



## ASSESSMENT OF WALL SALINITY IN THE SELECTION OF RENOVATION PLASTER SYSTEMS

*Arkadiusz Panuś*

ORCID: 0000-0002-9817-0192

Department of General Construction and Building Physics

Faculty of Geoengineering

University of Warmia and Mazury in Olsztyn

Received 21 September 2021, accepted 12 November 2021, available online 15 November 2021.

**Key words:** salinity analysis, colorimetry, salty wall, restoration plaster, ion chromatography.

### Abstract

This article presents issues related to assessing the degree of wall salinity to select plaster systems for renovations of damp building walls. The most commonly used salt concentration tests pose many difficulties. If used uncritically, they risk failing to select the right system or its incorrect make. The accuracy of the colorimetric method for testing chloride, nitrate, and sulphate content was analysed to exemplify the magnitude of the problem. Both multi-salt solutions of known concentrations and unknown composition extracted from drillings in the walls of a historical facility were examined. A comparative methodology using ion chromatography as a standard was employed in the research. The analytical methods and the selected modules of the „Statistica” software were used to analyse data and present the results. The colorimetric method has been shown to distort salt concentration values, posing a risk of unsuccessful repair work on high-salinity walls. A method for determining the correction reducing the measurement error has been proposed. The factors affecting the error were also mentioned. Attention has also been drawn to the resolution and application of a method with a correct concentration range intended to improve work efficiency and optimize the costs incurred in renovating the salty wall.

---

Correspondence: Arkadiusz Panuś, Katedra Budownictwa Ogólnego i Fizyki Budowli, Wydział Geoinżynierii, Uniwersytet Warmińsko-Mazurski, ul. Heweliusza 4, 10-724 Olsztyn, e-mail: [arkadiusz.panus@uwm.edu.pl](mailto:arkadiusz.panus@uwm.edu.pl).

## Introduction

When in operation, each facility is continuously exposed to adverse outdoor conditions. If the walls are not adequately protected, they may become wet and thus salty, as the transported water is, in fact, always a salt solution. Depending on the magnitude of the phenomenon, the salts cause relatively great damage to building materials due to crystallization. This problem has been known for years. In 420 B.C. HERODOTUS (420BC), an ancient Greek historian, said, "I observed... that salt exuded from the soil to such an extent as even to injure the pyramids". In modern times, information on this issue appeared already in 1895 (LUQUER 1895). Doehne estimated that in 2002, there were more than 1800 bibliographic entries in the scientific literature on the destruction of porous material caused by salts (DOEHNE 2002). Many of them have been cited in literature extensive review by DOEHNE (2002), GOUDIE, VILES (1997) and CHAROLA (2000).

The impact of the three salts (chlorides, nitrates and sulphates) is assumed to be the most significant for the building material (PAVLÍKOVÁ et al. 2011, PEŘINKOVÁ et al. 2021, WÓJCIK 2006). These are substances covered by instructions and recommendations from industry institutions and manufacturers. For example, the EUREKA EU-1270 programme proposed a salinity grade and damage classification based on the salt type and concentration (Tab. 1) (STILLHAMMEROVÁ 2006).

Table 1

EUREKA EU – 1270 salinity degree classification (% in mass)

Salt type	Class 0	Class 1	Class 2	Class 3	Class 4
Chlorides	0.00-0.01	0.01-0.03	0.03-0.09	0.09-0.28	>0.28
Nitrates	0.00-0.01	0.01-0.05	0.05-0.15	0.15-0.50	>0.50
Sulphates	0.00-0.02	0.02-0.08	0.08-0.24	0.24-0.77	>0.77

This classification uses five basic salinity degrees and identifies possible hazards and degradation degrees caused by these salts. According to Table 1 (STILLHAMMEROVÁ 2006), salinity classes are defined as follows:

- Class 0 – low salt concentration (trace amounts), no damage to the wall;
- Class 1 – very low salinity of the structure. Structures that are continuous moisture-borne engage in water capillary action (or other unfavourable phenomena) and may get damaged;
- Class 2 – average salinity of the structure. The life of the plasters and paintings is slightly reduced;
- Class 3 – high salinity of the structure. The life of plaster and paintings is reduced considerably. Despite the use of active vertical isolation, the wall is wet due to the hygroscopic nature of the salt;
- Class 4 – extra high salinity. The structure gets destroyed in a very short time.

In the context of damage, this classification is rather general because, in reality, the size of the damage is affected by the structure of the material under analysis. A small quantity of salt can cause extensive damage in material with small pore diameters, and conversely, high concentrations will not result in significant changes in materials with large pore diameters (BLÄUER BÖHM 2005). Such classifications only make sense if they refer to specific materials. Manufacturers of renovation plaster systems are well aware of this. Their products are designed to withstand the relevant concentration ranges. Depending on the substrate salinity, the contractor then selects appropriate materials to make the plaster resistant to harmful salts for up to 20 years. To simplify the wall renovation technology, manufacturers and contractors use a common classification language. The WTA Instructions 2-9-04, issued by the Technical and Scientific Association for Building Protection and Conservation of Monuments (WTA – Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege), serves as a reference (WÓJCIK 2010). Three salinity degrees for the three salts are defined in the WTA instructions (Tab. 2) (*WTA Merkblatt 2-9-04... 2004*). The plaster systems used are WTA-certified and are assigned to specific salinity concentration ranges. They are used to determine the number of system components and layer thicknesses (Tab. 3) (*WTA Merkblatt 2-9-04... 2004*).

