International Journal of
Environmental Sciences & Natural Resources
ISSN: 2572-1119

Juniper PUBLISHERS key to the Researchers

Review Article
Volume 9 Issue 5 - April 2018
DOI: 10.19080/IJESNR.2018.09.555773

Int J Environ Sci Nat Res

Review on Modeling the Spontaneous Imbibition in Porous Wicks Made of Natural Fibers

Liu Fang[1*], liu Yang and Ying Xu

Department of Geotechnical Engineering, University of Nanchang Hangkong, China

Submission: March 31, 2018; **Published:** April 11, 2018

***Corresponding author:**Liu Fang, Department of Geotechnical Engineering, University of Nan Chang Hang Kong, China,

Email: lfangnchu@gmail.com

Abstract

The modeling of spontaneous imbibitions of a liquid into porous wicks which are made from natural fibers has been investigated in the current research. There has been numerous numbers of mathematical models to predict the wicking properties. The application of all the models depends on some factors such as the microstructure of the wick, porosity, wicking liquid and etc. Lucas-Washburn equation is one of the initial and old wicking models to predict the height of liquid front as a function of time. Darcy's law as an applicable model is based on the movement of the liquid in the wick with a sharp front. However, the sharp-front model is unable to explain region of partial saturation. Richard's equation covers this drawback and predicts the absorbed liquid-mass into the wick as function of time. In this research we overview the application of theses famous theoretical models and their applicability.

Introduction

Recently porous wicks has been confronted a surge in its application in several important and useful industries and commercial applications from a simple example, its application in lightening torches [1] and air refreshers and scent dispensers, to an advanced examples of using porous wicks in propellant management devices (PMD) in rockets [2,3] and their usage in heat exchanger and solar panels applications [4-9]. Hence, modeling spontaneous imbibitions which is called the wicking process is so important in term of predicting the height of liquid front and other properties.

Discussion

During the wicking process of a fluid into a porous medium, as the imbibitions under capillary pressure [10-12], depending on many factors such as pore structure and the wicking fluid properties, we may confront with different type of liquid-front such as: Sharp front, Semi-Sharp front and diffusive front. Depending on the type of the liquid front, there have been many theoretical models to investigate this wicking phenomenon. The oldest method, porous wicks are modeled as a bundle of parallel capillary tubes which are aligned along the direction of the flow. Initially it was investigated by Lucas-Washburn [13] and later continued by other researchers who have added and completed that equation based on other assumptions [14-24]. In Lucas Washburn equation, they neglected the effect of the inertia and gravity effects and used the momentum balance equation to derive an analytical solution to predict the height of liquid front as a function of time and they presented their equation as

$$h = \sqrt{\frac{\sigma R_e \cos(\theta_d)}{2\mu} t} \qquad [1]$$

Where σ and μ are surface tension and viscosity of the wicking fluid and Re defined as the effective capillary radius. Based on the main assumption on which the Washburn equation is based, it is incapable of modeling 2D or 3D flows as the flow happens just in one direction. In addition, there are some fitting parameters such as hydraulic radius needed to be provided for the Washburn equation [25] and the actual microstructure of a porous medium is not made from a bundle of capillary tubes. These like mentioned drawbacks limit the application of the Washburn equation.

As a recent method to model wicking of liquids into porous wicks is based on using Darcy's law [26-28]. He developed his theoretical model based on his investigation on the relationship between flow-rate and the pressure gradient through a hydraulic resistance term. Darcy's model was built on the assumption that a clearly-identifiable liquid front progress during the wicking process and behind this sharp front all pores are filled by the wicking liquid the hat part of the wick is considered as a wet wick. There have been many efforts to develop the Darcy's law-based models for predicting and modeling liquid absorption in porous wicks [28-32]. In contrast with Washburn equation, Darcy's law allows researchers to model and predict the two and three -dimensional and, more importantly, it do not need any fitting parameter for hydraulic radius or capillary diameter.

