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Monitoring of Effectivity of Microwave Desiccation by Means of rod plug-in Antenna

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Abstract
This work describes the course of the experiment aimed to microwave (MW) desiccation of masonry by MW plug-in bar antenna applied to various types of brickwork. Experiment was carried on in the masonry manufactured from solid bricks, modern hollow brick form-pieces THERM and from aerated concrete blocks YTONG. Results of this experiment should determine what type of MW desiccation method is the best for the given material. The main criterion for this propriety was effectiveness (economical) of MW desiccation represented by massic loss of moisture.
Keywords: Microwave (MW) Desiccation, masonry, brick, plug-in Antenna, Moisture.

1. Introduction

1.1 Microwave radiation

Microwaves are electromagnetic waves occupying the area between dark heat and airwaves in the electromagnetic field. Microwaves represent high-frequency radiation from 300 MHz till 300 GHz.
In space, there is the radiation propagated from its source in waveform by light speed. That means, the electric and magnetic components of radiation are changing periodically in time. We assume a sinusoidal wave of radiation with the specific length of wave and frequency determining the wave change rate. [3]

$$\lambda = \frac{c}{f} \qquad [m] \qquad (1.1)$$

where: λ…wave length $[m]$;
c…wave propagation speed
f…microwave frequency $[Hz]$. [3]

When the microwave gets in to another material, the wave propagation speed and wavelength are changing. This appears depending on the electromagnetic characteristics of the material.

1.1.1 Source of the microwave radiation

Microwaves arise out of transformation of electric energy in generator. The generator consists of high-frequency tubes (magnetrons or klystrons accordance with the frequency). Microwaves are transported in wave-guide from the source to radiating antenna, which transfers waves in to the construction. [1]

1.1.2 Effect of the microwave radiation

For the present, there is known only one effect on biological materials and that is heat effect. Interaction microwave radiation with materials is influenced by constitution, structure and physical condition of material and by microwave's frequency and power. [2]

1.2 Masonry desiccation by means of microwave radiation

For moisture elimination are used microwaves with frequency of 2450 MHz, which comes up to wavelength of 122 mm. This frequency seams to be suitable for water heating.

1.2.1Microwave heating

Microwave heating is based on electromagnetic induction and provides warming directly in the material structure. The material is warmed from centre to the face. Is already known, that fast and economical heating are the main advantages of microwave method.

Mechanisms of transformation microwave energy to heat is described by formula:

$$P = 2\pi f \varepsilon \varepsilon'' E^2 \qquad [W.m^{-1}] \qquad (1.2)$$

where: P…. energy absorbed in volume unit [$W.m^{-1}$];

f….. frequency of microwave field [*2450 MHz*];

ε´… absolute permittivity [$F.m^{-1}$];

ε´´... leakage factor of material

E….. intensity of local electric field [$V.m^{-1}$]. [4]

1.2.2 Moisture removing

Method of moisture removing is connected with method of pest control. These methods are based on the microwave radiation with frequency of 2450 MHz working through the redeveloped construction. Subsequently, very fast change of molecular polarity occurs, which causes fast movement of loosely coupled water molecules. During the movement molecules hit, which cause heat energy. By operation of this energy, water is intensively changed into the water vapour, which evaporate out of the construction. Desiccation period of particular constructions depends on several factors (type and thickness of masonry, moisture degree, radiation intensity). [2]

In practices, there are especially two methods of microwave desiccation. (Fig. *1*.) The first one is carried out by surface funnel antenna. Non-destructive testing is the main advantage of this method. Inferior effectivity of this method is caused by reflection outside the desiccated construction. The second method of desiccation could be carried out by means of rod plug-in antenna. The antenna is established into the prebored opening in masonry and microwave energy enters the construction from its centre. Higher effectivity is indisputable advantage of this method. This method is also easily available for hollow materials. Destructive type of testing is the basic disadvantage of the method.

