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Adsorption and film forming of train of water droplets impacting porous stones

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ABSTRACT
The phenomenon of droplets impacting porous media is ubiquitous in rain events. Rain is a major source of moisture in buildings. When a water droplet impacts a permeable surface, it spreads on the surface and is absorbed into the porous material due to capillary action. This paper presents an experimental investigation of the absorption and film forming during train of liquid droplets impacting porous stones, towards establishing the fate of rain droplets during rain events.

KEYWORDS
Rain water droplet, porous materials, impact, absorption, film forming.

INTRODUCTION

The phenomenon of drop impacting porous media is ubiquitous in nature and is associated with mechanisms found in various industrial applications. Rain is a major source of moisture in buildings and a main agent of degradation.

When a liquid droplet impacts a permeable surface, it spreads on the surface and is absorbed into the porous material due to capillary action. The spreading behavior of the impinging droplet on the surface is known to depend on the properties of the liquid, i.e. density, viscosity and surface tension, impact conditions such as drop size and impact velocity, and the surface wettability and roughness (Lee et al. 2016a). In porous media, absorption is governed by both the properties of the liquid and of the porous medium, i.e. porosity, pore size, wettability (Lee et al. 2016b). Once the deposited droplet is completely depleted from the surface, the liquid further redistributes within the porous medium due to capillary forces, while evaporation occurs at the surface (Reis et al. 2003). In case of saturation of the porous medium, the remaining water lies at the surface in a pool, and, in the event of further impacts, a water film can build up.

For a better understanding of the absorption process inside porous media, observing directly the liquid content redistribution in the porous medium is required. Absorption in porous media has been studied with several non-destructive techniques, namely X-ray, neutron and gamma-ray radiography, magnetic resonance imaging (MRI) and nuclear magnetic resonance, and destructive techniques.

In this study, we aim to capture the full deposited droplet contact area, absorption and film forming process of trains of impinging droplets on natural porous stones by using neutrons as the means of investigation. Neutron radiography allows visualizing the moisture content distribution in porous stones. During the experiments, we measure the mass of deposited water to validate the neutron measurements. The deposition and absorption process of trains of impinging droplets is continuously characterized during deposition, absorption, evaporation and redistribution. We provide the total mass in/above the stone and moisture distribution, in a time-resolved manner.

METHODS

Samples

Three stones with varying porosity and uptake characteristics are selected: two sandstones (Meule and Bentheimer) and one limestone (Savonnières), Figure 1. The porous stones are cut in cubes of 20 x 20 x 10 mm3 for characterization and drop impact tests.

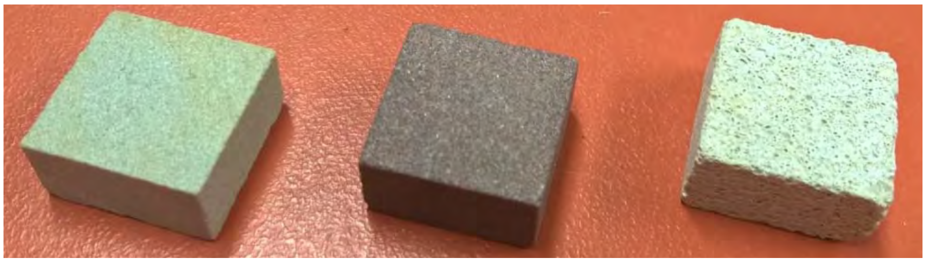

Figure 1. Photos of Bentheimer (left), Meule (center) and Savonnières samples.

Water droplet generation

Water droplets are generated at the flat tip of a needle by pushing a syringe pump. The droplets have an initial diameter of 2 mm. When the droplet is released, it accelerates by gravity reaching an impact velocity of 0.5 m/s, 1.0 m/s and 3.0 m/s, and the rates are varied to 4, 8 or 16 drops per minute.

Neutron radiography

The absorption process into the porous stone is captured by neutron radiography. In a nutshell, neutrons are attenuated by the hydrogen of water, but penetrate the porous stone, and then activate a scintillator which is photographed by a camera.