As it was mentioned formerly, one of the liquid-front types during the wicking process in porous wicks is diffusive front which happens due to some in homogeneity in microstructure of the wick. This type of front occurs specially when a wick is made of natural fibers and there are some fiber clustering which lead to a diffusive front. Darcy's law is unable to explain this type of front and there is no sharp and clearly identifiable front and we are dealing with partial saturation which is due to fiber clustering. Richard [29] proposed his model for modeling unsaturated flows in porous media. Richards' equation is a highly non-linear elliptic equation that predicts the diffusive saturation field throughout a porous medium as a function of time. Richard's equation as a useful tool to predict partial saturation has been solved numerically and analytically using various numerical schemes such as the finite difference method, the finite element method, and the boundary element method for different cases of porous wicks [30-38].

Conclusion

Depending the type of liquid-front during the wicking process in porous wicks, the wicking properties can be obtained and modeled on using different type of mathematical models. Darcy's law is most applicable and useful model for all wicking process with a sharp front and it covers the drawback of the Washburn equation. Although it is unable to do the predictions for partial saturation case which happens due to in homogeneity. In those cases of partial saturation, Richard's equation is able to determine the saturation level at any point of the wick during the wicking process.

References

1. Zarandi MAF, Pillai KM, Kimmel AS (2017) Spontaneous imbibitions of liquids in glass-fibre wicks. Usefulness of a sharp-front approach AICHE Journal 64(1): 294-305
2. Grebenyuk Y, Dreyer ME (2016) Wicking of liquid nitrogen into superheated porous structures. Cryogenics 78: 27-39.
3. N Fries K, Odic M, Conrath MD (2008) The effect of evaporation on the wicking of liquids into a metallic weave. Journal of Colloid and Interface Science 321(1): 118-129.
4. Balali MH (2015) An economical model development for a hybrid system of grid connected solar PV and electrical storage system. The University of Wisconsin Milwaukee, USA.
5. Balali MH, Nouri N, Omrani E, Nasiri A, Otieno W (2017) An overview of the environmental, economic, and material developments of the solar and wind sources coupled with the energy storage systems. International Journal of Energy Research 41(14): 1948-1962.
6. Haddad Z, Chaker A, Rahmani A (2017) Improving the basin type solar still performances using a vertical rotating wick. Desalination 418: 71-78.
7. Khairnasov S, Andraka CE, Baturkin V, Zaripov V, Nishchyk O (2017) Development of advanced high porosity wicks for the high temperature heat pipes of concentrating solar power. Applied Thermal Engineering 126: 1170-1176.
8. Matrawy KK, Alosaimy AS, Mahrous AF (2015) Modeling and experimental study of a corrugated wick type solar still: Comparative study with a simple basin type. Energy Conversion and Management 105: 1261-1268.
9. Mohammad Hasan B, Nouri N, Nasiri A, Seifoddini H (2015) Development of an economical model for a hybrid system of grid, PV and Energy Storage Systems. 2015 International Conference on Renewable Energy Research and Applications p. 22-25.
10. Masoodi R, Pillai K, Varanasi P (2010) The effect of hydraulic pressure on the wicking rate into the wipes. J Engd Fibers Fabrics 5(3): 49-66.
11. Pucci MF, Liotier PJ, Drapier S (2016) Capillary wicking in flax fabrics-Effects of swelling in water. Colloids and Surfaces A: Physicochemical and Engineering Aspects 498: 176-184.
12. Son HH, Seo GH, Jeong U, Shin DY, Kim SJ (2017) Capillary wicking effect of a Cr-sputtered superhydrophilic surface on enhancement of pool boiling critical heat flux. International Journal of Heat and Mass Transfer 113: 115-128.
13. Washburn EW (1921) The Dynamics of Capillary Flow. Physical Review 17(3): 273-283.
14. Bell JM, Cameron FK (1905) The Flow of Liquids through Capillary Spaces. The Journal of Physical Chemistry 10(8): 658-674.
15. Lucas R (1918) Rate of capillary ascension of liquids. Kolloid Z 23: 15-22.
16. Hanžič L, Kosec L, Anžel I (2010) Capillary absorption in concrete and the Lucas-Washburn equation. Cement and Concrete Composites 32(1): 84-91.
17. Mullins BJ, Braddock RD, Kasper G (2007) Capillarity in fibrous filter media: Relationship to filter properties. Chemical Engineering Science 62(22): 6191-6198.
18. Hamraoui A, Nylander T (2002) Analytical Approach for the Lucas-Washburn Equation. Journal of Colloid and Interface Science 250(2): 415-421.
19. Ji L, Shi B (2015) A novel method for determining surface free energy of powders using Washburn's equation without calculating capillary factor and contact angle. Powder Technology 271: 88-92.
20. O Loughlin M, Wilk K, Priest C, Ralston J, Popescu MN (2013) Capillary rise dynamics of aqueous glycerol solutions in glass capillaries: A critical examination of the Washburn equation. Journal of Colloid and Interface Science 411: 257-264.
21. Sorbie KS, Wu YZ, McDougall SR (1995) The Extended Washburn Equation and Its Application to the Oil/Water Pore Doublet Problem. Journal of Colloid and Interface Science 174(2): 289-301.
22. Szekely J, Neumann A, Chuang Y (1971) The rate of capillary penetration and the applicability of the Washburn equation. Journal of Colloid and Interface Science 35(2): 273-278.
23. Fries N, Quéré D (2010) Capillary transport processes in porous materials-experiment and model: Cuvillier, pp. 160.
24. Lavi B, Marmur A, Bachmann J (2008) Porous media characterization by the two-liquid method: effect of dynamic contact angle and inertia. Langmuir 24(5): 1918-1923.
25. Masoodi R, Pillai KM (2012) Wicking in porous materials: traditional and modern modelling approaches: CRC Press USA, pp. 380.