Table 2

WTA salinity degree classification no. 2-9-04 (% in mass)

Salt type	Low	Medium	High
Chlorides	<0.2	0.2-0.5	>0.5
Nitrates	<0.1	0.1-0.3	>0.3
Sulphates	<0.5	0.5-1.5	>1.5
Total salts	0.1-0.4/ <sup>1</sup>	0.4-1.0/ <sup>1</sup>	>1.0

<sup>1</sup> If the nitrate content accounts for more than 50% of the total salinity, low and medium salinity shall be ranked one degree up

Table 3

Renovation plaster system components according to WTA no. 2-9-04

Salinity degree	Layer layout	Thickness [mm]
Low	Rendering	≤5
	Renovation plaster	≥20
Medium to high	Rendering	≤5
	Renovation plaster	10-20
	Renovation plaster	10-20
	Rendering	≤5
	Base plaster	≥10
	Renovation plaster	≥15

Knowledge of of salt concentrations is of key importance here (PAVLÍKOVÁ et al. 2011, KONCA et al. 2016, GACZEK, FISZER 2014, KNOP 2016, NOCOŇ 2016). The pores of WTA restoration plasters are hydrophobic, which limits the deposition of salt in the plaster coating. If the substrate exhibits a medium to a high degree of salinity, double layer systems should be used, often with a base plaster storing salts (GACZEK, FISZER 2014) (Tab. 3). If the salinity of the substrate is incorrectly determined, mainly understated, the volume of the storage layer may be too small, which will cause premature saturation of the system and entail the necessity to rework, which involves significant costs. The situation is similar for the opposite. If concentrations get overestimated, the accepted (exaggerated) thickness of the storage layer puts the investor at risk of incurring unreasonable costs. Consequently, the investor questions the work effectiveness or states an abuse of material and thus refers the case to court. The judicial decisions are made based on the commissioned studies with the highest possible accuracy.

Contractors and architects typically use simple strip tests for salinity diagnostics. Some claim that they are estimates and do not give accurate results. There are no studies in the scientific literature describing the accuracy of these methods. Oberta used the colorimetric method (KOL) to research the capillary zone electrophoresis (CZE) method. The results showed deviations from the actual salt concentrations (Tabs. 4, 5) (OBERTA 2015).

Table 4  
Comparison of test results for concentrations of water-soluble salt (Cl<sup>-</sup>) obtained using the CZE method

Type of material	Solution concentration real [%]	Solution concentration determined with CZE [%]	Deviation in the results [%]
Brick	1.57	2.17	38.22
Sandstone	0.61	0.83	36.07
Limestone	0.99	1.77	78.79

Table 5  
Comparison of test results for concentrations of water-soluble salts obtained using the CZE and KOL method

Type of material	Concentration of solutions determined with KOL [%]			Concentration of the solution determined with CZE [%]		
	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Cl <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>
Brick	0.26 (0) <sup>1</sup>	0.30 (11) <sup>1</sup>	0.26 (-7) <sup>1</sup>	0.26 (0) <sup>2</sup>	0.27 (-11) <sup>2</sup>	0.28 (7) <sup>2</sup>
Sandstone	0.20 (-5) <sup>1</sup>	0.12 (-43) <sup>1</sup>	0.14 (-26) <sup>1</sup>	0.21 (5) <sup>2</sup>	0.21 (43) <sup>2</sup>	0.19 (26) <sup>2</sup>
Limestone	0.28 (0) <sup>1</sup>	0.32 (10) <sup>1</sup>	0.24 (-4) <sup>1</sup>	0.28 (0) <sup>2</sup>	0.29 (10) <sup>2</sup>	0.25 (4) <sup>2</sup>

<sup>1</sup> The value in brackets refers to the difference between the results obtained using the KOL and CZE methods

<sup>2</sup> The value in brackets refers to the difference between the results obtained using the CZE and KOL methods

The CZE method overstated the results by 36-79%. On the contrary, tests using the CZE and KOL methods (Tab. 5) gave similar values for chlorides. The difference in the results obtained using the KOL and CZE methods was -5-0%. It can thus be assumed that the deviation found in Table 4 for the CZE method is also applicable to the KOL method. For other salts, the differences in results obtained using CZE and KOL were more pronounced. For nitrates, they were -43-11% and -4-26% for sulphates. In both cases, the largest deviations applied to sandstone. Unfortunately, concerning nitrates and sulphates, it is difficult to make similar assumptions as for chlorides, as no comparison was made for CZE with the actual concentrations of these salts. Thus, we do not know what discrepancies (even hypothetical) can be expected when determining nitrate and sulphate concentrations using colorimetry. On the other hand, these parameters are very important for renovation works in salty facilities and should be carefully examined. In this work, the accuracy of colorimetric methods used in repair technology using renovation plasters was analysed for all of the above-mentioned salts.

## Materials and Methods

The following elements have been used for testing:

- Chloride titration test set in the range of 2-200 mg/L (0.0002-0.0200%)  $\text{Cl}^-$ ;
- Nitrate Test strips in the range 10-25-50-100-250-500 mg/L (0.0010-0.0025-0.0050-0.0100-0.0250-0.0500%)  $\text{NO}_3^-$ ;
- Sulphate Test strips in the range <200->400->800->1200->1600 mg/L (<0.02->0.04->0.08->0.12->0.16%)  $\text{SO}_4^{2-}$ .