The experiment for the absorption of drop impact is performed at the NEUtron Transmission RAdiography (NEUTRA) beamline of the Paul Scherrer Institut, Villigen, Switzerland. The NEUTRA beamline is operated with neutrons within a thermal spectrum (Lehmann 2008). The necessary exposure time for each image is 3 seconds and the nominal spatial resolution of the neutron radiography is 47.2 µm/pixel. Figure 2 shows a schematic overview of the neutron beamline and the experimental setup for drop impact.

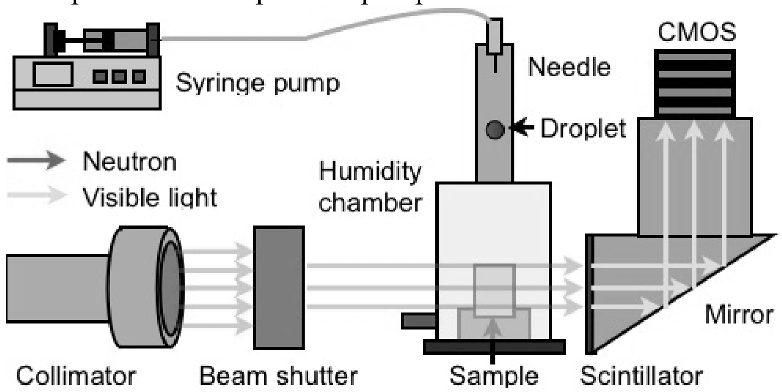

Figure 2. Schematic of experimental setup at NEUTRA beamline configuration.

Using Beer-Lambert law, the variation of attenuation of the neutron beam yields the moisture content, further details on image analysis and post-processing can be found in (Sedighi Gilani et al. 2012). Figure 3 shows the comparison between mass obtained from neutron images and deposition.

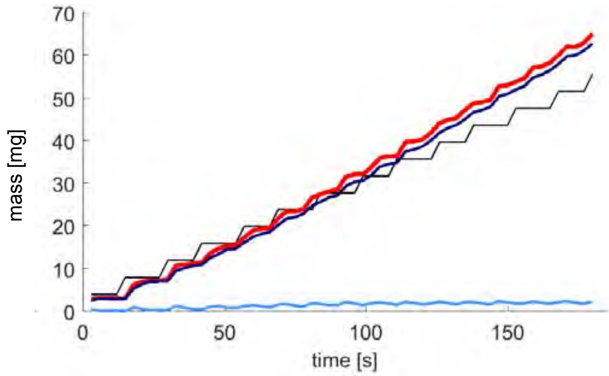

Figure 3. Validation by comparing total mass (mg) versus time comparing the total mass from neutron imaging (thick red) with actual water mass deposited (thin black). Total mass of water resting on the stone in blue, in the stone in dark blue.

RESULTS

We present here only the results for Savonnières but results of all 3 stones are presented at the conference. In general, the uptake is faster for Savonnières with more water in the stone and less on the surface. The other two stones undergo less moisture uptake in the same time and hence the surface water pool appears earlier and develops more.

