Capillarity in porous media at different scales

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In this short course, a systematic approach is taken to the understanding of capillarity in porous media at different scales. Current definitions of capillary pressure, which are mostly empirical in nature are revisited and it is shown that they are special cases of a more general theory of capillarity.
First, capillary pressure is defined at pore scale based on the equation of momentum conservation for a fluid-fluid interface. It is shown that, even at microscale, capillary pressure is equal to the difference in pressures of the two fluids only under static conditions. General equations for dynamic or non-equilibrium conditions are derived. Then, capillary pressure at the macroscale (Darcy scale) is introduced based on principle of thermodynamics, and its relationship to fluid pressures under static and dynamic conditions is explored. Non-equilibrium capillarity theory and its effects on the modelling of moisture transport and two-phase flow processes are discussed. Computational and experimental studies are presented that investigate new generalized equations in variety of systems, such water infiltration into dry soil, penetration of liquids into absorbing hygienic tissues, moisture transport in fuel cells.

Plan of lectures could be as follows (14 hours of lectures in five days, including exercises):

- ***Capillarity at pore scale*** **4 hours**
  Concepts of wettability and surface tension, and their link to interfacial energy
  The difference between surface tension and interfacial tension
  Will water always go up in a capillary tube (the role of fluid-solid interfaces)
  Quantitative analysis of rise (or fall) of fluid-fluid interfaces in a capillary tube
  What is the correct definition of capillary pressure?
  Young's and Young-Laplace equations in circular and noncircular tubes
  Momentum balance equation for a single interface
  Two-phase displacement in a tube; capillarity under dynamic conditions

- ***Capillarity at macroscale; fundamentals*** **4 hours**
  Measurement of capillary pressure-saturation curves at REV scale
  Various features of capillary pressure-saturation curves for hydrophobic and hydrophilic porous media
  Link between capillary pressure-saturation curve and pore-scale capillarity
  Derivation of capillarity equation at REV scale based on principles of thermodynamics
  Experimental studies of non-equilibrium capillarity under unsaturated or two-phase flow
  Practical significance of non-equilibrium capillarity in describing unsaturated or two-phase flow processes

- ***Capillarity at macroscale; computational and experimental studies*** **6 hours**
  Experimental and/or computational determination of capillary pressure-saturation curves for different kinds of porous media (soil, fuel cells, paper, tissues)
  Equations of two-phase flow including dynamic capillarity and their behavior
  Experimental studies of capillarity in soils and macroscale modelling
  Experimental studies of capillarity in hygienic products (diapers) and macroscale modelling