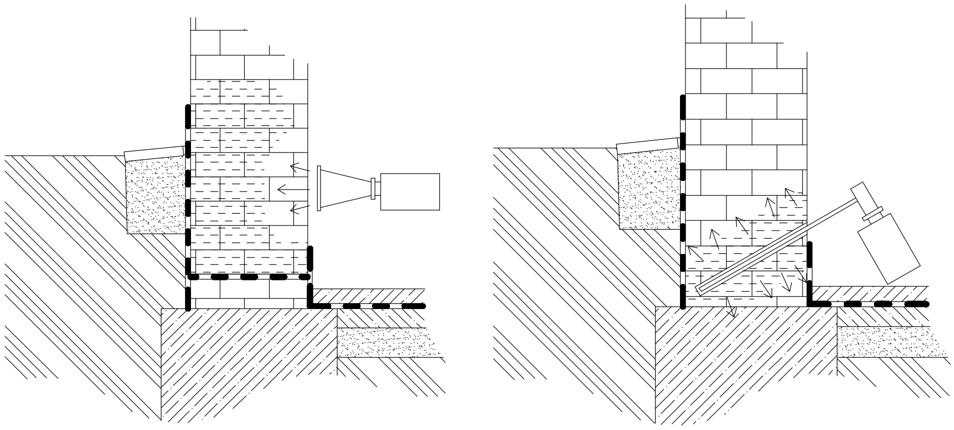


Fig.1. Microwave desiccation by means of surface funnel antenna and rod plug-in antenna [3]

2. Executed experiment

2.1. Experiment aims

The aim of the experiment was to specify the effectivity of microwave desiccation with usage of rod plug-in antenna. In experiment, there were used three types of masonry – solid brick, aerated concrete blocks Ytong and new-age hollow brick form-pieces Keratherm. Experimental results were compared by the method of standardisation with the theoretical results, which were calculated from the formula for approximate assessment of desiccation period.

2.2. Experiment character

The experiment was established on the analogy method, when the masonry was arranged in particular bricks or pillars. This method was chosen for easy manipulation with the desiccated material and better possibility to weigh samples.

2.2.1 Experiment samples:

- Pillars built up of three bricks CPP, cement-lime mortar 2,5 MPa, dimension 100x300x300 mm
- Blocks Ytong, dimension 300x250x600 mm
- New-age brick form-pieces Keratherm 44 P+D. Bricks were loaded with cement-lime mortar on its upper face to simulate bed joint and top masonry.

All samples were equipped by prebored openings, diameter of 24 mm, in which the rod plug-in antenna was situated. In pillars, which were built up of three solid bricks, the opening was prebored in to the middle brick.

Samples had been moistening in plastic pool for 96 hours. When the samples had been taken out of the pool, they were packed into the plastic film to keep the moisture.

The microwave radiator of power 1200 W had been used for samples desiccation. Samples and experiment process are shown at Fig. 2

Fig. 2. Microwave desiccation by means of microwave rod plug-in antenna

The drying process was performed with the use MW radiation and in between 240 minutes interval, which was divided into 16 drying-out 15 minutes cycles. In one cycle there was 12 minutes of drying and the 3 minutes break.

2.2.2 During the experiment there were observed these characteristics.:

- Weights of particular bricks;
- The weight decrements during the time of drying;
- Moisture content – calcium carbide method;
- Moisture content – gravimetric method;

Individual experimental values were then compared with the calculated simulation of the efficiency of MW radiation during the microwave drying-out. MW efficiency was determined individually for separate types of testes building materials, because of the proposal, that the values would vary.
In the experiment results there was used the the term „weight decrements“, that is why here written the specification: weight decrements means the decrease of the weight of the initial dried specimen in between two time-terms, in this case in the drying cycle. Let us say, the weight decrements during the determined time intervals. Because of the fact, that weight decrements are caused by moisture evaporation from dried samples, it can be considered, that they are the weight decrements of the moisture during the microwave drying-out.

2.2.3 Used measuring equipment

- Microwave dehumidifying apparatus with the smooth regulation of the power – polish company Plazmatronika: - MWD 2000 GMR 1200 (10-1200 W),
  - MW telescopic rod antenna,
- Hygrometric set Gann Hydromat CM;
- Digital scales Kern 572 DS;
- Digital scales Sartorius 500 kg;

3. Experiment results

Experiment was performed on three types of masonry, for better transparency the results are sorted according to the initial material, at the end there are listed overal results of all three investigated types of masonry.

