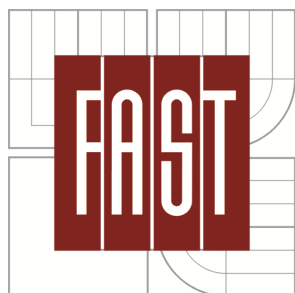


BRNO UNIVERSITY OF TECHNOLOGY

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ



FACULTY OF CIVIL ENGINEERING

INSTITUTE OF BUILDING STRUCTURES

FAKULTA STAVEBNÍ

ÚSTAV POZEMNÍHO STAVITELSTVÍ

EXPERIMENTAL DRYING AND DESALINATION OF BRICKS, SANDSTONES AND MASONRY UNDER AN APPLIED ELECTRIC FIELD

EXPERIMENTÁLNÍ ODVLHČOVÁNÍ A ODSOLOVÁNÍ CIHEL, PÍSKOVců A ZDIVA VLIVEM
ELEKTRICKÉHO POLE

SHORT VERSION OF DISSERTATION THESIS

Zkrácená verze disertační práce

AUTHOR

AUTOR

ING. ONDŘEJ MATYŠČÁK

SUPERVISOR

VEDOUCÍ PRÁCE

PROF. ING. MILOSLAV NOVOTNÝ, CSC.

BRNO 2014

1	MOISTURE IN THE BUILDING MATTERS.....	6
1.1	General knowledge about the hygric properties of the building matters.....	6
2	SALTS	7
2.1	The damaging concentration related to the salt anions.....	7
3	ELECTROKINETICS.....	7
3.1	Electromigration	8
3.2	Electro-osmosis.....	9
4	SPECIFICATION AND THE GOALS OF THE DISSERTATION	9
4.1	The specification of the issue.....	10
4.2	The goals of the dissertation.....	10
4.2.1	The optimization of the closed laboratory setup for the dewatering of the tap water saturated bricks due to electro-osmosis using the different types of clay poultices	10
4.2.2	Desalination of the sandstones under the laboratory conditions using one type of clay poultice.....	11
4.2.3	The optimization of the closed laboratory setup for the desalination of the bricks saturated with sodium chloride solution using the different types of clay poultices	11
4.2.4	Desalination of a brickwork in the pilot test.....	11
4.2.5	To desalinate the sandstone wall in the pilot scale test on the basis of laboratory results	12
5	THE METHODS USED IN THE DISSERTATION.....	12
5.1	Theoretical methods.....	12
5.1.1	The study of literature and the consultation with experts....	12
5.2	Experimental methods.....	12
5.2.1	Laboratory methods	12
5.2.2	Methods used in the pilot test	12

5.3	The comparative method.....	13
6	EXPERIMENTAL DRYING AND DESALINATION UNDER AN APPLIED ELECTRIC FIELD	13
6.1	EXPERIMENT 1 – To find out the combination of the clay poultices which is the most efficient for the dewatering of the tap water saturated bricks due to electro-osmosis under an applied electric field	13
6.1.1	Introduction.....	13
6.1.2	The goals of the experiment 1	13
6.1.3	The results and the conclusion.....	14
6.2	EXPERIMENT 2 – Desalination of sandstones using clay poultices with an applied electric field	15
6.2.1	Introduction.....	15
6.2.2	The goals of the experiment 2	15
6.2.3	The results and the conclusion.....	16
6.3	The additional experiment to experiment 2.....	17
6.3.1	The main goals of the additional experiment	17
6.3.2	The results and the conclusion.....	18
6.4	EXPERIMENT 3 – Desalination of the bricks contaminated with the sodium chloride under an applied electric field.....	19
6.4.1	Introduction.....	19
6.4.2	The goals of the experiment 3	19
6.4.3	The results and the conclusion.....	19
6.5	EXPERIMENT 4 – Desalination of a masonry in the pilot test under an applied electric field.....	20
6.5.1	Introduction.....	20
6.5.2	The goals of the experiment 4	20
6.5.3	The results and the conclusion.....	21
7	CONCLUSION AND FINDINGS OF SCIENTIFIC KNOWLEDGE	21

7.1	The optimization of the closed laboratory setup for the dewatering of the tap water saturated bricks due to electro-osmosis using the different types of the clay poultices.....	21
7.2	Desalination of the sandstones under the laboratory conditions using one type of clay poultice.....	22
7.3	The optimization of the closed laboratory setup for the desalination of the bricks contaminated with sodium chloride using the different types of clay poultices.....	22
7.4	The use of the electrokinetics for the desalination of constructions such as brickwork and sandstone walls	23
7.4.1	The choice of the suitable type of the clay poultice	23
7.4.2	The recommended setup for the desalination of the brickwork with the plaster when an electric field is applied	23
7.4.3	The recommended setup for the desalination of the sandstone wall under an applied DC field using the clay poultices	26
7.5	Assumption for the next experimental work based on the results from the dissertation.....	29
8	BIBLIOGRAPHY	29
9	CURRICULUM VITAE	32
10	ČESKÝ ABSTRAKT.....	33

1 MOISTURE IN THE BUILDING MATTERS

The moisture is an important factor in the civil engineering. The moisture is the technical-physical quantity which has the influence on the majority of mechanical and physical properties of the building matters and constructions (brickwork). The moisture as quantity describes the state of the building matter (brickwork), construction in relation to the volume of the water in any state. Among the mechanical properties the moisture has influence on the fabrication, strength, cold resistance and lifetime of the building matters. Among the physical properties it influences mainly thermal-technical properties, which have a huge impact on the environment. Wet building matters can also suffer from the biological corrosion (fungi).

1.1 General knowledge about the hygric properties of the building matters

Building materials are rarely completely dried up because the water can penetrate into the materials during the production, storage etc. The climate influences the materials as well. The water in the matters can be transported by diffusion of the water vapour, transmission, capillarity, absorption or sorption.

In the engineering practice, the water can occur in three phases, e.g. the solid phase as ice, the liquid phase as water and the gas phase as the water vapour. The building constructions such as outside walls, roofs, foundations are influenced with these phases mostly. The least influenced building constructions are the constructions with the lowest temperature and the moisture gradient and without the direct source of the moisture. From the view of the practice the most important properties for the moisture are sorption, absorption, capillarity, diffusion of the water vapour and the conductivity of the water. From the view of the rehabilitation of the existing buildings and constructions, it is necessary to know principles and behaviour of the water in these buildings and constructions. The moisture describes the state of the building matters (masonry), construction from the view of the water content in the matter in any phase.

