average distribution of wave numbers the characteristic wave number $\langle k \rangle$ in the x-direction is defined and calculated in the following way, using an average of k with the power spectrum as a weight

$$\langle k \rangle = \frac{\sum_k k\bar{S}(k)}{\sum_k \bar{S}(k)}. \quad (5)$$

The results in Fig. 6 show a decrease of finger frequency in time. As a trend we notice that at higher injection pressure the finger frequency decreases faster than at low injection pressure. However the simulation at $P_I = 250\ kPa$ differs from the other simulations. In this simulation we also observe a finger propagating directly along the right boundary in Fig. 2. Close to the wall this finger appears to propagate faster than the other fingers in this simulation. Because the simulation at $P_I = 250\ kPa$ is the only simulation where this appears it also stands out in the plots for the average wave number Fig. 6. This is presumably due to a finite size effect, and such outlier is frequently met in granular systems, which are known to present a large variability and sensitivity on details of the initial state. (see e.g. [17]). Otherwise for higher injection pressure, the finger frequency not only decreases faster but also drops to a lower value before the grains get compacted.

This coarsening of the finger frequency is the result of two mechanisms. First the pressure gradient between the finger tip and the outlet gets higher the closer the finger tip moves to the outlet. Assuming a linear pressure profile though the porous media the pressure would drop to zero on a shorter and shorter distance the closer the finger advances to the outlet. At the same time the gas also leaks into the side walls of the finger. This increases the pressure in the porous material around a finger. In the areas where this pressure increase takes place less advanced neighboring fingers would thus experience a lower pressure gradient. The speed of these fingers is thus reduced. This means the more a finger advances to the outlet the faster it moves. At the same time the pressure increase in the area around an advanced finger decreases the pressure gradient in front of less advanced fingers. This causes the less advanced fingers to propagate slower or to stop completely. This mechanism will result in a coarsening of the finger frequency. Further more we expect this mechanism to be active on a typical length scale which is comparable to the skin depth of the pressure profile. In the limit of a infinite pressure skin depth this mechanism is similar to the basic Saffman Taylor instability [23].

A second mechanism that will account for a coarsening of the finger frequency is the compaction of the grains on the sides of a finger. During the propagation the finger width increases and branches at a 90 degree angle arise on the sides of fingers. This compacts the granular material on the sides of an advancing finger. How far this compaction propagates on the sides depends on the properties of the granular material and also on the finger width and how the side branches develop. Where this compaction has occurred preceding fingers are slowed down or stopped. The size of the compaction front around the fingers sets a second length scale for the coarsening of the finger frequency.

CONCLUSIONS

The increase of the injection pressure primarily causes fingers to propagate faster through the granular packing. Fingers at high injection pressure also tend to be more branched and fracture-like than the fingers at low injection pressure. It was shown that the position of the fracture propagation in time increases with the square root of the injection pressure $\sqrt{P_I}$. Furthermore we discussed the observed coarsening of the characteristic spatial finger wavenumbers in terms of two mechanisms. A first mechanism that controls the coarsening arises from the fluid seepage into the granular media. Where the length scaled for this mechanism was argued to be of the size of the pressure skin depth. To further explain the coarsening a second mechanism causing the coarsening of the finger wavenumber was highlighted. This second mechanism introduces a length scale for the coarsening with the size of the compaction front in the granular material around a finger.

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Poster session. (Photo: O. Ramos)

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