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High-speed neutron tomography of dynamic processes

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Abstract

The study of fluid flow in porous media is of great importance to petrology, archeology, geology, etc. Different techniques have been developed such as visual inspection or radiography with X-rays or neutrons. The latter are particularly well suited because of the high neutron cross-section of hydrogen. This results in good contrast for water or organic fluids while being able to penetrate the bulk relatively easy. This article describes a high-speed tomography setup that enables the visualization of such phenomena in 3D instead of the classical 2D radiography. It was developed at the Ghent University (Belgium) and installed at the high-flux Neutrograph beamline at the ILL in Grenoble (France). For each tomography 100 projections of 320 × 240 pixels were taken at a rate of 10 frames per second, i.e. 10 s in total. This allows one to image dynamic processes that are slow compared to the measuring time. The samples studied in this experiment were mostly natural porous rocks commonly used in historical monuments. To protect these against degradation by water, much research is done on treatments with products such as consolidants and water repellents. The penetration of these products was successfully studied, as well as the resulting effects on the uptake of water. Other possible applications are transport mechanisms in soils, oil spills, wood, etc. All these are currently studied mostly in 2D. Expanding this to 3D can offer a clearer insight into these phenomena.

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Keywords: Neutron; Radiography; Tomography; Dynamic; Porous; Fluid; Water

1. Introduction

The study of fluid flow in porous media is of great importance to petrology, archeology, geology, etc. Different techniques have been developed such as visual inspection or radiography with

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X-rays or neutrons [1–3]. The latter are particularly well suited because of the high neutron cross-section of hydrogen. This results in good contrast for water or organic fluids while being able to penetrate the bulk relatively easy. The study of dynamic phenomena is generally limited to two dimensions. This article describes a high-speed tomography setup that enables the visualization of such phenomena in 3D on a timescale of 10 s. The setup was developed at the Ghent University (Belgium) and installed at the high-flux Neutrograph beamline at the ILL in Grenoble (France).

2. The setup

A key factor in achieving a high-speed setup is of course a high-intensity neutron beam. The Neutrograph beamline [4] at the ILL 58 MW research reactor (Grenoble, France) offers one of the most intense neutron beams in the world. It delivers a thermal neutron flux of $2.9 \times 10^9\,\mathrm{n/cm^2/s}$ and a fast flux of $2 \times 10^7\,\mathrm{n/cm^2/s}$. It has a mean L/D of about 120 and a useful beam area of $20 \times 16\,\mathrm{cm^2}$, making it ideally suited for high-speed applications requiring average resolution.

The actual setup is shown in Fig. 1. The neutron beam arrives from the right. The imaging system is based on a PCO Sensicam VGA CCD camera [5] with a resolution of 640 × 480 pixels, a dynamic range of 12 bit and it is Peltier cooled to −12 °C. The camera is lens-coupled to a ^{6}LiF/ZnS scintillator with a thickness of 420 μm from Applied Scintillation Technologies [6]. Its emission around 460 nm matches well with the spectral sensitivity of the CCD. Being Li-based it has both a high neutron cross-section and a low gamma sensitivity. Still the light path is bent over 180° using two mirrors to avoid gamma radiation hitting the CCD directly, thus causing bright spots. To collect the maximum amount of light from the scintillator, the light path was kept as short as possible (65 cm) and a fast 50 mm/*f*1.4 Nikkor lens was used at maximum aperture.

Everything was placed inside a light-tight box to avoid spurious exposure of the CCD. About 20 cm of lead was placed around and above the camera to shield it from gamma radiation. Exposed surfaces were covered with boron sheets to avoid activation by scattered neutrons.

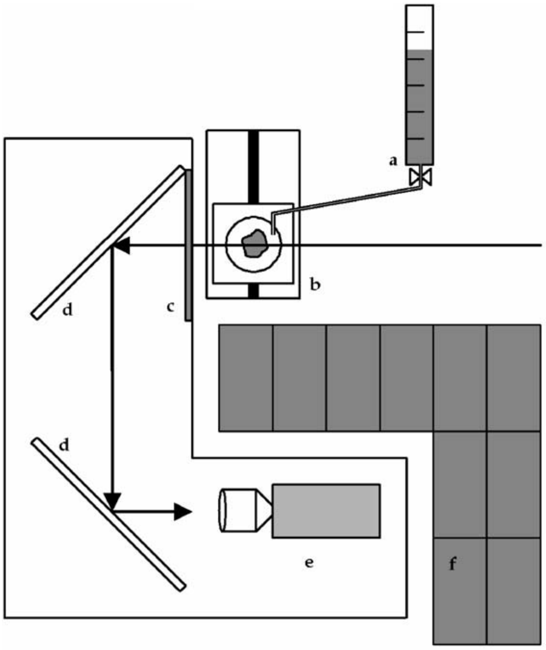

Fig. 1. The setup: a, fluid reservoir, valve and pipe; b, motor stage; c, scintillator; d, mirror; e, camera + lens; f, lead shielding.

To control the fluid supply to the samples, a remote-controlled proportional valve was connected to a reservoir holding the fluid under study and was placed beside the sample. The fluid was guided through a thin aluminum pipe to a position near or above the sample where it could be released as needed. The proportional valve allowed for excellent control over the flow rate and volume. The valve was regulated using an analog output board.

The motor stage was placed as close as possible to the scintillator to minimize geometric blurring due to the relatively high divergence of the beam. Depending on the size of the sample, the rotational axis was between 3 and 5 cm away from the scintillator. The samples had to be placed in a dish to hold the fluid. Consequently, this dish is present in all radiographs. Therefore the dish was made from aluminum to make it virtually invisible as shown in Fig. 2. The vertical edges of the dish cover the bottom quarter of the stone.