The following Table 1 shows the levels of the moisture in the brickwork. There are several levels of the moisture:

Table 1 The levels of the moisture in the brickwork. [1]

Levels of the moisture	Water content w [%]
Very low	$w < 3.0$
Low	$3.0 \leq w < 5.0$
Increased	$5.0 \leq w < 7.5$
High	$7.5 \leq w < 10.0$
Very high	$10.0 >$

2 SALTS

Soluble salts are considered as the most common source of the building damage in the building constructions mainly in the lower parts of the buildings. The sources in the building matters are different. Types and the amount of the salt concentrations in the building matters depend on the physical properties of the salts, the used materials, the amount of the moisture in the material, the way of its contamination and on many other factors related to the environment.

2.1 The damaging concentration related to the salt anions

Currently, only few countries have a threshold for the limits of the concentrations of the most common salt anions. Critical amount of the salts in the building matters are different in accordance with the type of the material, characteristic of the salt, amount of the moisture etc. Generally, to find out the limiting amount of the salts in the building construction is difficult. In the present dissertation, the threshold values according with ÖNORM 3355-1 [2] are taken into account. The used thresholds are related solely to the anions of chlorides (Cl^-), nitrates (NO_3^-) and sulphates (SO_4^{2-}). [3]

3 ELECTROKINETICS

Electrokinetics may be also called electrokinetic remediation. These methods offer a high efficiency in the decontamination of the fine pores soil. When an

electric field is applied across the porous material, the movement of ions in a solution starts. Minimally two electrodes are needed for such ion transport (see Fig. 1). Due to thus obtained electrokinetic process, radio-nuclides, heavy metals and other organic compounds or their mixed inorganic matters can be removed from the different porous matters. The method for the remediation of the soil was described in the previous studies [4] [5] [6] [7].

Electrokinetic processes consist of two main parts: electromigration and electro-osmosis. The following chapters are related to the use of the electrokinetic phenomena in the porous building materials.

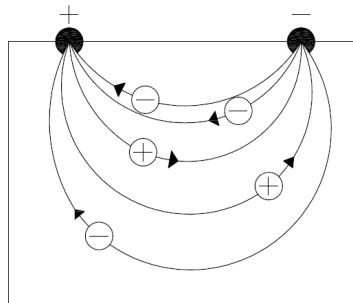


Fig. 1 Scheme of migration of ions towards the electrodes with the opposite polarity under an influence of electric field.

3.1 Electromigration

The transport of the dissolved salts is connected with the movement of the moisture. When an electric field is applied to a moist porous material the electric field is carried by ions in the pore solution. This process is called electromigration. Electric current is carried by electrons in the metallic electrodes. Processes, which transform electric current carried by electrons to the current carried by ions and vice-versa, are called “electrode processes”. These processes are dependent on the material of the electrodes, the applied potential and on the type of the electrolyte solution. Oxidation and reduction processes will occur at the anode and cathode, respectively. In addition to these processes, around the electrodes, where the dried place is, the ions can precipitate.

3.2 Electro-osmosis

After the application of the voltage into a fine-grained or porous material, ions which are in the solution (electrolyte) start to move by the electrical migration and this migration induces movement of the water in the direction to the positive or negative electrode in relation to the whole charge of the interface of a fine-grained or a porous material. In the case of the bricks, the internal surface has a negative charge. The internal surfaces will be polarized with the charges of the opposite polarity and then the chemical equilibrium will be maintained (see Fig. 2). Ions with the same charge as the charge of the internal surface are called co-ions. Opposite ions are called counter-ions. From this equilibrium double electric layer is created. Co-ions are presented much less in this double layer than the counter-ions. Application of the voltage causes the movement of the counter ions and co-ions towards the electrodes with the opposite signs. Because counter-ions are dominant against the co-ions inside the double electric layer, the water molecules around the counter-ions are dragged to the cathode electrode together with the counter-ions [8].

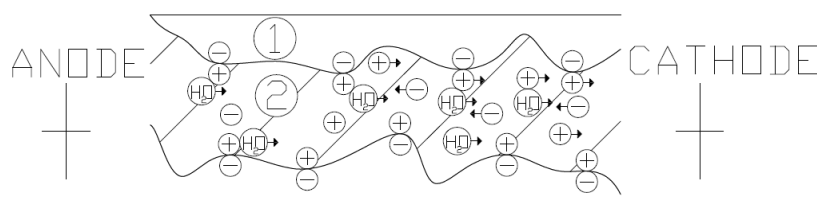


Fig. 2 The scheme of the internal surface of a porous material (brick). 1 – the internal surface (negative charge in the case of porous bricks); 2 – the solution (positive ions – counter-ions) and (negative ions – co-ions), hatch – a solution (electrolyte).

4 SPECIFICATION AND THE GOALS OF THE DISSERTATION

The dissertation deals with the extension of both theoretical and practical knowledge with the use of the electrokinetics in the field of civil engineering. The dissertation is focused on the sanitation of the building materials such as bricks, sandstones in relation to the moisture and the concentration of the most

common salts. The issues of the moisture and the salts are wide enough and contain much knowledge from the fields as chemistry and physics.

4.1 The specification of the issue

The dampness and a high concentration of different types of salts in the basement is the problem especially at the older buildings where the precautions such as the waterproofing membranes against the water are completely missing or badly done. The dissertation interconnects issues of the moisture and the salts. The theoretical part of the dissertation (chapter 1-5), describes the problematic of the moisture, salts, electrokinetics and their relations to the building matters.

The important parts of the fundamental knowledge are the initial conditions which are different in the laboratory and on the building site. The amount of the water and the distribution of the salts in some laboratory experiments are supposed to be uniform contrary to the water contents and distribution of salts in the pilot tests. Thus it is difficult to evoke the similar conditions in the laboratories as the initial conditions on the building sites are. In the experimental part of the dissertation, the electrokinetic methods for the dewatering and desalination are tested with the materials such as bricks and sandstones.

4.2 The goals of the dissertation

The main goals are in the complex experimental and the theoretical analysis of the dewatering and the desalination of the porous materials such as bricks, sandstones under the laboratory conditions and of the brickwork in the pilot test under an applied electric field. The final recommendations are based on these findings and analysis both from the laboratory and the pilot test.

4.2.1 The optimization of the closed laboratory setup for the dewatering of the tap water saturated bricks due to electro-osmosis using the different types of clay poultices

- To demonstrate electroosmotic flow and to find out which combination of the clay poultices is the most suitable and has the highest efficiency in

relation to the dewatering of the bricks which were saturated with the tap water.

