Development of the experimental stand for investigation of the drying process in moist walls

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Abstract. The paper presents development of the experimental stand for investigation of drying process in a part of a wall which consisted of about twenty bricks joined by mortar. The thermo-injection method was applied for drying. In the first stage of this method several holes are drilled in the moist wall and are used to mount heating probes. These probes supply air to holes and at the same time heat air and the wall up. Then hot air leaves the hole flowing along its boundaries and heating and drying the wall. In the second stage holes are used for impregnation of the wall with hydrophobic fluid which creates waterproof membrane. The stand was based on a precise platform balance applied to measure the variation of global moisture content in the specimen. Moreover, local variations of moisture content were measured applying TDR method. The temperature measurements were carried out using RTDs which were placed in different locations in the wall. Additionally, the IR thermography was applied to register temperature on the specimen surface. The stand was closed in an insulation chamber to decrease the impact of the surroundings. The paper contains the preliminary results of measurements which test operation of the stand.

1. Introduction

Many sources of water in building materials might be found. The rising of groundwater level, condensation of water vapour from humid air in partitions as well as atmospheric precipitations are typical examples. The existence of moisture in building materials is highly unfavourable for the building structure. Moisture changes mechanical properties of building materials, induces biological corrosion and salts decay and deteriorates properties of building thermal insulation [1-3]. Moreover, it influences on the indoor microclimate conditions as well as affects the comfort of the occupants and their health [4]. Moisture in building structures might be accumulated for a long time, especially in historical buildings [5, 6]. Due to mentioned problems, drying, waterproofing and renovation of walls are required in many buildings.

Not only in building materials drying process is of importance. Many industrial processes which use different types of porous media are struggling with this process, e.g., paper production, food processing, drug manufacturing and crops drying. Moisture transfer is also important in the clothing [7-9]. Wide range of different types of dried porous materials encountered in the industry constitutes large field for complex research of the drying phenomena. Generally, drying process might be classified in the following main groups:

- Convective drying [10-14].
Vacuum drying [14].
Microwave drying [13, 15-17].

The convective drying process is widely used particularly in the food processing for which the influence of the physical and chemical pre-treatment of products on the drying kinetics was found important [10]. Castro et al. [11] noticed that, the problem in modelling of convective drying, especially in fruits, is related mainly to availability of material properties, which may depend on the pre-treatment. These parameters should be determined experimentally. Moreover, the convective drying might be combined with the microwave or vacuum drying to obtain the higher drying ratio. It was found that the combined convective and vacuum drying attains good drying kinetic at relatively low drying temperature which depends on the product [14]. Depending on drying material, combination of these technologies allows for minimization of total drying time and for avoiding negative effects on final quality of temperature-sensitive products. The convective drying with microwave assistance was examined in [13, 16] and showed good result in increasing the drying kinetics. However, the main disadvantage of the microwave drying process is significant increase of the medium temperature, which might be harmful for sensitive products, e.g., for food, and negatively affects the final product quality [16]. The automatic temperature control during the microwave drying was proposed in [17] in order to avoid quality damage or undesirable changes of food colour and texture. The proposed microwave system kept drying rates constant in the middle stage-drying period by using the computer-aided infrared thermography system to adopt temperature levels during the process. The combined convective and ultrasound drying was also examined [16]. Although, better convection parameters and final product quality were obtained, the energy efficiency of the ultrasound was low. The ultrasound action caused the vibration effect which contributed to improve mass transfer rates. Concluding, when combining the convective drying with additional energy sources, e.g., microwave or ultrasound, an extremely important is their dosing (operation) time [16].

Convective drying is most valuable method in the case of drying of building materials and existing buildings. In this case heat and moisture transfer between flowing air and building material or structure depends on local climate conditions, e.g., on temperature, velocity and relative humidity of air [1]. In laboratory conditions the drying process of building materials was studied in free convection conditions or with low velocity forced convection in a climatic chamber [18, 19]. For high speed forced convection, special wind tunnels were built. These tunnels were of either open-flow [13, 20] or closed-loop [1, 21, 22] type. In the previous papers convective drying process was usually investigated for relatively small specimens (e.g., samples of dimensions of 3×3×3 cm [1] or 1×3×9 cm [20]) with one surface of the sample in contact with drying air [1, 20]. The whole brick placed in the wind tunnel was also investigated experimentally [21, 22]. Additionally, in [21] possibility of analysis of drying process in the part of the wall located in the wind tunnel was presented. Experiments described in the literature were conducted with air flow velocities up to 10 m/s, relative humidity in the range 10-90% and temperature up to 60°C [21, 22].

