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A System of Monitoring of Selected Parameters of Porous Substances Using the EIS Method in a Wide Range of Applications
Systém sledování vybraných parametrů porézních látek metodou EIS v širokém spektru aplikací

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METHODOLOGY FOR DETECTION OF MOISTURE DISTRIBUTION THROUGHOUT THE CROSS SECTION OF AUTOCLAVED AERATED CONCRETE MASONRY CONSTRUCTIONS BY APPLICATION OF EIS METHOD

Sanita Rubene[1], Martins Vilnitis[2]

Abstract – Contemporary construction trends are sustainable construction and efficient use of resources. Therefore, construction materials with high insulation parameters tend to become more popular. However, moisture content of construction materials has significant impact on the materials' physical properties, especially on heat resistivity properties. As autoclaved aerated concrete (AAC) masonry constructions have high heat insulation parameters if the masonry blocks are in air-dry state they comply with all contemporary construction trends. However, the moisture content of the AAC masonry blocks has siginificant impact on it's heat resistivity, therefore non-destructive monitoring of the drying process during the cladding stage is preferabe in order to increase the quality of the insulative properties of the delimiting Impact of moisture content on heat resistivity properties of AAC masonry constructions has been described in this paper.

Key words – autoclaved aerated concrete, electrical impedance spectrometry, determination of moisture distribution.

1 Introduction

Autoclaved aerated concrete (AAC) has high heat insulation parameters in air-dry state and all manufacturers in their technical data sheets state the properties of AAC in air-dry state. However, due to the technology of manufacturing process AAC masonry blocks can contain up to 50% moisture content after manufacturing. If AAC masonry blocks are delivered to the construction site and cladded in masonry construction in such condition then the delimiting construction will note be able to reach designed heat resistivity properties. Therefore, it is important to monitor the moisture content of the AAC in-situ.

A comprehenisive research about application of electrical impedance spectrometry EIS) for detection of moisture distribution throughout the cross section of AAC masonry constructions has been performed by authors. Methodology for detection of moisture distribution throughout the cross

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section of AAC masonry constructions has been developed within this research. A correlation equation (1) between the real part of electrical impedance and moisture content in AAC has been established.

$$y = -0.201 \ln (x) +2.6513 \qquad (1)$$

Therefore, it is possible to determine moisture content in AAC masonry constructions by application of EIS if the criteria for application of the developed methodology have been met.

2 Approbation of the developed methodology

For the approbation of the developed methodology for detection of moisture distribution throughout the cross section of AAC by application of EIS there were prepared three samples of AAC masonry wall construction with dimensions 1200 mm × 600 mm × 250 mm (length × height × thickness). AAC with 375 kg/m^3 density was used [1] and additional layer of heat insulation was attached on two samples. Most popular heat insulation materials which are usually used in Latvia were used – one of the samples was insulated with 100mm thick layer of mineral wool [2] (sample A) and the second sample was insulated with 100mm thick polystyrene insulation (sample B) [3]. The third sample was left without additional heat insulation layer in order to use it as a reference sample (sample C). Afterwards both insulated samples and the third sample, which was left without any additional insulation were covered with plaster from the external side of the insulation (e.g. the external side of the wall construction). Thus, a model of construction phase when the cladding of the masonry construction has been finished and the external finishing of the wall has been finished was simulated (Fig.1 (a) and (b)).

Fig. 1 (a) Sample constructions on stand

Fig. 1 (b) Sample constructions on stand

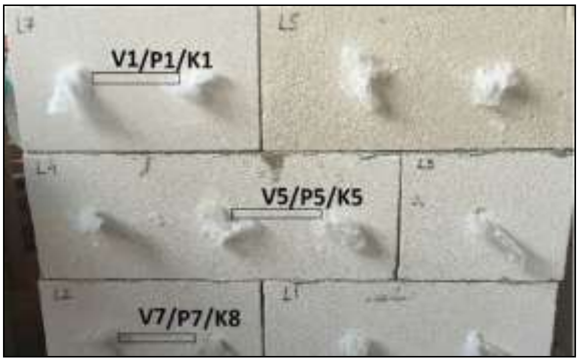


Fig. 1 (c) Measurement points on sample

The particular specimen were taken from the experiment described in [4] as the particular experiment is extension of the previous one.