- To find out the overall changes of pH in the closed laboratory setup.

4.2.2 Desalination of the sandstones under the laboratory conditions using one type of clay poultice

- To desalinate the sandstones under an applied electric field to levels meeting the safety limits where no damaging risk is expected.
- To find out an overall charge, the efficiency of the desalination as the removal of mass and removal rate of chlorides, nitrates and sulphates.
- To verify whether electro-osmosis takes place in the closed laboratory setup and how much.
- To find out whether the placement of the sandstones (original outer surface) in relation to the electrodes has any significant influence on the efficiency of the desalination.
- To verify the suitability of the mixture used as the clay poultices in relation to pH changes.

4.2.3 The optimization of the closed laboratory setup for the desalination of the bricks saturated with sodium chloride solution using the different types of clay poultices

- To find out which combination of the clay poultices has the highest efficiency in decreases of the chloride concentration.
- To find out which combination has the highest decreases in the water contents inside the bricks at the end of the experiments.
- To find out the overall changes of pH in the closed laboratory setup.

4.2.4 Desalination of a brickwork in the pilot test

- To find out the efficiency of the desalination as the removal of mass and removal rate of chlorides, nitrates and sulphates when the specific constant current is applied.

- To use the obtained experience from the test for the recommendations how to desalinate the brickwork with the highest efficiency.

4.2.5 To desalinate the sandstone wall in the pilot scale test on the basis of laboratory results

- To give recommendations for the high efficiency of desalination of the sandstone wall, on the basis of results from the laboratory experiments.

5 THE METHODS USED IN THE DISSERTATION

5.1 Theoretical methods

5.1.1 The study of literature and the consultation with experts

Theoretical knowledge was obtained mainly from the literature abroad, internet and from the cooperation with Denmark Technical University in Lyngby (DTU), Denmark.

5.2 Experimental methods

5.2.1 Laboratory methods

With the use of abstraction method, the real constructions were replaced with the simplified models such as simple bricks and sandstones. In these models, the simplified conditions were evoke mainly because of easier implementation for the dewatering and the desalination. In the laboratory experiments the following data were collected and calculated:

- The water contents, pH, voltage, concentration of chlorides, nitrates, sulphates;

5.2.2 Methods used in the pilot test

The dewatering and desalination of a real wall when an electric field was applied was also conducted. Firstly, the initial examination of the water contents and concentrations of salts from the samples taken from the wall of interest was done. On the basis of the evaluation of the initial water contents, concentration

of salts and the historic facts, it was found out which salts damaged the wall and the plaster mostly. After the application of clay poultices on the part of the wall, which was the aim of the desalination treatment, electric field was applied into these clay poultices.

In the pilot experiment the following data were collected and calculated:

- The water contents, voltage, concentration of chlorides, nitrates and sulphates;

5.3 The comparative method

The comparative method was used both for the experiments in the laboratory and in the pilot test. The results from the laboratory experiments were compared with each other. The results from the present pilot test were compared with the results from the previous pilot tests to get the final conclusions.

6 EXPERIMENTAL DRYING AND DESALINATION UNDER AN APPLIED ELECTRIC FIELD

6.1 EXPERIMENT 1 – To find out the combination of the clay poultices which is the most efficient for the dewatering of the tap water saturated bricks due to electro-osmosis under an applied electric field

6.1.1 Introduction

The electro-osmosis may be influenced significantly by the composition of the clay poultices together with the changes of pH during the electroosmotic flow. Therefore the following findings in the laboratory experiments might contribute to the improvement of the dewatering under an applied electric field. The experiment tightly follows the previous study [9].

6.1.2 The goals of the experiment 1

The experiment 1 focuses on:

- (1) to demonstrate the electroosmotic flow in the closed laboratory setup with the combination of two types of the clay poultices,
- (2) to find out which combination of the clay poultices is the most suitable and has the highest efficiency in relation to the dewatering of the bricks which were tap water saturated,
- (3) to find out which combination of the clay poultices creates the least amount of OH^- ions inside the bricks and inside the clay poultices,



Fig. 3 The used yellow bricks, the clay poultices – the mixture (white), the brick clay (brown); [10]

6.1.3 The results and the conclusion

The experiments were conducted with one type of yellow bricks which were tap water saturated and with two types of poultices.

- (1) The demonstration of the electroosmotic flow was found out because the decreases of the water contents were higher at the anode clay poultice than at the cathode clay poultice in the every case.
- (2) The combination of the poultices where the brick clay was used on the both sides of the closed laboratory setup showed that the brick clay was dried the least on the anode side from all experiments. In addition, the same combination (experiments 3, 9) showed even the highest decreases in the water contents inside the bricks from all experiments from the initial water contents (15.4–14.7 %) to the final water contents (14.5 and 12.7 %).
- (3) The combination where the brick clay was used on the both sides showed only the slight average increases in pH in relation to the initial

values of pH inside the bricks from the initial values (10.5 ± 0.03) to values (10.6–10.7).

- The lowest increase in pH was also measured at the cathode clay poultice from the initial pH of the brick clay (8.1) to values (8.5–8.2) in the experiments 3 and 9.

6.2 EXPERIMENT 2 – Desalination of sandstones using clay poultices with an applied electric field

6.2.1 Introduction

The present experiment 2 was conducted with the sandstones which were removed during the renovation from a historic warehouse. The sandstones contain chlorides, nitrates, sulphates and the work was focused on decreasing in the concentrations of all those, as they can cause irreversible damage. The technique of the poultices was used. The present experiment follows the previous studies [11] [12].

6.2.2 The goals of the experiment 2

The experiment 2 focuses on:

- (1) to see whether it is possible to desalinate the sandstones to levels meeting safety limits where no damaging risk is expected,
- (2) to verify whether electro-osmosis (the water movement under an applied DC field) takes place,
- (3) to find out whether the placement of the sandstones (original outer surface) in relation to the electrodes has any influence on the efficiency of desalination,
- (4) to verify the suitability of a mixture used as a poultice in relation to the pH changes and water contents,
- (5) to find out the removal rate, removed mass for chlorides, nitrates and sulphates when the constant current is applied,

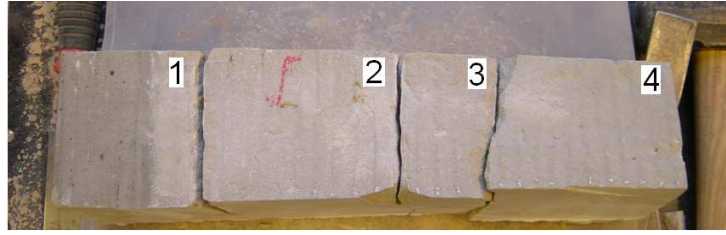


Fig. 4 Four segments of the stone 1. The stone segment 3 was used as the reference.

