of the radius of curvature in a plane perpendicular to the main plane. However the physical processes at work are similar to these mentioned in Keita et al. 2016 a): the Laplace pressure is at any time constant along all the interface, which means that the evolution of the interface shape is governed by capillary effects.

We can estimate the liquid volume loss from the apparent interface evolution, thus neglecting the curvature in the plane perpendicular to the main plane. This is done by computing for each picture the volume left free behind the apparent interface in the main plane. Then we represent the saturation, which we here define as the ratio of liquid volume still present in the tube to the initial volume, as a function of time. It appears that the saturation decreases linearly in time (see Figure 3) over our typical range of observation, i.e. a front penetration of about 25 mm.

Such a result is explained by the same arguments as in Keita et al. (2016 a): the air-liquid interface is pinned at the tube entrance, which imposes the existence of liquid films from the main front (inside the tube) to the tube entrance; the presence of these liquid-air interfaces in a confined system maintains a vapor density close to 1 in the air, which damps the evaporation; as a consequence, evaporation mainly occurs from the liquid-air interface around the tube entrance; since its shape remains apparently constant in this region, the evaporation remains constant; as a corollary the water transport inside the tube essentially takes place in the form of liquid moving in the thin films along the wall, which drains liquid from the large volume behind the main front, which can thus progress inwards.



**Figure 3:** Saturation as a function of time for the tests shown in Figures 2a and 2b, i.e. distilled water with hydrophilic surface (squares) and hydrophobic surface (circles). The triangles show data for gypsum saturated water with hydrophilic surface. The diamonds show data for gypsum saturated water plus PEG with hydrophilic surface. The triangles

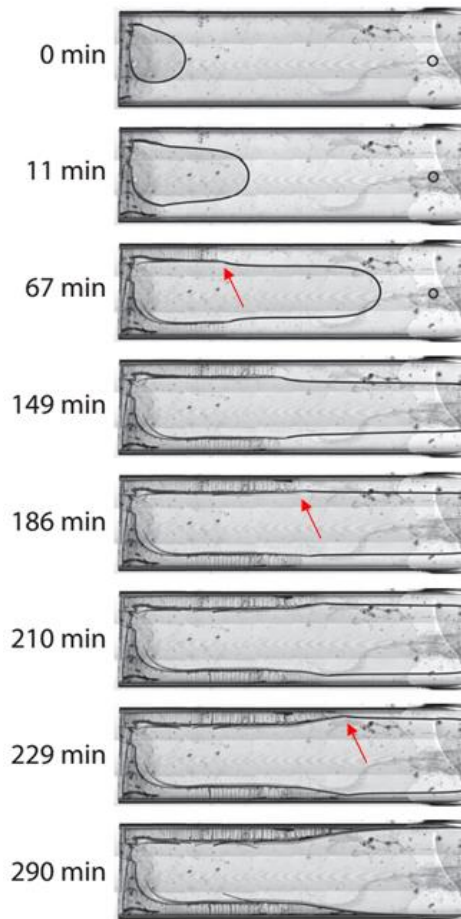
show data for gypsum saturated water + citric acid. Cross-squares saturated gypsum water with hydrophobic surface. The dotted line is a guide for the eyes.

With hydrophobic surface the evolution of the liquid-air interface during drying is completely different. We have a first stage during which this interface strongly deforms while remaining pinned at least on one side close to the entrance (see Fig.2b i) and ii)). Then, in a second stage, the interface is no longer pinned, and now progresses inwards while keeping a roughly constant shape (see Fig.2b iv) and v)). There may also exist a transient regime for which only one side is unpinned (see Fig.2b iii)). Note that there is no liquid films ahead of the points of contact of the main interface and the channel sides. This is consistent with the shape of the interface reaching the wall: the apparent slope discontinuity in the main plane suggests that it reflects the separation between a wet and a liquid region, which should exhibit a large contact angle due to the hydrophobic nature of the solid surface.

