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Salt Weathering on Buildings and Stone Sculptures

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Fine tuning of desalination poultices: try-outs in practice

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ABSTRACT

Desalination by poulticing of sculptures and building elements is a technique increasingly used in the field of (architectural) heritage conservation. However, desalination is still largely performed on a trial and error basis, without scientific knowledge of the transport mechanisms governing the process of salt extraction. In the framework of the EU project DESALINATION, a modular system of poultices has been developed, which is related to the pore size distribution of different types of substrates. Desalination according to this approach was applied on salt loaded elements of two historical buildings: the brick masonry masterpieces in the Waag building (city balance) in Amsterdam and the stone sculptures of the porticus of the Rubens' house in Antwerp. Preliminary poultice applications on test areas were carried out. The efficiency of the salt extraction was evaluated by measuring the salt content and distribution before and after desalination. In both case studies, promising results were obtained.

Keywords: salt, desalination, poultices, modular system, pore size

1 INTRODUCTION

Salt damage is a widespread phenomenon and a threat to the conservation of architectural heritage. For salt damage to occur, the presence of moisture is a necessary condition. Consequently, the prevention of moisture ingress can stop the development of salt damage. However, the removal of the moisture source in not always an easy task. An alternative and sometimes a supportive measure, is the reduction of the salt content in the material. Desalination can be an effective technique to reduce salt damage, especially in those cases where the damage is governed by dissolution/crystallization cycles of the salts in response to RH changes and no ingress of liquid water is involved.

Desalination by poulticing of sculptures and building elements is a technique increasingly used in the field of architectural heritage conservation (a.o. Verges-Belmin & Siedel 2005). However, it is still largely performed on a trial and error basis, without scientific knowledge of the mechanisms governing the process of salt extraction. The results of such interventions are often unpredictable and not always satisfactory.

The EC project DESALINATION (Contract no. 022714) aimed at improving the knowledge in this field by understanding the principles governing the process of salt extraction and by defining the criteria for a more conscious choice of a suitable desalination poultice. Two principles govern salt transport: diffusion (salt ions move due to differences in concentration) and advection (salt ions move together with water due to capillary forces). Diffusion, which is the principle at the base of desalination by water bath and by wet poulticing, can be very effective, but is a very slow process which requires that the object to be desalinated is kept wet for a long period. This is not always possible in the case of immovable objects. Differently from diffusion, advection is a relatively fast process: desalination by the application of a poultice which is allowed to dry by evaporation makes use of advection. Being advection governed by capillary forces, the effectiveness of desalination by poulticing will strongly depend on the pore size distribution of the substrate / poultice combination. A considerable improvement of the extraction efficiency will be obtained by fine tuning the pore size of the poultice to that of the substrate: a suitable extraction poultice should have pores which are smaller than those of the substrate but at the same time not too small, because the speed of water transport decreases significantly with pore size (Pel et al. 2010, Sawdy et al. 2010). A high total porosity is favourable too, as it enhances the extraction process and increases the salt storage capacity of the poultice. On the basis of these principles, a modular system of poultices has been developed (figure 1 and table 1). The modular system comprises 4 different classes of poultices, related to the pore size distribution of the substrate. Three of the poultice classes are intended for desalination according to the advection principle, and one of the classes is intended for diffusion based desalination. While this last poultice class can be used for all substrate pore size classes, it is however most appropriate for the smallest pore sizes (< 0.1 µm), which can not be desalinated using advective poultices. Poultices having pores of different pore sizes can be obtained by varying the components type and properties (clay type, sand grain size distribution, and cellulose fiber length) and the ratios between them, (Lubelli & van Hees 2010).

A desalination intervention according to this approach was carried out on salt loaded elements of two historical buildings: the brick masonry masterpieces in the Waag building (city balance) in Amsterdam and the stone sculptures of the Portico of the Rubens' house in Antwerp. At first the pore size distribution of the substrate was determined, on the basis of which a desalination poultice was selected and applied on test areas in situ. The evaluation of the effectiveness of the desalination is based on measurement of the Hygroscopic Moisture Content (HMC) and the salt content in the object before and after salt extraction.