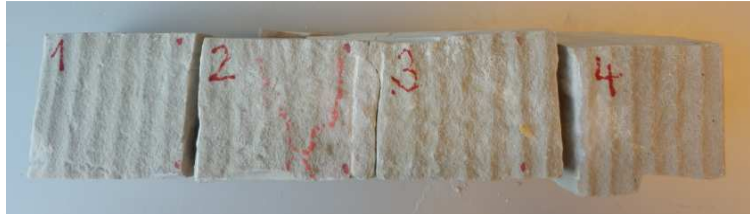


Fig. 5 Four segments of the stone 2. The stone segment 3 was used as the reference.

6.2.3 The results and the conclusion

The experiments were conducted with the salt contaminated sandstones from the historic warehouse. The concept of the electrokinetic desalination showed that the salt concentration could be reduced to the low concentrations.

- (1) In the segmented stones, the initial concentrations of chlorides (1670 and $425 \text{ mg}\cdot\text{kg}^{-1}$) were reduced to values (410 and $140 \text{ mg}\cdot\text{kg}^{-1}$); for nitrates from (1140 and $990 \text{ mg}\cdot\text{kg}^{-1}$) to values (415 and $310 \text{ mg}\cdot\text{kg}^{-1}$); for sulphates from (890 and $540 \text{ mg}\cdot\text{kg}^{-1}$) to values (175 and $30 \text{ mg}\cdot\text{kg}^{-1}$). The decreases in salt concentrations were within 5–11 days with 2 mA applied constant current, however, the concentrations were not decreased below limiting values in every case.
- (2) Electro-osmosis (movement of water) was proven, however, only in the clay poultice where the final water contents were significantly lower in the anode clay poultices than the final water contents in the cathode clay poultices. Inside the stone segments, the final water contents were similarly flat.
- (3) The placement of the stone segments showed its importance in these desalination experiments.
- (4) The pH was lower in the reference stone segments than pH in the segmented stones at the end of the experiments (the table shown in the

thesis). The used mixture as poultices showed suitability for desalination in relation to the pH changes and successfully neutralized the acidic front at the anode from electrolysis. The alkaline front at the cathode was high as a function of time.

- (5) The removal rate and removed mass for chlorides, nitrates and sulphates were found out (the table shown in the thesis). These findings might have been useful for the further application in the future pilot test.

6.3 The additional experiment to experiment 2

6.3.1 The main goals of the additional experiment

The main focus of the additional experiment is on:

- (1) to find out whether the higher constant current together with the more charge passed through the closed laboratory setup have any influence on the removal rate and removed mass of chlorides, nitrates, sulphates and thus on the decreases of the chloride, nitrate and sulphate concentrations in the sandstones,
- (2) to verify whether electro-osmosis (the water movement under an applied DC field) takes place more significantly when the stronger electric field is applied,
- (3) to confirm whether the placement of the sandstones (original outer surface) in relation to the electrodes has influence on the efficiency of the desalination when the stronger current is applied,
- (4) to find out the removed mass and removal rate for chlorides, nitrates and sulphates when the constant current is applied and to verify the suitability of the mixture used as the poultice in relation to pH changes.
- (5) from the obtained results to give recommendations for the application in the pilot test (read 7.4.3 The recommended setup for the desalination of the sandstone wall under an applied DC field using the clay poultices).

6.3.2 The results and the conclusion

The concept of the electrokinetic desalination of problematic salts followed the previous experiment with the sandstones. Electrokinetic treatment showed that the concentration could be reduced to the low concentrations. During the experiments with duration from (9 to 15 days) the initial concentration of chlorides, nitrates and sulphates were decreased significantly to the low concentrations and in the cases of sulphates, the decreases were below limiting values of concentrations from ÖNORM B 3355-1 [2].

- (1) In the stone segments, the initial concentrations of chlorides (1800 and 1550 $\text{mg}\cdot\text{kg}^{-1}$) were reduced to values between (1200 and 175 $\text{mg}\cdot\text{kg}^{-1}$); for nitrates from (1650 and 1150 $\text{mg}\cdot\text{kg}^{-1}$) to values between (1390 and 370 $\text{mg}\cdot\text{kg}^{-1}$); for sulphates from (1680 and 510 $\text{mg}\cdot\text{kg}^{-1}$) to values between (170 and 95 $\text{mg}\cdot\text{kg}^{-1}$).
- (2) The movement of the water was clearly seen, however, only in the clay poultice the water movement was significant. The highest difference in the water decreases was in the experiment 1 that had the longest duration.
- (3) The placement of stone segments confirmed its importance from the previous results because the biggest mass of chlorides (1.3–1.7 g) was removed in the experiments 2, 3 and in the case of nitrates, the removed mass was the biggest in the experiment 3 (0.9 g).
- (4) The removal rates of salt anions were found out and confirmed the supposed velocity of migrated ions (the table shown in the thesis).
- (5) The encourage results of desalination (removal rates of chlorides and nitrates) were used in the following recommendations for the desalination of the sandstone wall.

6.4 EXPERIMENT 3 – Desalination of the bricks contaminated with the sodium chloride under an applied electric field

6.4.1 Introduction

The experiment 3 was aimed at the desalination of the bricks contaminated with the sodium chloride solution. The experiment 3 was conducted with the use of technique of clay poultices placed externally with the use of electric field. Two types of clay poultices were tested in the combinations with the halves of bricks. The experiment tightly follows the previous work [13].

6.4.2 The goals of the experiment 3

The experiment 3 was focused on:

- (1) to find out which combination of the clay poultices has the highest efficiency in decreases of the chloride concentration,
- (2) to find out which combination of tested clay poultices has the highest decreases in the water contents inside the bricks at the end of experiments,
- (3) to find out which combination of the clay poultices creates the least amount of OH^- ions in the cathode clay poultice,



Fig. 6 The used yellow brick contaminated with NaCl solution (left) and the used closed laboratory setup (right). The wrapping is not shown. [14]

6.4.3 The results and the conclusion

The experiments were conducted with one type of yellow bricks which were submerged in the sodium chloride solution for 4 days. The initial concentration of chlorides was decreased significantly to very low concentration under an applied electric field within 10 days.