How to cite this article: Liu Fang1, liu Yang ,Ying XU. Review on Modeling the Spontaneous Imbibition in Porous Wicks Made of Natural Fibers.Int J Environ Sci Nat Res. 2018; 9(5): 555773. DOI:10.19080/IJESNR.2018.09.555773

26. Richards LA (2004) Capillary conduction of liquids through porous mediums. Journal of Applied Physics 1(5): 318-333.

27. Barari A, Omidvar M, Ghotbi A, Ganji D (2009) Numerical analysis of Richards' problem for water penetration in unsaturated soils. Hydrology and Earth System Sciences Discussions 6(5): 6359-6385.

28. Berninger H, Kornhuber R, Sander O (2011) Fast and robust numerical solution of the Richards equation in homogeneous soil. SIAM Journal on Numerical Analysis 49(6): 2576-2597.

29. Menziani M, Pugnaghi S, Vincenzi S (2017) Analytical solutions of the linearized Richards equation for discrete arbitrary initial and boundary conditions. Journal of Hydrology 332(1): 214-225.

30. Tracy F (2007) Three-dimensional analytical solutions of Richards' equation for a box-shaped soil sample with piecewise-constant head boundary conditions on the top. Journal of Hydrology 336(3): 391-400.

31. Varado N, Braud I, Ross P, Haverkamp R (2006) Assessment of an efficient numerical solution of the 1D Richards' equation on bare soil. Journal of Hydrology 323(1): 244-257.

32. Zlotnik VA, Wang T, Nieber JL, Šimunek J (2007) Verification of numerical solutions of the Richards equation using a traveling wave solution. Advances in water resources 30(9): 1973-1980.

33. Zarandi MAF, Pillai KM (2017) Spontaneous Imbibition of Liquid in Glass fiber Wicks, PartI: Validation of a Sharp-front Model. Submitted to AICHE 64(1): 294-305.

34. Landeryou M, Eames I, Cottenden A (2005) Infiltration into inclined fibrous sheets. Journal of Fluid Mechanics 529: 173-193.

35. Jaganathan S, Tafreshi HV, Pourdeyhimi B (2009) A realistic modelling of fluid infiltration in thin fibrous sheets. Journal of Applied Physics 105(11): 113522.

36. Masoodi R, Pillai KM, Varanasi PP (2007) Darcy's law-based models for liquid absorption in polymer wicks. AICHE journal 53(11): 2769-2782.

37. Masoodi R, Tan H, Pillai KM (2011) Darcy's law-based numerical simulation for modelling 3D liquid absorption into porous wicks. AICHE journal 57(5): 1132-1143.

38. Pillai KM, Advani SG (1996) Wicking across a fiber-bank. Journal of Colloid and Interface Science. 183(1): 100-110.