Investigating LNAPL drop hysteresis; Implications for residualisation and source zone assessment

JOHN HENEGHAN & RYAN WILSON

GPRG, KROTO RESEARCH INSTITUTE, UNIVERSITY OF SHEFFIELD, S3 7HQ

j.heneghan@sheffield.ac.uk

The University Of Sheffield.

GPRG Groundwater Protection & Restoration Group

Introduction

•Light non-aqueous phase liquids (LNAPLs) are frequently a source of persistent, difficult to remediate contaminants in aquifers.

•LNAPLs are characterised by their immiscibility with water, a specific gravity less than one and typically high toxicity.

•LNAPLs do not fully drain from porous media, even under high capillary pressures (Figure 1).

•The difference in imbibition and draining in Figure 1 is a consequence of differences in wetting behaviour.

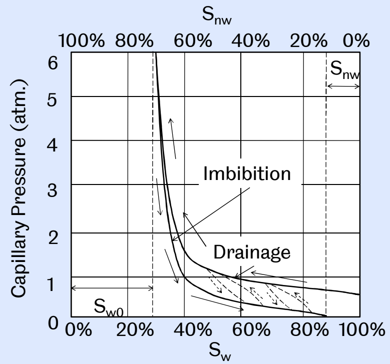

Figure 1 – Idealised capillary pressure/saturation curve for two immiscible fluids in a porous media, showing differences in imbibing and draining saturation states.

NAPL Wetting

•The process of residualisation (S_{nw} in Figure 1) is controlled in part by the NAPL wetting characteristics.

•Understanding NAPL wetting behaviour in specific porous media will help in the conceptualisation of a residual NAPL source zone.

•Understanding of source zone wetting characteristics will help in the design of remedial schemes such as free phase recovery by water flooding.

Wetting and Contact Angle

•The most common determinant of wetting is through the measurement of a static drop contact angle on a representative surface.

•Static contact angles only provide information on a system that is at equilibrium (i.e. neither imbibing or draining).

•In order to employ contact angle as a tool for assessing NAPL residualisation, hysteretic contact angles (advancing and receding) are considered to be superior to static values.

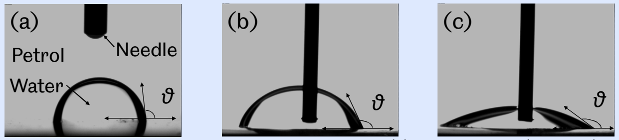

Figure 2 – petrol-water-quartz drop types; (a)-static drop (ϑ=97.8°), (b)-dynamic advancing drop (ϑ=103°), (c)-dynamic receding drop (ϑ=156.8°)

•The drop examples shown in Figure 2 can be considered as analogous to a water flood scenario (b) and water drainage by petrol invasion (c).

Results

•Experimental work has demonstrated that significant variation exists between advancing and receding contact angles both on and between a variety of mineral surfaces studied (Table 1).

Mineral phase	Static contact angle (ϑ)	Max. advancing angle (ϑ_a)	Min. receding angle (ϑ_r)
Quartz	98°	103°	157°
Haematite	94°	86°	128°
Calcite	71°	66°	134°

Table 1 – Petrol-water contact angles recorded in static and dynamic drop experiments (petrol is bulk liquid phase)

Implications

•Contact angle should be evaluated with respect to variation in mineralogy of porous media.

•The measurement of significant contact angle hysteresis questions the value of static contact angle measurements.

•In order to increase the accuracy of site conceptualisation and risk assessment, or the design efficiency of NAPL source zone remediation, wetting behaviour should be investigated.

•Contact angle should be considered as a dynamic variable and should be measured as such.

Summary

•NAPL wetting behaviour acts as a control on residual formation.

•Wetting is commonly measured by static contact angle.

•Hysteresis between advancing (invading) and receding (draining) drops can be significant, with the degree of hysteresis varying between mineral surfaces

Future work

•Possible future work includes;

•Investigating the effect of altering surface charge on LNAPL contact angle to improve free product recovery and reduce the percentage of residualised NAPL volume.

•Bench scale core saturation-drainage work to assess mineralogical affects on residualisation in aquifer samples

References

•Pinder, George, F & Gray, William, G. *Essentials of Multiphase Flow and Transport in Porous Media.* 257pp, John Wiley and Sons, Inc., New Jersey, 2008