- (1) The combination with the mixture as clay poultices used on the both sides showed the highest decreases in the chloride concentration between (80–99 %) in relation to the initial concentration of chloride. The final decreases in chloride concentration were below to limiting value.
- (2) The combination with the brick clay as the clay poultices on the both sides showed the highest decreases in the water contents inside the bricks from the initial water contents (18.9 and 19.0 %) to the final average water contents (9.9 and 9.5 %).
- (3) The combination with the brick clay on the anode sides and the mixture on the cathode side showed the lowest increases of pH in the cathode poultice (24.3–24.6 %) in relation to the initial value of pH (8.8) of the clay poultice.

6.5 EXPERIMENT 4 – Desalination of a masonry in the pilot test under an applied electric field

6.5.1 Introduction

The present pilot test follows tightly the previous studies [9] [15] where the similar electrode units were tested for the purpose of electrokinetic desalination.

6.5.2 The goals of the experiment 4

The main goals of the pilot scale test are:

- (1) to find out the efficiency of the desalination such as the removal rate, removed mass of chlorides, nitrates and sulphates when the clay poultices and the constant current were applied,
- (2) from the obtained results to give recommendations for the application in the pilot test (read 7.4.2 The recommended setup for the desalination of the brickwork with the plaster when an electric field is applied.),



Fig. 7 The reference old stable for the pilot test.

6.5.3 The results and the conclusion

The pilot test and tested utilized electrode units showed that the electrokinetic method worked in relation to the decreases of salt concentrations. The problems with too high resistance of the masonry were solved by spraying the tap water on the wall and wrapping the area around the electrode units with the plastic.

- (1) The efficiency of the desalination was found out. At the end of the pilot test, the initial concentration of chlorides ($700 \text{ mg}\cdot\text{kg}^{-1}$) was reduced to the value ($420 \text{ mg}\cdot\text{kg}^{-1}$), the initial concentration of nitrates ($19600 \text{ mg}\cdot\text{kg}^{-1}$) to value ($16000 \text{ mg}\cdot\text{kg}^{-1}$) and the initial concentration of sulphates from ($1600 \text{ mg}\cdot\text{kg}^{-1}$) to the value ($640 \text{ mg}\cdot\text{kg}^{-1}$).
- (2) From the obtained results following recommendations for the application in the pilot test are given.

7 CONCLUSION AND FINDINGS OF SCIENTIFIC KNOWLEDGE

7.1 The optimization of the closed laboratory setup for the dewatering of the tap water saturated bricks due to electro-osmosis using the different types of the clay poultices

- The tested combination of the clay poultices where the brick clay as poultice was used on the both sides showed the highest decreases in the water contents at the end of the laboratory experiments (read 6.1.3 The results and the conclusion),

- The same combination showed the lowest increases in pH in the cathode clay poultice (read 6.1.3 The results and the conclusion),
- The both types of tested clay poultices showed their buffering capacity in relation to the changes of pH in every experiment (read 6.1.3 The results and the conclusion),

7.2 Desalination of the sandstones under the laboratory conditions using one type of clay poultice

- The tested clay poultices in which the mixture (CaCO_3 +kaolin+distilled or tap water) was used on the both sides showed significantly high decreases in the chloride, nitrate and sulphate concentrations at the end of the desalination experiments (read 6.2.3, 6.3.2 The conclusions),
- The tested mixture buffered the acidification in every experiment with the sandstones (read 6.2.3, 6.3.2 The results and the conclusions),
- The placement of the electrodes in relation to the sandstone surfaces with the different salt concentration showed its importance. The higher removed mass and removal rates of chlorides and nitrates were calculated when the anode electrodes were placed towards the sandstone surface with the higher concentration of salts. The importance of the placement was confirmed in the additional experiment where the stronger current was applied into the electrodes (read 6.3.2 The results and the conclusion),

7.3 The optimization of the closed laboratory setup for the desalination of the bricks contaminated with sodium chloride using the different types of clay poultices

- The tested combination of clay poultices where the mixture (CaCO_3 +kaolin+distilled or tap water) was used on the both sides showed the highest decreases in the chloride concentration in the bricks at the end of the laboratory experiments (read 6.4.3 The results and the conclusion),

- The combination with the brick clay on the both sides showed the highest decreases in the water contents inside the bricks (read 6.4.3 The results and the conclusion),
- The both types of the tested clay poultices showed their buffering capacity in relation to pH changes in every experiment (read 6.4.3 The conclusion),

7.4 The use of the electrokinetics for the desalination of constructions such as brickwork and sandstone walls

In the present building practice, the electrokinetics as the method for the dewatering and desalination of the building matters and construction is successfully used.

7.4.1 The choice of the suitable type of the clay poultice

The choice of the suitable type of the clay poultice is an essential for the dewatering and desalination. The right choice influences the efficiency of the dewatering significantly.

The dewatering of the bricks and the brickwork

- For dewatering of bricks and brickwork, the brick clay used as the clay poultice showed the highest decreases in the water contents from the water saturated bricks. The used brick clay should contain approximately 17.0–18.0 % of carbonates,
- The set up of the constant voltage and good contact should be maintained.

7.4.2 The recommended setup for the desalination of the brickwork with the plaster when an electric field is applied

The following points describe the way how to set up electrode units for the desalination of the brickwork properly in order to get the highest efficiency for desalination:

- To have the visual survey and the knowledge from the history of the building – to find out the sources of the moisture and salts,
- To design a solution which avoids moistening of the construction,

Fig. 8 shows the area of a wall which should be desalinated.

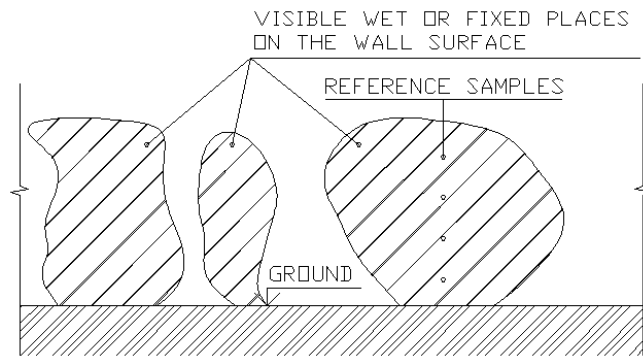


Fig. 8 The simplified scheme of a part of a wall which has to be desalinated.

