Interfacial Area-based Simulation in Fractured Porous Media: Microscale Determination

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Motivation

Inclusion of volume specific interfacial area as a primary variable has substantial advantages such as:

- less empiric system description
- less hysteretic systems
- quantification of mass transfer between fluid phases possible

Problem & Objectives

There are many examples of fractured porous media like groundwater aquifers, storage sites, or fuel cells. If interfacial area is to be included in the description of the system, constitutive relationships of the form

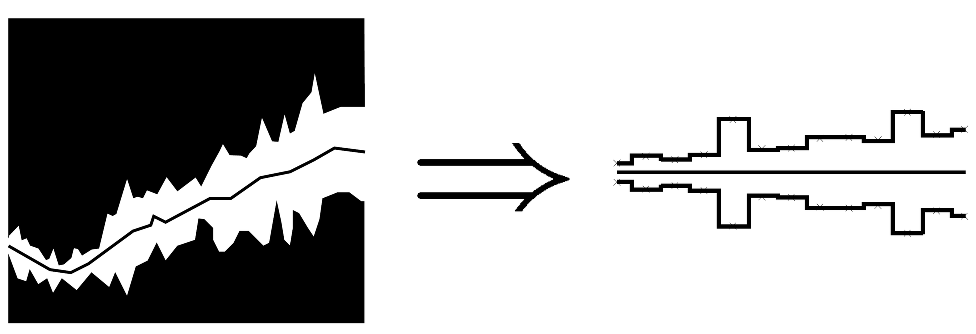
$$p_c = p_c(a_{wn}, S_w)$$

are needed.

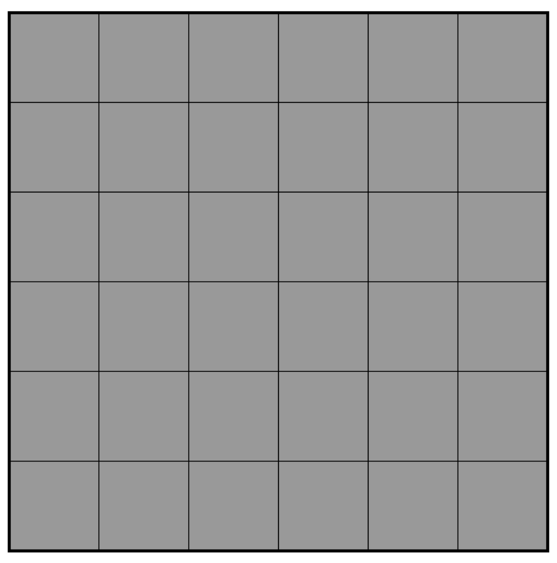
The major objective of this work is the determination of such **relationships for a single fracture** from micro scale simulation.

Fracture Description

In this work, a single fracture is considered. The fracture is described as a **Raster Element Model:**



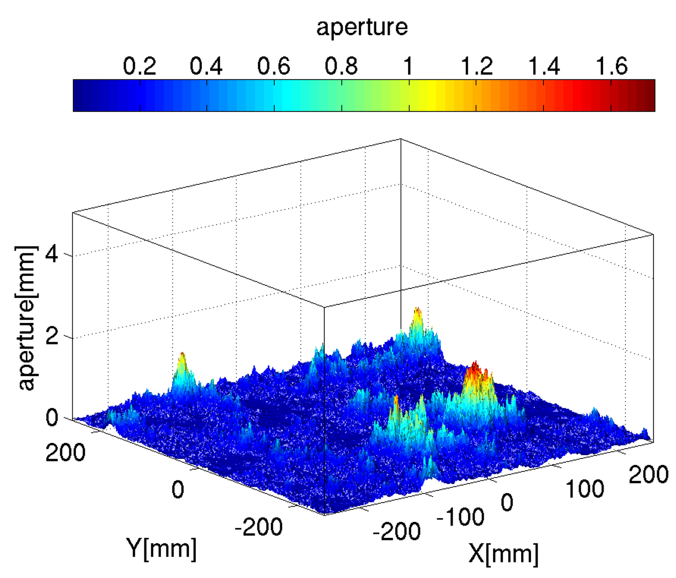
Thus, the fracture is conceptualized as a rectangular area comprised of fracture elements only differing in their fracture **aperture**. No explicit pore bodies and pore throats are assigned.



