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Design and applications of a climatic chamber for in-situ neutron imaging experiments

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Abstract

Due to the high sensitivity for hydrogen, the detection and quantification of moisture and moisture transport processes are some of the key topics in neutron imaging. Especially when dealing with hygroscopic material, such as wood and other porous media, it is crucial for quantitative analyses to know and control the ambient conditions of the sample precisely. In this work, a neutron transparent climatic chamber is presented, which was designed and built for the imaging facilities at the Paul Scherrer Institut (PSI), Villigen (CH). The air-conditioned measuring system consists of the actual sample chamber and a moisture generator providing air with adjustable temperature and relative humidity (%RH) (up to a dew point temperature of 70°C). The two components are connected with a flexible tube, which features insulation, a heating system and temperature sensors to prevent condensation within the tube. The sample chamber itself is equipped with neutron transparent windows, insulating double walls with three feed-through openings for the rotation stage, sensors for humidity and temperature. Thermoelectric modules allow to control the chamber temperature in the range of -20°C to 100°C. The chamber allows to control the climatic conditions either in a static mode (stable temperature and %RH) or in dynamic mode (humidity or temperature cycles). The envisaged areas of application are neutron radiography and tomography investigations of dynamic processes in building materials (e.g. wood, concrete), food science and any other application necessitating the control of the climatic conditions.

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Keywords: Neutron imaging; in-situ experiments; climate controlled sample chamber

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1. Introduction

Qualitative and quantitative investigations on the moisture content and its changes over time are one of the important topics which are studied using neutron imaging methods. The examined materials and questions are manifold and range amongst others from porous building materials such as concrete, asphalt, stone or timber (Poulikakos et al. 2013, Zhang et al. 2011, Dewanckele et al. 2014, Sedighi-Gilani et al. 2012) over the water content of fruits (Defraeye et al. 2016) to the behaviour of canvas used for paintings (Boon et al. 2015). As most of the studied materials are hygroscopic, the ambient climatic conditions are crucial for the interpretation. So far, for many experiments carried out at PSI only the temperature and relative humidity could be documented but in many cases not controlled in a proper way. For several experiments, first attempts to control the climate were successfully carried out using provisional solutions (Mannes et al. 2009, Hendrickx et al. 2016), nevertheless these were no permanent reliably reproducible solution unlike the permanent installation, which is available at the NIST imaging facility (Hussey et al. 2010). To overcome this issue, a dedicated climate controlled in-situ measurement system was constructed and built for the neutron imaging facilities at PSI.

Nomenclature

PTFE	Polytetrafluoroethylene
PSI	Paul Scherrer Institut
RH	relative humidity in %rh
ROI	region of interest
ΔT	temperature difference achievable compared to ambient temperature in K

2. Methods

The system for the control and regulation of climatic condition, i.e. temperature and relative humidity (RH), consists of three components: a neutron transparent sample chamber, a vapour/moisture generator and a connecting tube. The experimental chamber as well as the moisture generator can also be used separately for experiments or preconditioning and storage of samples. The experimental chamber features automatic temperature control, the moisture generator produces an air flow with a defined temperature and moisture content; the connecting tube transports the moist air from the moisture generator to the experimental chamber assuring that any condensation within the transporting tube is minimised. In normal (i.e. combined) operation all three components are electronically connected and controlled by a computer using a LabView based interface.
In the following the three components will be described in detail.

2.1. Sample chamber

The sample chamber is designed to fit the medium-sized detector system (“Midi-Box”) used at the neutron imaging facilities at PSI featuring a maximum field-of-view of 150 mm x 150 mm (Kaestner et al. 2011). The design of the experimental chamber follows the dimensions of the indicated setup as the neutron transparent windows in the front and back side of the chamber fit these dimensions. The inner dimensions of the actual measuring chamber are 160 x 160 x 160 mm^3. Figure 1 shows a detailed drawing of the sample chamber.

The walls of the chamber are built as a multi-layered sandwich construction. The innermost layer consists of 1 mm thick borated aluminium fixed at a distance of 20 mm on copper plates, which differ in thickness from 10 mm on the lateral sides to 5 mm on top and bottom. The borated aluminium, which can also be found on the front panel around framing the neutron transparent window, reduces the irradiation and thus activation of the copper chamber as well as capture of neutrons scattered by the sample. The copper cuboid is covered by a 30 mm thick aerogel insulation layer wrapped in neoprene. This insulation layer is finally enclosed by a 1.5 mm aluminium cladding serving as protection against mechanical damage and fixation point for external components. The front and back panel of the experimental chamber show similar composition with exception of the neutron transparent windows,