3.1. Pillars of full burned bricks (FBB) CPP on lime-cement mortar (LCM) 2,5

The process of the experiment on the pillars made of FBB is recorded in the *Table 1)* and the diagrams *Diagram. 1. a Diagram. 2.*

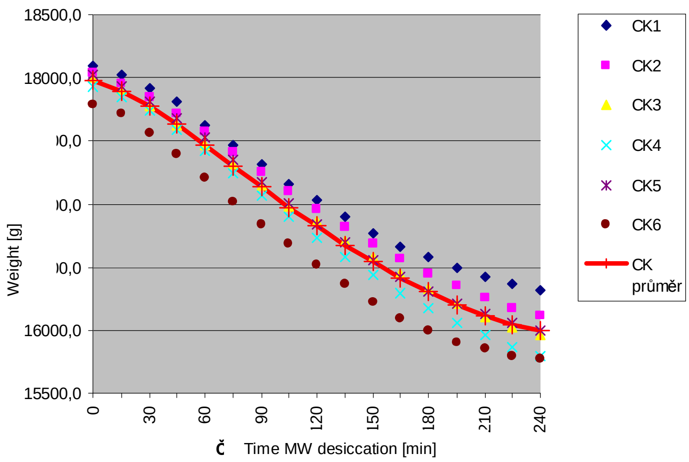


Diagram. 1. Weight decrements of the separate pillars in the time of MW drying and the curve od the mean decrease of weight of pillars during the MW drying-out made of FBB on LCM

Drying-out cycle	Adapting piece No.	CK1	CK2	CK3	CK4	CK5	CK6
	Moisture content [g]	1767,5	1847,0	1753,0	1722,5	1806,5	1726,0
Total weight decrement [g]		**1776,0**	**1916,5**	**2034,0**	**2131,0**	**2027,0**	**2023,5**
Remnant moisture after MW drying [g]		8,50	69,50	281,00	408,50	220,50	297,50

Table. 1. Weight decrements of moisture in the pillars of FBB during the MW drying

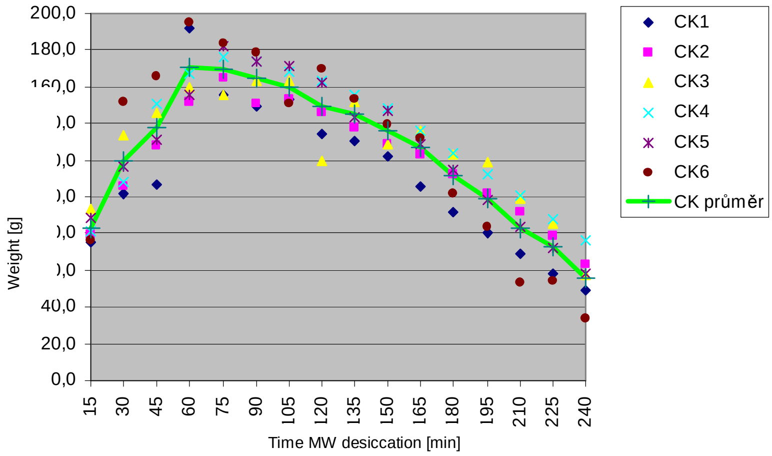


Diagram. 2. The process of decrements of moisture in the pillars of FBB during the MW dryingand the curve od the mean decrease of moisture- weight in pillars during the MW drying-out made of FBB

3.2 Porous-concrete blocks YTONG

This part of the experiment was performed on the porous-concrete blocks YTONG. In the following *Table 2.* and *Diagram 3.* and *Diagram 4.* there are listed the trends of moisture changes during the MW drying-out with the use of MW rod antenna.

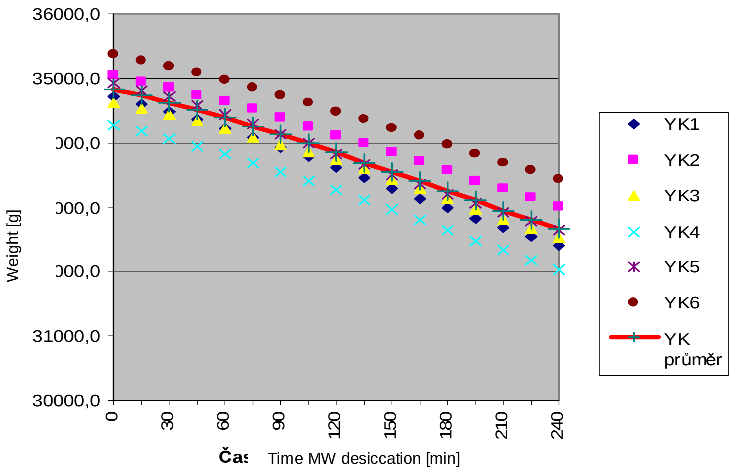
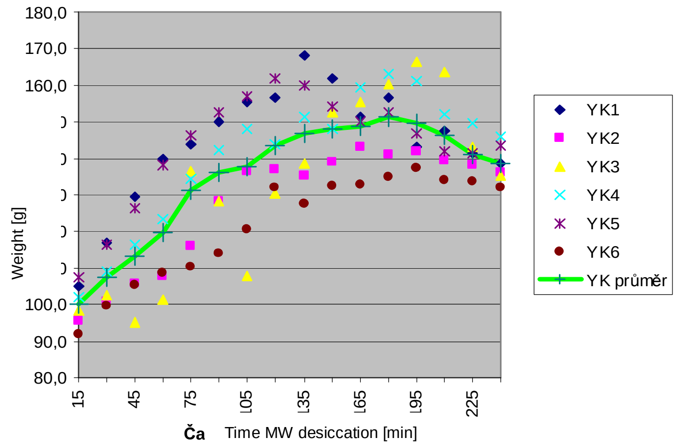


