# Horizontal Redistribution of Two Fluid Phases

# Experimental Investigations

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## Introduction

Horizontal redistribution of two fluid phases is a special case of flow in porous media and describes the simultaneous imbibition and drainage within one domain.

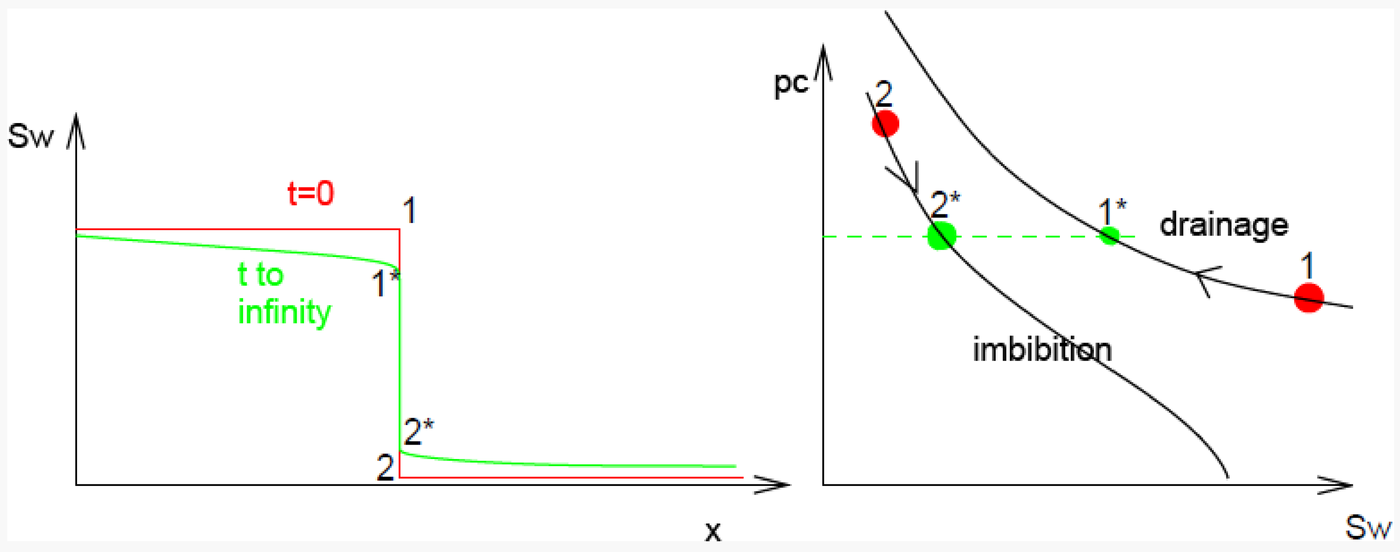


*Fig.1 left: Initial and final distribution of saturation, right: dedicated process in the $p_c$-$S_w$- relationship*

The problem was formulated and investigated theoretically by Philip [1991]:

- infinitely long horizontal, 1-d, homogeneous porous medium
- initial saturation discontinuity
- based on unsaturated flow equation by Richards [1931]
- accounted for capillary hysteresis by using pre-known capillary pressure-saturation curves

→ The results show a persisting saturation discontinuity at the drainage-imbibition interface and continuity of capillary pressure.

Since then, further theoretically work was done but no experimental validation. Moreover, due to its simplicity the setup would provide a suitable system for investigating driving forces.

## Research Goal and Open Questions

The aim of this work is

- to provide experimental data for the horizontal redistribution of two fluid phases to validate Philip´s results
- to test the presence of additional driving forces and with that the validity of the extended Darcy´s Law

Therefore, the following questions are addressed:

1. Will a saturation discontinuity persist at the drainage-imbibition interface?

2. Will uniform saturations and pressures be established in both subdomains after the flow of fluids ceases?

## Materials & Methods

**Setup**

- plexiglas flume (l x h x w = 200 x 3 x 4 cm)
- sand packing: $\rho_P$ = 1650 kg/m³, $d_{50}$ = 0.275 mm
- 2 subdomains initially separated by a thin aluminium plate