Table 1. Modular system of poultices : Each poultice category is suitable to desalinate substrates having certain categories of pore sizes. A = most appropriate poultice for salt extraction; P = possible suitable poultice for salt extraction

Poultice		Pore size of substrate (µm)			
		< 0.1	0.1-1	1-10	10-100
Advection	1		A	P	P
	2			A	P
	3				A
Diffusion	4	A	P	P	P

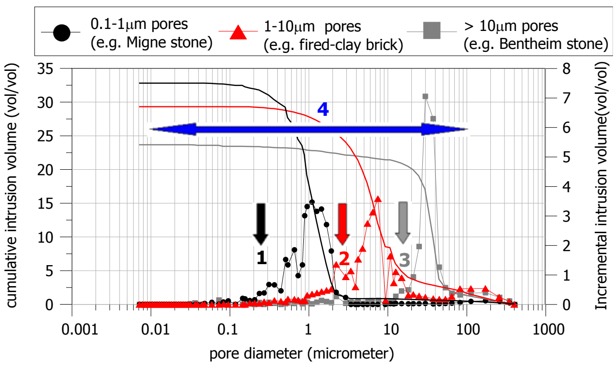


Figure 1. Modular system of poultices: the arrows indicate the pore size the most appropriate poultice (indicated as A in Table 1) should have for each class of pore size of the substrate

2 SHORT DESCRIPTION OF THE TEST OBJECTS

2.1 The masterpieces in the Waag building

The tower of the masons in the Waag building in Amsterdam (1481-1492) hosts valuable brick masonry masterpieces (17th century): these masonry panels, with very thin joints and curved shapes, are suffering from severe salt crystallization damage (figure 2). The damage is due to dissolution/crystallization cycles, induced by air RH changes, of the hygroscopic salts (mainly sodium chloride) present in the masonry (Lubelli & van Hees 2007). Taking into account the specific circumstances, (difficulties in controlling the climate and absence of moisture sources other than the air RH) desalination of the masonry masterpieces was considered to be a sound option to limit further salt damage. This paper presents the results of an on-site desalination test for which one of the masterpieces located on the first floor of the tower served as a test panel (figure 3).

Figure 2. (left) Salt crystallization damage on one of the masonry masterpieces
Figure 3. (right) Selected test area (internal wall of the tower at the 1st floor)

2.2 The Portico of the Rubens' house

The Portico of the Rubens' house in Antwerp (figure 4), designed by the Flemish painter himself, dates back to the first decades of the 17th century. The arch is decorated by several stone sculptures and architectural elements made of different types of natural stone (petit granit, Avender limestone, Lede sandy limestone and Oberkirchen sandstone). Some of the Lede and Oberkirchen sculptures are showing damage in the form of scaling and sanding of the surface (figure 5). A rather important salt content was measured in the stone, consisting of chlorides and nitrates, apart from gypsum. An investigation on the possibility of desalinating these objects by poulticing was considered necessary. In order to evaluate benefits and risks of a desalination intervention, test applications were carried out on selected areas (see figure 4).

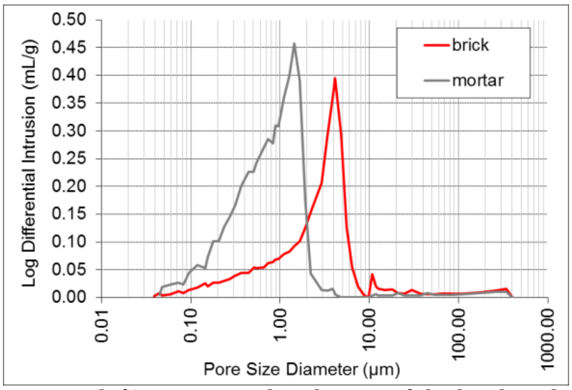
Figure 4. (left) Portico of the Rubens' house in Antwerp; the location of the test areas are reported (location 1: Oberkirchen stone; locations 2-4: Lede stone)
Figure 5.Exfoliation of a relief in Oberkirchen sandstone

3 MATERIALS AND METHODS

The following methodology was applied for the desalination of both objects:
1. Measurement of the pore size distribution of the substrate(s)
2. Selection of a suitable poultice on the basis of the pore size distribution of the substrate/poultice combination
3. Application in-situ on test areas (two applications)
4. Evaluation of the extraction efficiency by measurement of the HMC and soluble ion content in the substrate before and after desalination