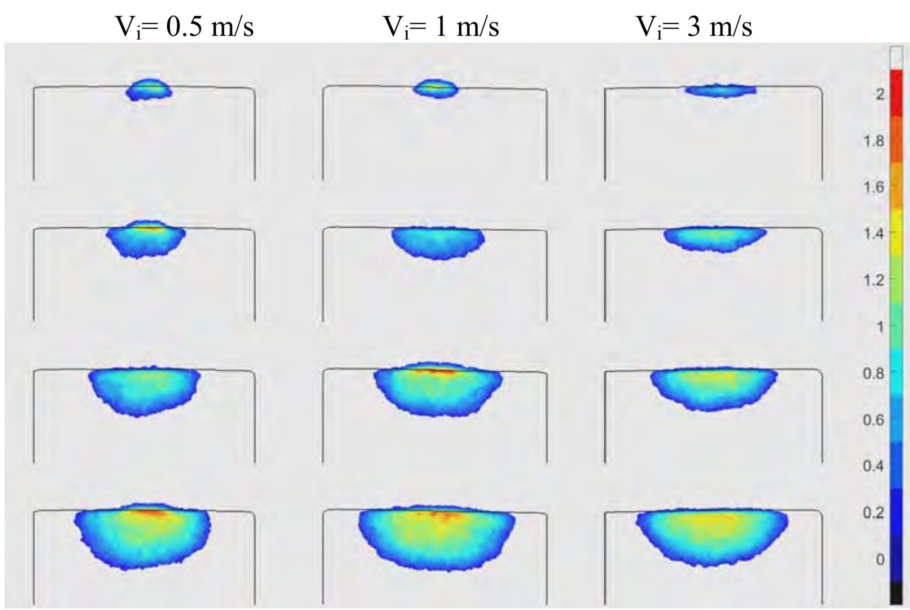

Figure 4. Moisture content (in thickness (mm) per pixel) for train of water droplets on Savonnières at the rate of 4 drops per minute for three impact velocities from top to bottom after 3, 33, 93 and 180 seconds.

In Figure 4, moisture content distribution is given after deposition of 1, 3, 7 and 13 droplets for three impact velocities. Absorption occurs from the deposited droplet into the steones via the contact area, With time, water is transported in the stone further and further from the point of impact. In time water distribution has an elliptical shape that is quite independent from the impact velocities, as, by that time, the contact area is similar in all these cases.

Figures 5 and 6 provide moisture content profiles versus time above and below the stone surface, taken at the center of the droplet and right below/above the surface respectively. Faster droplet rate leads to the development of water accumulation and thus water pool and film on the surface.

F= 4 drops/s F= 8 drops/s F= 16 drops/s

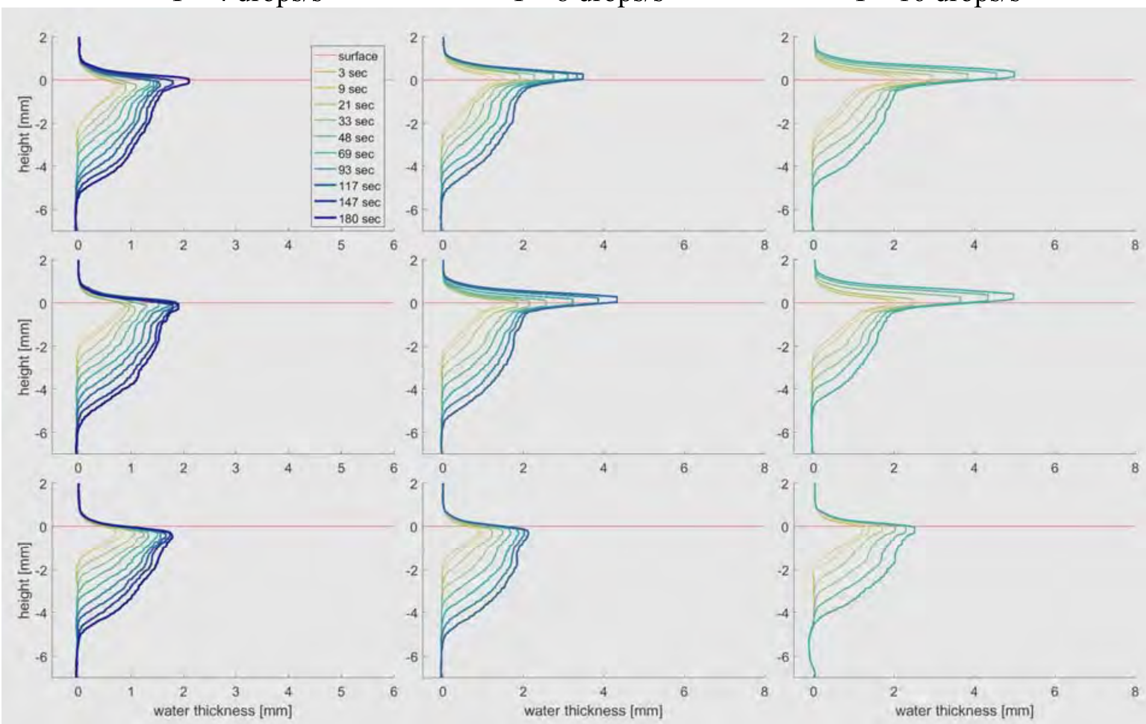

Figure 5. Vertical moisture content profiles for train of water droplets on Savonnières at the rate of 4, 8 and 16 drops per minute for three impact velocities from top to bottom of 0.5, 1 and 3 m/s. Pink line represents the stone surface.