Thanks to the randomness feature of the crystallization phenomenon itself, it is important to keep in mind that the results are reproducible from a qualitative point of view, i.e. the two regimes and the corresponding trends are obtained in each case, but the exact shape of the interface and the time for unpinning vary from one test to another. In this context we can only discuss global tendencies in such data. We observe a decrease of the drying rate when the saturation decreases (see Fig.3), due to the fact that the interface unpins from one or two sides, so that there is no more liquid film allowing a fast transport towards the channel exit. Instead, drying now relies on evaporation at some distance from the exit and vapor has to diffuse along this distance.

#### *Impact of the presence of elements in suspension in the liquid*

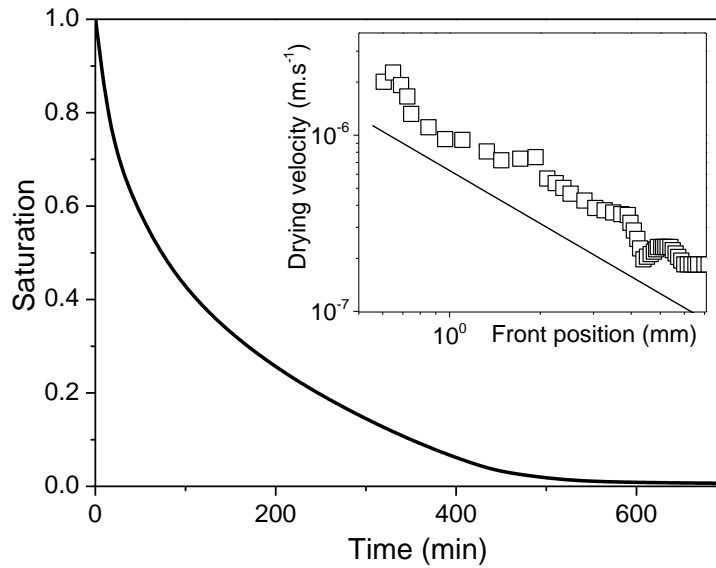
In this preliminary study of the flow characteristics during drying of a channel filled with a liquid, and before considering the case of a saline solution which is the main scope of this work, it seems useful to have a look at the impact of the presence of some “coarse” elements in suspension in the liquid. Here we consider the case of stabilized hydrophilic colloidal silica nanoparticles (Ludox HS-40 diameter: 20 nm, density  $\sim 2.45$ ) suspended in water (pH = 9.8 to maintain the particle electrostatic repulsion), so that particle segregation or sedimentation are negligible. The experiment is carried out in the channel type used in Keita et al. (2016 a), which gives liquid films of larger thickness along the channel sides, when the main interface progresses inwards. Here, with a suspension, we also see initially a wide interface forming around the channel entrance and growing inward (see Fig.4, 0 and 11 min), as for a pure liquid (see Keita et al. 2016 a) for the same channel shape or Fig.2a for our standard channel shape). However we also observe that the liquid films along the channel side soon transform in regions of particle accumulation which roughly appear as “crystallized” areas with fractures (see Fig.4, 67, 149, 186 min). These fractures indicate the presence of a compacted zone, similar to previous observation in a channel (Dufresne et al. 2003) or in porous media (Keita et al. 2014, Keita et al. 2016 b). These areas grow in time as the main interface progresses farther. Finally, when the main interface reaches the channel extremity, the drying process is now taking place via evaporation of the side films whose thickness decreases. Also, the “crystallized” area goes on growing but its thickness progressively decreases (see Fig.4, 210, 229, 290 min).



**Figure 4:** Successive views (at different times) of the drying of a Ludox suspension (10%) in a capillary (open side: left hand). The growing curved line corresponds to the liquid air-interface position (see text). The region of particle deposit is the darker grey region along the (upper and lower) walls. The region extends over an increasing distance inside the channel, which corresponds to the front position shown by red arrows in some pictures.