3.1 Pore size distribution of the substrate

The pore size distribution of the substrates was measured by Mercury Intrusion Porosimetry (MIP). In the case of the brick masonry masterpieces in the Waag building, both the pore size of the brick and of the mortar were measured.The brick has mainly pores in the range of 2-5 µm; the mortar, constituted by lime binder only, has pores between 0.2 and 2 µm (figure 6). Being the joints very thin, the poultice was selected on the basis of the pore size of the brick only. In the case of the Portico of the Rubenshuis the pore size distribution of the two stone types (Lede sandy limestone and Oberkirchen sandstone) was measured (figure 7). Both stone types have a unimodal pore size distribution with most pores between 3 and 10 µm.



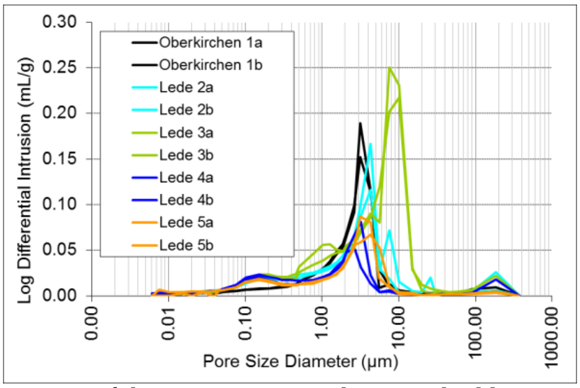


Figure 6. (left). Pore size distribution of the brick and the mortar of the masterpieces in the Waag building
Figure 7. (right) Pore size distribution of the Lede and Oberkirchen stone sculptures of the Portico of the Rubens' house

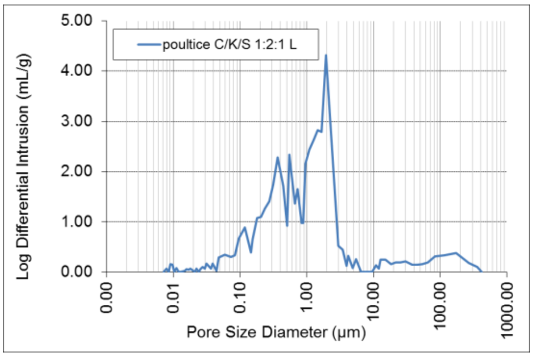


Figure 8. Pore size distribution of the selected salt extraction poultice

3.2 Design of the poultice

On the basis of the pore size of the substrate, a salt extraction poultice was selected, having a high total porosity consisting mainly of pores smaller than those of the substrate (advection poultice type 2, according to table 1). The same poultice was used in both cases, the main pore sizes of the brick of the Waag being quite similar to those of the natural stones of the Portico. The selected poultice is made of cellulose fibers, clay (kaolin) and sand (grain size 0.5-1 mm) in proportion 1:2:1 by weight. The pores of the poultice have mainly a size between 0.1 and 2 µm and the total open porosity is about 50% by volume (figure 8). As known, kaolin may leave a white residue, which might be a problem in the case of dark coloured and/or particularly sensitive surfaces. In the case of the masonry of the Waag, the residue was removed by brushing and by the surface and by the use of latex.

3.3 Application of the poultice

Salts can be transported only in solution; this implies that the substrate should be wetted prior to salt extraction. The selected poultice has pores of smaller size than those of the substrate : this means that extraction of salt solution is enhanced, while transport of water from the poultice to the substrate is limited. The substrate needs therefore to be pre-wetted prior to the application of the poultice. The amount of water to be introduced in the substrate constitutes a tricky point in the desalination process. Too much water implies the risk that salts get transported deeper in the substrate, while a too little water amount might be not enough to dissolve the salts. On the basis of capillary absorption tests performed in laboratory, a water amount of 2 l/m^2 was chosen. This amount of water is enough to wet these substrates up to at least 3 cm depth. In the case of the natural stones, the absorption was much slower than in the brick. Therefore, sufficient pre-wetting had to be obtained by spraying the water at intervals of about 15 minutes until about 2 liter water / m^2 was absorbed. After pre-wetting the substrate the poultice was applied. Care was taken to ensure a good contact between the poultice and the substrate. After 4-5 days the poultice was replaced with a new one.