Diagram. 3. Graphic trend of weight decrements of YTONG blocks during the MW drying—out with the marked mean weight decrement

Drying-out cycle	Adapting piece No.	YK1	YK2	YK3	YK4	YK5	YK6
	Moisture content [g]	12584,5	12662,5	12764,0	12088,0	12655,5	13039,0
Total weight decrement [g]			**2042,5**	**2116,5**	**2250,5**	**2297,0**	**1947,5**
Remnant moisture after MW drying [g]			10620,0	10647,5	9837,5	10358,5	11091,5

Table 2. Weight decrements trend in YTOING blocks during MW drying-out



Diadram 4. The process of the weight decrements in YTONG blocks during the MW drying—out and the curve of the mean weight decrements in these blocks during the drying

3.3 Modern hollow ceramic brick pieces KERATHERM

The third tested materials were modern ceramic brick pieces KERATHERM. The course of testing and the partial results are stated below in the Table 3.and in the Diagrams number 3, 5 and 6.

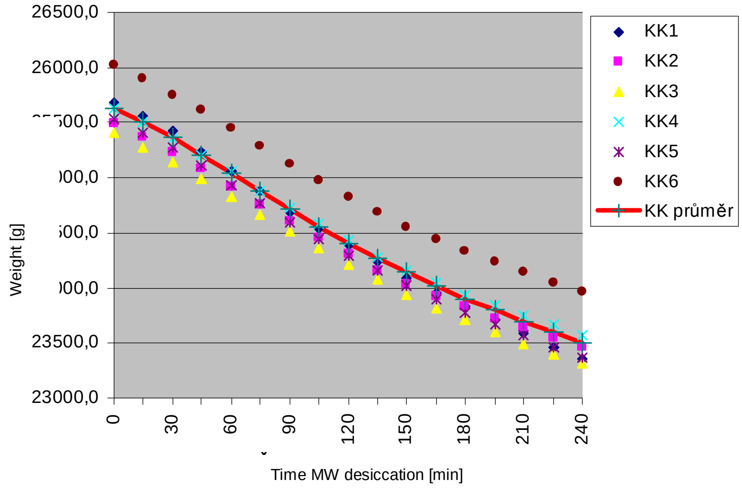


Diagram. 5. The weight decline course of the hollow ceramic brick pieces KERATHERM within MW desiccation. The diagram shows the average weight decline of the brick pieces KERATHERM within MW desiccation.

Desiccative cycle	Brick pieces indication	KK1	KK2	KK3	KK4	KK5	KK6
	Moisture amount [g]	4048,0	3798,5	3525,5	3909,0	3613,5	4241,5
Total weight loss [g]		**2334,0**	**2032,5**	**2087,0**	**2046,0**	**2167,0**	**2058,0**
Residual weight after MW desiccation		1714,0	1766,0	1438,5	1863,0	1446,5	2183,5

Table 3. The moisture weight loss course of the brick pieces KERATHERM within MW desiccation.