Parallel, relevant concentrations were determined for the same solutions using ion chromatography (IC). Borelli described it as highly accurate (BORRELLI 1999). The authors' own studies confirmed this opinion. The accuracy of the chromatograph used proved very high. For the tests, a chromatograph equipped with a conductometric detector and UV-vis detector with a photodiode array and an ion-exchange column dedicated to separating anions such as chlorides, nitrates and sulphates was used. An external standard was used for determining the so-called calibration curve. It showed a correlation between the value measured by the apparatus and the test substance concentration. It was based on an analysis of several samples of known concentrations and integrals, the so-called peaks on the chromatogram (Fig. 1). The results of the studies exhibited a very high degree of correlation.

Model fit to the trial through the coefficient of determination  $R^2$  (the closer it is to unity, the better the fit). When determining calibration curves for chlorides, nitrates and sulphates, the  $R$ -square ( $R^2$ ) approximation value was always above 0.9998 (Tab. 6, Fig. 2). However, for comparing several populations of result,

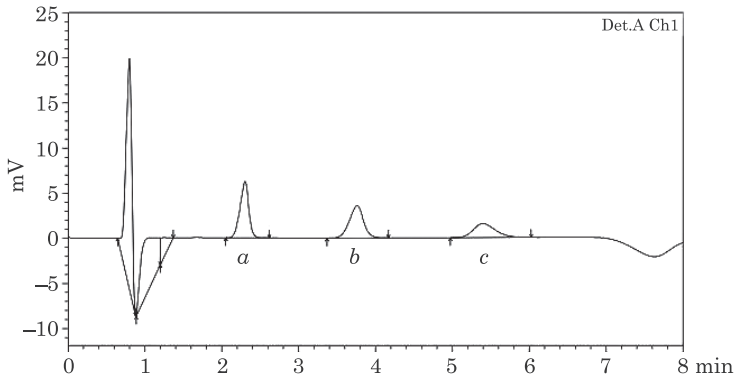


Fig. 1. Chromatogram with marked peaks for (a) chlorides, (b) nitrates, (c) sulphates

a coefficient of variation was used (RSD – relative statistical deviation) (if the resulting RSD is less than 25%, the results are assumed to be only slightly variable). For the calibration curves, the coefficient of variation of the RF response factor (RF %RSD) were 1-6% (Tab. 6, Fig. 2), where the RF response factor was defined as the quotient of the peak surface area and the concentration (or vice

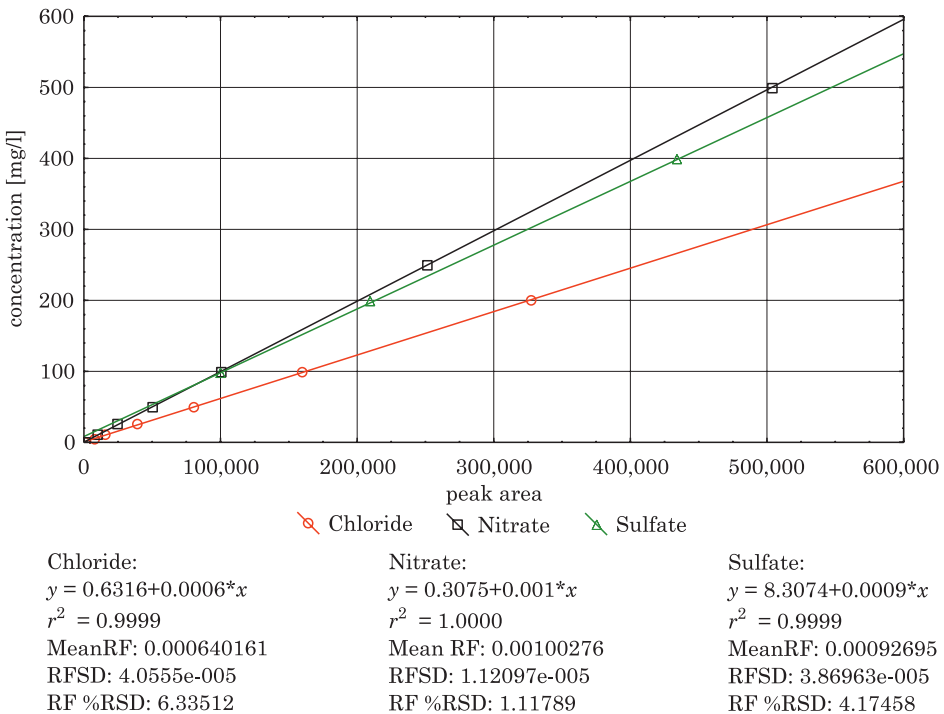


Fig. 2. Correlation curves of chlorides, nitrates, and sulphates

versa) of the standard solution. Therefore, the curve presented a very good fit to the results in the analysed range. Statistically, all values calculated from the correlation function obtained were subject to a minor error.

Table 6

Comparison of the obtained statistical calibration curves

Correlation curve	$R^2$	RF %RSD
Chlorides	0.999870	6.34
Nitrates	0.999997	1.12
Sulphates	0.999883	4.17

It was planned to run tests on two types of samples to determine the accuracy of the colorimetric method. In particular, measurements were performed for solutions of known and unknown concentrations. First, solutions with known concentrations were analysed in the ranges corresponding to the colorimetric method. Three multi-saline solutions were prepared: NaCl, NaNO<sub>3</sub> and NaSO<sub>4</sub> with (in mass) concentrations according to Cl<sup>-</sup> – NO<sub>3</sub><sup>-</sup> – SO<sub>4</sub><sup>2-</sup>, proportions as given below:

- solution no. 1: 0.0000-0.0000-0.0100%;
- solution no. 2: 0.0005-0.0010-0.0200%;
- solution no. 3: 0.0010-0.0025-0.0400%.