These original drying characteristics have a rather simple qualitative explanation. Considering the Peclet number value, the suspended particles, although colloidal, do not have time to diffuse significantly through the liquid, they are essentially transported with it. Since we have seen that most of the evaporation takes place around the extremity of the side films where the liquid is transported from the interior of the channel, the suspended particles follow this motion and stop at the liquid-air interface at this film extremity. The accumulated particles then can tend to dry or remain somewhat wet if evaporation from this medium (particles+water) is too slow, but anyway we can now hardly expect a significant liquid motion through the porous medium formed by this particle packing whose permeability is extremely small (it scales with the square of the particle radius). Assuming such flow is negligible we deduce that evaporation will now take place essentially around the front of the crystallized area progressing inwards. This explains the continuous decrease of the drying rate in time (see Fig.5), as drying relies on the evaporation then vapor diffusion across this forming (through ion crystallisation) zone. Finally, when the main interface has reached the channel end and the side film thickness decreases, the amount of particles, associated with an elementary liquid evaporation and further advance of the crystallized region, decreases, which explains that the deposit thickness decreases. Actually this scheme corresponds to that assumed to occur for the drying of the same type

of suspension in a porous medium, which was finally illustrated by a schematic description for a single channel representing the porous medium (see Keita et al. 2014).



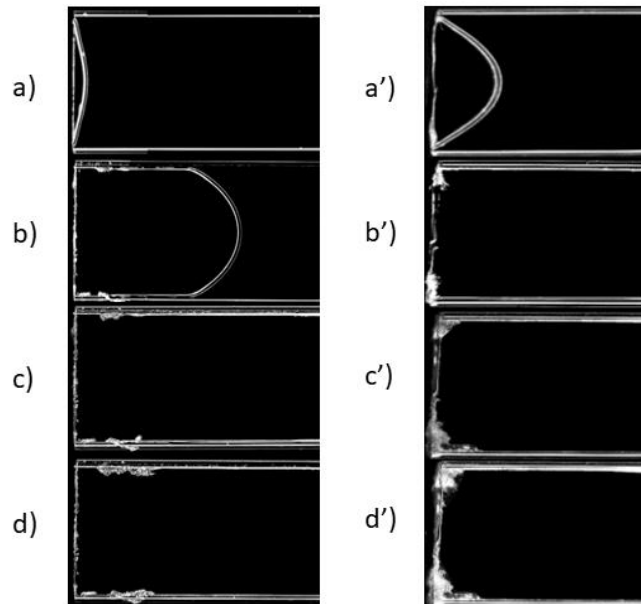
**Figure 5:** Saturation vs time for the drying of a channel filled with a Ludox suspension (same test as in Figure 4). The inset shows the drying rate ( $V$ ) as a function of the front position. The continuous line is the theoretical drying rate assuming evaporation via vapor diffusion in the channel from a vapor saturated region at the front position (see text).

Let us assume that a dry region develops inside the sample from its exit. In that case we can assume that the liquid evaporates exactly from the limit of the wet region, where  $n = 1$ , and the vapor diffuses to the free surface over a distance  $h$ , i.e. the thickness of the dry region, before reaching the external boundary layer. Note that the saturated front occupies the whole cross-section, so that diffusion is essentially 1D (along the main channel direction). We assume that the relative humidity at the channel exit sample free surface is  $n_0$ . Under such conditions, from the second Fick's law, we get the water mass evaporating by unit time:  $dm_w/dt = -\rho_0 S D_0 \nabla n = -\rho_0 S D_0 (1 - n_0)/h$ , with  $S$  the sample cross-section,  $D_0 = 2.7 \times 10^{-5} \text{ m}^2 \cdot \text{s}^{-1}$  the coefficient of diffusion of vapor in the air, and  $\rho_0 = 23.4 \text{ g} \cdot \text{m}^{-3}$  the maximum vapor density in air. The drying rate, defined as  $V = -(1/S\rho) dm_e/dt$ , in which  $\rho$  is the liquid density, thus expresses as  $V = (1 - n_0) \rho_0 D_0 / \rho h$ . We ignore the exact value of  $n_0$  in our test, but its minimum value is 0, so that the maximum drying rate under these assumptions can be computed by taking  $1 - n_0 = 1$ . The corresponding drying rate values, considering that  $h$  is given by the front position determined from the pictures (see Fig.4), appear to be smaller than the observed values on average by a factor about 2, which means that a more realistic value for  $n_0$  would lead to an even larger discrepancy between the model and the data. Thus the assumption of vapor diffusion mainly starting from the front position is apparently wrong. Some significant evaporation would rather take place from other points along the particle deposit, which would accelerate drying with regards to the above model prediction. As a corollary, some liquid flow should be maintained through the particle deposit region, which would thus not be perfectly dry.