→ $l_1$ = 65 cm, $S_{w1}$ = 0.23, $l_2$ = 135 cm, $S_{w2}$ = 0.70

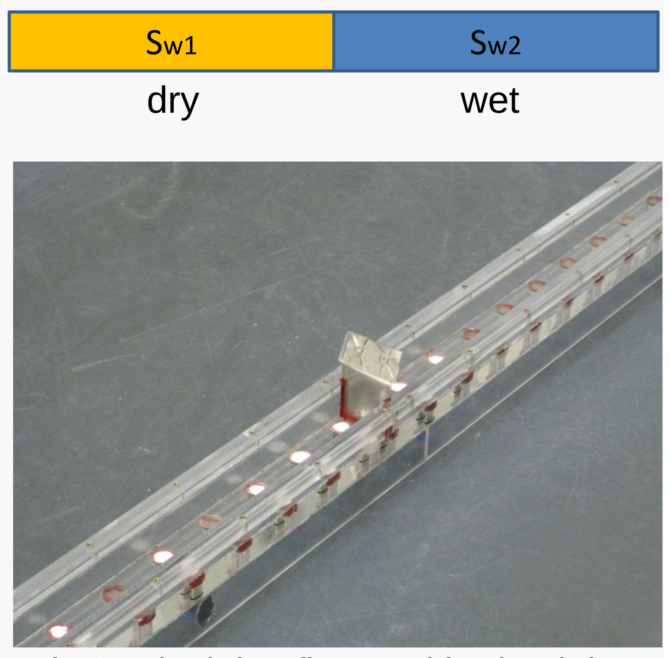


*Fig.2: Plexiglas flume with aluminium plate*

**Measuring Devices**

*Saturation:*

- water saturations are measured using a movable gamma-system
- 34 measuring points, higher discretization near the drainage-imbibition interface

*Pressure:*

- pressures of air and water are monitored with air-wet and water-wet tensiometers connected to pressure transducers

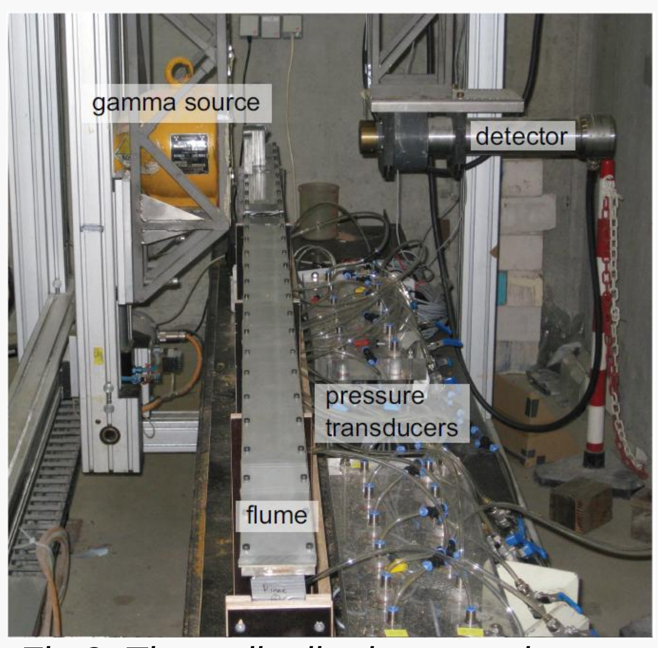


*Fig.3: The redistribution experiment*

**Conducting the Experiment**

- removal of aluminium plate
- logging data of saturation and pressure on measuring PC´s
- when flow of fluids ceases experiment is stopped
- final gravimetrical measuring of packing density and water content

