UNDERSTANDING THE TRICKLE

Trickle-bed reactors are the oldest and most abundant type of multiphase reactors in the world. They are found in industries that range from oil refineries to waste water treatment plants and are usually used whenever both a liquid and a gas need to be contacted with a solid. The solid (usually in the form of pebble-sized spherical or cylindrical beads) is charged into a cylindrical reactor where it remains stationary under its own weight. The gas and liquid are fed from the top. At relatively low flow rates, the liquid trickles over the packing.

Trickle beds have been studied extensively over the past five decades. However, the intricacies of the gas-liquid-solid interactions (hydrodynamics) make it difficult to properly explain the physics governing the flow. In many cases, low temperature and pressure glass set-ups were used in the laboratory. The translucent glass walls revealed a wealth of information, including that more than one type of flow regime exists.

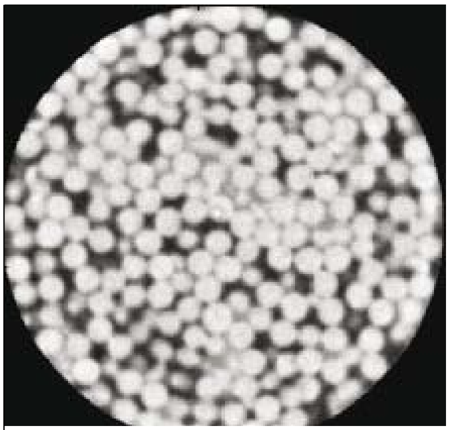
At low fluid flow rates the liquid indeed "trickled" over the particles, but at higher rates; pulses of alternating liquid and gas traversed the bed. In the trickling regime, liquid maldistribution was expected, but without seeing inside the bed, it was difficult to quantify. Moreover, subsequent studies indicated that the flow close to the wall is not representative of the flow structure inside the bed.

The Reaction Engineering Laboratory at the University of Pretoria has been working in collaboration with the South African Neutron Radiography (SANRAD) facility, at the South African Nuclear Energy Corporation, NECSA, to implement NECSA's X-ray computed tomography capabilities to address this issue.

X-ray computed tomography was originally developed for imaging in the medical field, but it has since been applied to other fields, including non-destructive materials testing. In principle, it is capable of imaging the inside of optically opaque materials in three dimensions. It is especially suited to trickle-flow imaging because its non-intrusive nature leaves the reactor's internals undisturbed.

Insofar as the hydrodynamics of the flow is concerned, proper distinction between the three phases (gas, liquid and solid) can be achieved by optimising the control variables of the facility.

In this study, 15 minutes was necessary to obtain relatively high-quality three-dimensional images. An implicit assumption in the final image is that the flow remained stable during the scan time. As this is not necessarily the case, the stability of the flow was confirmed using X-ray radiography in the same set-up prior to each scan.



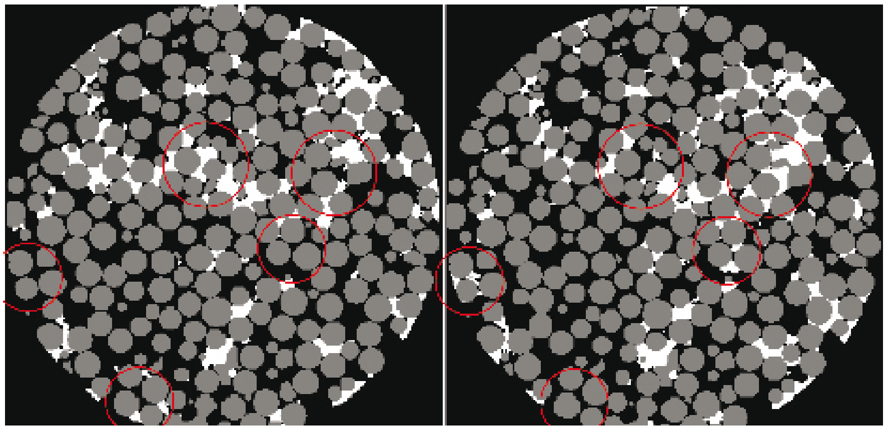
→ 1 Cross-section of a tomographical reconstruction

An example of a cross-section of the resulting three-dimensional image is shown in *→ 1*. The circles are cross-sections of the spherical catalyst particles used in the experiment. Take note that the full three-dimensional volume image is available, although only a cross-section is shown.