3 Methodology for detection of moisture distribution throughout the cross section of AAC by application of EIS

3.1 Frequency analysis

The EIS method is based on measurements of resistance of AC circuit. Therefore, the measurement result is a frequency dependant value, which depends on number of factors that characterize the properties (such as porous structure, density changes, moisture saturation rate etc.) of the material measurements are taken upon.

The results of performed frequency analysis display that for all specimen the most suitable frequencies are in range from 6.3 kHz to 20 kHz and vary significantly (Fig.2. to Fig.11.). Therefore, it is possible to conclude that the structure of AAC material has significant impact on determination the preferable measurement frequency for further monitoring of the material by EIS measurements. Such statements have been also introduced in previous researches performed on porous materials by other non-destructive approaches [5, 6].

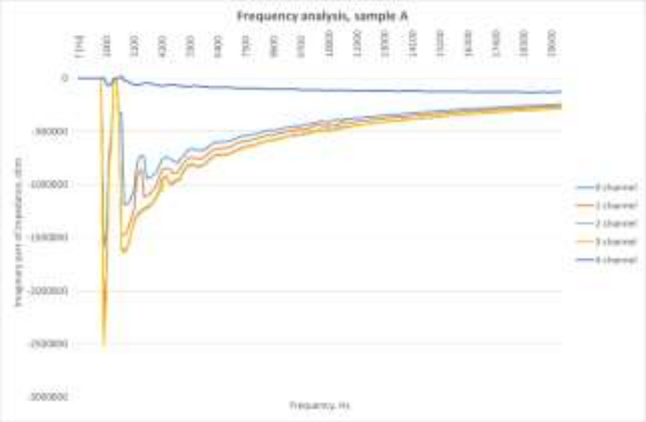


Fig.2 Results of frequency analysis for sample A

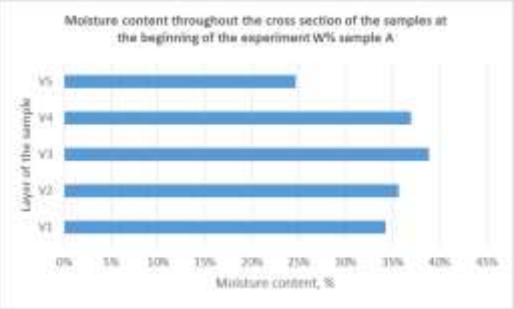
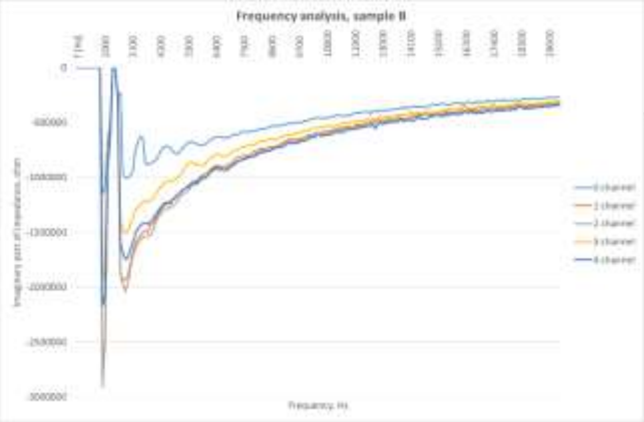


Fig.3 Initial moisture distribution throughout the cross section of sample A, %



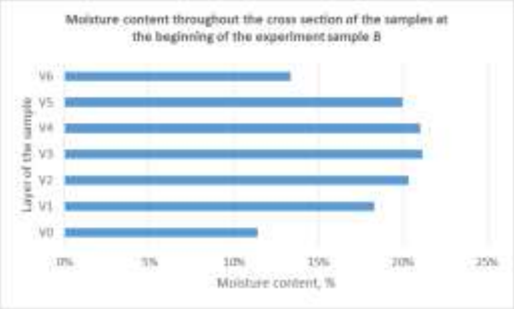
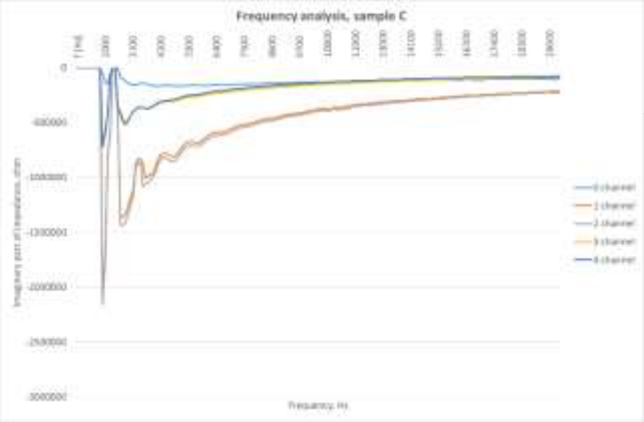


