IMAGINE: A NEW COLD NEUTRON IMAGING STATION AT LLB

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Technical specifications

IMAGINE (Fig.1) is located in the neutron guide hall on a cold neutron guide. The guide cross section is 25 mm x 50 mm and delivers cold neutrons with 3Å <λ<20 Å. The spectrometer sits on a marble floor and the detector position can be easily moved up to 10 m from the source allowing L/D = 400. In a typical configuration (FOV = 80 mm, source 20 mm diameter, L = 4m), the flux is 2x107 neutrons/s/cm². In the present state, a sCMOS camera (from Photonics Science) coupled with various scintillators (50 - 100 µm thickness) is used for the data acquisition. The sample is set on a table which allows up and down movements together with a 360° sample rotation for tomographic measurements. The table can accept loads above 100kg. A concrete casemate is after the pin-hole gives access to a velocity selector or a chopper. Various sample environments are (or will) be available shortly: humidity chamber, gas chamber, furnace, liquid cell, pressure cell. Future evolutions include the setup of the velocity selector and access to polarized neutrons. At longer term, time-of-flight measurements shall be performed, when a proper detection system is available.

Scientific case

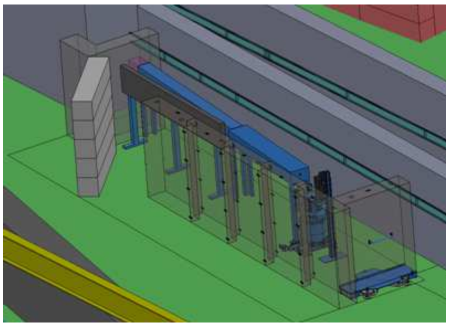

Figure 1: The IMAGINE station

Neutrons imaging is a non-destructive and non-invasive technique which allows to obtain materials structural characterization and defects at the microscopic length scale. Neutrons penetrate most materials to depths of several centimeters. Classically, neutron imaging has been used for quality control in industries that require precision machining such as aircraft or motor engineering. Neutron tomography has also been used in the cultural heritage studies to authenticate paintings and examine artifacts made of metal or stone. Due to its high sensitivity to hydrogen, neutron radiography and tomography can be used to measured humidity transport in soil. It is also a valuable non-invasive tool to study in situ root development in soil. Today, one important application of neutron radiography is in testing the performance of fuel cells (in operando) by imaging water or hydrogen flow in situ. The scientific case of IMAGINE station already allows to cover all these classical topics.

First Experiments on IMAGINE

The first measurements performed on IMAGINE station deal mostly with agro-food science.

1- Quality grading of cork stoppers: amount of defects inside the material

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Cork is used in a variety of products going from construction materials to gaskets, but its most important use is as a stopper for premium wines. The technology of stopping wine bottles with cork originated in 1680 with the first use of cork to seal Champagne by Dom Pierre Pérignon. The principle requirements for using cork as stoppers are the homogeneity of the cork and the loss of cavities and / or cracks. The quality grading of cork is based on visual analysis taking into account the three main types of defects: pores (lenticular channels), physiological anomalies (nails, clay), pathogenic anomalies (insect galleries). All these inspections allow to analyzing only the external surface of the stoppers. Thus cracks or holes inside the stopper are not detected. When viewed from a radial perspective, the cork cellular structure is a homogeneous tissue of thin walled cells orientated in an alveolar, honeycomb type pattern of hexagonal sections with no intercellular spaces. When viewed from an axial or a tangential perspective, the cells appear as rectangular prisms stacked base to base, parallel to the radial axis (Silva et al, 2005). Average cork cells are 45 µm

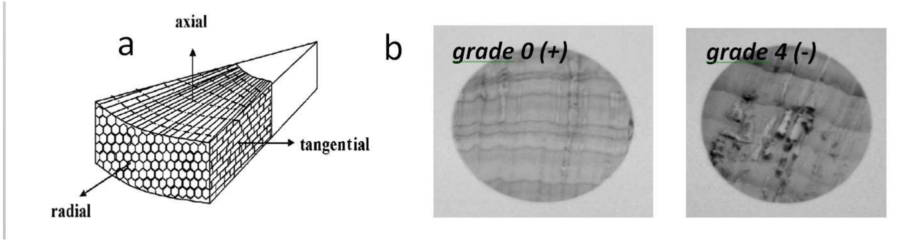

Figure 2: a- three dimensional structure of the cork from Silva et al. 2005 / b: Neutron radiographies of two slides of different qualities cork stoppers (IMAGINE instrument, 120 s exposure, 100 µm scintillator)