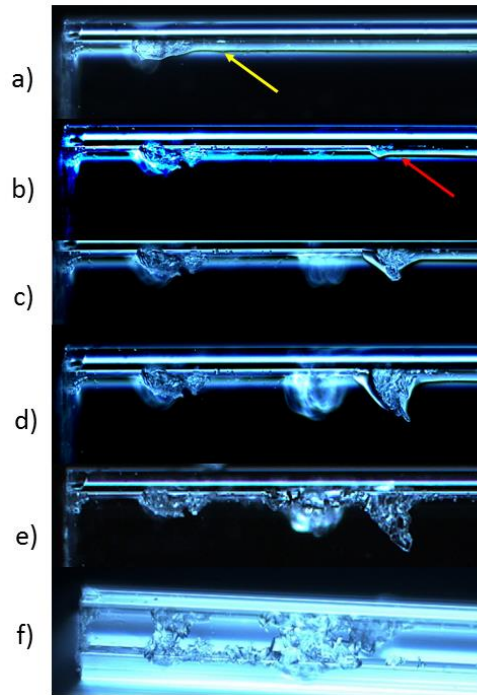


### *Drying of an ionic solution*

When drying an ionic solution in a hydrophilic capillary we at first sight get the same behavior as without ions in solution: the interface starts to deform and when it has reached some specific shape it progresses inwards, leaving a liquid film behind it along the channel sides (see Fig.6i). However we can also see that deposits of crystals are left behind the main interface along the sides (see Fig.6i b). These deposits grow in time, in thickness and along the channel axis inwards (see Fig.6i b,c,d). This result is somewhat unexpected: if the liquid film was still pinned at the channel entrance as for the drying of pure water (see Figure 2) we would expect a progressive accumulation of crystals at more or less the same place close to the entrance. Here it appears that some crystal deposit may be formed along the channel side at some time (see Fig.7a), and then stops growing (see the main crystal on the left in Fig.7b and next ones). At the same time a new crystal deposit is formed farther inward and significantly grows (see main deposit on the right in Figure 7). This phenomenon appears to be associated with a kind of dewetting of the wall between the two deposits: in Figure 7 we can see that the main liquid film (in the foreground) beyond the first deposit along the channel side (shown by the yellow arrow in Figure 7a), disappears between the first and second picture, while simultaneously the next deposit appears, so that afterwards one may see a liquid film (shown by a red arrow in Figure 7b) in the forefront only beyond this new farthest deposit. The newly formed deposit will then grow as long as the liquid film remains pinned to it (see Figure 7c,d,e). Actually a side view (see Fig.7f) also shows that there is no discontinuity of the crystal deposit along the wall, which means that the film likely dewetted the wall progressively. Therefore, there is a dewetting effect linked to the crystallization process.



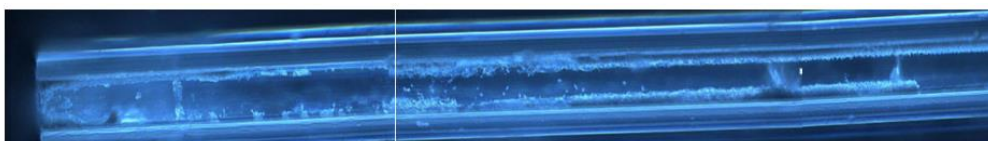
**Figure 6:** (i) Successive views of a Calcium sulfate solution drying in a hydrophilic capillary at times : a) 0, b) 27 min., c) 57 min., d) 153 min. (ii) Successive views of a Calcium sulfate solution with tween 20 drying in a hydrophilic capillary at times : a) 2 min., b) 17 min., c) 56 min., d) 94 min. Note that after its initial visible evolution on the first pictures, the main liquid-air interface further progresses on the right and is not visible on the next pictures.