- To think about the future placement of the electrode units. The same type of the electrode units as in the experiment 4 are supposed to use for the desalination purpose.
- The supposed placement of the electrode units on the brick wall (see Fig. 9 and Fig. 10).

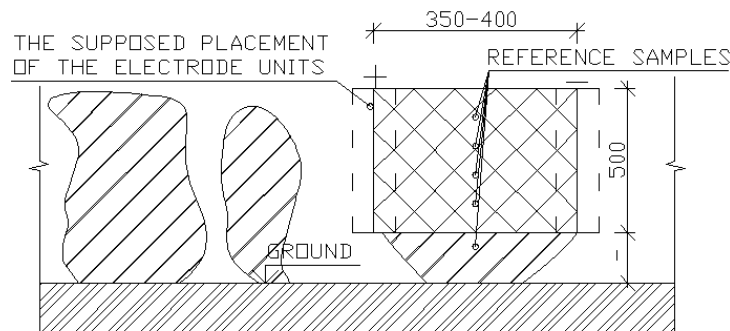


Fig. 9 The area from where the initial (reference) samples were taken (drilled). Dashed lines – the supposed placement of the electrode units;

- To take the initial (reference) samples from the wall between the supposed placement of the electrode units (see Fig. 9),
- To take the reference samples by drilling in the brickwork from the different heights above the ground and to analyse the initial water contents and the initial salt concentrations. The samples should be taken from the whole depth of the brickwork. In general, it is supposed that the salts are distributed in higher concentrations at the outer surface of the brickwork between the layer of a plaster and bricks,

- The finding of the salt concentrations in the whole cross section of the wall may be useful for better placement of the electrode units and thus for the improvement of the efficiency of desalination,
- From the ion chromatography, the initial concentration of chlorides, nitrates and sulphates may be calculated.
- The next step is the placement of the electrode units on the wall and set up of constant current. The electrode units should be placed on the same side of the brick wall where the higher concentration of salts is. The Fig. 10 shows the suitable placement of the electrode units on the brickwork.

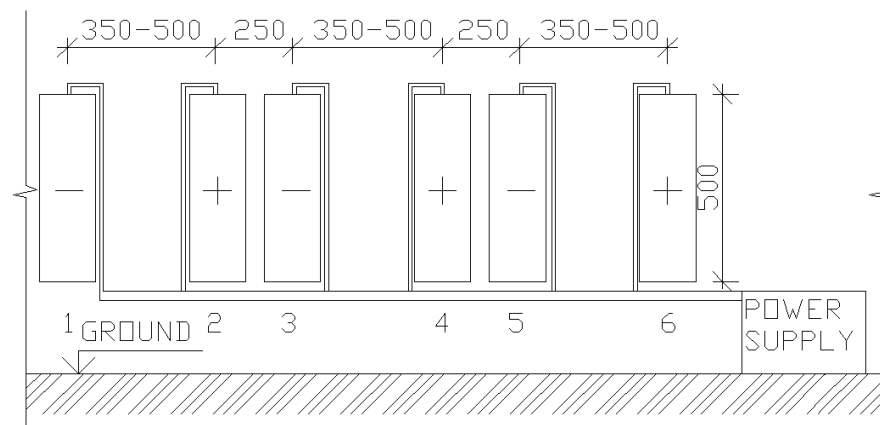


Fig. 10 The view on the electrode units and their recommended placement on the brick wall from the outer wall surface.

- The closer the electrode units are placed the higher current is possible to set up. The distance 350 and 500 mm between electrode units is recommended,
- To spray the distilled water on the brickwork in the case of too high resistance,
- To wrap a part of a wall which is being desalinated,
- To keep the clay poultices on the place until the voltage of the power supply gets its maximum,
- The process of desalination should be running until the removed grams of chlorides, nitrates and the sulphates gets steady pattern as clear in the Fig. 11,

- During the tests, it is suitable to take samples which may show the efficiency of the desalination so far.
- At the end of the desalination treatment, to take the final samples and to compare the concentrations with the concentration at the beginning and with the norm ÖNORM B 3355-1 [2].

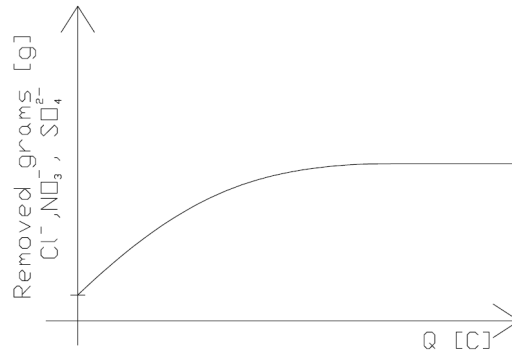


Fig. 11 The supposed pattern of the complete desalination based on a mass removal of salt anions and transferred charge.

7.4.3 The recommended setup for the desalination of the sandstone wall under an applied DC field using the clay poultices

The following points describe the way how to set up electrode units for the desalination of a sandstone wall properly in order to get the highest efficiency for desalination:

- The visual survey and the knowledge from the history of the building – to find out the sources of the moisture and the salts,
- To design a solution which avoids moistening of the construction,

Fig. 8 shows the area of a wall which should be desalinated.

- To think about the future placement of the electrode units. The same type of the electrode units as in the experiment 4 are supposed to use for the desalination purpose.
- The supposed placement of the electrode units on the sandstone wall (see Fig. 12, Fig. 13 and Fig. 14).

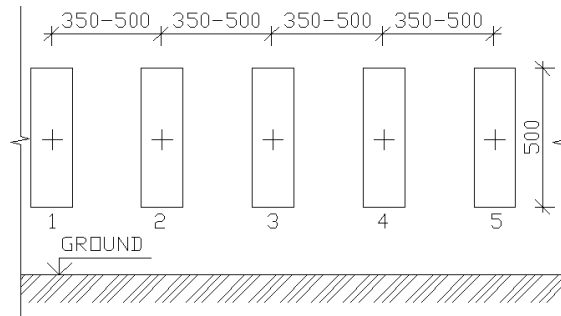


Fig. 12 The front view on the electrode units and their recommended placement on the outer surface of the sandstone wall. The connection to the power supply is not shown.