Information about the fracture is gained from laboratory measurements. From this data, statistical parameters, describing the fracture aperture distribution, are calculated:

- mean
- standard deviation
- correlation length

By means of this information, fracture aperture distributions can be generated:



Simulation Description

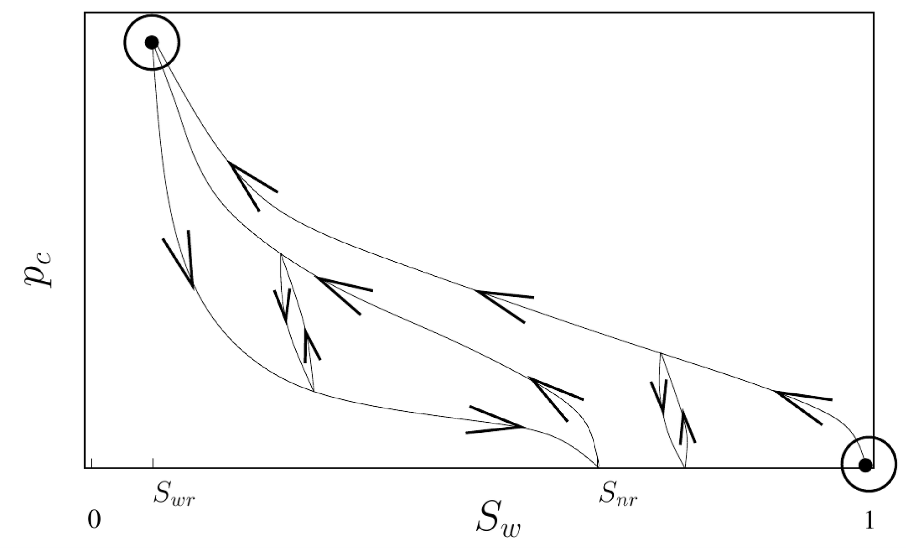
(1) The fracture is initially fully water saturated.

(2) Invasion starts over one boundary of the fracture. The invasion is implemented as a fixed pressure difference of the two phases. Invasion takes place as long as new fracture elements can be occupied.

(3) If no more fracture elements can be occupied, the according parameters (saturation and specific interfacial area) are calculated.

(4) Capillary pressure is changed and the new two phase configuration with the according data triplet (p_c, S_w, a_{wn}) is determined.

(5) This process is repeated until there are data points for the whole area of the hysteresis loop.



Mobility Assumptions

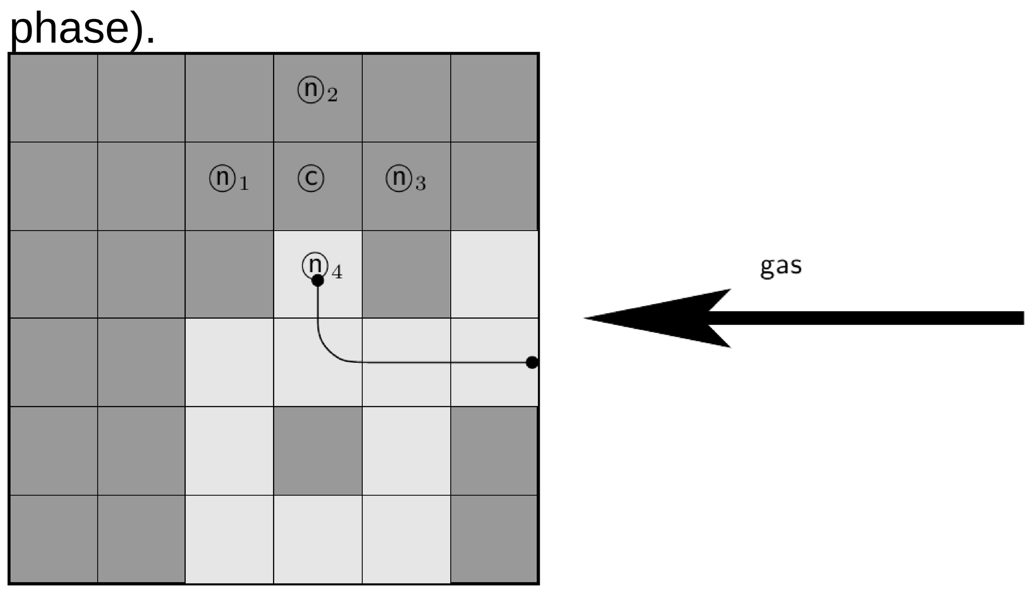
Invasion takes place over one boundary of the fracture. Withdrawal of the other phase takes place over the opposing boundary.