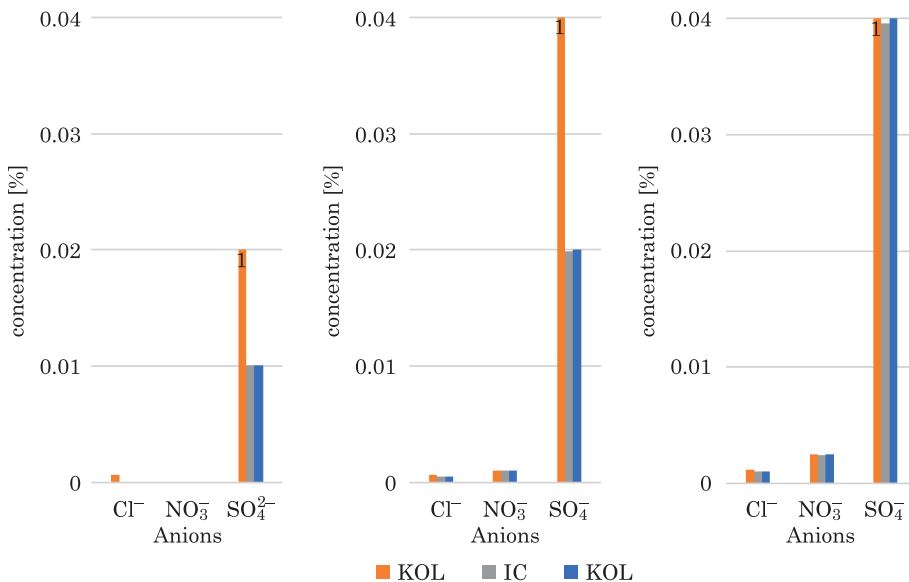
Tests on samples of unknown concentrations were then performed. The salt solutions were extracted from wall drillings of building facilities. 10 g of material was weighed, poured into 100 mL of demineralized water, stirred for 30 s, and filtered through quantitative hard filter papers (type 390, weight 84 g/m<sup>2</sup>). Individual samples (drillings) differed by colours, so they were grouped according to them. In this way, seven groups with three samples each were obtained, on average. An attempt was made to determine the discrepancy between the colorimetric method and ion chromatography results with such a population of results. To this end, the results obtained by the IC method were taken as a reference against which the results obtained in the KOL methods were compared. Deviations from the IC method were obtained.

## Results

### Solutions of Known Concentrations

When testing nitrate concentration, the colorimetric method determined the salt concentration without any error. The colours on the strips matched the standard colours for the individual concentrations (Fig. 3). However, when measuring chloride concentrations with the colorimetric method using titration,

errors have occurred. A so-called blind trial (solution free from the test substance) yielded a positive result. In a sample that did not contain any chlorides, the test detected a concentration of 0.0006%. This is a row of magnitude equal to the test resolution, as concentration is determined by adding drops with a volume equal to 6 mL of reagent (this corresponds to a concentration of 0.0006%). The other deviations resulted from the limitation resulting from constant volume (multiples of 6 mL) (Fig. 3). The greatest difficulties were encountered in the colorimetric sulphate test. Even though we prepared concentrations corresponding to the ranges indicated on the strips, the individual parts acquired imprecise colours. They overstated the values, which were difficult to determine precisely because the subsequent colour (indicative of higher concentrations) was only partially coloured (Fig. 3). To the contrary, the ion chromatography method determined the solutions with a high degree of precision within limits given to prepare the calibration solutions (Fig. 3).



<sup>1</sup>Concentration above the indicated value, slightly coloured towards the next concentration range (strip field)

Fig. 3. Comparison of test results for concentrations of water-soluble salts obtained using the IC and KOL method: *a* – solution no. 1, *b* – solution no. 2, *c* – solution no. 3

## Solutions of Unknown Concentrations

The results obtained for the reference concentration measurement method, IC, fell within the following ranges:



- 0.004-0.565% for chlorides (Appx 1);
- 0.002-1.225% for nitrates (Appx 1);
- 0.009-0.495% for sulphates (Appx 1).

The differences (deviations) in the KOL and IC results were in the range -65%÷50%. The discrepancies ranged from -100% to 100% for nitrates, and -60% to 2,122% for sulphates (Fig. 4, Appx 1). The deviation varied depending on the concentration of the test solution, inversely proportional. As the concentration decreased, the value of the deviation tended to increase. For nitrates and chlorides, this was accompanied by a tendency to increase range. The range of the deviation values for the nitrate test was still within the limit of low and medium salinity (according to WTA), and it was not noticeable at subsequent thresholds. The deviation values read from Figure 4 for each WTA threshold are given in Table 7.