Fig.4 Results of frequency analysis for sample B **Fig.5 Initial moisture distribution throughout the cross section of sample B, %**



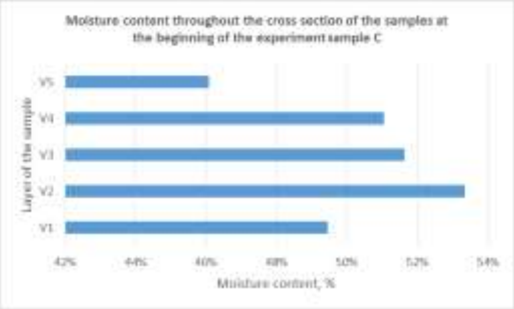
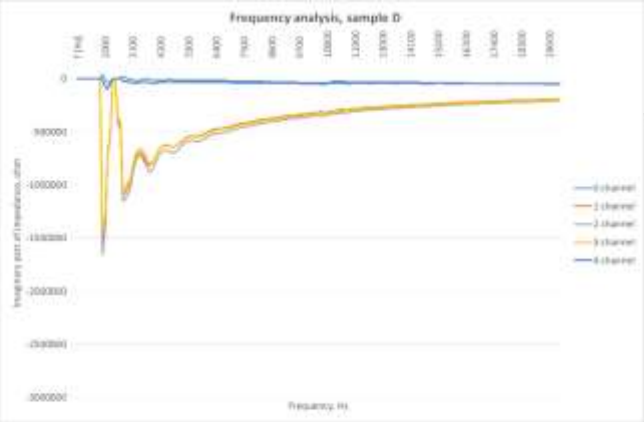


Fig.6 Results of frequency analysis for sample C **Fig.7 Initial moisture distribution throughout the cross section of sample C, %**



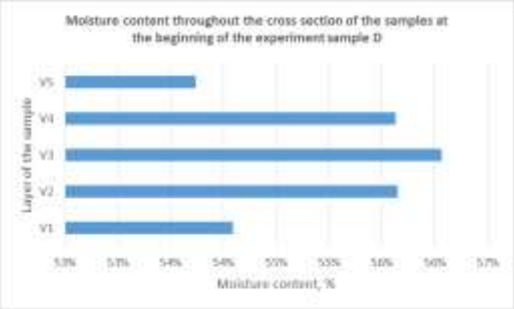


Fig.8 Results of frequency analysis for sample D **Fig.9 Initial moisture distribution throughout the cross section of sample D, %**