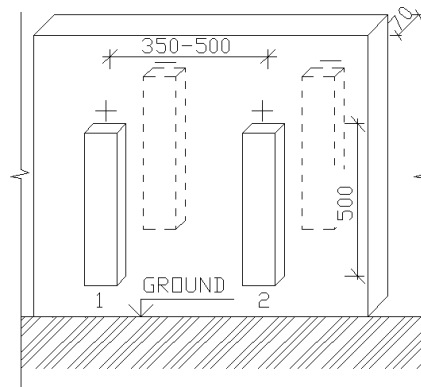


Fig. 13 The scheme of the placement of the electrode units in the axonometric projection on the part of the sandstone wall. The electrode units are placed exactly on the opposite sides and connected to the power supply (not shown). The dashed line – the electrode units on the opposite side (interior).

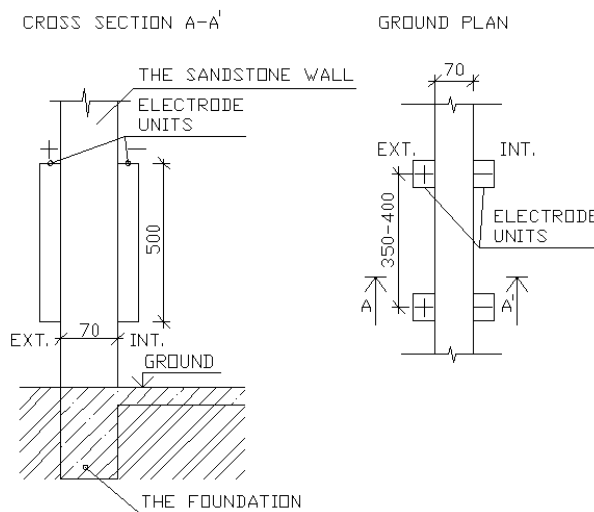


Fig. 14 The scheme of the placement of the electrode units and the distance between them. On the left (the cross section), on the right (the ground plan). EXT. - exterior, INT. - interior;

- To take the initial (reference) samples from the wall between the supposed placement of the electrode units (see Fig. 9).
- To take the reference samples by drilling in the sandstone wall from the different heights and to analyse these samples for the initial water contents and initial salt concentrations. The samples should be taken from the different depth of the wall because the significantly high concentration of the salts may be measured even towards the internal surface of the sandstone wall. This was found in the laboratory experiment 2.
- The finding of the salt concentrations in the whole cross section of the wall may be useful for better placement of the electrode units and thus for the improvement of the efficiency of desalination,
- From the ion chromatography, the initial concentration of chlorides, nitrates and sulphates may be calculated:
- To place the electrode units filled with the mixture or brick clay on a sandstone wall and to set up the constant current. The electrode units should be placed on a sandstone wall in the following order (see Fig. 12 to Fig. 14). The closer the electrode units are placed the higher current is supposed to be to set up. The distance 350 and 500 mm between the electrode units is recommended,
- To spray the distilled water on the sandstone wall in the case of too high resistance,
- To wrap a part of a wall which is being desalinated,
- To keep the clay poultices on the place until the voltage of the power supply gets its maximum,
- The desalination process should be running until the removed grams of chlorides, nitrates and sulphates gets steady pattern as clear in the Fig. 11,
- During the tests, it is suitable to take samples which may show the efficiency of the desalination so far.
- At the end of the desalination treatment, to take the final samples and to compare the concentrations with the concentration at the beginning and with the norm ÖNORM B 3355-1 [2].

7.5 Assumption for the next experimental work based on the results from the dissertation

The future experimental work should be aimed at the extension of the theoretical and the practical knowledge of the processes during the dewatering and the desalination when an electric field is applied. The changes which occur during the electrolysis on the electrodes seem to be limiting factors as for the efficiency of the dewatering due to electro-osmosis as for desalination. The following points might be investigated in the future:

- To analyze the changes at the anode electrode as H_2 is created from the chemical reaction at the anode. The gas might have been taken away directly from the closed laboratory setup. That action might have improved and increased the efficiency of dewatering and desalination,
- The pH influence the dewatering and the desalination significantly therefore it might have been useful to find out and to test the mixtures which can buffer the increases in OH^- ions at the cathode electrode,
- To test the materials which were desalinated by applied electric field for the mechanical properties as the compressive strength, bend strength etc.,

8 BIBLIOGRAPHY

- [1] Č. n. i. Praha, ČSN P 73 36 10. *Hydroizolace staveb sanace vlhkého zdiva, základní ustanovení.*, Praha: Český normalizační institut Praha.
- [2] K. Šuhajda, *Sanace vlhkého zdiva staveb, Využití tyčové antény při mikrovlnném vysoušení zdiva*, Brno, 2006.
- [3] ÖNOR.M.B. 3355-1, *Trockenlegung von feuchtem Mauerwerk - Teil 1: Bauwerksdiagnose und Planungsgrundlagen* Berlin. ASI Austrian Standards Institute Österreichisches Normungsinstitut (Herausgeber) Deutschland, Bundesrepublik, Beuth Verlag, 2006.
- [4] I. Rörig-Dalgaard, *Preservation of murals with electrokinetic - with focus on desalination of single bricks*, Lyngby, Denmark: Technical

- University of Denmark, Department of Civil Engineering, 2008.
- [5] A. N. Alshawabkeh, A. T. Yeung a M. R. Bricka, „Practical aspects of in-situ electrokinetic extraction,“ in Journal Of Environmental Engineering, 1999, pp. 27-35.
- [6] L. M. Ottosen a P. E. Jensen, „Electro-remediation of heavy-metal contaminated soil,“ v Soil and Sediment Remediation: Mechanisms, technologies and applications, 1 editor, IWA Publishing, 2005, pp. 264-288.
- [7] C. D. Ferreira, P. Jensen, L. M. Ottosen a A. Ribeiro, „Preliminary treatment of MSW fly ash as a way of improving,“ Journal of Environmental Science and Health Part A, č. 43, pp. 837-843, 2008.
- [8] A. J. Pedersen, L. M. Ottosen a A. Villumsen, „Electrodialytic removal of heavy metals from different fly ashes. Influence of heavy metal speciation in the ashes,“ Journal of Hazardous Material, pp. 65-78, 2003.
- [9] K. J. Laidler, J. H. Meiser a B. C. Sanctuary, Physical Chemistry, 4 editor, Houhton Mifflin company, 2003, pp. 269-293.
- [10] L. M. Ottosen, I. Rörig-Dalgaard, P. K. Larsen, I. Brajer, P. Bollingstoft, M. Marciniak a M. Svane, Salt Weathering on Buidings and Stone Sculptures, Copenhagen: Technical University of Denmark - Department of Civil Engineering, Brovej, Building 118, 2800 Kgs. Lyngby, Denmark, 2008.
- [11] M. L. Ottosen a I. Rörig-Dalgård, „Drying brick masonry by electro-osmosis,“ in Proceedings of the Seventh International Masonry Conference, London, 2006.
- [12] O. Matyščík, L. Ottosen a I. Rörig-Dalgaard, „Vysoušení cihel pomocí elektrického pole.,“ Stavební obzor, č. 10, pp. 187-191, červen 2013.

