# REFERENCES


Abu-Hassanein, Z.S., and Pantazidou M. (1998), "Infiltration of high viscosity low density DNAPL in saturated porous media", *Proceedings Centrifuge 98*, 595-599.

Brook H. and Corey, A.T. (1964), "Hydraulic properties of porous media", *Colorado State University Hydrology paper*, No.3, March.

Coumoulos H., Soga K., Illangasekare T. (2000), "1G and centrifuge tests on DNAPL migration in saturated porous media with inclined layer-modelling techniques", *Proceedings of International Symposium on Physical Modelling and Testing in Environmental Geotechnics*, La Baule France, 301-308, May.

Demond, A.H. and Lindner A.S. (1993), "Estimation of interfacial tension between organic liquids and water" Environmental Science & Technology, volume 27, No.12, 2318-2331.

Fetter, C.W. (1992). Contaminant Hydrology. Macmillan Publishing company.

Kaluarachchi, J.J., and Parker, J.C. (1989), "An efficient finite element method for modeling multiphase flow", *Water Resources Research*, 25, No.1, 43-54, January.

Kueper, B.H., and Frind, E.O. (1991), "Two-phase flow in heterogeneous porous media 1.model development", *Water Resources Research*, 27, No.6, 1049-1057, June.

Kuper, B.H., and Frind, E.O. (1991), "Two-phase flow in heterogeneous porous media 1.model application", *Water Resources Research*, 27, No.6, 1059-1070, June.

Kuppusamy T., Sheng J., Parker, J.C., and Lenhard, R.J. (1987), "Finite-element analysis of multiphase immiscible flow through soils", *Water Resources Research*, 23, No.4, 625-631, April.

Lakshmi N.Reddi, Hilary I. Inyan. (2000). Geoenvironmental engineering, principle and applications. Marcel Decker, Inc.

Lenhard, R.J., Parker, J.C., and Kuppusamy T. (1987), "A parametric model for constitutive properties governing multiphase flow in porous media", *Water Resources Research*, 23, No.4, 618-624, April.

Li X. and Zienkiewicz, O.C. (1992), "Multiphase flow in deforming porous media and finite element solutions", *Comput. Struct.*, 45(2), 211-227.

Muraleetharan, K.K., and Wei, C.-F (1999a). "U_DYSAC2:Unsaturated Dynamic Soil Analysis Code for 2-dimensional problems." *Computer Code*, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, Oklahoma, October.

Muraleetharan, K.K., and Wei, C-.F.(1999b), "Dynamic behavior of unsaturated porous media: governing equations using the theory of mixtures with interfaces (TMI)", *International Journal forNumerical and AnalyticalMethods inGeomechanics*, 23, 1579-1608.

Pantazidou M., Abu-Hassanein, Z.S, Reimer, M.F. (2000), "Centrifuge study of DNAPL transport in granular media", *Journal of Geotechnical and Geoenvironmental Engineering*, 105-115, February.

Rahman, N.A.,and Lewis, R.W (1999), "Finite element modelling of multiphase immiscible flow in deforming porous media for subsurface systems", *Computer and Geotechnics*, 24, 41-63.

Schrefler, B.A., D'Alpaos L., Zhan, X.Y., and Simoni L. (1994), "Pollutant transport in deforming porous media", *European Journal of Mechanics and solids*, 13, No.4, 176-194.

Sleep, B.E., and Slykes, J.F., (1993) "Compositional simulation of groundwater contamination by organic compounds 1.model development and verification", *Water Resources Research*, 29, No.6, 1697-1708, June.

Sleep, B.E., and Slykes, J.F., (1993) "Compositional simulation of groundwater contamination by organic compounds 2.model applications", *Water Resources Research*, 29, No.6, 1709-1718, June.

Spiessl, S.M., and Taylor, R.N. (2000), "2D centrifuge modelling of DNAPL infiltration in homogeneous saturated soils", *Proceedings of International Symposium on Physical Modelling and Testing in Environmental Geotechnics*, La Baule France, 325-333, May.

Van Genuchten, M.T. (1980), "A closed-form equation for predicting the hydraulic conductivity of unsaturated soil", *Soil Science Society American Journal*, 44, 892-899.

Wei, C.F. (2001), "Static and dynamic behavior of multi porous media : Governing equations and finite element implementation", PhD. Thesis, University of Oklahoma.

Wei, C.-F., and Muraleetharan, K.K. (2002a) "A continuum theory of porous media saturated by multiphase fluids: I. Linear poroelasticity." *International Journal of Engineering Science,* 40, 1807-1833.

Wei, C.-F., and Muraleetharan, K.K. (2002b) "A continuum theory of porous media saturated by multiphase fluids: II. Lagrangian description and variational structure." *International Journal of Engineering Science,* 40, 1835-1854.

