Numerical Simulation of Capillary Rise in Millimetric Cylindrical Tubes

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Abstract:

Capillarity can be used in engineering nature-inspired slip-resistant surfaces, containing millimetric grooves, to provide an efficient grip on a solid floor with a small amount of liquid layer. Although literature has substantially reported analytical analysis and experimental data on capillary filling, numerical formulations provide the closest representation of the actual capillary filling process. Thus, in this work, a numerical model was developed to closely represent the natural filling of single-phase water inside a milli-metric-sized conduit of cylindrical shape, that demonstrates a single unit of the anti-slip surface matrix. A phase field numerical model was used to simulate the capillary imbibition of water inside the groove. The numerical approach, implemented in COMSOL Multiphysics, was based on a Diffuse Interface Model (DIM), using Cahn-Hillard equations to predict the liquid rise in a column, over time. The work studied the effect of the cylinder radius (0.05 – 0.5 mm), height (2 – 4 mm), and water-surface material combinations, for different wetting potentials represented by different contact angles (50 – 90°). All results showed the meniscus formation, through reorientation of the fluid surface, due to the initial inertial effect at the entry of the capillary tube. The results showed that radius has a significant effect on the water level rise (*h*) over time (*t*); the conduit height is directly proportional to the rise time, with a negligible effect on the *h* - *t* curve; and the wetting potential of the surface material does not have a prominent effect on the rise time, nor in the *h* - *t* curve. The rise in water level as a function of time showed good agreement with theoretical and experimental data from literature. Furthermore, the minimum time to complete 1 step is 61.5 times more than the Maximum time to fill the grooves. Therefore, this nature inspired solution fits well for anti-slip surfaces which can be

used in industrial, construction, fishing and many more slip-prevention functions. The flow parameters retrieved, throughout the rise time, can be used in developing anti-slip surfaces, used under more severe conditions than the solid surfaces with small fluid layers, such as icy surfaces to provide solution to slip and fall problems in Nordic countries resulting in loss of billions of dollars and degradation of human living standards.

Keywords:

Nature Inspired Slip-resistance Surface, Capillarity, Finite Element Modelling, Phase Field Method, COMSOL Multiphysics, Meniscus Development Picturization

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