The resolution is approximately 120 microns per voxel (the three-dimensional analogue to a pixel). The slight graininess to the image is a characteristic of computed tomography. When the gas and liquid are introduced, all three phases can be identified (as in *→ 2*).

Advanced processing techniques can be used to obtain pertinent information about the local structure of the gas and liquid flow as a function of variables like flow rates and pre-wetting steps. In particular, the impact of flow history on the liquid morphology is studied in depth.

The computed tomography technique lends itself to unparalleled visualisations of the interior of this type of chemical reactor. However, extraction of quantitative data from the images is not a trivial exercise. Nevertheless, these investigations give good indication that the flow morphology is relatively stable for up to 12 hours; global bed parameters like the volume fraction of liquid in the bed and the gas-liquid and liquid-solid areas are reproducible; and the exact flow morphology is slightly non-reproducible in that successive runs



→ *2 Liquid (white) distributions for two runs at the same conditions (compare the areas with red circles to see the differences)*

at exactly the same conditions result in the liquid being distributed somewhat differently. The pre-wetting procedure or flow history has a major impact on the type of flow structure that is obtained.

Some examples of these observations are shown in → *2* and → *3*. → *3* shows only the liquid in the column.

The intention is for the tomographic mapping of the bed to form the experimental basis of an ongoing investigation into the fundamental mechanics responsible for governing multi-phase flow in packed beds. Present flow models are unable to capture the irreproducibility of the flow structure or the effects of pre-wetting. Ultimately, the most important aspect of the present investigation is whether these phenomena impact on the performance of the reactor. This is the subject of present investigations.

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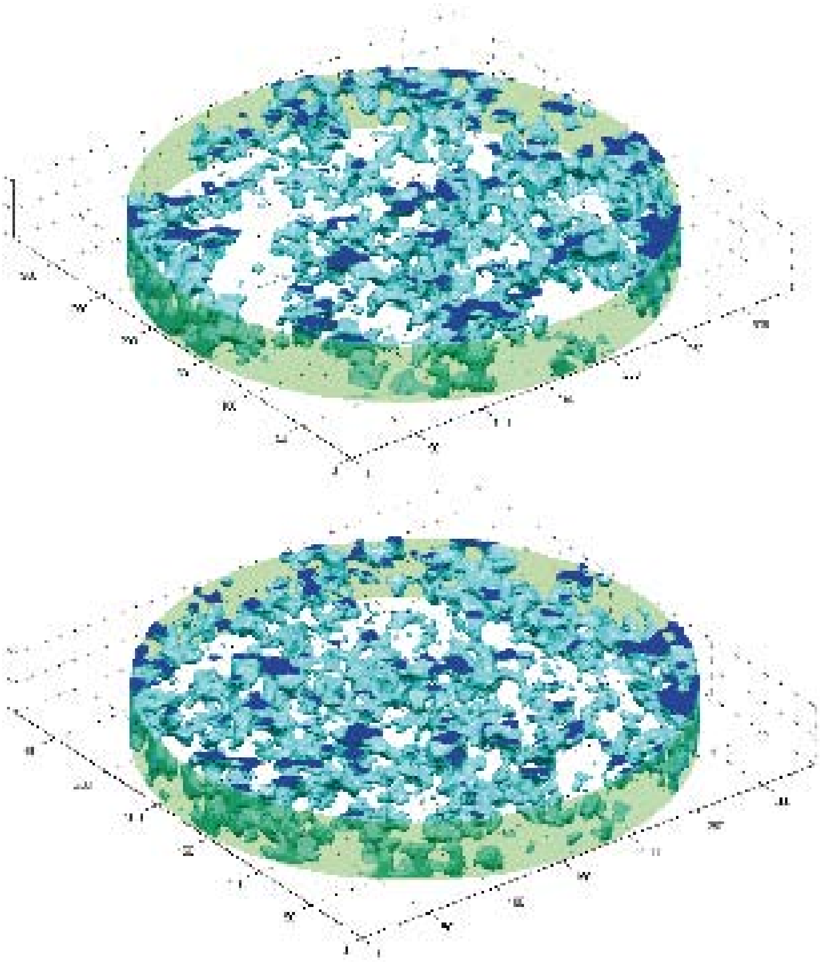

→ *3 Liquid (blue) distributions in three dimensions for two different pre-wetting modes (dark blue is a slice plane through the liquid) – notice the non-irrigated areas*