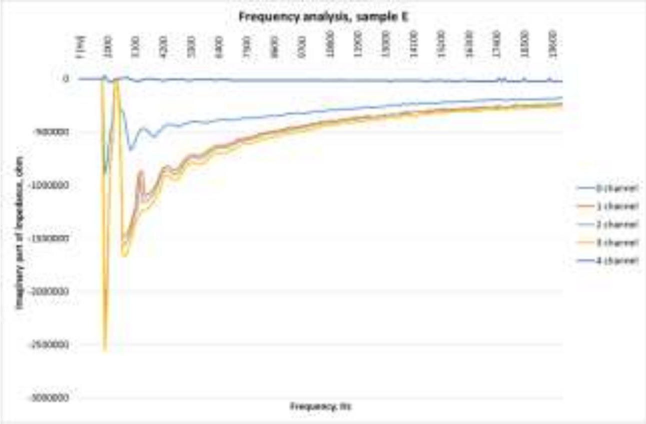


Fig.10 Results of frequency analysis for sample E

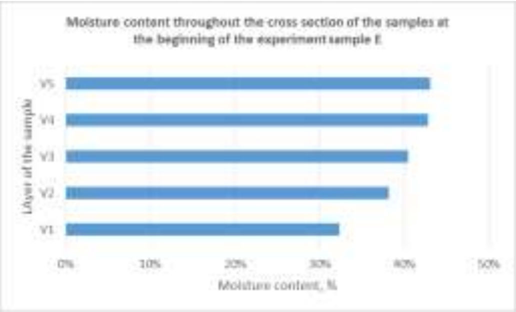


Fig.11 Initial moisture distribution throughout the cross section of sample E, %

After comparing the frequency analysis data with the information (Fig.2 – Fig.11) of moisture distribution throughout the cross section of the samples, it can be concluded that the density changes of the material, which are caused by moisture content of the porous material have significant impact on the results of frequency analysis. It can be observed that the regions of the samples with higher moisture content and thus with higher density have wider frequency ranges, which are suitable for EIS measurements. However, it should be taken into consideration that the samples with large differences of the moisture content throughout the cross section of the sample also had large differences of impedance measurement results. Therefore, the moisture distribution measurements should be performed on the specimen prior frequency analysis in order to determine initial moisture distribution throughout the cross section of the sample in relative means using an average measurement frequency of 8 kHz – 10 kHz, which has been detected as suitable for moisture distribution measurements in AAC.

3.2 Correlation between real part of electrical impedance and moisture content in AAC

When a suitable measurement frequency for the EIS measurements in AAC material has been detected it is possible to apply EIS measurements for detection of moisture distribution throughout the cross section of the AAC material. However, these measurements have only relative character if a correlation between the EIS measurement result and a moisture content of the AAC sample is not known. As it is important to be aware of the moisture content in the construction materials in absolute means, a necessity of development of correlation equations between the EIS measurement results and the moisture content of the AAC samples arise.

In order to develop correlation equations between the moisture content in AAC masonry constructions (moisture content in % upon an weight of dry mass) and the result of EIS measurement of real part of electrical impedance (ohm), a research with set of experiments has been performed.

In order to correlate values of EIS measurements with the absolute values of moisture content in cross section of the sample correlation graphs were prepared for each type of AAC samples (Fig.12 – Fig.16).

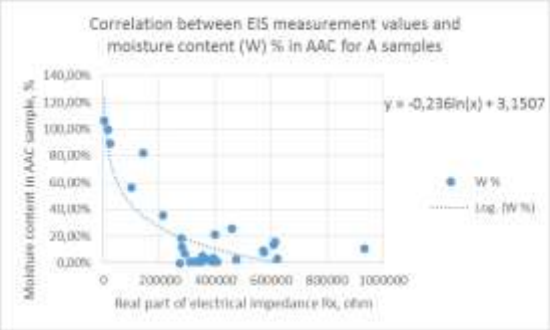


Fig.12 Correlation between EIS measurement values and moisture content of the samples of A series in %

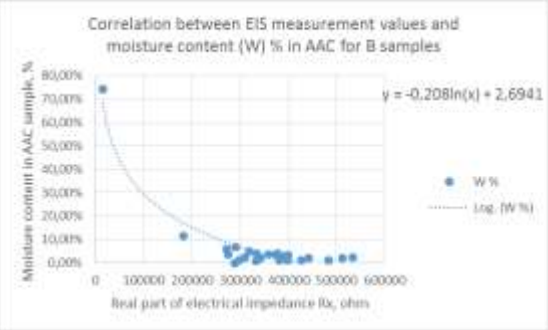


Fig.13 Correlation between EIS measurement values and moisture content of the samples of B series in %

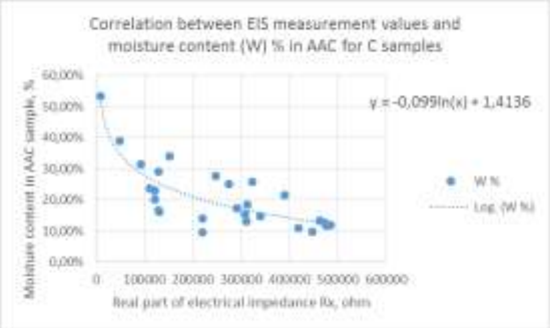


Fig.14 Correlation between EIS measurement values and moisture content of the samples of C series in %

