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Emulating liquid drainage in oscillating packed beds for marine applications

Jian Zhang, Seyed Mohammad Taghavi, Faïçal Larachi*
*Department of Chemical Engineering, Faculty of Science and Engineering, Laval University, Québec G1V 0A6, Québec, Canada; *Corresponding author E-Mail: Faical.Larachi@gch.ulaval.ca*

1. Introduction Gas-liquid flows in oscillating porous media have been the subject of thorough studies with respect to both hydrodynamics and mass transfer [1,2]. Compared to classical vertically-erected reactors/contactors, the use of packed beds on floating platforms or ships requires specific attention in their design to account for the relation between their efficiency and the reactor sea-state convolution to the ship dynamics. Ship motion and sloshing induced by wind and wave dynamics could lead to severe operational challenges of floating packed reactors, especially on safety when the unit shutdown becomes compulsory. Hence, when extreme circumstances oblige halting the operation of floating reactors, knowledge of the dynamics of sea-perturbed gravity-driven liquid drainage becomes a key consideration.

If liquid drainage in vertical stationary packed beds has been a classical topic, study of the liquid drainage dynamics in inclined and oscillating packed beds subject to sea perturbations remains by and large an uncharted territory. Assima et al [3] reported the only study showing that vessel obliquity can be a method to control the liquid draining time in packed beds. However, a survey of the open literature relevant to packed beds indicates virtually a total absence of reports on the drainage dynamics in oscillating packed columns. Therefore, the object of the present contribution is to measure and analyze the key characteristics of a liquid draining in an oscillating porous medium in terms of translational and rotational perturbations such as those encountered in the marine context.

2. Method The experimental setup examining the effect of packed bed motion on liquid drainage is illustrated in Fig. 1. A hexapod with six-degree-of-freedom motions including translations (surge, sway, heave) and rotations (roll, pitch, yaw) is employed to mimic the dynamic motions of floating vessels. The glass-bead packed bed consisting of 57 mm inner-diameter and 1200 mm high acrylic column is embarked on the robot to mimic packed beds on floating platforms. The dynamic liquid saturation is monitored by two wire-mesh sensors (WMS), 600 mm afar, to investigate the draining dynamics under various ship excitations. Water and water/glycerin mixtures are used as liquid phase fed by a peristaltic pump to completely fill the column. After the poral volume in the bed is completely saturated with liquid, the bed is allowed to drain freely while the hexapod is set in motion. The details regarding WMS can be found in former research [1].

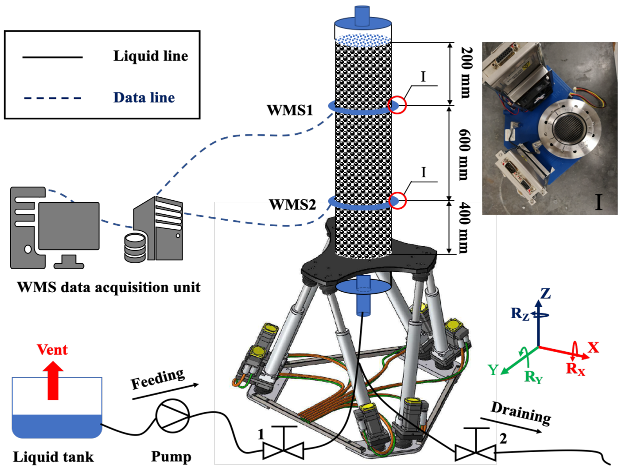

Figure 1. Experimental setup of the stationary & moving packed bed with WMS measurement embarked on hexapod.

3. Results and discussion The *perturbed* gravity-driven drainage of water in a packed bed subjected to tilting (15°, 25°, roll and roll + pitch) and non-tilting (yaw, sway, heave and sway + heave) perturbations is monitored by means of WMS from initially flooded beds until a free-drainage steady state is ultimately reached for the bed. As can be seen in Fig. 2, the liquid drainage history features three main stages regardless of the imposed hexapod constraint. The fastest stage, S1, is triggered immediately after displacement of the liquid front at the WMS embedded position. During this stage, ca. 70% of the poral liquid content is drained. It is straightway followed by a slower S2 period whereby liquid drainage of the now-partially saturated pores is responsible for the discharge of ca. 30% of the liquid. This can be clearly distinguished by the sudden change of the liquid draining rate in Fig. 2. Finally, a steady state of liquid saturation (S3) is achieved corresponding to a bed that has completely eluted its dynamic liquid saturation.