Droplets spreading on the surface depends on impact velocities. Then, water is transported in the stone further and further from the point of impact. In time water distribution has an elliptical shape that is quite independent from the impact velocities. Faster droplet rate leads to the development of water accumulation and thus water pool and film on the surface. Film forming is found to be dependent on both transport properties and saturation degree of the stones. Moisture distribution within the porous stones, which are here all rather isotropic, is found to be dependent on impact velocity and thus of maximum spreading, for the first droplets of the train. Afterwards, the pooling of water yields similar moisture distribution.

CONCLUSIONS

This paper presents an experimental investigation of absorption and film forming during trains of liquid droplets impacting porous stones. Neutron radiography is used to quantify moisture absorption in three natural stones of varying porosity and moisture uptake characteristics. Film forming is found to be dependent on both transport properties and saturation degree of the stones. Moisture distribution within the porous stones, which are here all rather isotropic, is found to be dependent on impact velocity, and thus maximum spreading, for the first droplets of the train. Afterwards, the pooling of water yields similar moisture distribution. This experiment provides very detailed information of rain droplet absorption and redistribution in porous materials and can be used in conjunction with rain deposition modeling to understand the fate of water with the built environment.

F= 4 drops/s F= 8 drops/s F= 16 drops/s

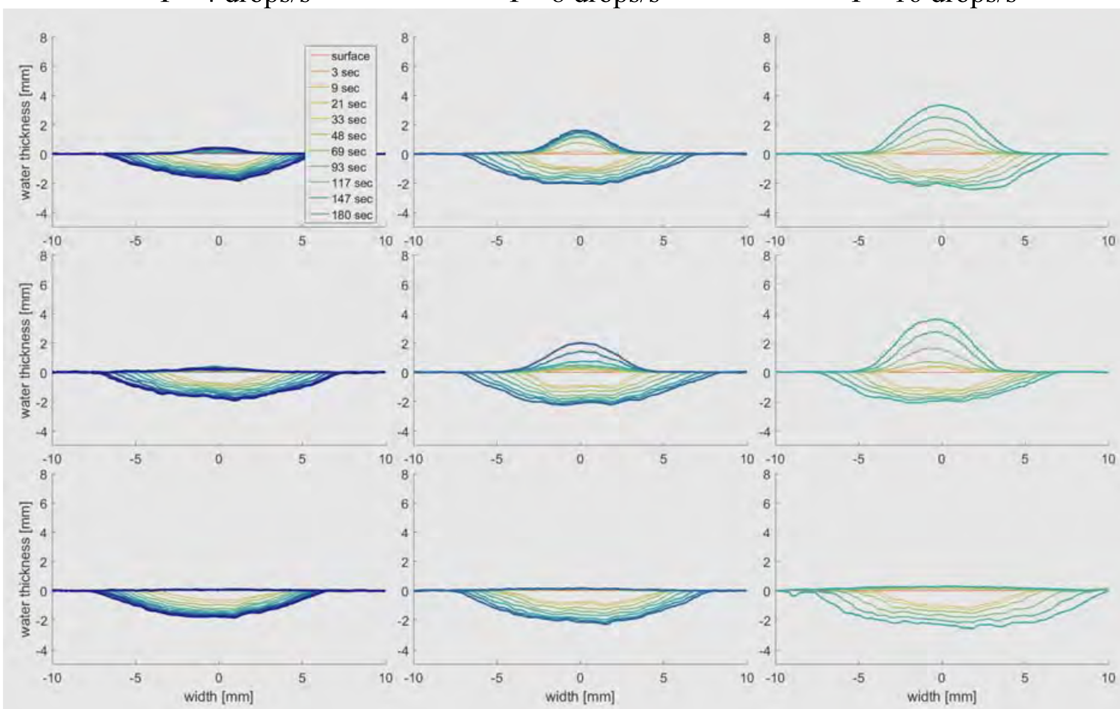

Figure 6. Horizontal moisture content profiles above and below the contact line for train of water droplets on Savonnières at the rate of 4, 8 and 16 drops per minute for three impact velocities from top to bottom of 0.5, 1 and 3 m/s.

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