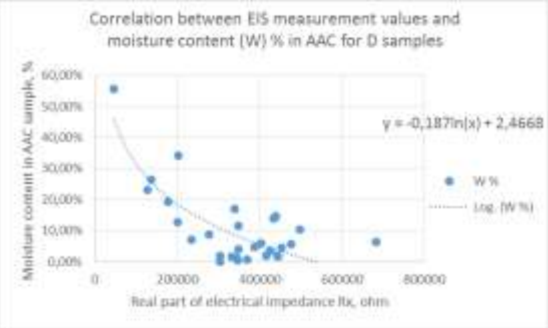


Fig.15 Correlation between EIS measurement values and moisture content of the samples of D series in %

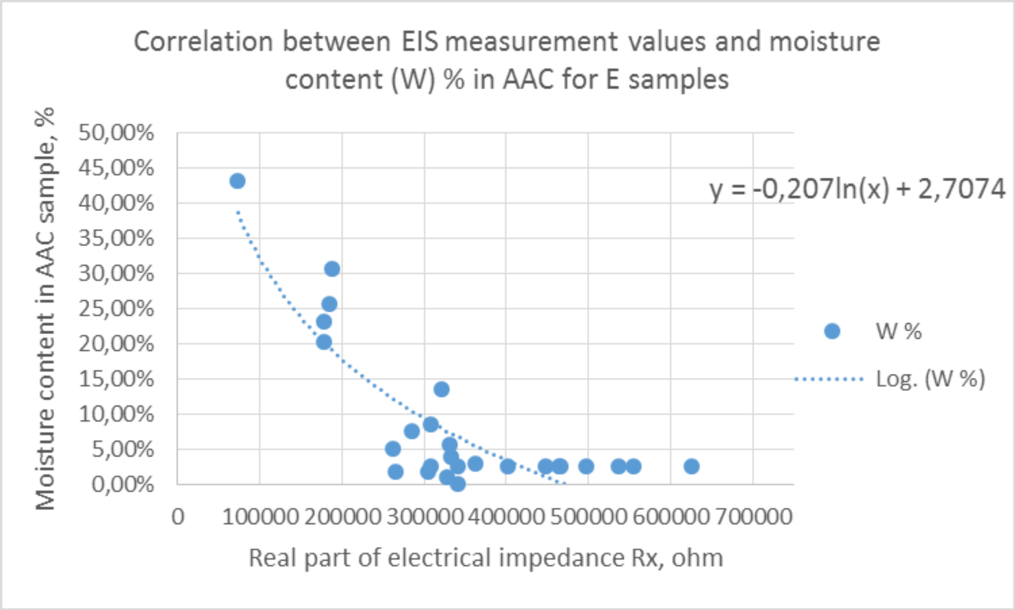


Fig.16 Correlation between EIS measurement values and moisture content of the samples of E series in %

3.3 Monitoring of moisture migration throughout the cross section of AAC masonry constructions

After the specimen were constructed the initial moisture distribution was determined by EIS. As the EIS measures the resistance values, the determination of the moisture content in the AAC material can be detected by application of correlation equations. Such correlation equation (2) between the electrical resistivity values of the respective AAC material and its moisture content has been developed by authors [7] and tested in laboratory conditions.

$$y = -0.236 \ln(x) + 3.1507 \qquad (2)$$

The EIS measurement results provided information about the initial moisture distribution throughout the cross section of the sample constructions (Fig.17 to Fig.19)

The average moisture content of the AAC blocks at the beginning of the experiment was 25% of the dry mass of AAC. The moisture distribution throughout the cross section of all specimen was even with the exception of the channel 4, where the least moisture content was observed in all specimen. This fact can be explained with the least impact of humid construction processes (e.g. finishing mortar on sample C or insulation installation mortar on samples A and B) on the internal side of the specimen construction.