One of the methods of convective drying and waterproofing of building materials and structures is the thermo-injection method [23-27]. This method was developed in Poland in the nineties of the previous century and is based on drilling an array of holes in the wet wall with a pitch of several centimetres. In the first stage of this method special heating probes are mounted in holes. These probes supply air to holes and at the same time heat the wall and flowing air up. The hot air leaves the hole flowing along its boundaries and heats and dries the wall. In the second stage, when the moisture content of the wall is lower than 4% weight special hydrophobic fluid is injected to holes. This process creates the membrane inside the wall which is impermeable for water and prevents from rewetting of the wall [23-27].

Investigations of drying process applying the thermo-injection method were never carried out before. Therefore, this method is for the first time studied in this work. The paper presents the development of the experimental stand for the investigation of heating and drying process of the part of the wall made of several red bricks by applying the thermo-injection method. The test measurement has been carried out and preliminary results are shown and discussed.
2. Description of the experimental stand

2.1. General assumptions
The developed stand should fulfil several requirements. Main are following:
- Separation from the surroundings which will prevent the specimen from external interactions, i.e., external forced convection as well as heat and water vapour exchange.
- Measurement of temporal variation of the mass of the whole specimen.
- Measurement of temporal variation of the local temperature in several points in the sample.
- Measurement of temporal variation of the local moisture content in several points in the sample.
- Measurement of temporal variation of air parameters in the chamber and at the inlet to drying device.
- Measurement of temporal variation of energy consumption by the drying device.

![Figure 1. Simplified schematic of the experimental stand.](image1)

![Figure 2. Control and data acquisition device.](image2)

2.2. Concept of the stand
The concept of the stand is presented in figure 1. The insulation from the surroundings consisted of a supporting structure made of steel tubes, a water vapour impermeable foil made of polyethylene and a heat insulation made of mineral wool. A little higher pressure than atmospheric one was maintained inside the chamber to avoid the infiltration of ambient air. Moreover, the excess of air in the chamber was flowing out to the surroundings by openings located close to the bottom of the chamber. To ensure measurement of the variation of the total mass of the sample the platform balance (RADWAG HY10 HRP150) with high precision and resolution on the level of 1 g was used. The balance was connected to the acquisition system (see figure 2) via RS232 cable. This configuration allowed for mass variation measurement within small time intervals. Temperature variations in the specimen were measured in two ways. Firstly, the surface distribution of temperature was registered with the IR thermography. Secondly, temperature variation inside the specimen was recorded using several 4.5 mm diameter sheathed resistance temperature detectors (RTDs, PT1000) made from platinum wire with resistance equal to 1000 Ω in 0°C and with 3-wire connection – see figure 3 for locations of RTDs in the specimen. The variation of the local moisture content was measured by applying time domain reflectometry (TDR) method which is based on high frequency electric signals (E-TEST TDR/MUX/MPTS with FP/mts probe). Temperature and relative humidity of air inside the chamber as well as temperature and relative humidity of ambient air provided to the drying device were measured with use of thermohydrometers (APAR AR252). Additionally, the power consumed by the drying device was recorded by using the
power meter. All measurement devices were connected to the programmable logic controller which recorded, stored and visualized measured data as well as controlled the drying process (see figure 2).

3. Test measurement
In order to verify assumed parameters of the stand the one 40 W heating probe was placed in the specimen and used during test measurement. Air for drying process was taken by the drying device from the room where the stand was located without any conditioning before providing it to the probe.

3.1. Specimen preparation
The specimen was built as the part of the wall which consisted of 21 ceramic red bricks joined by mortar with approx. 81.5 kg of dry mass. The schematic structure of the specimen is presented in figure 3. In the middle of the specimen 20 cm depth and 20 mm diameter hole was drilled and then the heating probe was placed inside it. Additional four drillings, around drying hole, of 10 cm depth and 4 mm diameter each were prepared for RTDs. Moreover, for measurement of the local moisture content four drillings of 5 cm depth and 4 mm diameter each for the TDR detector were made close to the highest and lowest location of RTD holes. The considered building structure was conditioned in the surrounding for one month to obtain the proper mortar binding. After this period the specimen was fully submerged in water for another month. Shortly before measurement the considered building structure was removed from water and covered with water and water vapour proof foil made of polypropylene. Mass of absorbed water was equal to approx. 11.1 kg which correspond to moisture content of 13.5% weight. The foil covered all sides except the side with drillings. Free spaces between surface of holes and measurement probes were filled up with a mixture of brick powder and water. Subsequently, the building structure was positioned on the platform balance and measurement began. The photography of the part of the wall with heating and measurement probes is shown on figure 4.