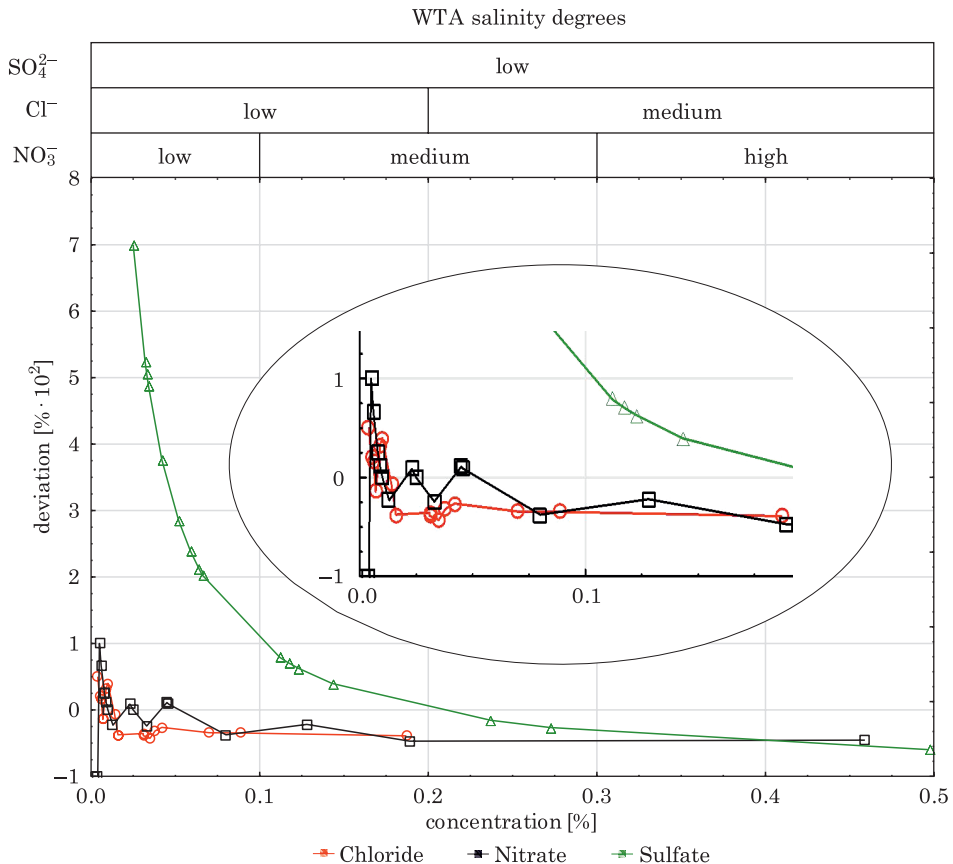


Fig. 4. Deviations in results obtained using colorimetry methods for concentrations of chlorides, nitrates, and sulphates from IC measurements

Table 7

Deviation values for WTA salinity degrees no. 2-9-04		
Salt type	Salinity threshold [%]	Deviation [%]
Chlorides	0.2	-40
Nitrates	0.1	-30
	0.3	-46
Sulphates	0.5	-60

No end of the decreasing trend was observed for chlorides and sulphates. Deviations (negative) may increase as the concentrations of chloride and sulphates increase. For the nitrate test, stabilization of the results was observed at  $-45\pm 1\%$ . Nitrate tests posed much more problems in interpretation than in the previous test at known concentrations matching the test ranges. In this respect, there was no difference in the sulphate test.

## Discussion

In the case under analysis, high accuracy in nitrate and chloride measurements was achieved in the range of known concentrations (assigned to scale for colorimetric method tests). The situation significantly changed when solutions with a natural distribution of concentrations obtained from the facility were taken into account, and a significant deviation in the KOL-IC results was observed. A diminishing trend in changes in deviation values as a function of concentrations was observed for all tests. The sulphate test was particularly distinguishing, whereas the variation in deviations was similar for nitrates and chlorides. The scatter of the deviation values appeared similar. As the concentrations increased, the repeatability of the error value increased as well. At salinity thresholds (according to WTA), i.e. 0.2% for chlorides and 0.3%, it presented a high level. Less repeatability in error values was obtained at a salinity level of 0.1% for chlorides and 0.5% for sulphates. Thus, in Table 7, we precisely defined the value of deviations for specific salinity degrees in a way corresponding to error repeatability.

The results obtained using colorimetric methods varied from the conclusions drawn based on the Oberta study. The latter suggested positive deviations exceeding the actual chloride concentrations by more than 36%. However, in a direct study, negative deviations were obtained for WTA salinity thresholds. In the case of nitrates, the deviations were similar to the chloride test. The largest errors were obtained for the sulphate test. For this test, taking measurements proved problematic. The measurement was the most ambiguous because the

fields in the strips were partially coloured, and the resolution was the smallest of all methods.

Underestimated values obtained with the colorimetric method under investigation may be detrimental to the success of repair work on salty walls. A correction may be applied to the colorimetric test to reduce the measurement error, either using the deviations from Table 7 or by determining salt concentration using more accurate methods. Ion chromatography is a well-proven method. It requires a small amount of extract (approximately 1 cm<sup>3</sup>). For tests on historical sites (which require repairs most often), this becomes a major advantage since other methods require more material to be collected. The weighing method requires 50 cm<sup>3</sup> of extract obtained by pouring 1 to 5 g of the sample per 100 cm<sup>3</sup> (DOMASŁOWSKI et al. 2011). Machine price is the major disadvantage of the IC method. However, it is increasingly applicable to testing wall salinity (FRANZONI et al. 2011, FRANZONI et al. 2014, FRANZONI, BANDINI 2012, LUBELLI et al. 2018, LUBELLI 2006, GONÇALVES et al. 2006, CAMUFFO 2018, SARDELLA et al. 2018, SARDELLA et al. 2018, MARAVELAKI-KALAITZAKI et al. 2003, GONÇALVES 2007). However, these colorimetric tests may be a good complement to ion chromatography. Their advantage is that they are dedicated to a specific type of salt. An on-site exam can also be performed. However, when using such tests, attention should be paid to concentration ranges. The upper limit of the Chloride Test in question is 0.2% (200 mg/L). This is merely where mid-range concentrations start, according to WTA. Therefore, it will be impossible to distinguish between average and high salinity and select appropriate components of the renovation system for salty walls.