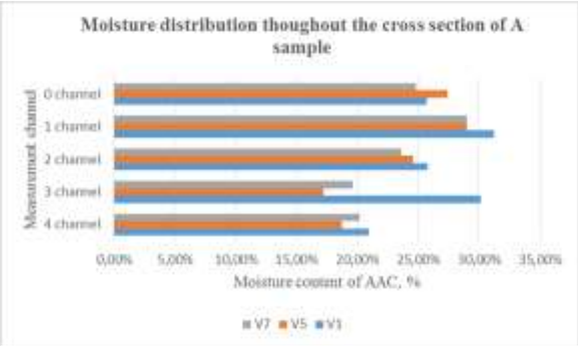


Fig. 17 Moisture distribution throughout the cross section of the A sample measurement points at the beginning of the experiment

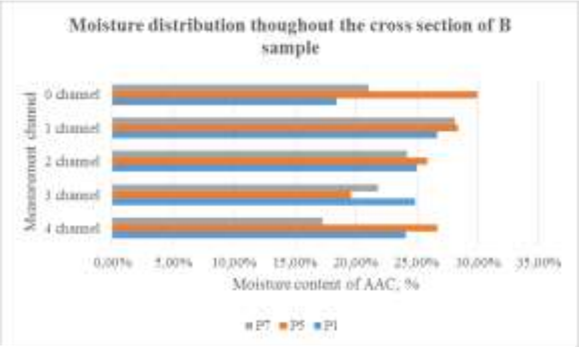


Fig. 18 Moisture distribution throughout the cross section of the B sample measurement points at the beginning of the experiment

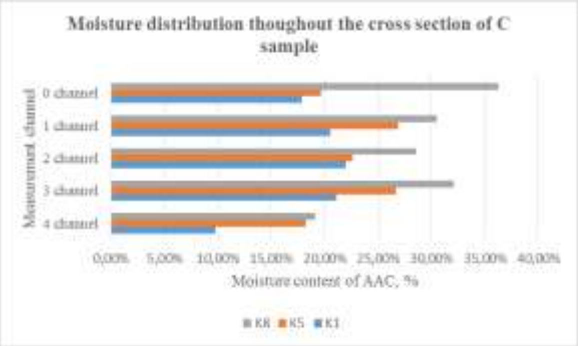


Fig. 19 Moisture distribution throughout the cross section of the C sample measurement points at the beginning of the experiment

Further, the moisture distribution changes throughout the cross section of the specimen were monitored by application of EIS measurements three times a week and certain dynamics of drying process were established for each sample construction. Fig. 20 to Fig. 22 display the changes of moisture distribution throughout the cross section of the AAC samples with different external finishing. The obtained data was merged in one surface graph for each sample and the division of the data on *x* axis allow to follow the changes of the moisture distribution throughout the cross section of the specimen during the whole period of the experiment.

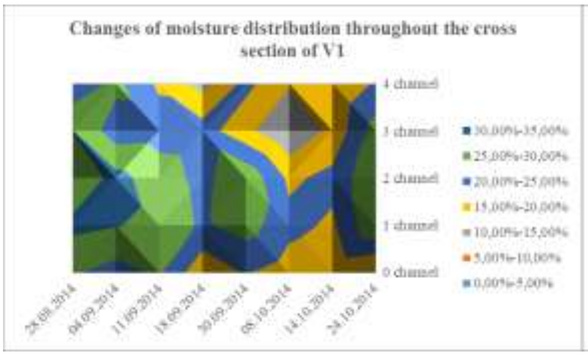


Fig. 20 Changes of moisture distribution throughout the cross section V1 of A specimen construction during the experiment

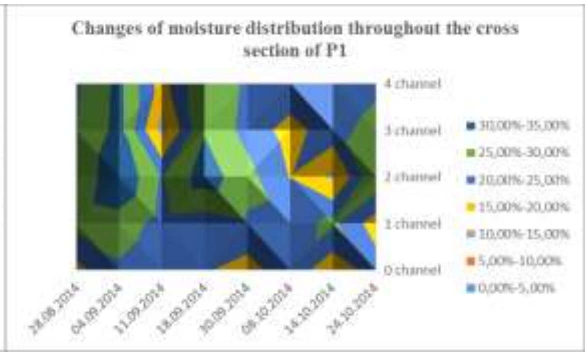


Fig. 21 Changes of moisture distribution throughout the cross section P1 of B specimen construction during the experiment