- [13] G. Skibsted, L. M. Ottosen a P. E. Jensen, „The possibility for using electrokinetics for desalination of sandstone with low porosity.,“ 8th fib International PhD Symposium in Civil Engineering, pp. 455-460, 20-23 June 2010.
- [14] L. M. Ottosen a I. V. Christensen, „Electrokinetic desalination of sandstones for NaCl removal - Test of different clay poultices at the electrodes,“ *Electrochimica Acta*, pp. 192-202, 2012.
- [15] L. M. Ottosen a I. Rörig-Dalgaard, „Desalination of a brick by application of an electric DC field,“ *Materials and Structures*, pp. 961-971, 15 October 2009.
- [16] O. Matyšček, L. Ottosen a I. Rörig-Dalgaard, „Odsolování cihel kontaminovaných v roztoku chloridu sodného účinkem elektrického pole.,“ *Stavební obzor*, č. 11, pp. 38-40, leden 2014.
- [17] L. M. Ottosen, I. V. Christensen, G. Pedersen a J. M. Paz-García, „Development of electrode units for electrokinetic desalination of masonry and pilot scale tests at three locations for removal of chlorides.,“ *Scientific Advances and Innovative. The 9th Symposium on Electrokinetic Remediation*, pp. 129-130, 27-30 June 2010.
- [18] L. M. Ottosen, I. Rörig-Dalgaard a A. Villumsen, „Electrochemical removal of salts from masonry - Experiences from pilot scale,“ *Salt Weathering on Buildings and Stone Sculptures : Proceedings from the international conference*, pp. 341-350, 2008.
- [19] M. Castellote, C. Andrade a C. Alonso, „Measurement of the steady and non-steady-state chloride diffusion coefficients in a migration test by means of monitoring the conductivity in the anolyte chamber. Comparison with natural diffusion tests,“ č. 31, pp. 1411-1420, 2000.
- [20] O. Matyšček, L. Ottosen a I. Rörig-Dalgaard, „Změny pH v cihlách a

příložných prvcích využitím elektrického pole.," Stavební obzor, č. 10, pp. 202-204, červenec 2013.

- [21] O. Matyščík, L. Ottosen a I. Rörig-Dalgaard, „Změny vlhkosti a pH při odsolování cihel účinkem elektrického pole.," Stavební obzor, č. 11, pp. 15-16, březen 2014.

9 CURRICULUM VITAE

EMPLOYMENT

February 2011 – present

Ph.D. student,

Employer: Brno University of Technology, Faculty of Civil Engineering,

Veveří 331/95, 602 00 Brno, Czech Republic

Position: teacher assistant - Reconstruction of buildings, Ph.D. student

October /2012 – January / 2013 part time job

September /2013 – December / 2013

Employer: P.P. Architects s.r.o., Horova 38 b, 616 00 Brno, Czech Republic

Position: planner

Working with project documentation, technical reports, design and planning of reconstructions and new buildings

March – June / 2011

part time job

Employer: PROJEKTinvest, s.r.o., Nám. T. G. Masaryka 1281, 760 01 Zlín, Czech Republic

Position: planner

Working with project documentation, technical reports, design and planning of reconstructions, reconstruction of a family house and baths in Teplice nad Bečvou

March – November / 2010

full time job

Employer: 1.Vasto s.r.o., Na Dolansku 295/9, 75501 Vsetín, Czech Republic

Position: master builder

Working with project documentation, labour supervisor, responsibility for rigid adherence to project, plan and safety measures, delivery of materials and tools, quality control inspector

Realized projects

- reconstruction of Basic School Komenium Olomouc, 8.května
- additional building of Informatic centre on Soláň
- concreting of swimming bath at a family house (in Hustopeče nad Bečvou)
- thermal insulation of a family house (in Janová)

June – September / 2009

part-time job

Construction of boarding house

Position: Labourer on construction, manipulation with concrete mixture, working on basement of building, groundwork around the house

EDUCATION

2011 – Present

Brno University of Technology, Faculty of Civil Engineering, Czech Republic

Doctoral course Civil Engineering – Building Constructions

2011 – 2013

Denmark Technical University (DTU) in Lyngby, Denmark

Faculty of Civil Engineering – research work Desalination and moist removal from brickwork in laboratory conditions and pilot scale test by using DC field.

2008-2010

Brno University of Technology, Faculty of Civil Engineering, Czech Republic

Masters course Civil Engineering – Building Constructions

2004-2008

Brno University of Technology, Faculty of Civil Engineering, Czech Republic

Bachelors course Civil Engineering

2000-2004

Gymnázium Rožnov pod Radhoštěm (secondary school)

1991-2000

Elementary school (primary school in Velké Karlovice)

10 ČESKÝ ABSTRACT

Odvhlčování a odsolování stavebních konstrukcí je v současné době velmi diskutované téma. V současnosti jsou používány různé způsoby jak pro odvlhčování tak pro odsolování stavebních konstrukcí. Existující metody jsou účinné, ale je nezbytné vyvíjet stále nové případně starší metody vylepšovat. Problematika vlhkosti ve stavení konstrukci je spojená se solemi, které v ní mohou být rozpuštěny a společně dále putovat. Tyto soli pak mohou působit

škody v konstrukcích a měnit jak mechanické tak fyzikální vlastnosti stavebních materiálů.

Základní požadavky pro vysoušecí a odsolovací techniky jsou rychlost, účinnost a ekonomický faktor. Presentovaná práce se zabývá odvlhčováním a odsolováním použitím elektrokinetických metod společně s technikou příložných prvků. V první části disertační práce jsou popsány základní teoretické principy v oblasti vlhkosti a solí. V druhé části (experimentální) byly provedeny série měření v laboratoři a v in situ.

V této části disertační práci jsem odvlhčoval a odsoloval cihly, pískovce vlivem účinku elektrického pole. Snažil jsem se optimalizovat laboratorní nastavení, aby odvlhčení a odsolení cihel a pískovců vlivem účinku elektrického pole bylo co největší. Další měření bylo provedeno v in situ, kde byla také použita technika příložných prvků společně s aplikací elektrického pole.