

Some questions and comments on DPE 180 papers

1. Long, J., Hyder, M.N., Huang, R.Y.M., Chen, P.: "Thermodynamic modeling of contact angles on rough, heterogeneous surfaces," *Advances in Colloid and Interface Science* 118 (2005), Issue 1-3, 173-190.

J. Long et al. paper is a well written journal indeed. I was amazed by their model and how they were able to compare it with experimental results. However, I think the paper contains few typing mistakes as follows:

1. In page 181 and in the right column paragraph, in the ninth line from top (or 7th line from bottom) the capital letter "B" should be small letter "b". This is very confusing as they are referring to figure 8.
 2. In figure 8, the subscripts of ΔF are wrong. ΔF_1 should be on top (i.e. the grey curve) and ΔF_2 should be at the bottom (i.e. the dash dotted).
 3. In figure 9, the first region should be I not II and certainly the second region from the left should be II not I.
 4. In page 188 under Appendix B, the 10th line from the bottom of the paragraph, the angle 35 deg should be 25 deg.
2. Morrow, N.R.: "Physics and Thermodynamics of Capillary Action in Porous Media," *Ind. & Eng. Chem.* (June 1970) 62, No. 6, pp 32-56.
 1. Figure 18 gives the relation between work of displacement and surface free energy. I understand the primary drainage and secondary drainage efficiencies but I do not understand the way imbibition efficiency was calculated. In page 52 under **Efficiency of Imbibition** paragraph imbibition is described as the conversion of free surface energy into external work. Hence, (to me) the imbibition efficiency should reflect this behavior (decrease of surface free energy). If we look at figure 18 'c' we see that water imbibition decrease surface free energy down to S_o of 13%. This means that the imbibition efficiency was not 100% because it did not expel all oil out due to entrapment of oil. At the start of imbibition S_o was 79% and was decreased to 13% at the end of imbibition. This means 66% was the actual displacement of oil out. Why don't we calculate the imbibition efficiency wrt to drainage by $66/79$ which gives 83.5%? In the paper this value is determined from $73/79$ which gives 92.5? The paper considered the 13% S_o at the end of imbibition as stored free energy and as part of efficiency determination. Well (to me) this 13% is rather a deficiency in the imbibition! Appreciate your clarification. Thanks.

I guess it is a matter of efficiency of return of stored energy, and not oil recovery. During imbibition there may be thermodynamically irreversible motions taking place, e.g., sudden rearrangement of fluid distribution without changes in saturation. These types of motion means loss of stored surface energy in the pores, and the imbibition process ends at $p_c=0$ without having returned the energy stored in the previous displacement process.

3. Hassanizadeh, S.M., Gray, W.G.: "Thermodynamic Basis of Capillary Pressure in Porous Media," *Water Resources Research* 29 (Oct. 1993), no. 10, 3389-3405.

1. This paper has changed my understanding of P_c .
2. In page 3400 under equation 42 there must be a typing mistake in the 4th line under equation 42. $P^n - P^w$ should be smaller than P^c for S^w to be positive. The sign should change from ">" to "<".

I agree. There must be a misprint regarding the inequality for the second case.

4. Måløy, K.J., Furuberg, L., Feder, J., and Jøssang, T.: "Dynamics of Slow Drainage in Porous Media," *Phys. Rev. Lett.* (1992) 68, No. 14, pp 2161-2164

1. In page 2162 the sentences describing the curves (a & b) under figure 2 are not similar to the description in the paragraph in the text. The paragraph which describes the curves is the second paragraph starting with "In Fig. 2(a) we show...". Notice that the paragraph in the text is referring to curve (a) as distribution of jumps whereas under the figure is referred to as distribution of intervals.

I agree with your comment. There Figure caption is not in agreement with the text.

6. Radke, C.J., Kavscek, A.R., and Wong, H.: "A Pore-Level Scenario for the Development of Mixed Wettability", paper SPE 24880 presented at the 1992 Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington DC, Oct. 4--7.

First, strongly suggest that this paper is read from the published journal

Kavscek, A. R., H. Wong, and C. J. Radke, A Pore-Level Scenario for the Development of Mixed Wettability in Oil-Reservoirs, *AICHE Journal*, 39, 1072-1085, 1993.

These are questions/comments from the SPE paper

1. This paper perhaps has been the most beneficial to me so far. It contains a lot of good and new explanation of capillary distribution and displacement of fluids at different Wettability conditions and in different regimes.
2. In equation (5) I wonder why the sigma term (IFT) is not shown in the equation. Is it missing?

Must be a misprint.

3. It was extremely striking to me to see that at the end of primary drainage the largest pores would still be water wet, while the intermediate sized pores would have been converted to mixed oil wet. The basis of this conclusion in the paper was based on the fact that the pores had convex shapes, and it was based on equation (3) and figure (3). I always thought the largest pores would be

converted to oil wet more easily than the smaller pores. As I read the paper I realized that this situation would be opposite for concave pores. My question here is how realistic this situation is in real rocks; is this theory widely accepted (smaller convex pores can more easily get mixed oil wet than larger convex pores)? I have examples of low perm and high perm rocks (all came from the same formation and treated with the same crude oil at the same high temp) where the tight rocks showed large spontaneous imbibition compared to the high perm rocks. Did this mean that the pores in those samples were of concave shape?

I would be careful to draw firm conclusions about actual measurements and "abstract" pore shapes. The pore cartoons of the paper are widely used to "explain" mixed wettability, but the capillary pressure curve depends also on the pore throat size and distribution. I do not know of an accepted viewpoint that smaller convex pores can more easily get mixed oil wet than larger convex pores.

4. In page 168 at the 4th line from top, fig 9 should be fig. 7.
5. In page 168 under **Secondary drainage** at the end of the first paragraph at 6th line it should be as follows: "...occurs between points G and P through M on Fig.11".
6. In page 169 in the last paragraph of the column to the left both Fig 13 (at 3rd and 5th lines) should be Fig 11.
7. In the last paragraph in page 170 there might be a fundamental typing mistake in line # 4 from the bottom. The sentence reads as follows: "A convex pore shape places the thinnest brine films in the **largest pores**" The "largest pores" should be the "intermediate sized pores", shouldn't it?

I am a little confused here. At what capillary pressure level should the thickness of the brine films be compared? At the entry pressure?

8. Under figure 9 (b) it should be "pores during spontaneous imbibition" not "forced imbibition".
10. Kaminsky, R. and Radke, C.J.: "Water Films, Asphaltenes, and Wettability Alteration", paper SPE 39087 presented at the 1998 SPE/DOE Improved Oil Recovery Symposium, Tulsa, OK, April 19-22.

Note that here also there is a journal version of this paper

Kaminsky, R., and C. J. Radke, Asphaltenes, water films, and wettability reversal, *SPE Journal*, 2, 485-493, 1997.