**Figure 7 :** Successive views of the drying of the drying of a Calcium sulfate solution in a hydrophobic capillary: zoom on one of the wall. The arrow meaning is explained in the text.

According to these observations we deduce that in this situation the formation of crystal deposit tends to induce some depinning of the line of contact, which then progressively move inwards with the crystal deposit. A similar effect was inferred from observations (with MRI) of drying characteristics of plasters (Seck et al. 2016). This effect induces a decrease of the drying rate, since the line of contact, around which most evaporation occurs, moves away from the channel entrance, so that vapor has to diffuse through a growing distance.

For the drying of an ionic solution in a channel with hydrophobic surface the same phenomena as for pure water (see Fig.2b) is observed: a main interface without liquid film along the wall sides and with a somewhat chaotic evolution, but on average essentially a drying associated with a dewetting of the channel from its entrance inwards. This has a particular consequence for the formation of crystals: as there is no particular path of liquid transport in the channel, there is no particular region of accumulation and instead the deposits are approximately uniformly distributed along the different walls (see Fig.8). This reflects a rather regular withdrawing of the main interface in time, so that the drying rate continuously decreases (see Fig.3) as the front of evaporation withdraws in the capillary.



**Figure 8:** Side view of the hydrophobic capillary after drying of a Calcium sulfate solution.

Adding citric acid in a gypsum solution generally induces a delayed crystallization as it is one of the most efficient settling retarder used for gypsum (Singh and Middendorf 2007), which affects crystal morphology. Using this type of additive we get a rate of drying rather close to that for a simple saturated gypsum solution (see Fig.3). The aspect of crystals is nevertheless effectively different but they are still formed all along the wall of the channel (see Fig.9), indicating a priori a progressive withdrawal of the wetted region. This is the marker of a limited liquid transport in the region of crystal deposits, but it is not possible to conclude that there are not still some slight residual flow and evaporation in this region.



**Figure 9:** Side view of the hydrophilic capillary after drying of a Calcium sulfate solution plus citric acid.

Finally, we can test the impact of wetting properties of the solution by adding surfactant in a gypsum saturated solution. Here we see that we now significantly accelerate the drying process (see Fig.3), which now occurs at a rate not too far from that observed for a pure water solution. Note that the impact of surfactants on the evaporation rate of NaCl solutions was observed to be negligible (Qasi et al. 2017), so that assuming this is the same for the Calcium sulfates solutions this implies that the drying rate essentially depends on the liquid distribution in the capillary. Moreover, the surfactants may, in some cases, be incorporated in the crystals (Qasi et al. 2017), but we will not particularly study this aspect. Looking at the evolution of the crystal distribution in time we find that, in contrast with observations for the gypsum saturated solutions (see Figs.6-9), crystals develop essentially and accumulate just at the channel entrance (see Fig.6ii). This means that, all along the process, the liquid now wets the channel up to a distance close to the entrance, and thus can continuously bring ions in this region. Thus we have a continuous liquid film along the wall, which allows a liquid transport towards the channel entrance where it evaporates. This explains that the drying rate remains close to that observed for pure water in a hydrophilic channel (see Fig.3).

## Conclusion

In the objective of understanding the impact of crystallization on the drying rate of porous media filled with low solubility ionic solutions, we carried out tests with an extremely simple structure, namely a thin straight channel, in which capillary effects are dominant throughout the process of liquid extraction. From a general point of view, it appears that the impact on the drying rate will essentially depend on the position of the line of contact induced by such effects, resulting in a decrease of the drying rate if the line of contact is progressively displaced inwards. Even in such a simple geometry we observe a great sensitivity of the drying rate to the elements initially suspended in the liquid and which can deposit along the wall. This is due to the fact that the drying rate results from the gradient of vapor density in the channel, which depends on the liquid distribution along the channel wall, which in turn is very sensitive to the formation of deposits or to dewetting processes possibly associated to the

crystallization. This implies that small changes in the formulation of the solution or the wetting characteristics of the porous medium may strongly affect the drying rate.

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