- each fracture element is tested individually
- different sets of criteria for drainage and imbibition
- common criterion: only those fracture elements can be invaded, that are big (drainage) or small (imbibition) enough respectively:

$$a_{cut} \gtrless 2\frac{\sigma}{p_c}$$

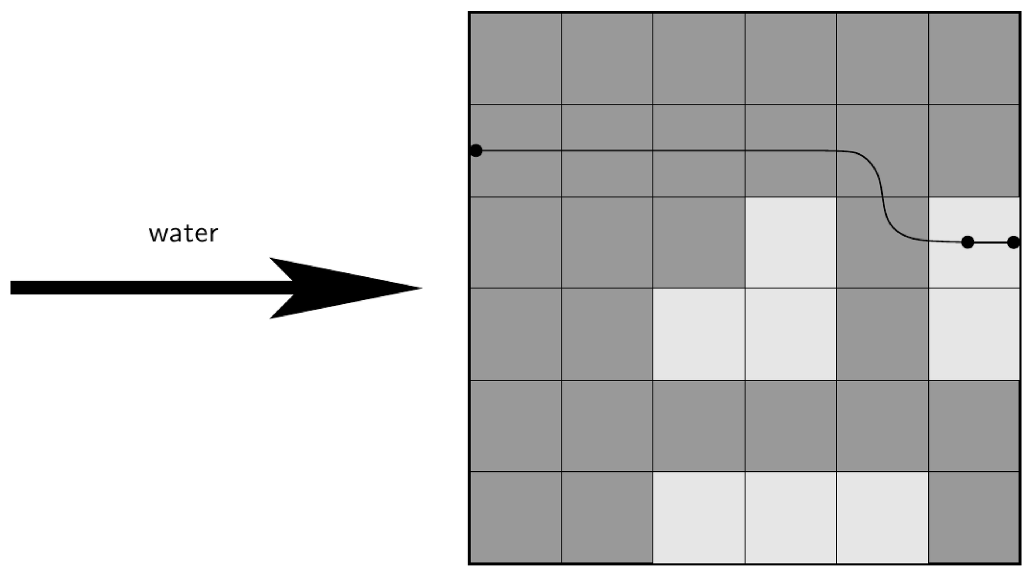
Drainage Criteria

- connected gas in a neighboring fracture element
- the water of the considered fracture element is assumed to be always mobile (**no trapping** of water phase).



Imbibition Criteria

- connected water in a neighboring fracture element
- connected gas in a neighboring fracture element (**tight trapping** of gas phase).



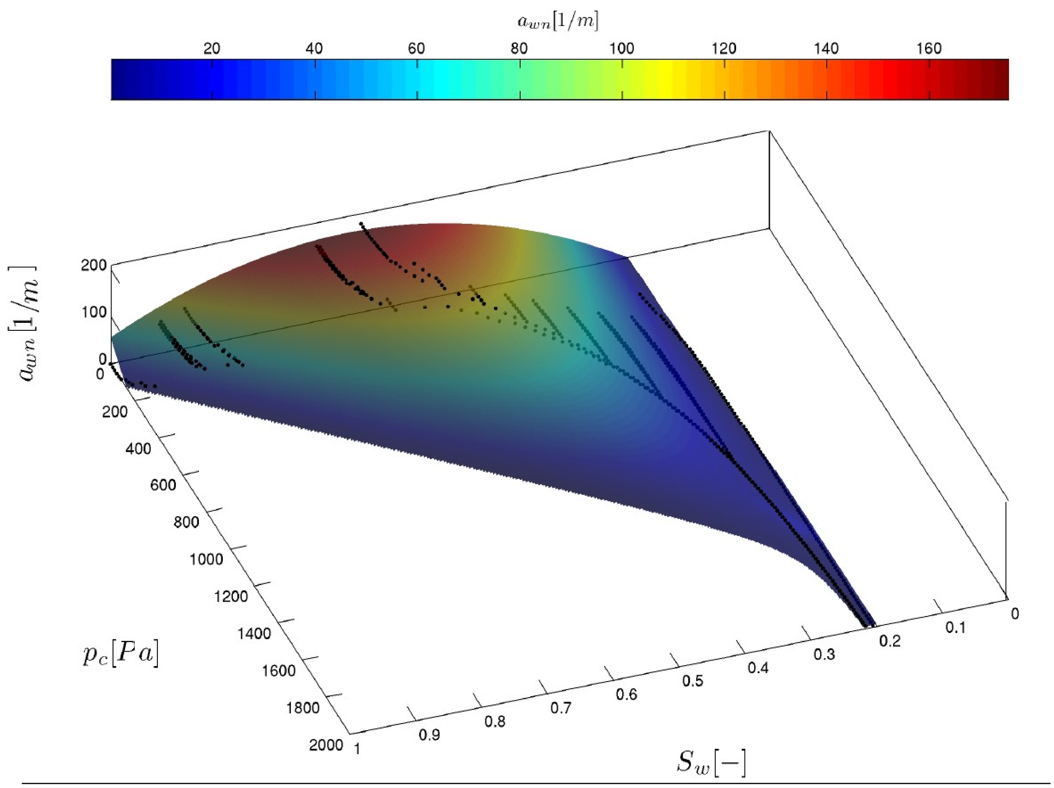
Connected pathways are neighboring fracture elements which are fully saturated with the respective phase and form a connection between the considered fracture element and the respective boundary.