To be on the safe side, if we roughly assume a very high degree of salinity and it is average, then the costs of the materials used would be unjustifiably high. If, in turn, we attempt to determine salinity when the concentration is out of scale, we would need to keep repeating the test, iteratively approaching the scale through subsequent tests. Samples obtained from drillings taken from the same site must be diluted so that the test covers its range. This can consume large amounts of test material, time and accumulate measurement error due

Table 8

Comparison of salt concentration ranges in colorimetric tests  
with the wall salinity classification by WTA no. 2-9-04

Test	Concentration range
Nitrate Test	0.100-0.250-0.500% (after correction for dilution 1 g-10 dm <sup>3</sup> )
WTA no. 2-9-04	<0.1 (low); 0.1-0.3 (medium); >0.3% (high)
Sulphate Test	0.4->0.8->1.2->1.6% (after correction for dilution 1 g-10 dm <sup>3</sup> )
WTA no. 2-9-04	<0.5 (low); 0.5-1.5 (medium); >1.5% (high)

to successive dilutions of the solution. The same is true for matching the scale on the test strips against the salinity classification used by the WTA. In the case analysed, the scale did not match this classification (Tab. 8). This causes difficulties in accurately determining the salinity degree.

## Conclusions

The use of colorimetric methods for measuring salt concentrations for repairing salty walls using renovation plaster technology should be carefully evaluated in each case. Within certain concentration ranges colorimetric methods can produce results that differ significantly from the actual values. If the colorimetric method underestimates the salt concentration in the wall, there is a risk that the renovation of salty walls using the renovation plaster technology will fail. However, if the test overestimates the concentration, it exposes the investor to unreasonably high costs. This can entail severe financial consequences imposed on the test contractor.

Different colorimetric methods generate different measurement errors. To use a given measurement method, we should learn what the measurement error of the method is. Attention should be paid to the resolution of the test used and to the principles of measurement. Greater accuracy will be obtained if the measurement is performed with a test in which the individual concentration intervals get coloured differently. The more intervals and colours on a strip test, the higher the resolution and accuracy of the measurement. In a sense, one can calibrate a given test with the method presented above. The ion-exchange chromatography can be used as a reference in assessing the accuracy of salt concentration measurements in walls. Samples for testing should be taken from such locations to represent the concentration distribution in the tested facility. If the test results indicate that the test range is too narrow, economic considerations dictate that a test that can determine all salinity levels should be used.

What is important for the application of restoration plaster technology are the deviations of the result obtained by the colorimetric method, which is at the level of the WTA salinity degree thresholds, i.e. concentrations of 0.1; 0.2; 0.3; 0.5% (in mass). They may serve as a correction for the result obtained with a given colorimetric method provided that such deviation shows there is repeatability for successive concentrations. The accuracy of the correction in a given concentration range is obtained in direct proportion to the repeatability of the deviation.

Ion exchange chromatography may also be used as the main measurement method and the colorimetric method as a complementary method. It is especially applicable when dealing with a multi-anion solution with peaks overlapping

on the chromatogram. Assigning specific anions to the individual tests of the colorimetric method may help resolve doubts concerning the assignment of specific anions to peaks on the chromatogram and accelerate analytical work.

### Acknowledgments

I acknowledge any support given by Professor Robert Wójcik, especially for the donation of research materials (powder samples drilled from building wall).


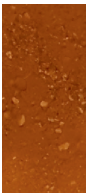
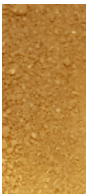
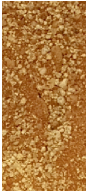
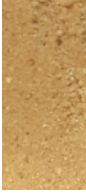
### References