## Results

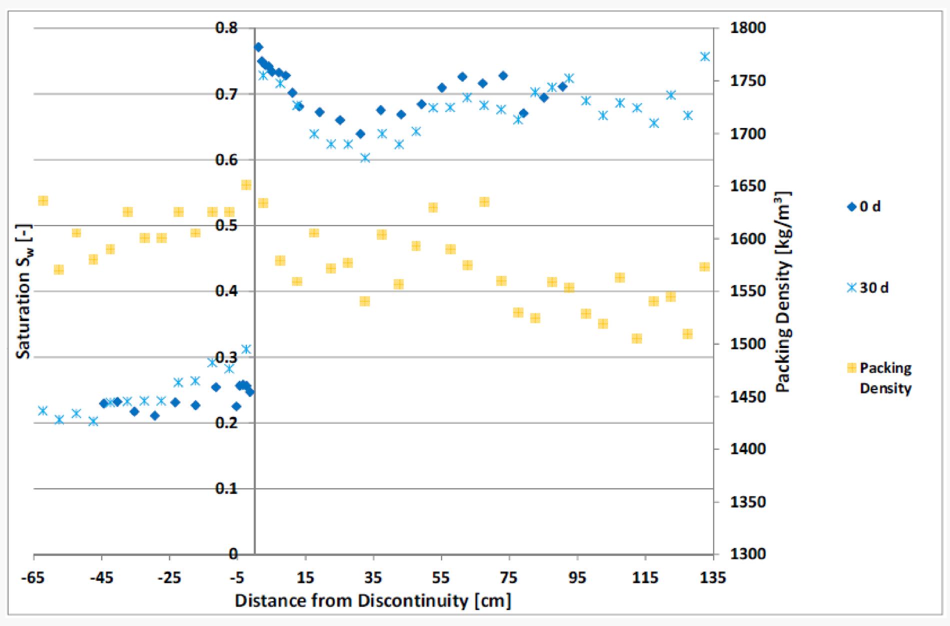


*Fig.4: Packing density along the flume and saturation after 0 and 30 days*

- different propagation behavior of the saturation in the subdomains caused by higher mobility of water in a higher saturated soil
- local gradients of saturation already existed before starting the experiment due to small inhomogeneity in packing density
- gradients persisted throughout experiment
- saturation discontinuity after 30 days of experiment confirmed

**Imbibing Subdomain**

*Saturation (Fig. 5a):*

- fast and large increase of saturation near the interface
- horizontally limited reach
- final saturation close to interface reached within a few days at different values

*Wetting-phase pressure (Fig. 5b):*

- fast and large change on positions near the interface
- final pressures not equal throughout subdomain

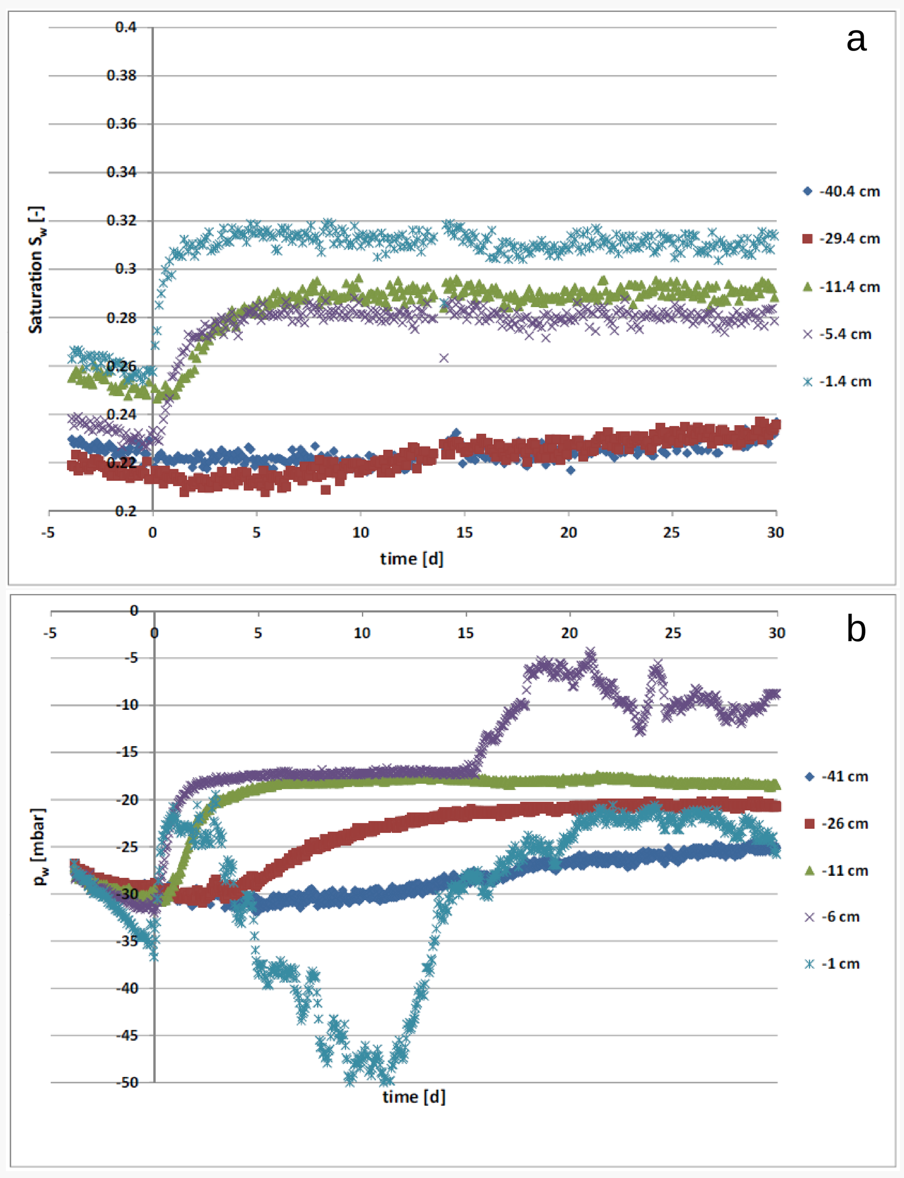


*Fig.5: Development of (a) saturation and (b) pressure in the imbibing subdomain*