White, M.D., Oostrom M., and Lenhard, R.J. (1995), "Modeling fluid flow and transport in variably saturated porous media with the STOMP simulator. 1.Nonvolatile three-phase model description", *Advances in Water Resources*, 18, No.6, 353-364.

# APPENDIX

# Appendix A : Matrices Used in the U_DYSAC2 Finite element formulation

The final matrix equation solved by U_DYSAC2 (Muraleetharan and Wei 1999a) is:

$$Ma + Cv + K_p d + P_{\text{int}} = F_{ext} \tag{A.1}$$

$$\begin{bmatrix} M_{UU} & 0 & 0 \\ M_{IU} & 0 & 0 \\ M_{NU} & 0 & 0 \end{bmatrix} \begin{Bmatrix} \ddot{U} \\ \ddot{P}^I \\ \ddot{P}^N \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ C_{IU} & C_{II} & C_{IN} \\ C_{NU} & C_{NI} & C_{NU} \end{bmatrix} \begin{Bmatrix} \dot{U} \\ \dot{P}^I \\ \dot{P}^N \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & K_{II} & 0 \\ 0 & 0 & K_{NU} \end{bmatrix} \begin{Bmatrix} U \\ P^I \\ P^N \end{Bmatrix} = \begin{Bmatrix} F_U \\ F_I \\ F_N \end{Bmatrix} - \begin{Bmatrix} F_{\text{int}} \\ 0 \\ 0 \end{Bmatrix}$$

where

$$M_{UU} = \int_\Omega \delta_{ij} \rho N_A N_B d\Omega$$

$$M_{IU} = \int_\Omega \rho^I N^I_{A,i} \xi^I_{ij} N_B d\Omega$$

$$M_{NU} = \int_\Omega \rho^N N^N_{A,i} \xi^N_{ij} N_B d\Omega$$

$$C_{IU} = \int_\Omega \alpha_{IU} N^I_A N_{B,i} d\Omega = \int_\Omega (n^I + \frac{\partial n^I}{\partial \varepsilon_v}) N^I_A N_{B,i} d\Omega$$

$$C_{II} = \int_\Omega \alpha_{II} N^I_A N^I_B d\Omega = \int_\Omega (\frac{n^I}{K^I} - \frac{\partial n^I}{\partial S}) N^I_A N^I_B d\Omega$$

$$C_{IN} = \int_\Omega \alpha_{NI} N^I_A N^N_B d\Omega = \int_\Omega \frac{\partial n^I}{\partial S} N^I_A N^N_B d\Omega$$

$$C_{NU} = \int_\Omega \alpha_{NU} N^N_A N_{B,i} d\Omega = \int_\Omega (1 - n^I + \frac{\partial n^I}{\partial \varepsilon_v}) N^N_A N_{B,i} d\Omega$$

$$C_{NI} = \int_\Omega \alpha_{NI} N^N_A N^I_B d\Omega = \int_\Omega \frac{\partial n^I}{\partial S} N^N_A N^I_B d\Omega$$

$$C_{NN} = \int_\Omega \alpha_{NN} N^N_A N^N_B d\Omega = \int_\Omega (\frac{n - n^I}{K^N} - \frac{\partial n^I}{\partial S}) N^N_A N^N_B d\Omega$$

$$K_{II} = \int_\Omega N^I_{A,i} \xi^I_{ij} N^I_{B,j} d\Omega$$

$$K_{NN} = \int_\Omega N^N_{A,i} \xi^N_{ij} N^N_{B,j} d\Omega$$

$$F_U = \int_\Omega \rho N_A b_i d\Omega + \int_\Gamma N_A \overline{t}_i(t) d\Gamma$$

$$F_I = \int_\Omega \rho^I N^I_A \xi^I_{ij} b_i d\Omega - \int_\Gamma N^I_A \overline{v}^I_n d\Gamma + \int_\Omega \frac{\hat{e}}{\rho^I} N^I_A d\Omega$$

$$F_N = \int_\Omega \rho^N N^N_A \xi^N_{ij} b_i d\Omega - \int_\Gamma N^N_A \overline{v}^N_n d\Gamma + \int_\Omega \frac{\hat{e}}{\rho^N} N^N_A d\Omega$$

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Mr.Ayuth Manonukul was born in Udornthani, Thailand, on September, 21st 1978. He finished his high secondary school from Triumudom Suksa school in 1996. In 2000, He graduates in Bachelor of Engineering (Chemical Engineer) from faculty of Engineer, Chulalongkorn University, Thailand. After that, he worked for 2 years in Bangchak Oil Refinery as position of process/technical engineer. In 2002 He continued further study for Master degree of Science in Environmental Management inter-Department Program in Environmental Management, Graduate School, Chulalongkorn University and achieved Master degree in April 2004.