- BLÄUER BÖHM C. 2005. *Quantitative Salt Analysis in Conservation of Buildings*. Restoration of Buildings and Monuments, 11(6): 409-418. <https://doi.org/10.1515/rbm-2005-6001>.
- BORRELLI E. 1999. *Introduction, Salts*. In: *ARC Laboratory Handbook*. 1<sup>st</sup> ed. Eds. Ch. McDowall, C. Rockwell. ATEL S.p.A., 3: 3-24.
- CAMUFFO D. 2018. *Standardization Activity in the Evaluation of Moisture Content*. J. Cult. Herit., 31: S10-S14. <https://doi.org/10.1016/j.culher.2018.03.021>.
- CHAROLA A.E. 2000. *Salts in the Deterioration of Porous Materials: An Overview*. J. Am. Inst. Conserv., 39(3): 327-343. <https://doi.org/10.2307/3179977>.
- DOEHNE E. 2002. *Salt Weathering: A Selective Review*. Geol. Soc. Spec. Publ., 205: 51-64. <https://doi.org/10.1144/GSL.SP.2002.205.01.05>.
- DOMASŁOWSKI W. 2011. *Zabytki kamienne i metalowe, ich niszczenie i konserwacja profilaktyczna*. 1<sup>st</sup> ed. Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Torun, p. 1-565.
- FRANZONI E., BANDINI S. 2012. *Spontaneous Electrical Effects in Masonry Affected by Capillary Water Rise: The Role of Salts*. Constr. Build. Mater., 35: 642-646. <https://doi.org/10.1016/j.conbuildmat.2012.04.098>.
- FRANZONI E., BANDINI S., GRAZIANI G. 2014. *Rising Moisture, Salts and Electrokinetic Effects in Ancient Masonries: From Laboratory Testing to on-Site Monitoring*. J. Cult. Herit., 15(2): 112-120. <https://doi.org/10.1016/j.culher.2013.03.003>.
- FRANZONI E., SANDROLINI F., BANDINI S. 2011. *An Experimental Fixture for Continuous Monitoring of Electrical Effects in Moist Masonry Walls*. Constr. Build. Mater., 25(4): 2023-2029. <https://doi.org/10.1016/J.CONBUILDMAT.2010.11.047>.
- GACZEK M., FISZER S. 2014. *Tynki Specjalne*. Część 2. Builder, 6: 60-64.
- GONÇALVES T.D. 2007. *Salt Crystallization in Plastered or Rendered Walls*. Thesis for the degree of PhD, Technical University of Lisbon, Lisbon.
- GONÇALVES T.D., RODRIGUES J.D., ABREU M.M., ESTEVES A.M., SILVA A.S. 2006. *Causes of Salt Decay and Repair of Plasters and Renders of Five Historic Buildings in Portugal*. Proc. Int. Conf. Heritage, Weather. Conserv. HWC 2006, 1 (January): 273-284.
- GOUDIE A., VILES H. 1997. *Salt Weathering Hazard*. Wiley, Chichester, p. 1-256.
- HERODOTUS. 420BC. *Book 2*. The History of Herodotus, 2.
- KNOP K. 2016. *Wyprawy tynkarskie na bazie tynków renowacyjnych*. Renowacje i Zabyt., 4: 186-187.
- KONCA P., MAĆKOWIAK A., KONIORCZYK M. 2016. *Renovation plaster as a protection against salt crystallization induced damage*. J. Civ. Eng. Environ. Archit., 63(3): 177-184. <https://doi.org/10.7862/rb.2016.199>.
- LUBELLI B.A.A. 2006. *Sodium Chloride Damage to Porous Building Materials*. Thesis for the degree of PhD, Delft University of Technology, Delft.
- LUBELLI B., CNUUDE V., DIAZ-GONCALVES T., FRANZONI E., VAN HEES R.P.J., IOANNOU I., MENENDEZ B., NUNES C., SIEDEL H., STEFANIDOU M., VERGES-BELMIN V., VILES H. 2018. *Towards*

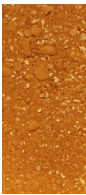
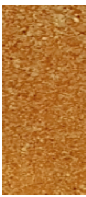
- a More Effective and Reliable Salt Crystallization Test for Porous Building Materials: State of the Art.* Mater. Struct., 51(2): 55. <https://doi.org/10.1617/s11527-018-1180-5>.
- LUQUER L.M. 1895. *The Relative Effects of Frost and the Sulphate of Soda Efflorescence Tests on Building Stones.* Trans. Am. Soc. Civ. Eng., 33(1): 235-247. <https://doi.org/10.1061/TACEAT.0001181>.
- MARAVELAKI-KALAITZAKI, P., BAKOLAS, A., MOROPOULOU, A. 2003. *Physico-Chemical Study of Cretan Ancient Mortars.* Cem. Concr. Res., 33 (5), 651-661. [https://doi.org/10.1016/S0008-8846\(02\)01030-X](https://doi.org/10.1016/S0008-8846(02)01030-X).
- NOCOŃ M. 2016. *System tynków renowacyjnych quick-mix.* Renowacje i Zabyt., 4: 176-179.
- OBERTA W., ŁUKASZEWICZ J.W. 2015. *Badania soli rozpuszczalnych w wodzie za pomocą strefowej elektroforezy kapilarnej.* Acta Univ. Nicolai Copernici, 46: 363-378. [https://doi.org/10.12775/AUNC\\_ZiK.2015.014](https://doi.org/10.12775/AUNC_ZiK.2015.014).
- PAVLÍKOVÁ M., PAVLÍK Z., KEPPERT M., ČERNÝ R. 2011. *Salt Transport and Storage Parameters of Renovation Plasters and Their Possible Effects on Restored Buildings' Walls.* Constr. Build. Mater., 25(3): 1205-1212. <https://doi.org/10.1016/j.conbuildmat.2010.09.034>.
- PEŘINKOVÁ M., DLÁBIKOVÁ I., POSPÍŠIL P., BÍLEK V. 2021. *Research into the Influence of Subsoil on Sulphates, Nitrates and Chlorides Accumulated in Renovation Plasters Used for Rehabilitation of Monuments in the Czech Republic.* J. Cult. Herit., 49: 197-210. <https://doi.org/10.1016/j.culher.2021.01.011>.
- SARDELLA A., DE NUNTHIS P., BONAZZA A. 2018a. *Efficiency Evaluation of Treatments against Rising Damp by Scale Models and Test in Situ.* J. Cult. Herit., 31: S30-S37. <https://doi.org/10.1016/J.CULHER.2018.03.020>.
- SARDELLA A., DE NUNTHIS P., RIZZO M., GIOSUÈ C., TITTARELLI F., BONAZZA A. 2018b. *In Situ Performance Evaluation of Chemical Injections against Rising Damp: A Case Study in Italy.* Measurement, 130: 128-136. <https://doi.org/10.1016/J.MEASUREMENT.2018.08.011>.
- STILLHAMMEROVÁ M. 2006. *Short Overview on Problems of Water Soluble Salts in Slovak Republic.* European Research on Cultural Heritage, 5: 119-123.
- WTA Merkblatt 2-9-04 Sanierputzsysteme. 2004. Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege, München.
- WÓJCIK R. 2006. *Anti-damp wall protection using the non-isothermal injection method.* Thesis for the degree of associate professor, University of Warmia and Mazury in Olsztyn, Olsztyn.
- WÓJCIK R. 2010. *Ochrona budynków przed wilgocią i wodą gruntową.* In: *Budownictwo ogólne. Fizyka budowli.* Vol. 2. 1<sup>st</sup> ed. Eds. J. Panas, M. Siarkiewicz. Arkady, Warszawa, p. 913-981.