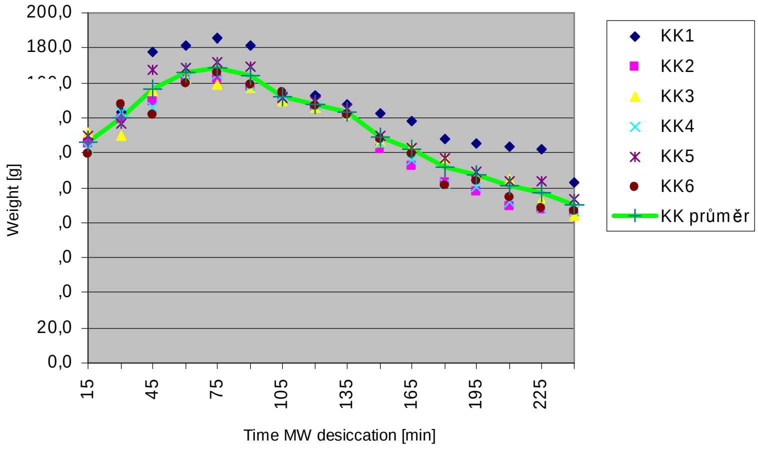


Diagram. 6. The moisture weight loss course of the hollow ceramic brick pieces KERATHERM within MW desiccation. The diagram shows the average moisture weight loss of the brick pieces within the desiccation.

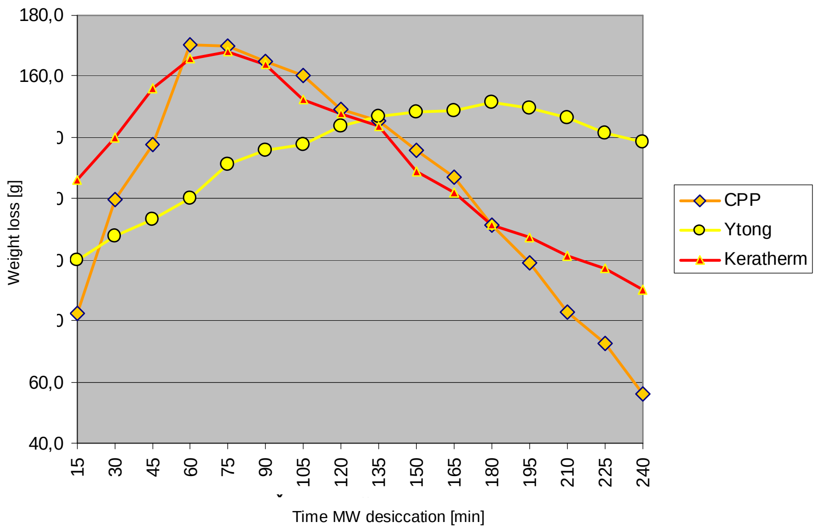


Diagram. 7 .Graphic review of the moisture weight loss in particular types of the masonry within MW desiccation.

The massic moisture of the test samples were observed within the experiment. The starting equilibrium moisture was found out by the Carbide Calcium method. The changes in moisture were determined subsequently by gravimetric method. The resulting figures are stated in the Table 4 and in the Diagram 8.

Brick pieces indication	CK	KY	KK
Equilibrium moisture [%]	3,6	2,4	2,9
Moisture after moistening[%]	14,9	60,6	21,1
Moisture loss [%]	12,7	10,0	10,0
Residual moisture [%]	2,3	50,7	11,1

Table 4. The average massic moisture of the test samples within MW desiccation.

MW desiccation efficiency was determined in particular masonry types by the mathematical simulation. The simulation assumes parity between the specific boil internal latent heat and evaporation internal latent heat at the boil temperature of the liquid. The simulation is based on the relation between the specific boil internal latent heat which is the same as the evaporation internal latent heat at the boil temperature of the liquid. The actual approximate MW desiccation output in the particular masonry can be theoretically determined from this relation.

$$P_v[W] = \frac{l_v\left[J.kg^{-1}\right].m[kg]}{t[s]} \qquad (3.1)$$

Provided that lv ……. Specific internal latent heat of water evaporation (17 °C) [$MJ.kg^{-1}$],

m …… liquid weight (weight losses) [kg],

P ……. desiccative device output (1200 W) [W],

t …….. desiccation time (720 s) [s].

The MW desiccation output could have been determined by the adjustment of the above stated relation:

$$\eta[\%] = \frac{P_v[W]}{P_s[W]}.100 \qquad (3.2)$$

provided Pv …… MW desiccation calculating output [W],

Ps …… actual output of MW desiccative device [0-1200 W],

η …… MW desiccation efficiency in the individual masonry [%].