3.2. Results of test measurement
Temperature variations in four points in the wall (i.e., T3, T4, T5 and T6 – see figure 3) registered by RTDs during test measurement are presented in figure 5. Slightly lower temperatures registered by T3 and T6 detectors than by T4 and T5 ones were caused by larger distances from drying hole of T5 and T6 probes than T4 and T5 ones. In the first stage of the drying process rapid drop of temperature registered by all RTDs was observed. This effect was caused by the intensive evaporation of water from the surface of the specimen to the air in the chamber. The specimen before the beginning of the
measurement was saturated with water and then shortly after removing from the water bath was mounted on the stand. Next, the specimen temperature increased slowly and after approx. 40 h of the drying process the temperature again started to decrease to saturation parameters in the drying material – the second stage of drying began. This second decrease of temperature corresponded to the evaporation of water contained deeper inside the specimen. After approx. 60 h of the drying process the temperature started rising slowly. Temperature fluctuations observed in the second stage of the drying were effects of variation of parameters of the ambient air used as drying medium. The change of the total mass of the specimen and the local relative moisture content (defined as a ratio of current to initial local moisture content) are presented in figure 6 and 7, respectively. The moisture lost rate is monotonic through the whole measurement. This is a consequence of using of only one heating probe for which the continuous evaporation of liquid moisture in different parts of the sample occurred through the whole measurement. The change in the local moisture content corresponded to the change in the local temperature what was especially visible during the first several hours of the process when rapid evaporation from the surface took place and the TRD probe registered sudden drop of the local moisture content. Because of only one heating probe was applied the specimen was not fully dried and process was stopped after 150 h. In practise, during drying of real masonry walls by applying thermo-injection method the heating probes are mounted densely with horizontal pitch of approx. 10 cm.

![Figure 5. Temporal temperature variations in the specimen measured by RTDs.](image1)

![Figure 6. Lost of moisture mass in the specimen in time.](image2)

![Figure 7. Variation of local relative moisture content measured by TDR close to T5 hole.](image3)
Figure 8. Thermograms showing temperature distribution on the surface of the specimen for different time instants during drying process (minimum and maximum on the scale are 25°C and 35°C, respectively).

Figure 8 presents contours of temperature on the surface of the sample during measurement. Infrared camera was positioned 1 m from the specimen surface. The specimen surface emissivity was assumed equal to 0.95. The first stage of drying in which surface evaporation was dominating is presented on thermograms which corresponds to time instants of 0 and 18 and 43 h of the drying process. In the second stage drop of surface temperature caused by evaporation of water in deeper parts of the specimen is presented on thermograms which corresponds to time instants of 50 and 100 and 150 h of the drying
process. The brightest point on thermograms corresponded to the heating probe surface which was at temperature equal approx. 80°C.

4. Conclusion
The paper presents development of the experimental stand for measurements of drying process in the part of the wall which was made of several bricks. The stand in the form of the chamber with the specimen inside with one hole for placing the heating probe was build and equipped with platform balance, several RTDs and TDR probe. The test measurement was carried out and the results obtained led to the following conclusions. Better controlling of the drying process is required to eliminate fluctuations of the specimen temperature. This might be achieved by the stabilisation of air parameters (i.e., temperature and relative humidity) inside the chamber and at the inlet to the drying device. Moreover, number of holes and heating probes in the specimen should be increased to intensify drying process and reduce time of measurements. This action should be accompanied with increase of the number of RTDs and TRD probes. In addition, the effect of surface evaporation should be eliminated or controlled by conditioning the specimen, after removing it from the water bathing, in controlled conditions before the start of measurement. After proposed modifications of the stand and measurement procedure, the stand will be applied in the process of validation of mathematical and numerical models of heat and moisture transfer in porous building materials which are currently under development [28, 29].

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