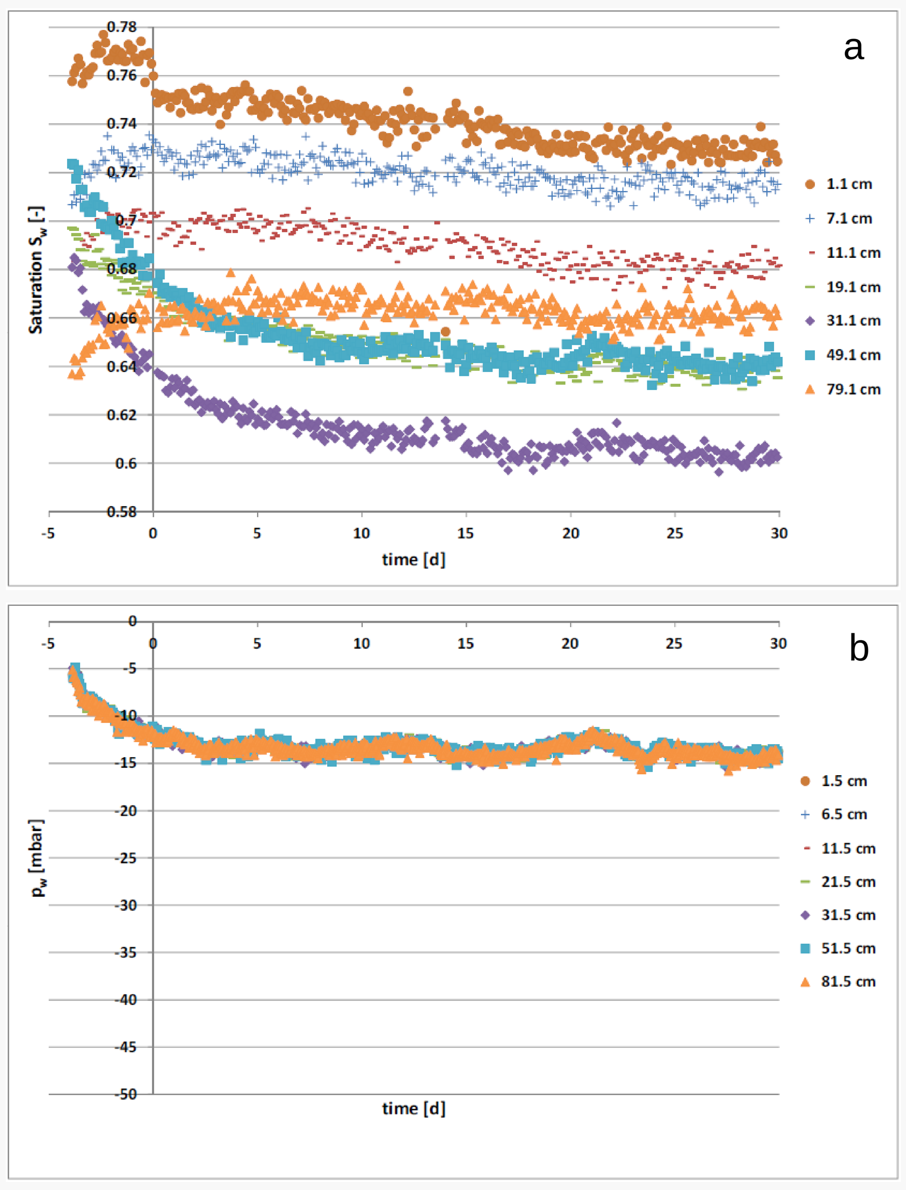


*Fig.6: Development of (a) saturation and (b) pressure in the draining subdomain*

**Draining Subdomain**

*Saturation (Fig. 6a):*

- initial saturation is still drifting
- slight decrease throughout experiment
- extend of saturation change larger than in imbibing subdomain

*Wetting-phase pressure (Fig. 6b):*

- no pressure gradients between transducers observable

## Discussion & Conclusions

1. Saturation discontinuity persisted even after 30 days of experiment
2. Saturations on each subdomain are not constant even after the flow of fluids ceases

→ gradients in saturation and pressure still exist after the system (nearly) reached equilibrium

The results imply that

→ gradients of saturation are additional driving forces capable of balancing existing pressure gradients at equilibrium

→ a more complete formulation of Darcy´s Law is needed for a more precise description of two-phase flow as suggested e.g. by Hassanizadeh and Gray [1993a, b]

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