3.4 Evaluation of the efficiency of salt extraction

The efficiency of salt extraction (E) can be defined as the amount of salt which is extracted from the substrate related to the initial amount.and is calculated according to:

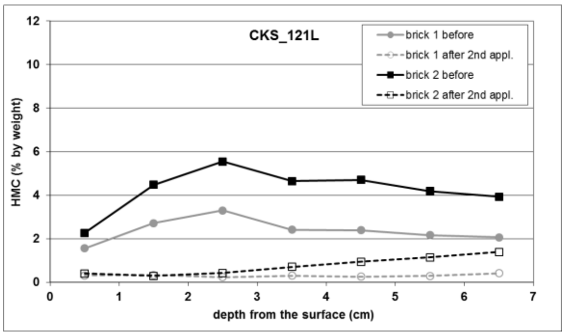
$$E_{(0\text{-}x\,cm)} = 100 * \frac{(\text{salt before}_{0\text{-}X\,cm} - \text{salt after}_{0\text{-}X\,cm})}{\text{salt before}_{0\text{-}X\,cm}} \qquad (1)$$

The efficiency can be determined at each depth (e.g. $E_{0\text{-}1cm}$ is the efficiency at the depth 0-1 cm from the surface) or averaged over a certain depth. In the first case more information about salt migration can be obtained. The efficiency of salt extraction was evaluated on samples collected by means of powder drilling (5 mm diameter)in the substrate before and after 2 applications of the poultices. Samples were collected of each test area, at different depths (0-1 cm, 1-2 cm etc. up to 7 cm in the case of the brick of the Waag and 5 cm in the case of the sculptured stones of the porticus of the Rubens' house). The powder samples were dried at 40 °C and then stored at 20 °C and 96% RH for 4 weeks; after this period their moisture uptake (Hygroscopic Moisture Content, HMC) was gravimetrically measured. The HMC gives a reliable indication of the presence of hygroscopic salts. The principles and a detailed description of this method are reported elsewhere (De Witte et al. 1998, Lubelli 2006). In the case of the porticus of the Rubens' house, ion chromatography analyses were performed too and the amount and type of ions present before and after desalination were determined.

4 RESULTS

4.1 Brick masonry masterpieces in the Waag building in Amsterdam

The HMC distribution before and after two applications of the poultice is reported in figure 9. The efficiency of salt extraction at different depths, calculated on the basis of the HMC values, is reported in figure 10. This can be considered a very good desalination efficiency (more than 80% reduction of the HMC) at all depths. No salt accumulation in depth has been measured (the thickness of the masonry of the masterpieces is 7 cm and a gap exists between the masterpieces and the masonry behind).



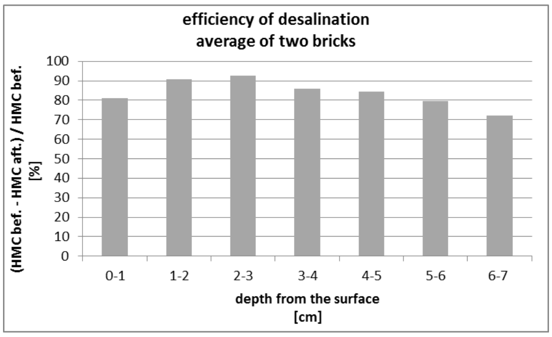


Figure 9. (left) HMC distribution before (continuous line) and after two applications of the poultice (dashed line) measured on two bricks on the test area

Figure 10. (right) Effectiveness of desalination at different depths, obtained in the test area of the brick masonry masterpieces in the Waag building

4.2 Stone sculptures of the Portico of the Rubens' house

Figures 11-14 illustrate the ion content and HMC before and after desalination in the test areas. At locations 1, 3 and 4 the salt load, consisting mainly of nitrates and chlorides, is importantly reduced after desalination. The HMC decreases considerably as well, the most soluble salts being the most hygroscopic as well. Due to its low solubility, the gypsum content remains almost unvaried after desalination. At location 2 some migration of the salts in depth is observed.

