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Wicking of a Wetting Fluid in a Layered Porous Medium Saturated with a Viscous Non-Wetting Fluid

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Wicking is the capillary phenomena by which a preferentially wetting liquid is drawn into a porous medium due to surface tension forces. The Washburn equation, governing the spontaneous invasion of a wetting fluid in a capillary was developed in the early 1900's. The equation can also explain a wide variety of impregnation processes in homogeneous porous media effectively. However, there are cases where the porous media is heterogeneous, like in the geological layers of oil reservoirs, where applicability of the Washburn equation is limited at large scale. Most of the heterogeneities in geological layers is due to various factors such as, wettability, geometry of the pores, tortuosity of the medium etc., In recent studies, it is observed that the wicking phenomena is significantly affected by the grain sizes in a hydrodynamically interacting layers of porous medium. Experiments in heterogeneous bi-layered porous medium show that the wetting fluid imbibes faster in the fine pores and slower in the larger pores. However, in three layered porous medium, wicking is dependent on permeability ratio and capillary pressure ratio of the layers. In addition, the arrangement of the layers with respect to each other also impacts the wicking rate. It is still unknown that how the viscosity of the resident fluid impacts the flow behavior in the layered porous medium.
In the present work we explore the wicking behaviour in the layered porous medium, when a viscous non-wetting fluid is already present in the porous medium. We explain the wicking phenomena by using a quasi one-dimensional lubrication approximation model including the insights from the simulations in analogous system of pores. Further, the numerical model explaining the wicking phenomena is supported by the anticipated pressure gradients in the porous medium followed by experimental observations of the same.
In developing the numerical model for spontaneous imbibition, we consider the possible cases of wicking in a two layered porous medium, i.e., (i) wicking is faster in the fine pores, (ii) wicking is faster in the large pores. For each of the possible cases, we develop the numerical model and verify the same with the anticipated pressure gradient graphs. Our analysis of the model shows that the case (ii) is never possible. Experimentally, we show a similar wicking pattern as predicted by our quasi 1-D, Wasburn like model for a layered porous media. Wicking in fine pores is observed to occur at a faster rate than the wicking in large pores as predicted by the one-dimensional model. We compare the results of the experiments with the numerical model and find that the proposed one-dimensional model sufficiently explains the spontaneous imbibition in a two layered porous medium. We have also extended our model for three layered porous medium, where the arrangement of the layers alo impact the wicking behavior.
This work provides insights into the physics of wicking in layered porous media and will be applicable to fields like oil recovery from fractured reservoirs, ground water remediation and paper wicking.

References

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