Simulation Results

In order to describe the obtained data points in a closed form, it is necessary to find functions which fit these data points.

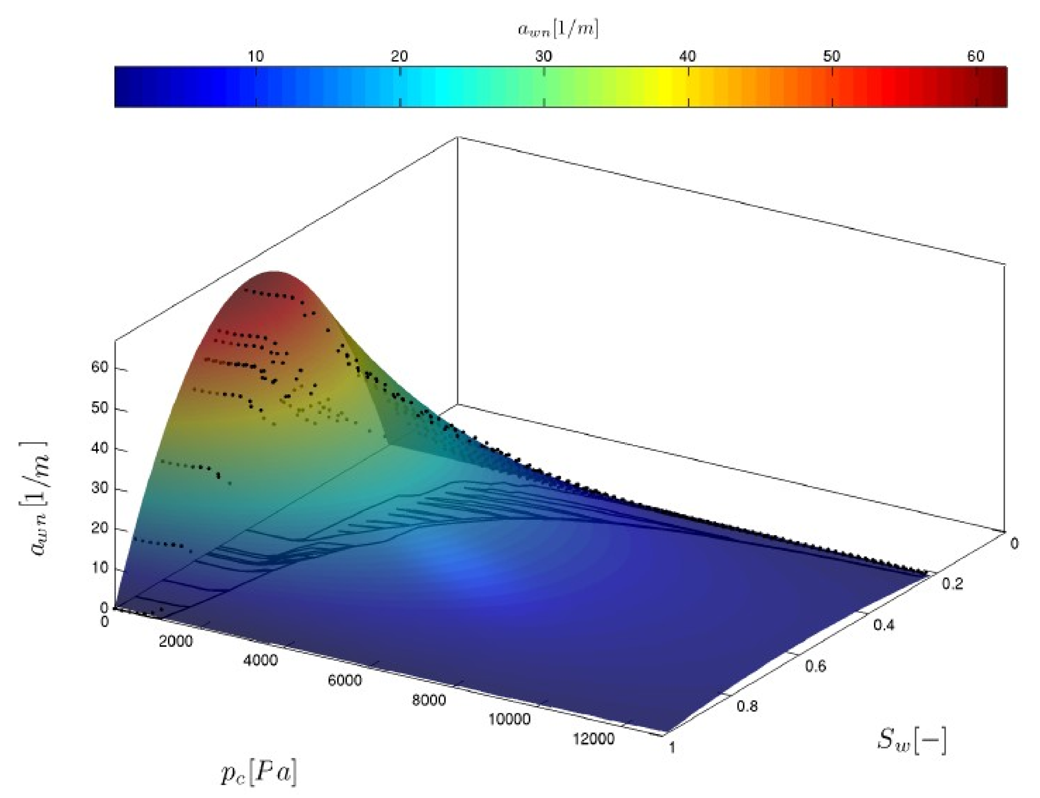
First, a polynomial of second order was chosen. In this case six parameters have to be fit to the data points:

$$a_{wn} = a_1 + a_2 \cdot S_w + a_3 \cdot p_c + a_4 \cdot S_w^2 + a_5 \cdot S_w \cdot p_c + a_6 \cdot p_c^2$$



Additionally, a new parametrization including further information and an exponential member was chosen. Only three parameters need to be fit:

$$a_{wn} = a_1 \cdot (S_{wr} - S_w) \cdot (1 - S_w) + a_2 \cdot (S_{wr} - S_w) \cdot (1 - S_w) \cdot e^{a_3 \cdot p_c}$$



The result looks promising

- less steep gradients
- bigger area of positive function values

Fitting to both model functions resulted in **coefficients of determination r>0.95** for more than 20 realizations.

Summary / Outlook

? Validity of mobility assumptions has to be tested experimentally.

✓ Construction of non-hysteretic constitutive relationships is possible

✓ High agreement between model function and data points

Literature

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[6] Nuske, K. P. (2009). *Determination of interfacial area - capillary pressure – saturation relationships for a single fracture.* Master's thesis, Universität Stuttgart.

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