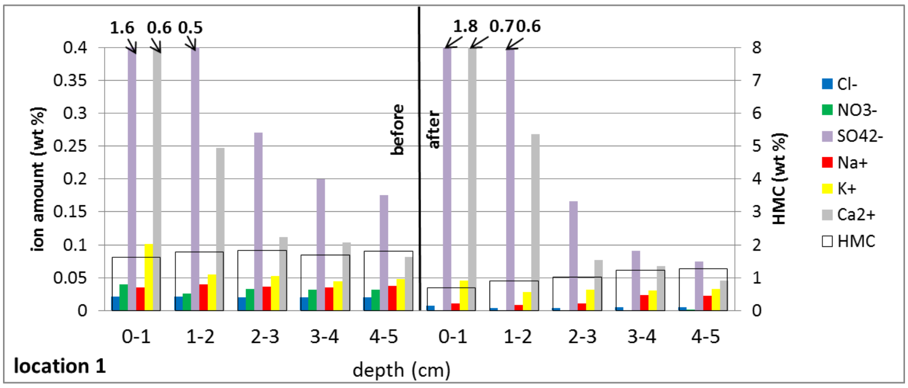


Figure 11. Ion content (coloured bars) and hygroscopic moisture (open bars) content before and after desalination at location 1 (Oberkirchen stone). The Ca^{2+} and SO_4^{2-} content remains unvaried whereas the amount of Cl^- and NO_3^- decreases.

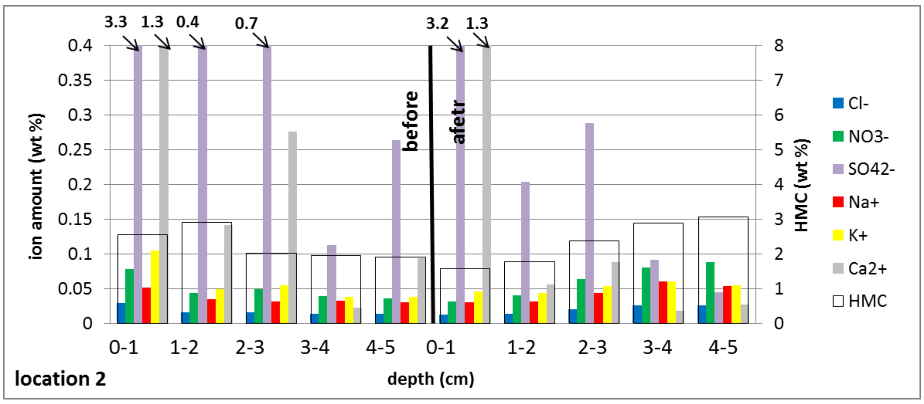


Figure 12. Ion content (coloured bars) and hygroscopic moisture (open bars) content before and after desalination at location 2 (Lede stone). The Ca^{2+} and SO_4^{2-} content remains unvaried whereas the amount of Cl^- and NO_3^- decreases at the surface and increases in depth.

The efficiency can be calculated on the basis of different parameters (the (total) ion content or the HMC) and its value will depend on this choice. As the hygroscopic salt are the most harmful ones, an evaluation of the efficiency based on the HMC values will give a reliable indication of the decreased risk of salt damage after desalination. In figure 15 the efficiency, calculated on the basis of the HMC values, is reported. At location 1, 3 and 4 a good desalination efficiency has been obtained at all depths. The efficiency is higher in the first cm's near the surface and decreases with depth. At location 2 the negative values observed at 2-5 cm are due to migration of the salts in depth. Possible explanations can be too strong pre-wetting, or a too early loss of adhesion of the poultice.

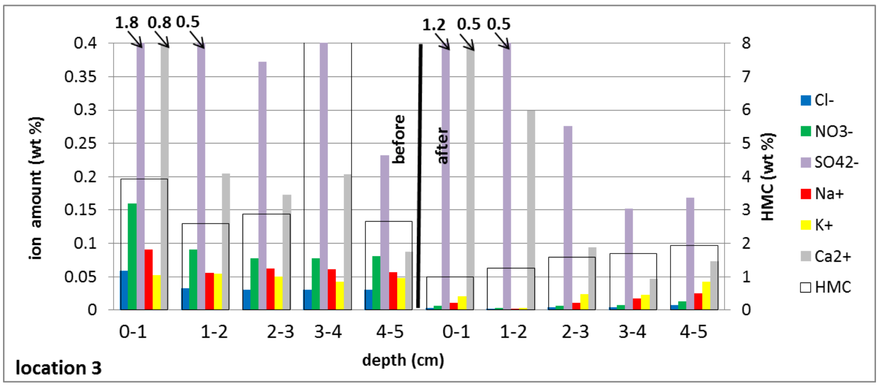


Figure 13. Ion content (coloured bars) and hygroscopic moisture (open bars) content before and after desalination at location 3 (Lede stone). The Ca^{2+} and SO_4^{2-} content remains unvaried whereas the amount of Cl^- and NO_3^- decreases.