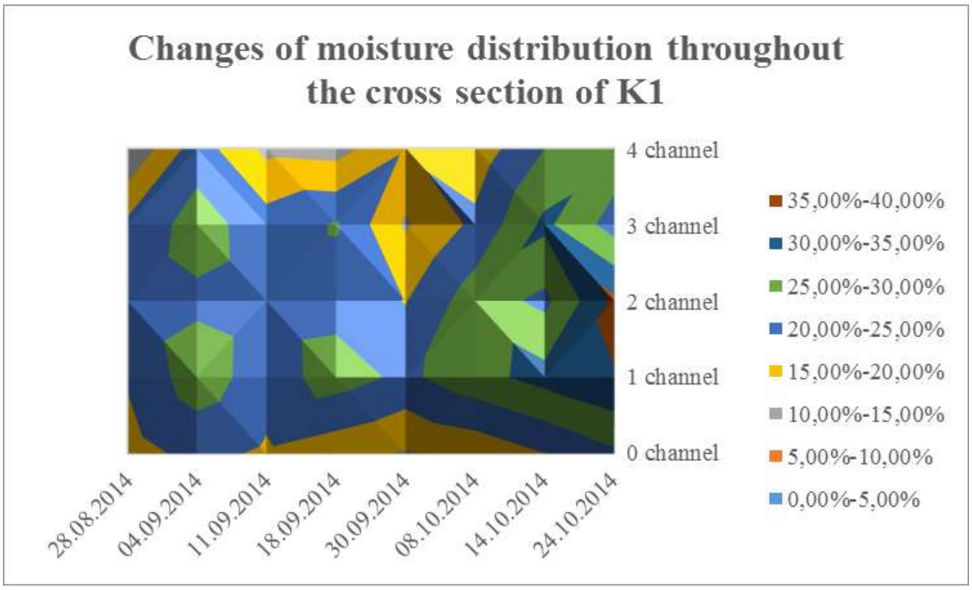


Fig. 22 Changes of moisture distribution throughout the cross section K1 of C specimen construction during the experiment

4 Conclusions

Comprehensive analysis of the results obtained during the experimental part of the research prove that the electrical impedance spectrometry can be applied on autoclaved aerated concrete masonry constructions for non-destructive measurements of moisture distribution throughout the cross section of the masonry construction. A methodology for application of EIS for non-destructive monitoring of moisture migration throughout the cross section of AAC masonry constructions with Z-meter device has been developed.

- EIS can be applied on AAC masonry constructions for non-destructive detection of moisture distribution throughout the cross section of the AAC masonry construction with average precision of 70%;
- Prior the application of the EIS on AAC masonry constructions a frequency analysis must be performed in order to detect most suitable EIS measurement frequency; for most common types of AAC in Latvian construction market the measurement frequency for EIS is 8000Hz;
- The contact surface between the measurement probe and AAC masonry construction must be as close as possible. However, the impact of the contact surface on the accuracy of the measurement results does not exceed 3% of the reference result;
- The most precise measurement results can be obtained without any contact surface covering between the measurement probe and the AAC;
- EIS measurements can be performed in any range of measurement distances between measurement probes. However, the measurement distance between probes has impact on the determination of the measurement frequency. For measurement distance range from 150mm to 300mm, which comply with measurement distance within borders of one masonry block, the most suitable measurement frequency is 8000Hz;
- Correlation equation between EIS measurement results and moisture content in AAC masonry constructions has been established. Correlation has logarithmic character and slightly differs depending on the type of AAC. The equation developed during the research is $y = a \ln(x) + C$;
- Large cracks and masonry joints have significant impact on the EIS measurement results, therefore EIS should not be applied for detection of moisture content in AAC sections with masonry joints in absolute means. However, EIS can be applied in such sections for non-destructive monitoring of moisture migration in relative means.

During the researches performed in the framework of these theses following suggestions for the improvement of the Z-meter device has been developed:

- Self-drilling measurement probes should be manufactured;
- Software update for automatic frequency analysis should be developed;
- Software of the Z-meter device should be updated with the correlation equations between the EIS measurement results of most common types of AAC and moisture content rate of AAC.

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