Resulting efficiency of MW desiccation device within the experiment is to be found according to particular masonry types in the Scheme 5. The particular efficiencies in the individual cycles for each type of the masonry were averaged for the better clarity.

Desiccative Cycle	Material / Desiccation time [min]	CPP	Ytong	Keratherm
MW desiccation average efficiency [%]		**38,7**	**42,1**	**41,4**

Table 5. The MW desiccation average efficiency figures [%] in the particular masonry types within the MW desiccation time.

3.4. Results summary

The test results have confirmed the theoretic assumptions. Assumptions derived from the theoretical analysis stated MW desiccation by the plug-in bar antenna as an efficient measure in this masonry types. Resulting MW desiccation efficiency is nearly the same in all three masonry types. The weight losses or more preciously moisture weight losses in the masonry can be seen in the diagrams.

3.4.1 Solid burnt bricks masonry:

- Moisture decline - start of desiccation – slow decline,
  - course of desiccation – more rapid moisture decline,

- final desiccation phase (there is only a little amount of massic moisture left) – de-moisturizing slowly finishes and moisture losses fluctuate around zero.

Moisture decline is described in the Diagram 1

Weight losses - starting weight losses grow is relatively rapid,
- reaching the weight losses maximum values,
- slow decline of the weight losses,
-the value of weight losses fluctuates around zero at the end of the desiccation – it is a straight line

Weight losses of moisture are described in the Diagram 2.

3.4.2 Aerated concrete blocks YTONG:

- Aerated concrete blocks were moistured to very high moisture.
- Moisture decline - start of desiccation – very slow decline,
  - course of desiccation – nearly the same massic moisture declines within the whole course of MW desiccation,
  - final desiccation phase can not be seen clearly from the diagram, since the moisture value were very high in the concrete blocks. We assume that during the longer MW desiccation the moisture decline will slowly stop and the moisture losses will fluctuate around zero.

Moisture decline in the concrete blocks YTONG is described in the Diagram 3.

- Weight losses - starting weight losses grow is very slow,
  - reaching the weight losses maximum values. The losses do not differ much from the regular weight losses.
  - a very slow weight losses decline,
  - weight losses value of moisture should fluctuate around zero at the end of MW desiccation – values should creep on the level.

The desiccation hasn't been carried out to the entire dryness of the aerated concrete blocks due to its time intensity. The course of moisture weight loss is described in the Diagram 4.

3.4.3 Modern hollow ceramic brick pieces KERATHERM:

The course of MW desiccation was very similar to the course of desiccation in solid burnt bricks masonry.

- Moisture decline - desiccation start – slow decline,
  - the course of desiccation – slightly more rapid moisture decline comparing to the starting phase,
  - the final desiccation phase – the curve of moisture weight losses fluctuates around zero.

Moisture decline in the brick pieces KERATHERM is described in the Diagram 5.

- Weight losses - starting weight loss is relatively rapid,
  - reaching the weight losses maximum values caused slow fluctuation of the weight losses values,
  - slow weight loss decline,
  -during the longer MW desiccation the moisture weigh losses will fluctuate around zero.

Moisture weight losses in modern hollow ceramic brick pieces are described in the Diagram 6.

4. Conclusions

Comparing the moisture weight losses in three masonry types within MW desiccation we found out the following: the grow of moisture weight losses in the solid burnt bricks masonry is similar to the ceramic brick pieces KERATHERM. The weight losses graphic course is nearly the same and so are the weigh losses maximum values. The grow of the weight losses was very slow and the maximum values reached lower values; this comparison is described in the Diagram 7.

Other object of this experiment was MW desiccation with the use of plug-in bar antenna.

The particular MW desiccation efficiency values at the particular time for each type of the masonry were averaged for the better clarity. The experiment's result shows nearly the same efficiency of the plug-in bar antenna in the all three masonry types.

Efficiency absolute values of the MW desiccation in the individual masonry types fluctuated from 30% to 55-60%. The average efficiency values of MW desiccation with the use of the plug-in bar antenna were stated in every masonry type. The average MW desiccation values are stated in the Scheme 4. and the Diagram 7.

In order to gain more accurate values it would be necessary to entirely dry the masonry or more preciously to dry it until equilibrium moisture is gained (as it has been done in the solid burn bricks masonry).

Based on the carried out experiments we can claim the MW desiccation as fast and relatively economical method. It can be also used for the hollow ceramic brick pieces desiccation.

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