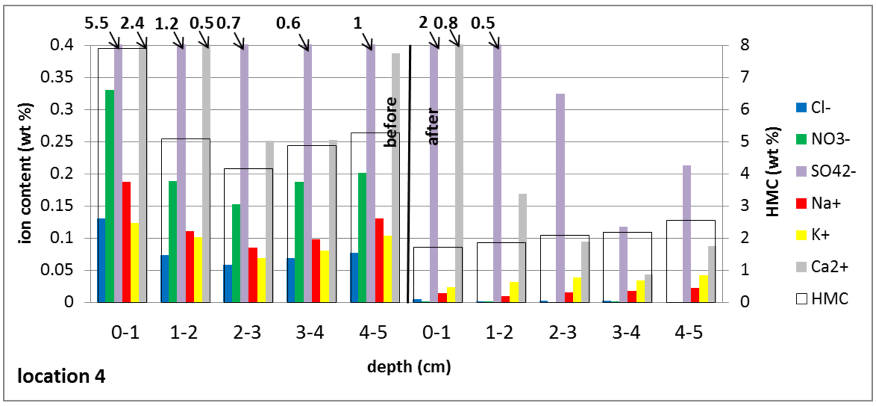


Figure 14. Ion content (coloured bars) and hygroscopic moisture (open bars) content before and after desalination at location 4 (Lede stone). The Ca^{2+} and SO_4^{2-} content remains unvaried whereas the amount of Cl^- and NO_3^- decreases.

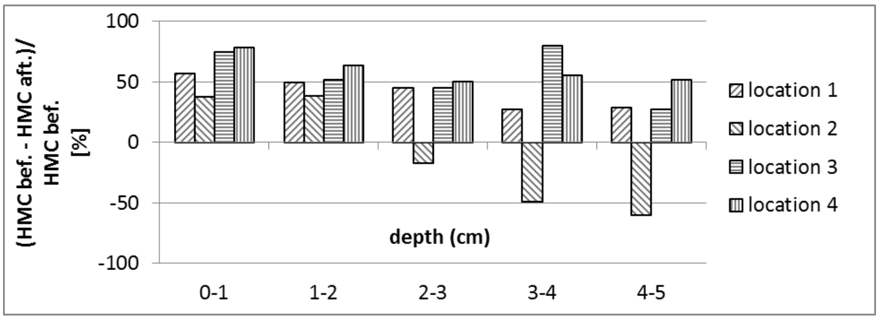


Figure 15. Efficiency of desalination at different depths, obtained in the test areas of the Portico of the Rubens' house on the basis of HMC measurements. Only in one case, location 2, no clear extraction was obtained.

5 DISCUSSION AND CONCLUSIONS

The results obtained for both test objects are satisfactory and show that an effective salt extraction can be achieved by just a few poultice applications, provided that a suitable poultice is chosen on the basis of the pore size distribution of the substrate. Besides, the control of other parameters, like the amount of water provided by pre-wetting, the adhesion of the poultice to the substrate and the period during which the poultice is left on the object, is necessary to achieve an effective salt extraction. Not only the amount of extracted salt was substantial, but the depth reached by desalination was considerable as well: a decrease of the salt content was measured up to 7 cm depth in the brick of the Waag building. As expected, depending on the solubility of the salts, selective extraction was achieved: chlorides and nitrates were in most cases almost completely extracted whereas the amount of gypsum remained nearly unchanged. Selective extraction may have consequences for the range of RH in which the new salt mixture, left in the wall after desalination, is activated by air RH, since this may differ from that prior to desalination (Sawdy & Heritage, in press). However, the more soluble salts generally being the most harmful, the risk of salt damage after the proposed treatment will be considerably reduced.

HMC measurements of powder, sampled from the substrate before and after desalination, may be easily used in practice as control of the efficiency of the desalination intervention.

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