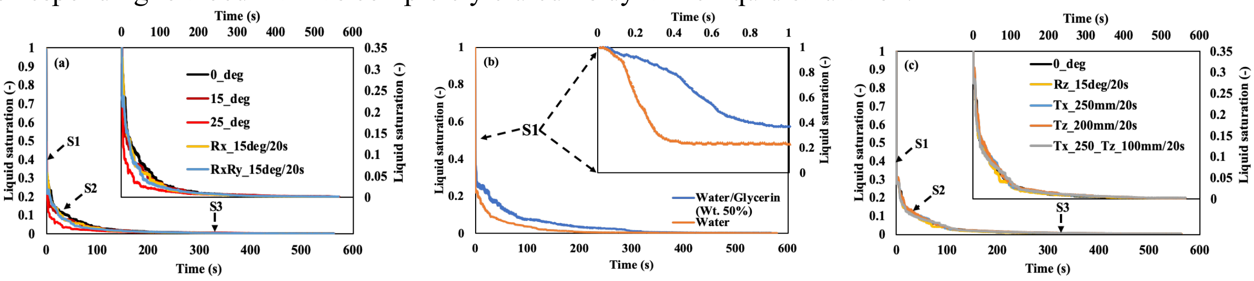

Figure 2. Effect of tilting (a), liquid viscosity (b) and non-tilting (c) motions on the dynamics of liquid saturation drainage (zoom insets are to show more drainage features).

The fast draining stage, S1 featuring an abrupt liquid front is observed in all investigated courses of experiments (Figs. 2a-c). By comparing the liquid drainage dynamics of water and water/glycerin mixture for the vertical column, it can be concluded that the flow is mainly dictated by gravity and viscous forces in the early moments of drainage. A five-fold increase of liquid viscosity results in a reduced drainage rate during period S1, Fig. 2b.

The gravitational driving force fades away with the depletion of the poral liquid at the expense of the resisting viscous forces and the gradually emerging capillary force which both contribute to the slowing down drainage during stage S2. The relative contribution of gravity due to column tilt (Fig. 2a) and of acceleration due to column rotation (Fig. 2a) on the liquid drainage can be characterized by the column inertia-to-gravity forces ratio, R_{IG}, [4,5]:

$$R_{\mathrm{IG}} = \frac{\text{inertia}}{\text{gravity}} = \frac{H \cdot 4 \cdot \pi^2}{g \cdot P^2}$$

g = gravitational acceleration, H = elevation above center of rotation, P = oscillation period.

Increasing *static* column inclinations translates in accelerated liquid drainage during S2 stage. The higher local bed permeability adjacent to the column wall region combined with the build-up of more liquid the more tilted the column contribute to an increase of the gravitational driving force thus prompting faster liquid drainage (Fig. 2a). For column angular amplitude equal to the static bed inclination (e.g., 15°), roll and roll & pitch rotational excitations with finite oscillating period (e.g., P = 20 s) of the column contribute to slow down the liquid drainage dynamics with respect the static inclined column ($P = \infty$). In the illustrated case where H = 0.4 m (see Fig. 1, WMS2), P = 20 s and g = 9.8 m/s^2, R_{IG} = 0.4% is thus sufficient to prompt measurable inertial effects in stage S2 (Fig. 2a). On the contrary, the absence of inertial effects under non-tilting oscillations (Fig. 2c) is remarkable. Finally, stage S3 is reached once a balance between gravity and capillary is achieved where inertial effects due to column oscillation or gravity effects due to column inclination are not anymore observable.

4. Conclusion The draining dynamic of floating packed bed is assessed based on a systematic experimental study using a state-of-art apparatus combining hexapod and an embarked packed bed instrumented to measure liquid saturation through high spatial-temporal WMS. The results reveal tilting moving can facilitate liquid drainage. Nevertheless, non-tilting motions have marginal impact on liquid drainage performance.

References

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