tall with a hexagonal face of 20 µm and with a thickness of 1 µm. The first objective of the experiments performed by neutron imaging on cork stoppers with IMAGINE was to compare the amount of defects between natural cork Grade 0 (high quality) and Grade 4 (low quality), evaluating the empty space volume into different samples of each quality. Figure 2 presents the image obtained for two samples of different grades.

2- Milk powders dissolution in water: impact of agglomeration and formulation

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Milk protein powders are used as ingredients by the food industry in many applications which generally require the powder to be dissolved back into aqueous medium. The process of reconstitution of the powder in water can be divided into different steps: wetting, dispersing and dissolving (Marabi, 2007). Among these steps, the wetting of the particles is very often the rate-controlling step (Gaiani, 2009). The study of flow of liquid through porous materials finds a big importance in numerous domains and various imaging techniques (X-Ray, NMR and Neutron) were developed to visualize it through a material. The aim of these experiments was to better understand the impact of powders agglomeration (tableting), and composition on the dispersion steps and more particularly on wetting, and dissolution. Skimmed milk and sodium caseinates powders (functional milk powders) have been studied. These powders were formulated in the presence of various excipients which have to either allow the faster dissolution of the tablet, or on the contrary delay it, for example: methylcellulose (thickener used for tablet coating) maltodextrin and lactose (dispersing agents). Milk powders have been agglomerated to form tablets of 3 mm. Kinetics of dissolution of these different samples have been studied by neutron imaging after addition of water. Images acquisition have been as fast as possible (40 s) to be able to follow the fast kinetics. Figure 3 presents a tablet of milk powder after few minutes of hydration.

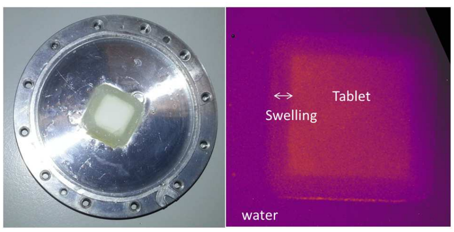

Figure 3 : (left) Tablet of milk powder after few minutes of hydration in its aluminum cell (right) Neutron radiography performed in 40s on IMAGINE

3- Grapevine root growth: beneficial effects of arbuscular mycorrhizal fungi

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Most grapevine varieties are susceptible to cryptogamic diseases and numerous treatments are required to ensure the quantity and quality of the harvest. In an objective of sustainable viticulture, there are increasing societal request, political incitation and winegrower's awareness to reduce the use of pesticides. For these reasons, alternative / complementary strategies of protection are investigated. One of them is the use of elicitors to induce plant resistance to pathogens by stimulation of their innate immune system (for review, see Adrian et al., 2012). Some plants know how to recognize and exploit other bodies, in particular germs present in the soil, which help them by facilitating the access to the water and to the mineral elements which, with the CO_2 of air, constitute their nutrients. For example, Arbuscular Mycorrhizal (AM) fungi are able to establish a symbiotic interaction with the roots of 80% of plant families. AM fungi lead to a root morphology modification and development of a complex ramifying network in soil which allows

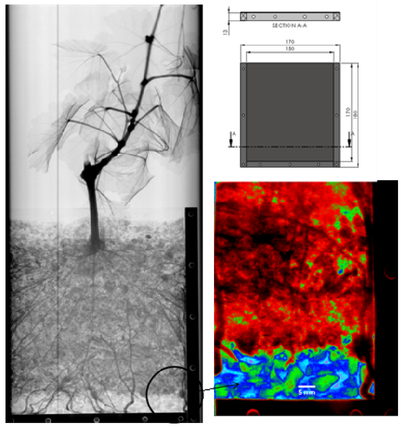
Figure 4: Neutron images of a grapevine herbaceous cutting cultivated by the AgroEcology team (Dijon) in an aluminium flat container (LLB design, Helary A.). The left « black and white » image has been performed with an image plate detector (neutronography station G4.5) and the right color one comes from the IMAGINE station (40 s of expo-

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