Sub-second and Dynamic Computed Tomography Development at the Canadian Light Source

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Introduction: Dynamic CT is an emerging technique of uninterrupted acquisition of radiographic projections of a sample as it forms, deforms, or interacts to external conditions [1]. However, a basic principle for correct tomographic reconstruction is that the sample remain unchanged during CT acquisition to avoid motion artefacts. To capture dynamic processes, either the sample stability is controlled above the limitations of the capture device, or tomographic data needs to be acquired faster [1, 2]. The former is used in dynamic CT joint studies through precisely controlled joint movements at clinical scanners [3]. The Canadian Light Source (CLS) uses the latter approach as the high flux is several orders of magnitude greater than laboratory X-ray sources and well suited for sub-second acquisitions [1, 4]. The greater temporal resolution allows for tomographic reconstruction of an evolving sample and the changing internal structures can be captured and visualized [1]. Dedicated micro-CT systems are also capable of dynamic CT with scans on the order of 2 CTs/min [5]. Computational and mechanical constraints limit dynamic CT studies to small samples for short periods of time. Research applications have been in material sciences and preliminary studies in small animals and medical implant design [1, 3, 6]. In this abstract, dynamic CT was used to visualize the wet granulation process of pharmaceutical powders once in contact with water.

Methods: This study was performed at the 05B1-1 beamline at the CLS with a photon flux density of 10^{12} photons/mm^2/s in a filtered white beam. Projections of 2000×664 px at 5.3 µm/px were captured by a Hamamatsu AA-40 beam monitor with a 200 µm thick LuAG scintillator coupled to a PCO.DIMAX HS4 camera. With a 50 cm sample-to-detector distance, each individual scan consisted of 500 projections over 180° in 0.5 s. The wet granulation experiment consisted of a micropipette of deionized water, controlled by a syringe pump, held 2.5 cm above the powder bed. On a motorized rotation stage, cylindrical vessels containing the powders were positioned 26 m away from the light source. Two pharmaceutical powders, lactose monohydrate (LMH) and microcrystalline cellulose (MCC), were scanned for 20 and 13 s respectively once the water droplet contacted the powder bed. With a 1 ms temporal resolution, individual moments of the granulation process were reconstructed through selections of 500 consecutive projections. This allowed for characteristics such as the consolidation of the granule shape and the subsequent growth of pores to be visualized in animations with 1 ms interval between frames.

Results: In a single slice, the granule consolidated its shape for LMH (Fig 1 c) and less so for MCC (Fig 1 d) while both became more porous over the elapsed scan time. Focused on a sample area consisting of only solid granule, the total pore area in the sample was plotted over the scan time (Fig 1 e). Both granules grew during wetting however the MCC granule spread farther outward. Both samples shrank as pores formed (Fig 1 f).

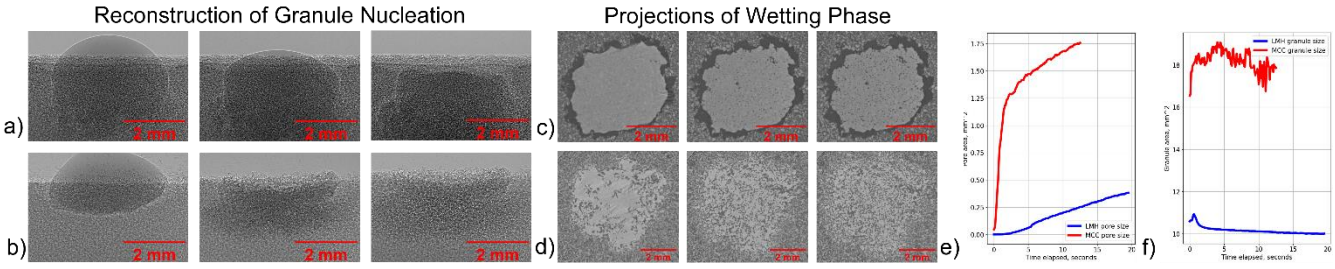

Fig 1: The early, middle, and late stages of wetting and nucleation are shown for LMH (a, c) and MCC (b, d). Sample pore area and granule area over the elapsed scan time for LMH in blue and MCC in red (e, f).

Conclusions: This abstract aimed to illustrate the dynamic CT capabilities at the CLS. The high-flux X-rays and high-speed camera can acquire a full tomographic dataset in 0.5 s. The dynamics of wet granulation were reconstructed with a temporal resolution of 1 ms. There were significant motion artefacts during the wetting due to droplet motion. The subsequent nucleation was better visualized with analysis on the granule shape and porosity. Faster data acquisition at the CLS is feasible for 0.5 ms resolution which may mitigate the persistence of motion artefacts during wetting.

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