## Appendix 1

Comparison of test results for concentrations (in mass) of water-soluble salts obtained using the IC and KOL method

Group		Sample	Concentration of chlorides [%]		Concentration of nitrates [%]		Concentration of sulphates [%]	
No.	Photo	No.	KOL	IC	KOL	IC	KOL	IC
1	2	3	4	5	6	7	8	9
1		15/100B/40-70	0.006 (-14) <sup>1</sup>	0.007	0.010 (25) <sup>1</sup>	0.008	0.200 (1900) <sup>1</sup>	0.010
		14/10A/40-160	0.007 (17) <sup>1</sup>	0.006	0.010 (0) <sup>1</sup>	0.010	0.200 (213) <sup>1</sup>	0.064
		1/100B/40-151	0.020 (-35) <sup>1</sup>	0.031	0.050 (11) <sup>1</sup>	0.045	0.200 (40) <sup>1</sup>	0.143
2		4/100B/10-130	0.058 (-35) <sup>1</sup>	0.089	0.100 (-47) <sup>1</sup>	0.189	0.200 (71) <sup>1</sup>	0.117
		14/10A/10-157	0.006 (50) <sup>1</sup>	0.004	0.000 (-100) <sup>1</sup>	0.002	0.200 (2122) <sup>1</sup>	0.009
		5/100B/40-34	0.006 (-14) <sup>1</sup>	0.007	0.010 (67) <sup>1</sup>	0.006	0.200 (2122) <sup>1</sup>	0.009
3		9/100B/10-103	0.200 (-65) <sup>1</sup>	0.565	0.500 (-59) <sup>1</sup>	1.225	0.200 (-60) <sup>1</sup>	0.497
		4/10A/80-135	0.010 (-38) <sup>1</sup>	0.016	0.010 (100) <sup>1</sup>	0.005	0.200 (700) <sup>1</sup>	0.025
		14/10A/80-163	0.012 (-33) <sup>1</sup>	0.009	0.010 (-23) <sup>1</sup>	0.013	0.200 (63) <sup>1</sup>	0.123
4		8/10A/40-114	0.026 (-32) <sup>1</sup>	0.038	0.050 (-38) <sup>1</sup>	0.080	0.200 (376) <sup>1</sup>	0.042
		15/100B/10-67	0.013 (-7) <sup>1</sup>	0.014	0.025 (-24) <sup>1</sup>	0.033	0.200 (506) <sup>1</sup>	0.033
		14/200C/10-159	0.007 (17) <sup>1</sup>	0.006	0.010 (11) <sup>1</sup>	0.009	0.200 (-26) <sup>1</sup>	0.272
5		11/100B/10-94	0.020 (-43) <sup>1</sup>	0.035	0.100 (-22) <sup>1</sup>	0.128	0.200 (203) <sup>1</sup>	0.066
		18/10A/40-42	0.031 (-26) <sup>1</sup>	0.042	0.250 (-46) <sup>1</sup>	0.459	0.200 (-16) <sup>1</sup>	0.237
		18/10A/1-39	0.046 (-34) <sup>1</sup>	0.070	0.500 (-41) <sup>1</sup>	0.842	0.200 (239) <sup>1</sup>	0.059

cont. Appendix 1

1	2	3	4	5	6	7	8	9
6		8/10A/80-117	0.010 (-38) <sup>1</sup>	0.016	0.010 (25) <sup>1</sup>	0.008	0.200 (79) <sup>1</sup>	0.112
		10/10A/80-181	0.006 (20) <sup>1</sup>	0.005	0.000 (-100) <sup>1</sup>	0.004	0.200 (525) <sup>1</sup>	0.032
		4/200C/40-134	0.019 (-39) <sup>1</sup>	0.031	0.050 (9) <sup>1</sup>	0.046	0.200 (488) <sup>1</sup>	0.034
7		11/100B/40-97	0.014 (40) <sup>1</sup>	0.010	0.025 (0) <sup>1</sup>	0.025	0.200 (1011) <sup>1</sup>	0.018
		1/10A/10-147	0.114 (-39) <sup>1</sup>	0.187	0.025 (9) <sup>1</sup>	0.023	0.200 (285) <sup>1</sup>	0.052

<sup>1</sup> The value in brackets refers to the difference (deviation) between the results obtained using the KOL and IC methods